# Investigation of Loop Flows
# Across Combined Midwest ISO
# And PJM Footprint
# Phase II

**November 12, 2008**

# Table of Contents

# Executive Summary

In May, 2007 Midwest ISO and PJM first conducted the study of investigation of loop flows across combined Midwest ISO and PJM footprint. The Phase I study, “The Investigation of Loop Flow Across the Combined Midwest ISO and PJM Footprint”, involved increasing the understanding of the impact that external market participants have on the creation of loop flows on Lake Erie area and PJM Southeast versus Southwest interface. As a result of this study, the Midwest ISO and PJM recommended the creation of an energy schedule tag archive that contains tag impacts, market transfer impacts, and generation-to-load impacts for flowgates from the Interchange Distribution Calculator (IDC).

The purpose of the Phase II Loop Flow Study (Phase II Study) was to develop mechanisms to identify and understand the sources of loop flows on key flowgates. The 35 flowgates that were included in the Phase II Study have a history of significant transmission congestion, significant market-to-market flows, and a high quantity and/or duration of TLR implementations. PJM and Midwest ISO chose three dates that represented sufficiently large flows on the transmission system:  August 8, 2007; August 20, 2007; December 5, 2007.  PJM was able to acquire saved EMS state estimator cases for these days, representing the most accurate model of the system conditions available.

A new analysis tool, Transmission Adequacy and Reliability Assessment (TARA) developed by PowerGEM, is capable of solving EMS generated power flow cases while simultaneously performing contingency analysis.  In the Phase II Study, TARA was used to generate the Transfer Distribution Factors (TDF) from the Source to the Sink using saved cases that matched the analysis time frame. Two methods of analysis were performed. The Method I (Contract Path Flow) analyzes financial constructs between control areas and applies those procedures to calculate flowgate impacts.  This method attempts to calculate the tagged impacts, market transfer impacts, and generation-to-load impacts, but the results are limited by a lack of available NERC tag data.  PJM only archives historical NERC tag between PJM and other external entities, which reinforces the Phase I Study recommendation for an interconnection-wide tag archive.  Method II (Actual Energy Flow) attempts to compensate for this insufficient data problem by analyzing the actual tie flow between control areas.

Both Method I and Method II show significant amounts of flow impacts on the studied flowgates are sourced from other entities besides Midwest ISO and PJM.  For flowgates involved in the Lake Erie loop, analysis shows that Midwest ISO, IESO, NYISO and PJM all have generation-to-load impacts.  Likewise, flowgates on the southern PJM border with non-market entities also exhibit generation-to-load impacts from the external control areas.  These results reinforce the Phase I Study recommendation for all entities to improve their data transparency by reporting their generation-to-load impacts to the IDC for constraint mitigation.

# Review of the Phase I Study

In the summer of 2006, PJM and Midwest ISO were tasked with a Joint and Common Market Initiative to conduct an inter-regional loop flow study to address large observed inadvertent flows on several PJM and Midwest ISO scheduling interfaces. The study involved a number of NERC flowgates across the two regions, with emphasis on determining the causes of loop flow and its impact on reliability.

The study involved reviewing historical NERC tag information obtained from OATI, which revealed surprising scheduling activity on PJM's southern scheduling interfaces. Purchase-Selling Entities (PSE) were scheduling contracts into PJM on one scheduling interface and out on a different scheduling interface, a practice known as "wheeling". PJM assigns a price to each scheduling interface using Location Marginal Prices at the border, and the Source and Sink of the schedule's NERC tag defines which scheduling interface is used for settlements. If the transmission system is congested, the prices between the two interfaces would differ; for example, a west-to-east constraint would result in high eastern prices and low western prices. This sends an economic signal that it is desirable to sell into PJM's eastern region, or buy from the western region, so as to relieve the amount of energy flowing in the direction of the constraint.

Obtaining the NERC tag information proved a laborious event for PJM and Midwest ISO. OATI maintains the IDC database which coordinates schedules between control areas, and makes the data available to the control areas in real-time. Neither PJM nor Midwest ISO have access to tags for outside areas after two days have lapsed, yet to perform reasonable loop flow analysis, one needs to know the schedules that are being transacted by the neighbors to calculate parallel path flow. Requesting historical NERC tag data from OATI involved several months of legal agreements before data could be exchanged.

Analysis revealed that schedules were being wheeled into PJM on the Southeast Interface and out on the Southwest Interface during times of congestion, but the Source and Sink Control Areas on the tag were both sufficiently south of PJM. Because of this, a negligible amount of energy would actually flow through PJM's transmission system. In effect, PSEs could arbitrage the difference in interface pricing by building a contract path to cross PJM's borders and earn money without contributing counter-flow to relieve the constraint.

In August 2006, PJM moved to combine the Southeast and Southwest Interfaces into a Southern Interface with separate Import and Export prices. This eliminated the ability of foreign PSEs to arbitrage the pricing, and brought the schedules on the southern interfaces closer to actual flow, reducing overall loop flows.

On the northern interfaces, however, a different phenomenon occurs on the Lake Erie Loop. PJM, NYISO, IESO and Midwest ISO each operate independent markets and direct transmission operations around Lake Erie in a diamond formation, but only PJM and Midwest ISO have a Joint Operating Agreement that requires reporting generation-to-load impacts for constraints. If one market has excess generation, it will attempt to sell it to a neighbor but actual flow of the energy will take a different path. If there is a transmission constraint, the entities have no choice but to issue a TLR action to curtail schedules, an economically undesirable event.

IESO and ITC (a transmission owner in the MECS control area in Midwest ISO) have been working together to implement a physical solution to the loop flow issue using Phase Angle Regulating (PAR) transformers. PARs allow the transmission operator to dynamically control the amount of power that can flow through the device by changing the winding ratios.

PARs currently exist or will exist on the four lines that form the Michigan-Ontario interface. These PARs were designed to push-back on approximately 400 MW of circulation flow with all four PARs in-service. With only three of the four PARs in-service, the push-back will be approximately 100-200 MW. Since Lake Erie circulation flows have gotten as high as 2000 MW, it is obvious that these PARs are not able to manage loop flows on this interface (i.e. have scheduled equal actual) for all time periods.

In March 2003, the B3N PAR was forced out of service, and its replacement has been a physically and politically difficult process. It is anticipated that by mid-2009, a replacement PAR on B3N will be in-place and available to manage circulation flow across this interface.

At the conclusion of the Phase I Study, the four parties recommended the commissioning of the Michigan-Ontario phase angle regulators as soon as possible to mitigate the loop flow around Lake Erie. IESO indicated that after the implementation of the PARs, they would measure the reduction in loop flow to determine the effectiveness of these devices. The Phase I Loop Flow Study showed that the range of PAR regulation could fully control about two-thirds of the total hours of mismatch between schedule and actual flows, with the remaining hours having flow reduced.

Additionally, any congestion management program agreements with IESO would be contingent on the analysis performed after the PARs were placed in service. By the spring of 2008, facilities agreements were developed for the PARs. A full set of operating procedures on the use of the PARs were developed in summer 2008. As of fall 2008, one of the PARs is regulating, two are available to regulate during emergencies and the fourth replacement PAR has been ordered.

Because of the difficulty experienced in obtaining the energy schedules, the Midwest ISO, PJM, NYISO and IESO recommended creating an Energy Schedule Tag Archive to improve the transparency of data exchanged between the four parties, OATI, and other entities in the Eastern Interconnection. The recommendation for a tag archive has been included in a Parallel Flow Visualization/Mitigation SAR as submitted to NERC by the Midwest ISO, PJM and Southwest Power Pool.

## Purpose of the Phase II Study

In the fall of 2007, PJM and Midwest ISO defined the scope for the Phase II study, which was presented to the Joint and Common Market stakeholders. The study further analyzes flowgates in and around their respective regions. PJM and Midwest ISO were directed to investigate the ability to identify the impacts of loop flows on a selected list of flowgates. Specifically:

> The Phase II Study will identify flowgates located within the two markets that have experienced congestion during the last two years. An analysis will be made that identifies the source of all net flows on the flowgate. The analysis will examine data for specific dates and times when these flowgates experienced high flows and will identify the contributors to these high flows. The contributors will be sorted into those coming from the flowgate owner(s) versus those coming from outside entities. Midwest ISO and PJM will, to the extent possible based on available data, take into account system conditions (outages, transfers, generator dispatch, and load levels) as it identifies loop flow contributors.

PJM and Midwest ISO chose several dates that represented sufficiently large flows on the transmission system: August 8, 2007, the PJM peak day; August 20, 2007, large north-to-south flows; December 5, 2007, large south-to-north flows. PJM and Midwest ISO were able to acquire saved EMS state estimator cases for these days, representing the best model of the system conditions available. Using this data, the study also investigated the impacts of NERC tags (schedules), Market Transfers, and Generation-to-Load flows on a set of chosen flowgates. The flowgates that were chosen have a history of significant transmission congestion, Market-to-Market activity between PJM and Midwest ISO, and/or high levels of TLR activity in 2007.

The first flowgate criteria involved analyzing constraints that bound in the PJM and Midwest ISO markets in 2007. If a transmission facility is overloaded, and the respective market needs to move generation out of merit order in order to relieve the constraint, the constraint is said to be "bound". Constraints with large binding hours indicate that the facility is routinely constrained and can be expensive to control because of the costs incurred to operate the generation.

As part of the Joint Operating Agreement between PJM and Midwest ISO, each entity models and calculates its generation impact on constraints that exist in the other's transmission system. Each entity has a "firm flow entitlement" (FFE) to allow a certain amount of flow on the flowgate. The FFE is used in the Market-to-Market settlement process. If the non-monitoring RTO operated above its FFE, it makes a settlement payment to the monitoring RTO. If the non-monitoring RTO operated below its FFE, the monitoring RTO makes a settlement payment to the non-monitoring RTO. Market-to-Market coordination automatically exchanges shadow prices for bound constraints. When the non-monitoring RTO has a lower shadow price, they will bind the monitoring RTO's constraint as if it were a local constraint in the market. At the end of a billing cycle, each entity will exchange money with the other party to balance the cost of meeting the flowgate entitlements. As a net result, the reliability of the system is improved as the system allows any control area in Midwest ISO or PJM that impacts a constraint to economically re-dispatch its generation to control the constraint, while allowing a payment mechanism between the markets to cover the costs of the re-dispatch.

Each generator injects energy into and each load withdraws energy from the interconnection, with flow following the path of least impedance. Prior to the development of FERC open access, each control area was considered relatively isolated and self-sufficient, producing enough energy for local load plus any exporting contracts. As open access took effect, so did the concept of using economic transactions to serve load when this was more cost effective than dispatching local generation. It became more common to schedule large amounts of power from an area of cheap production to a more expensive market via transactions. The IDC was created to provide a mechanism to identify and curtail those transactions when the interregional flows became too large and caused congestion on neighboring transmission because of the distribution of flow.

As Midwest ISO created and PJM expanded their markets, control areas that used to explicitly tag the transfer of energy became internalized, and per tradition, internal transfers from generation to load within a control area are not NERC tagged. In the case of Midwest ISO where market transactions between control areas within the market are not tagged, NERC granted a waiver that replaced the use of tags with the use of market flows (generation-to-load flows plus market transfer flows). In the case of PJM which operates as a multi-zone control area where the impact of over-generating zones transferring its non-tagged surplus to under-generating zones, it also reports market flows to the IDC that are subject to curtailment during TLR. PJM and Midwest ISO support this requirement with automated congestion management software, in which each system reports hourly impacts of market flows on coordinated flowgates.

Because the IDC generation-to-load so far has only applied to Midwest ISO, PJM and Southwest Power Pool (SPP) market entities, this concept is referred to as “Market Flow”. However, the basic concept that generation serving geographically distant load within the same control area applies equally to any control area, such that any area should be able to calculate its internal generation-to-load impacts on NERC flowgates without having to dispatch as a market.

# Flowgate Analysis Methodologies

## *Evolution of Analysis Tools*

In late 2006, PJM began working with PowerGEM to develop new software to review activity in its real-time market. The software analyzes historical State Estimator snapshots, merges market information with real-time performance, and generates optimal solutions to highlight opportunities where the production cost of the market could have been reduced by changing operations. Known within PJM as "Perfect Dispatch", the new software pushed the envelope on rapidly generating power flow solutions.

In 2007, PowerGEM released TARA, a tool capable of solving EMS generated power flow cases and simultaneously perform contingency analysis. The state estimator contains a mathematical model of the electric system reconciled with real-time metering from the field. All control areas strive to accurately represent real-world assets in their models, and routinely update existing impedances to improve the modeling of existing assets as well as new construction.

Control areas typically model their internal assets as precisely as possible, then use a NERC Multi-Regional Modeling Working Group (MMWG) interconnection model to represent neighboring systems. External regions often use "equivalenced" impedance values to reduce the complexity of the external models while retaining the solution's integrity. PJM's EMS state estimator groups its assets into a total of 50 areas containing 77 transmission zones, with 46 zones representing PJM. The remaining 31 zones represent control areas in the Midwest ISO, NYISO and the other NYPP zones, TVA and the other SERC zones, SPP, etc.

Every 5 minutes, the state estimator outputs a save case in PSSE Revision 26 format, containing the full model of all active equipment: online generation, in-service lines and transformers, and all of the other objects online at the time of the save. Because the case is the same model that is used for real-time dispatch, with the same topology and transmission impedances, we are confident that the results produced by the power flow software are equivalent to flows observed in real-time.

After determining the list of flowgates for the Phase II Study, PJM mapped the NERC Book of Flowgates back to the EMS model. This allows TARA to calculate pre- and post-contingency flows using the EMS supplied transmission model, which reproduces the PJM EMS Security Analysis results used in real-time constraint control. Additionally, TARA can produce generation shift factors and load distribution factors that match the PJM EMS Alleviate Overload and Congestion Management tools. This allows us to reproduce distribution factor data that typically is not archived due to data volume.

Similar to other power flow software, TARA works with a "sub-zone" definition file to calculate distribution factors. Each sub-zone represents generation or load within a set of zones defined in the power flow file, allowing the aggregation of multiple zones into a single block. TARA calculates a flowgate distribution factor for the sub-zone (weighted by energy) with respect to a reference (slack) bus. Combining generation sub-zone with load sub-zone distribution factors results in a transfer distribution factor for the impact for any energy allocated to flow on that transfer path.

$$\text{Flowgate Impact}_{A\,B} = \text{Energy}_{A\,B} \times \text{Transfer Distribution Factor}_{A\,B}$$

$$\text{Transfer Distribution Factor}_{A\,B} = (\,\text{GDF}_A - \text{LDF}_B\,) \text{ from zone A to zone B}$$

## *Method I: Contract Path Flow*

Analysis of the source of flow on the interconnection involves tracing flow back to injections to and withdraws from the system. One commonly accepted method of tracking flow is to categorize the injections by the purpose for which it was produced, for example, energy for serving scheduled interchange, serving internal load, or serving load in other market areas. This quantization requires complete top-down knowledge of all causes of generation to source all flows. This presents a difficulty when the classifications are not known, such as not having a full view of NERC tags to resolve scheduled interchange.

The Method I approach to finding the sources of loop flow is to analyze the financial constructs that exist in the modern electric system and apply those procedures in calculating flowgate impacts. The two recognized categories of flow on flowgates are tagged impacts and generation-to-load impacts.

Tagged Impacts are the component of flow on a flowgate that occurs due to the scheduled exchange of energy between control areas. To fully explain why this impact occurs, we will first review the fundamentals of control area operation.

Each control area has a balancing obligation such that generation and interchange within the area equals its load and losses; this is traditionally referred to as the tie component of the Area Control Error (ACE):

$$\text{Balance}_A = (\,\text{Generation}_A + \text{Interchange}_A - \text{Load}_A - \text{Losses}_A\,) = 0$$

Each control area may schedule its interchange with external areas in the interconnected grid. Through the Open Access Same-Time Information System (OASIS), each control area has the ability to create transactions with external areas. These transactions follow a defined “contract path” that transfer the energy from the source area to the sink area using the transmission systems of intermediary areas. Scheduled energy is assumed to be sourced from the pool of all resources in an area, since capacity-backed contracts with a single energy source are relatively rare in market areas. Likewise, contracted energy does not financially sink to a single point load – energy is distributed to all loads in the destination area.

If any area schedules to sell energy to an external area, it creates a contract representing an “export” for a certain MW amount, and raises its generation above its native demand by the equal amount.

$$\text{Interchange}_A = \text{Imports}_A - \text{Exports}_A$$

$$\text{Balance}_A = (\,\text{Generation}_A - \text{Exports}_A - \text{Load}_A + \text{Imports}_A - \text{Losses}_A\,) = 0$$

$$\text{Balance}_A = (\text{Generation}_A - \text{Exports}_A) - (\text{Load}_A + \text{Losses}_A - \text{Imports}_A) = 0$$

$$\text{Balance}_A = (\text{Generation}_A - \text{Exports}_A) - (\text{Demand}_A - \text{Imports}_A) = 0$$

Tagged impacts are currently calculated by OATI using the IDC. OATI operates the IDC with a seasonal interregional MMWG model combined with the NERC SDX information to represent real-time topology changes. By combining the schedules of the entire eastern interconnection with this model, the IDC is able to calculate the impact of moving generation positions to serve these schedules.

For the Phase II Study analysis, PJM used historical tag data from the Settlements archive. The source and sink information for each schedule was derived from its NERC tag, and mapped to equivalenced zones in the state estimator model. Like the IDC, energy from the source zone was assumed to serve the exporting schedule equally across all online generation. Energy sinking to a zone was applied across all active demand in the zone. TARA was then used to generate the TDFs from source zone to sink zone using the saved case that matched the analysis time frame.

$$\text{Exports}_Z = \text{Exports}_A \times (\text{Generation}_Z / \text{Generation}_A)$$

$$\text{Imports}_Z = \text{Imports}_A \times (\text{Demand}_Z / \text{Demand}_A)$$

$$\text{Tagged Impact}_{Z\,X} = \text{Exports}_{Z\,X} \times (\text{GDF}_Z - \text{LDF}_X) \text{ from zone Z to external X}$$

$$\text{Tagged Impact}_Z = \Sigma\, (\text{Tagged Impact}_{Z\,X}) \text{ over all external areas X}$$

For bilateral deliveries internal to a control area, energy from source (generation) to sink (demand) is not tagged. PJM uses a security constrained dispatch to economically balance generation and load across the entire RTO. To reduce complexity, PJM models its control area as separate regions referred to as “control zones”, with each zone representing a market expansion region; this enables PJM to continue to support the OATI IDC. Midwest ISO likewise uses a security constrained dispatch to balance its generation and load by generating interchange schedules for its control areas. The flow from an over-generating control area to under-generating control areas represents its market transfer flow.

Each control zone can then be treated as a net Supply area or Demand area, equivalent to over-generation relative to its local load, and under-generation relative to its local load.

$$\text{Supply}_Z = (\text{Generation}_Z - \text{Exports}_Z) - (\text{Demand}_Z - \text{Imports}_Z)$$

$$\text{Balance}_A = (\Sigma\, \text{Supply}_Z) \text{ over all zones Z in area A} = 0$$

Because of geographic diversity, the generation in an area is often not physically located near the demand, so this creates an opportunity for energy to be distributed across the transmission network as it sinks to the nearest load. If the least impedance path crosses the boundary of transmission operated by one area, and impacts the transmission of a neighboring area, the impact is referred to as a “generation-to-load impact”.

If a zone is over-supplying its native load ($Supply_Z > 0$), then we can assume that all native load in the zone is being supplied by the native generation, and there is excess generation that is serving load in other zones within the same area. Likewise, if a zone is under-supplying its native load, then all of the generation in the zone is serving itself, and there is no excess energy that can be transferred to other zones.

$$\text{Energy for Area}_Z = \text{Generation}_Z - \text{Exports}_Z$$

$$= \text{Energy for Market Transfer}_Z + \text{Energy for Generation-to-Load}_Z$$

Where $Supply_Z > 0$,

$$\text{Energy for Market Transfer}_Z = (\text{Generation}_Z - \text{Exports}_Z) - (\text{Demand}_Z - \text{Imports}_Z)$$

$$\text{Energy for Generation-to-Load}_Z = (\text{Demand}_Z - \text{Imports}_Z)$$

Where $Supply_Z < 0$

$$\text{Energy for Market Transfer}_Z = 0$$

$$\text{Energy for Generation-to-Load}_Z = (\text{Generation}_Z - \text{Exports}_Z)$$

Similar to a control area to control area transaction impact, we can calculate a generation impact on a flowgate for energy that moves from an over-generating zone Z to an under-generating zone Y within the same control area. When there is more than one zone that is under-supplied in the same area, energy is split by supply-ratio share among all of the receiving zones.

$$\text{Market Transfer Impact}_{Z\,Y} = (\text{Energy for Market Transfer}_{Z\,Y}) \times (GDF_Z - LFD_Y) \text{ from zone Z to zone Y}$$

Finally, generation that is allocated to serve native load within the same zone also has a generation-to-load impact based on the zonal distribution factor to a flowgate. Market or non-market, a control area serves its internal load with generation assets that exist within the control area's boundaries. Generation serving this load is not tagged, but because of the topology of the transmission grid, there exists a percentage of energy that flows out of the control area's borders and returns to serve the load. This "generation-to-load" path of energy flow has an impact on a flowgate, which can be calculated as a transfer distribution path of a zone sourcing and sinking to itself:

$$\text{Generation-to-Load Impact}_Z = (\text{Energy for Generation-to-Load}_Z) \times (GDF_Z - LFD_Z)$$

## *Method II: Actual Energy Flow*

One fact in energy transfer is that energy flows on the path of least impedance, and does not completely obey the financial path that marketers would like it to take. Each electron on the grid is indistinguishable once it enters the transmission system, and flow on an individual transmission element cannot be physically "painted" to know its source.

In Method II, each subsystem is modeled to be as small as possible. The actual energy flow in and out of these small subsystem areas is captured through inter-ties. Raw data generated by PJM's EMS state estimator was used to group generators and loads into small areas of the PJM pool. Due to lack of external data, this generator and load grouping into smaller areas was not available for some external regions in this study.

At the control area level, there are imports and exports:

$\text{Imports}_A$ = Energy on ties into area A

$\text{Exports}_A$ = Energy on ties out of area A

The Method II approach to flowgate analysis is to use the generation and demand on an area-by-area basis without bringing economic factors directly into account. Energy carried on the area's inter-ties can be organized into Importing and Exporting based on the direction of flow.

$\text{Balance}_A = (\text{Generation}_A - \text{Exports}_A) - (\text{Demand}_A - \text{Imports}_A) = 0$

$\text{Exports}_A = \text{Imports}_A + \text{Generation}_A - \text{Demand}_A$

In Method II, the energy that is exported from an area can be tracked to energy that is generated locally or to energy that is flowing into the area from a neighbor. Energy that enters an area and flows out can be referred to as "Thru Flow", since the energy is sourced from an outside area sinking to another outside area with energy travelling through the local transmission system.

$\text{Exports}_A = \text{Thru Flow}_A + \text{Energy for Transfer}_A$

If an area is under-generating relative to its native load, then energy flows from the importing ties supports the local load. If an area is over-generating, then the local load is fed by local generation, and the excess generation flows out to the grid.

For each area in the power flow file, we can calculate the net supply:

$\text{Supply}_A = \text{Generation}_A - \text{Demand}_A$

Where $\text{Supply}_A > 0$

$\text{Thru Flow}_A = \text{Imports}_A$

$\text{Energy for Transfer}_A = \text{Generation}_A - \text{Demand}_A$

$\text{Energy for Generation-to-Load}_A = \text{Demand}_A$

Where $\text{Supply}_A < 0$

$\text{Thru Flow}_A = \text{Imports}_A + \text{Generation}_A - \text{Demand}_A$

$\text{Energy for Transfer}_A = 0$

$$\text{Energy for Generation-to-Load}_A = \text{Generation}_A$$

Flowgate impacts are calculated

$$\text{Transfer Impact}_{A\,B} = (\text{Energy for Transfer}_{A\,B}) \times (\text{GDF}_A - \text{LFD}_B) \text{ from area A to neighbor B}$$

$$\text{Generation-to-Load Impact}_A = (\text{Energy for Generation-to-Load}_A) \times (\text{GDF}_A - \text{LFD}_A)$$

The Energy for $\text{Transfer}_{A\,B}$ is calculated from the Energy for $\text{Transfer}_A$, which is the extra energy generated in area A and transferred neighboring areas; it is allocated by the actual energy flows of tie-lines.

## Analysis Results by Region

In conducting the Phase II Study, the flowgates were broken into five geographic regions relative to PJM and Midwest ISO:

- Northeast Region
- PJM/Midwest ISO Central Seam
- PJM/Midwest ISO Northwest Seam, PJM
- PJM/Midwest ISO Northwest Seam, Midwest ISO
- Southeast Region

For each flowgate in the Phase II study, we were able to produce results showing components of flow for each study method. The process produced a large volume of data, so for each geographic region, a select number of flowgates were chosen for additional detailed analysis. The full output of the study for all flowgates over all dates is available at:

> http://www.jointandcommon.com/working-groups/joint-and-common/downloads/20081114-loop-flow-study-full-list-of-flowgates.zip

Modeling information for the analysis below is sourced from PJM's EMS state estimator, which limits the accuracy of the results for external systems. PJM's real-time power flow model is the result of merging the transmission models of internal transmission companies combined with equivalent models of external areas. This reduction ensures that the impedance values of the transmission network are equivalent, however, line flow from the model at nodal levels will no longer match actual observed flows.

To increase the accuracy of the model used in the Phase II Study, control areas would require a combined model updated by all partners in the interconnection. Such a model currently exists in the OATI IDC, updated by local control centers using SDX. The IDC only offers a limited window of time where calculated data can be downloaded for archiving. As of the fall of 2008, historical models, tags, and distribution factors are not available for the chosen dates.

Given the data release issues and time required to obtain NERC tags for Phase I, PJM and Midwest ISO have chosen not to pursue gathering interconnection-wide tag data for the Phase II study. Because PJM only has access to historical tags that intersect the PJM control area, we cannot accurately reproduce parallel path flows unless the tag is a "wheeling" schedule whose contract path crosses PJM's border.

# *Northeast Region*

| | |
|---|---|
| 20 | Erie West-Erie South 345 kV line |
| 23 | Roseland-Cedar Grove F 230 kV l/o Roseland-Cedar Grove B |
| 9159 | ONT-ITC |
| 7102 | QFW-(Queenston Flow West) |

Flowgates in the Northeast Region are impacted by Lake Erie loop flow. The report contains detail information on two of the Northeast Region flowgates, flowgate 23 and flowgate 9159.

## Flowgate 23

Flowgate 23 was chosen since it is the most frequently congested flowgate near the border between NYISO and PJM.  Figures 1 and 2 show the impact of each entity at every half hour on December 5, 2007. Figure 1 is the result using Method I, which is based on contract path. PJM only has the transaction data between PJM and other entities, but PJM does not have the transaction information from one external entity to another external entity. The impact of other entities is insufficient, thus, PJM is shown as the only entity having a large impact.

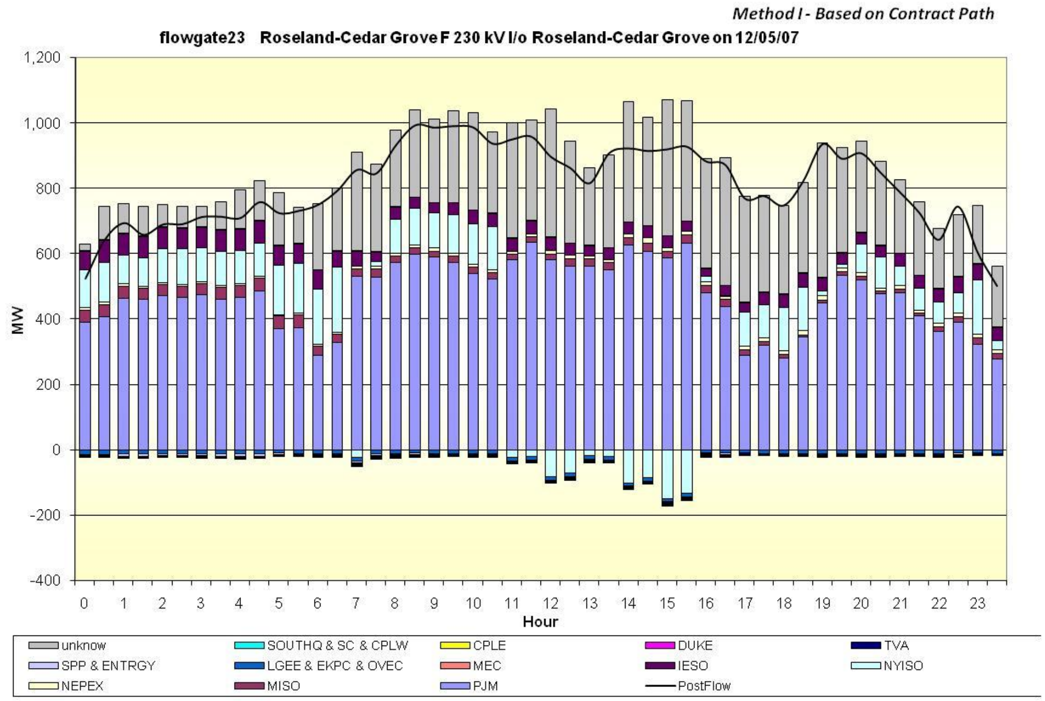


Figure 1: Impact of entities on Flowgate 23 by using Method I

Method II results indicate that PJM and NYISO flow impacts are about equal on flowgate 23 (Figure 2). Unknown flows make up the remaining third of the flows observed on flowgate 23 in Method II.

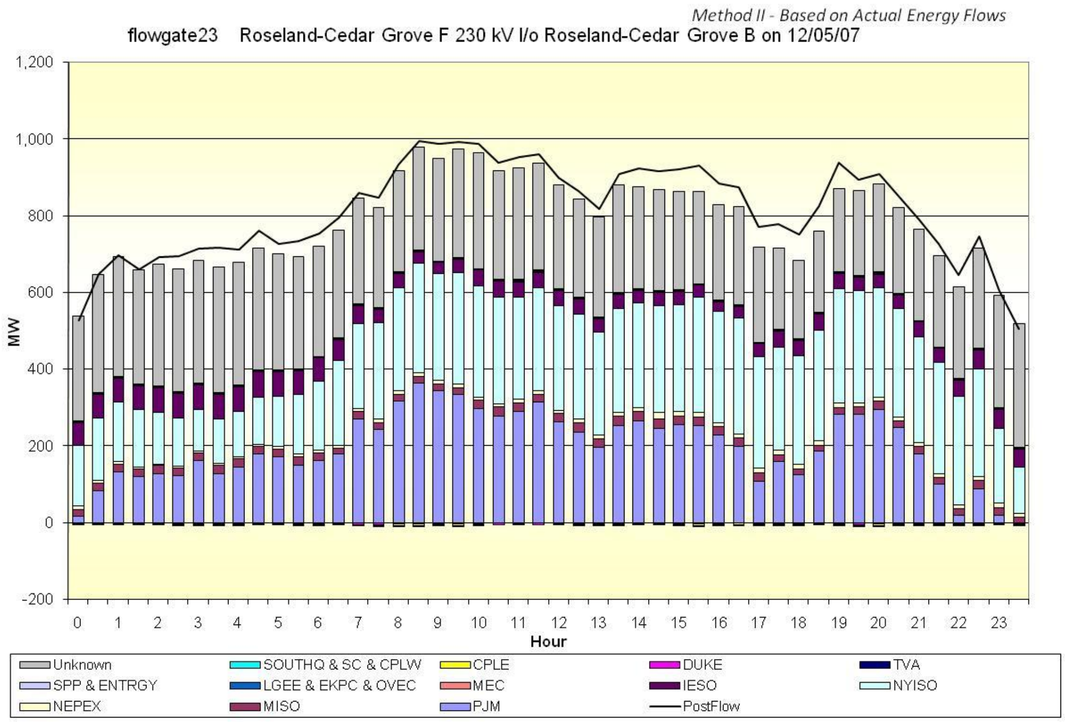


Figure 2: Impact of entities on Flowgate 23 using Method II

Figure 3 and 4 provide one snapshot of data to reveal further information. Figure 3 shows generation-to-load impact, market transfer impact and tagged impact at 8:30 on December 5, 2007. The impacts to Flowgate 23 at this time are mainly caused by PJM's markets. PJM exports to NYISO make up approximately half of PJM's impact on flowgate 23 while PJM generation serving load in Public Service North makes up the other half of PJM's impact. NYISO generation-to-load makes up about one-third of the total impact observed on flowgate 23, which is UPNY's generation supporting SENY's load. Additionally, circulation flow of about 1,000 MW is observed among PS, SENY, RECO in the counter-clockwise direction (Figure 4).

The areas surrounding Flowgate 23 are PS, JC, RECO, UPNY and SENY. UPNY had 4,000 MW of extra generation at 8:30 on December 5, 2007 while all other areas were short of generation, as shown in Table 1. The transfer impacts of UPNY's extra generation on its neighbors are shown in Table 2.

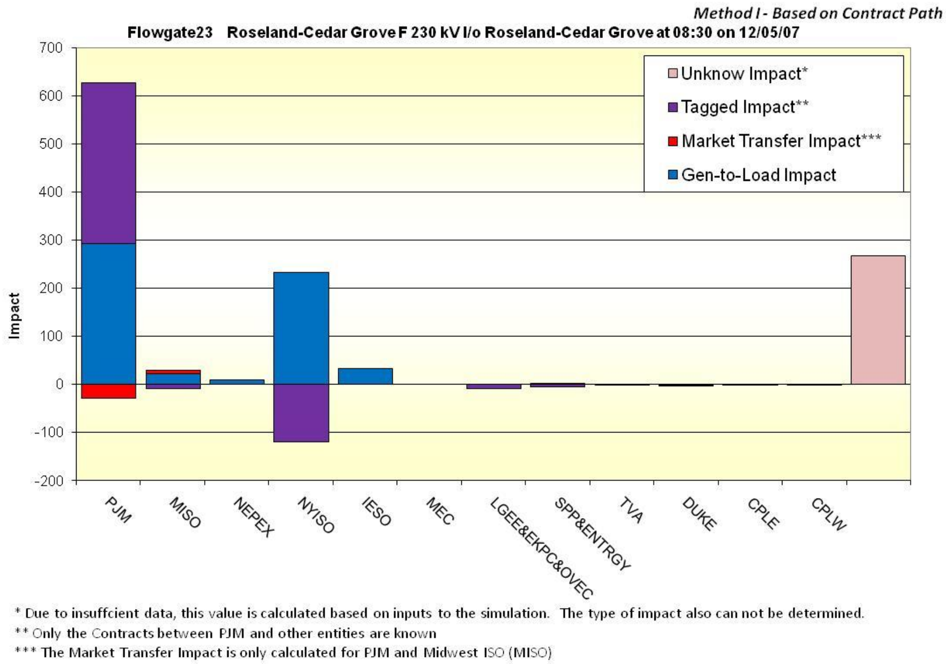


Figure 3: Different types of impact on Flowgate 23 at 8:30 on 12/05/07

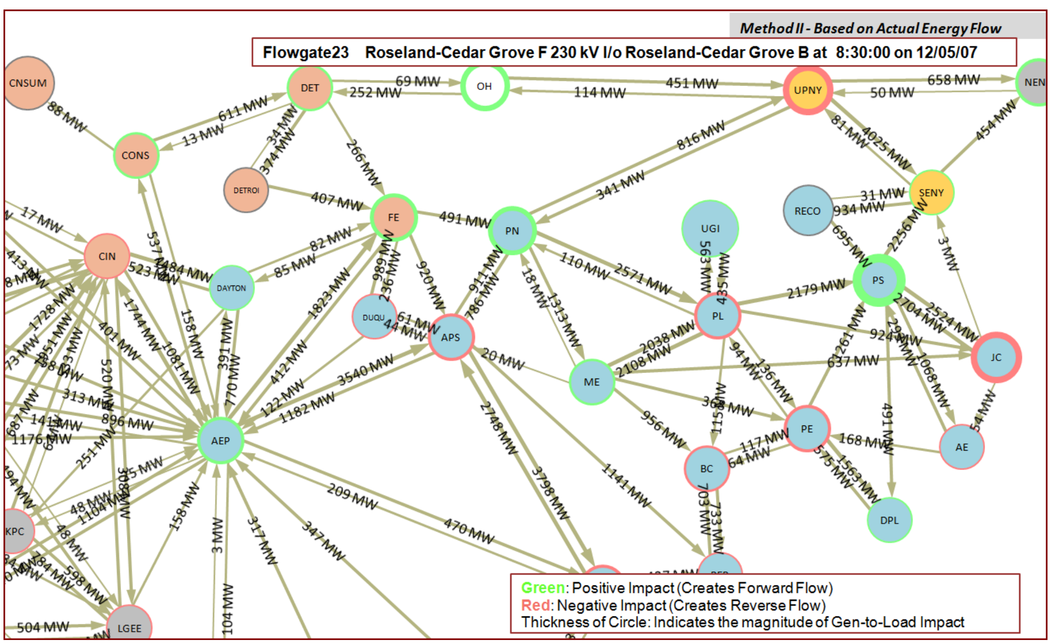


Figure 4: Snapshot of actual energy flow at 8:30 on 12/05/2007

Table 1: Generation-to-Load Impact of areas surrounding Flowgate 23

| Date | Time | Area | Gen | Load | Losses | Export | Import | Dfax | Generation-to-Load Impact |
|---|---|---|---|---|---|---|---|---|---|
| 12/05/07 | 8:30:00 | PS | 5276 | 5978 | 90 | 6336 | -7132 | 0.072 | 379.9 |
| 12/05/07 | 8:30:00 | JC | 1923 | 3176 | 72 | 2761 | -4085 | -0.029 | -56.3 |
| 12/05/07 | 8:30:00 | RECO | 0 | 206 | 1 | 726 | -9338 | -0.001 | 0 |
| 12/05/07 | 8:30:00 | UPNY | 5151 | 1116 | 296 | 5138 | -1398 | -0.043 | -61.3 |
| 12/05/07 | 8:30:00 | SENY | 4000 | 8765 | 81 | 1469 | -6315 | 0.001 | 3.6 |

Table 2: Transfer Impact between areas surrounding Flowgate 23

| Date | Time | From Area | To Area | TDF | Transfer Impact |
|---|---|---|---|---|---|
| 12/05/07 | 8:30:00 | UPNY | PN | -0.125 | -31.0 |
| 12/05/07 | 8:30:00 | UPNY | SENY | 0.079 | 232.0 |
| 12/05/07 | 8:30:00 | UPNY | NENB | 0.047 | 22.7 |
| 12/05/07 | 8:30:00 | UPNY | OH | -0.067 | -5.6 |

## Flowgate 9159

Flowgate 9159 is the interface between the IESO and the Midwest ISO. Figures 5 and 6 show the impact of each entity at every half hour on August 20, 2007. The impacts of entities based on Method I and II are similar. Generation-to-load impacts of NYISO, IESO, and Midwest ISO are counter-clockwise around Lake Erie. PJM generation-to-load impact is clockwise around Lake Erie. One significant impact was from IESO's generation-to-load impact of about 550 MW in the counter-clockwise direction (Figure 7). Schedules from PJM to Midwest ISO have a counter-clockwise impact of approximately 300 MW. Schedules from PJM to NYISO have a clockwise impact of approximately 123 MW at 15:00 on August 20, 2007 (Figure 7). Figure 8 shows the counter-clockwise actual flow around Lake Eire.

Based on snapshot data of Tables 3 and 4, transfer impact from UPNY is significant as well, which sent extra generation to SENY and IESO to create the counter-clockwise impacts of 227 MW and the clockwise impacts of 117 MW on Flowgate 9159, respectively. When IESO's extra generation moved to DET, 368 MW counter-clockwise impact was created on Flowgate 9159 at 15:00 on August 20, 2007.

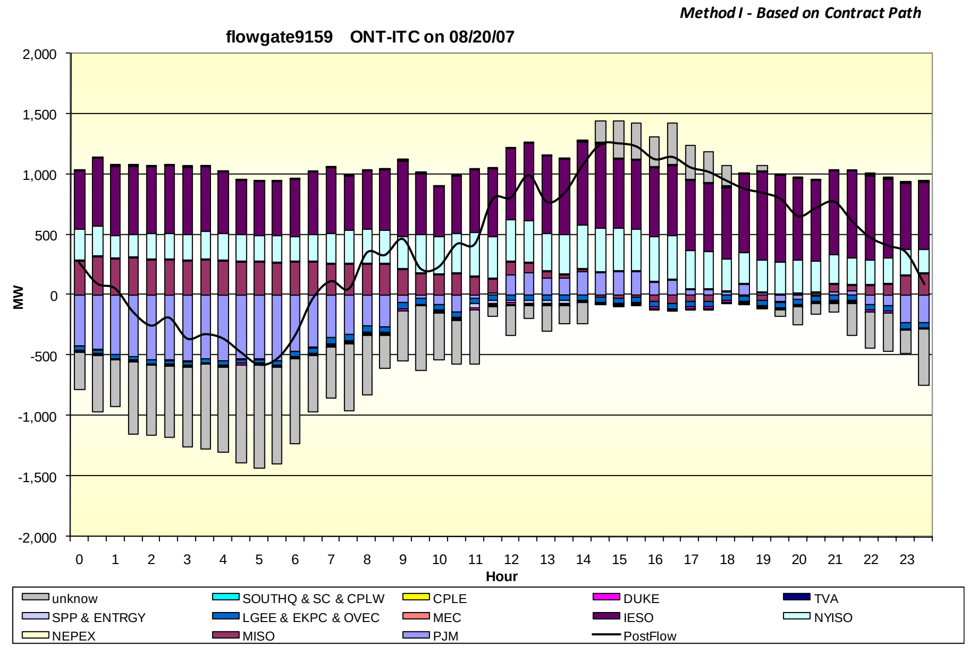


Figure 5: Impact of entities on flowgate 9159 using Method I

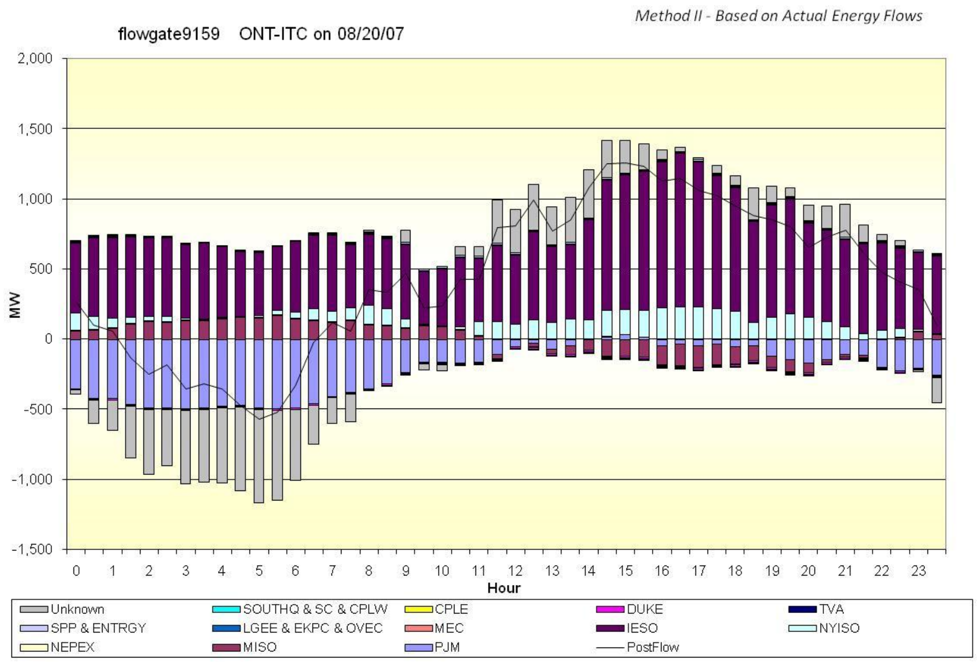


Figure 6: Impact of entities on Flowgate 9159 using Method II

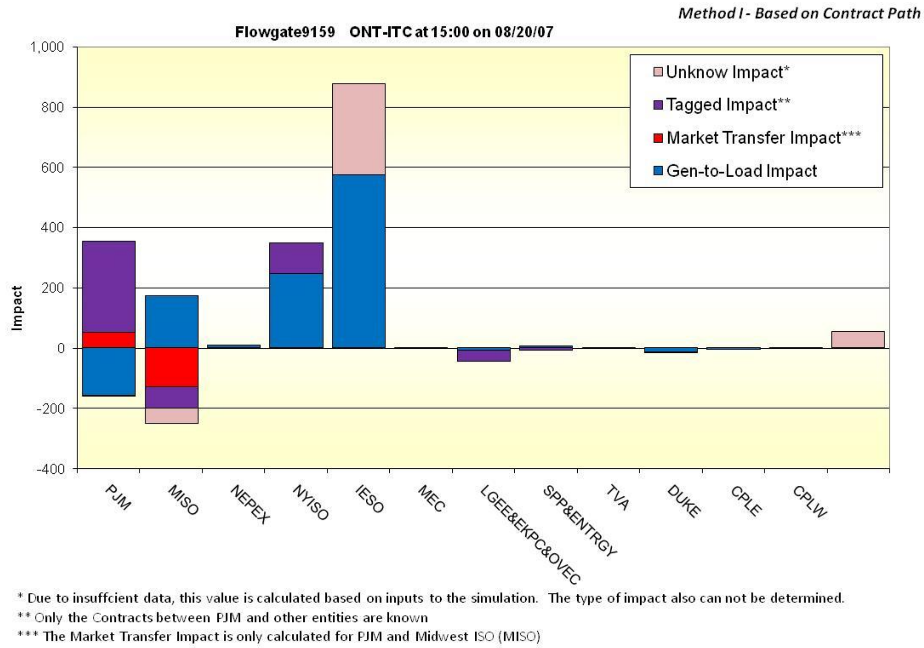


Figure 7: Different types of impact on Flowgate 9159 at 15:00 on 8/20/07

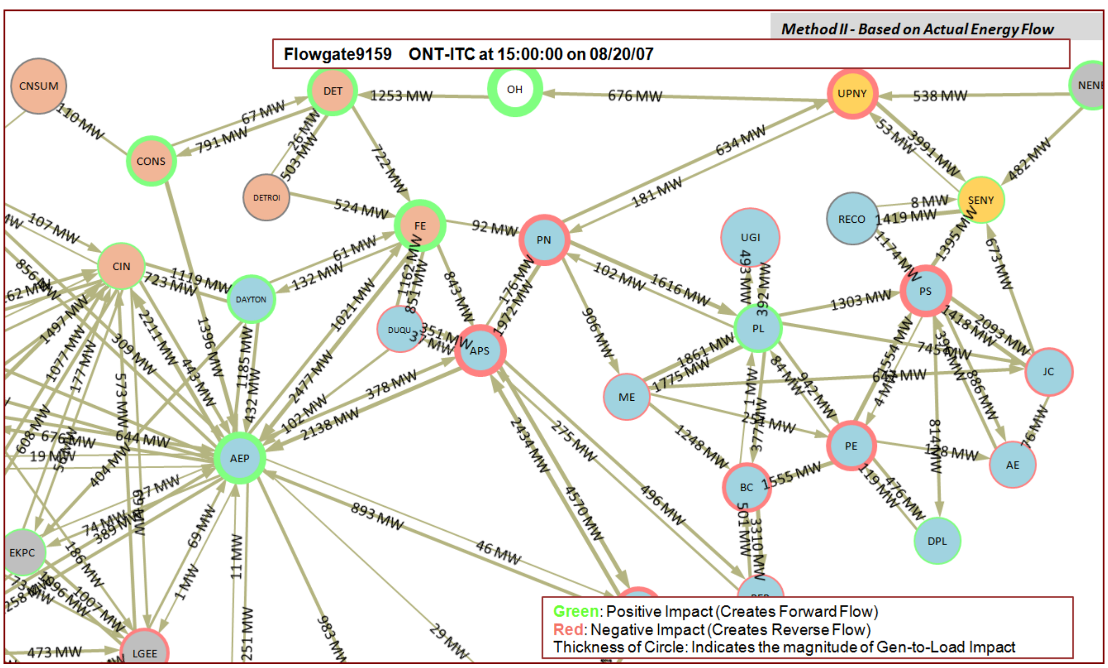


Figure 8: Snapshot of actual energy flow at 15:00 on 8/20/2007

Table 3: Generation-to-Load Impact of areas around Lake Erie

| Date | Time | Area | Gen | Load | Losses | Export | Import | Dfax | Generation-to-Load Impact |
|---|---|---|---|---|---|---|---|---|---|
| 08/20/07 | 15:00:00 | PS | 5566 | 6144 | 73 | 5193 | -5844 | -0.013 | -72.9 |
| 08/20/07 | 15:00:00 | PL | 6788 | 4872 | 130 | 5738 | -3953 | 0.002 | 7.5 |
| 08/20/07 | 15:00:00 | PN | 6833 | 2177 | 79 | 5129 | -551 | -0.024 | -53.0 |
| 08/20/07 | 15:00:00 | APS | 7299 | 5938 | 197 | 7416 | -6252 | -0.012 | -72.4 |
| 08/20/07 | 15:00:00 | AEP | 21749 | 20632 | 719 | 9850 | -9452 | 0.003 | 72.6 |
| 08/20/07 | 15:00:00 | FE | 9894 | 8707 | 283 | 4395 | -3490 | 0.010 | 89.9 |
| 08/20/07 | 15:00:00 | DET | 8121 | 7409 | 41 | 2017 | -1346 | 0.003 | 24.6 |
| 08/20/07 | 15:00:00 | DETROI | 0 | -47 | 0 | 550 | -503 | 0.000 | 0.0 |
| 08/20/07 | 15:00:00 | UPNY | 6164 | 2366 | 174 | 4848 | -1225 | -0.013 | -33.8 |
| 08/20/07 | 15:00:00 | SENY | 4019 | 9026 | 69 | 1472 | -6549 | 0.000 | 1.6 |
| 08/20/07 | 15:00:00 | IESO | 12561 | 11821 | 163 | 1253 | -676 | 0.050 | 596.8 |
| 08/20/07 | 15:00:00 | CONS | 5158 | 4323 | 53 | 1573 | -791 | 0.006 | 27.7 |
| 08/20/07 | 15:00:00 | NEPEX | 8059 | 6972 | 67 | 1020 | 0 | 0.0013 | 9.2 |

Table 4: Transfer Impact between areas around Lake Erie

| Date | Time | From Area | To Area | TDF | Transfer Impact |
|---|---|---|---|---|---|
| 08/20/07 | 15:00:00 | PN | PL | -0.012 | -16.7 |
| 08/20/07 | 15:00:00 | PN | UPNY | -0.151 | -85.3 |
| 08/20/07 | 15:00:00 | DET | FE | -0.137 | -32.9 |
| 08/20/07 | 15:00:00 | UPNY | PN | 0.114 | 15.4 |
| 08/20/07 | 15:00:00 | UPNY | SENY | 0.076 | 227.3 |
| 08/20/07 | 15:00:00 | UPNY | IESO | -0.231 | -116.5 |
| 08/20/07 | 15:00:00 | IESO | DET | 0.639 | 368 |
| 08/20/07 | 15:00:00 | CONS | AEP | -0.079 | -54.5 |

## *PJM/Midwest ISO Central Seam*

| | |
|---|---|
| 100 | Kammer #200 765/500 kV xfmr l/o Belmont-Harrison 500 |
| 122 | Wylie Ridge #7 tx l/o Wylie #5 tx (SPS in-service) |
| 141 | Elrama-Mitchell 138 kV l/o Sammis-Wylie Ridge 345 kV |
| 2470 | Ashtabula-Erie West 345 (flo) Sammis-Wylie Ridge 345 |
| 3270 | State Line-Wolf Lake 138 flo Burnham-Sheffield 345 |
| 2352 | PRNTY-MTSTM500/BLACKO-BEDNGT500 |
| 2353 | BLACKO-BEDNGT500-PRNTY-MTSTM500 |
| 2517 | Northeast Ohio Interface |
| 2519 | Ohio Eastern Interface |

Flowgate100 was selected because it is in the middle of the Midwest ISO/PJM RTO seam and is a reciprocal flowgate. Before using TARA, PJM only had PJM and Midwest ISO historical market flow data which left a large portion of impacts unknown as shown in Figure 9. TARA was able to identify the impact of others, even though the unknown portion still existed. The Kammer flowgate shows the impacts from many entities other than the Midwest ISO and PJM, as shown in Figures 10 and 11. Figure 12 shows a snapshot of the energy flows, the thickness of the line and circle indicates the magnitude of generation-to-load impact.

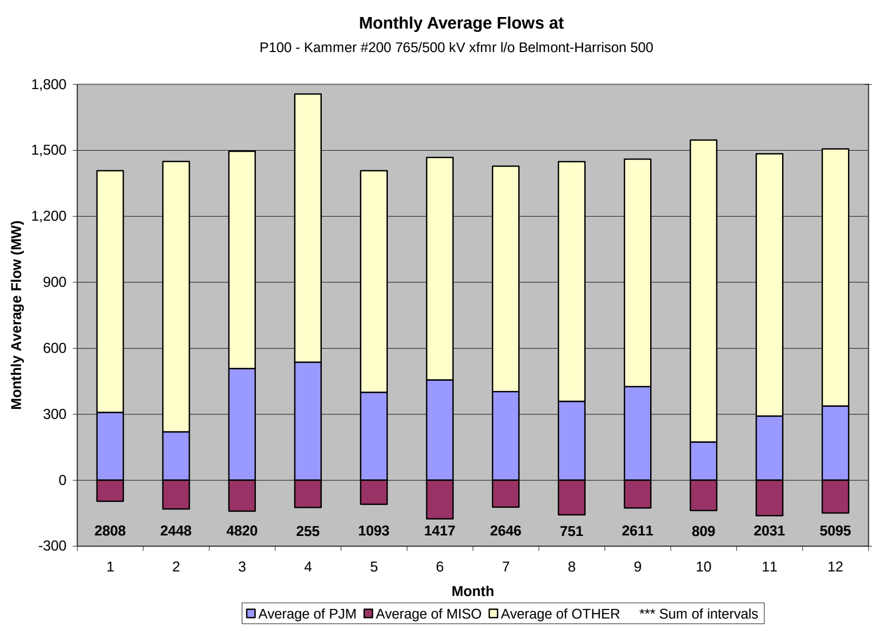


Figure 9: PJM and Midwest ISO market flow data

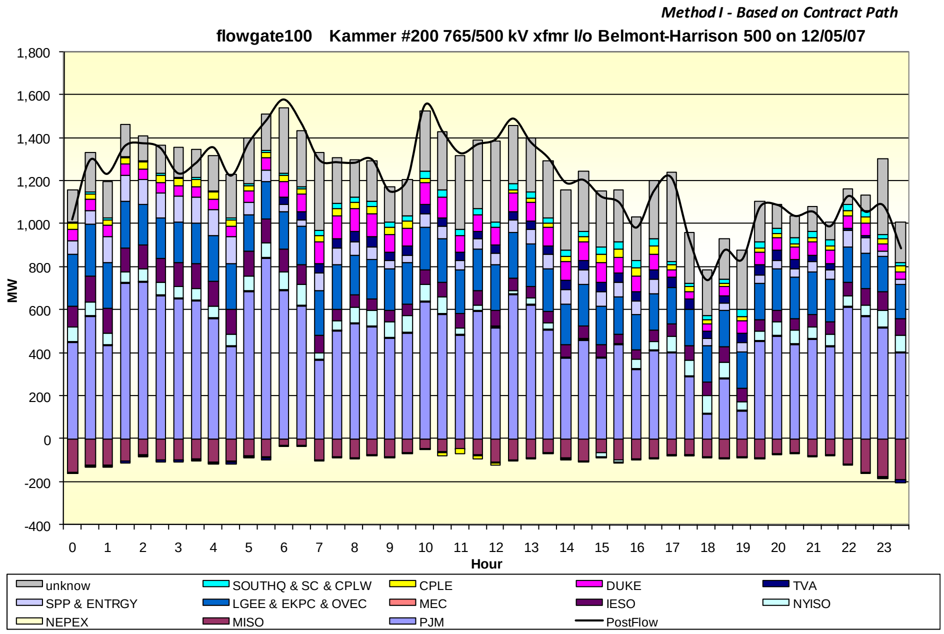


Figure 10: Impact of entities on Flowgate 100 using Method I

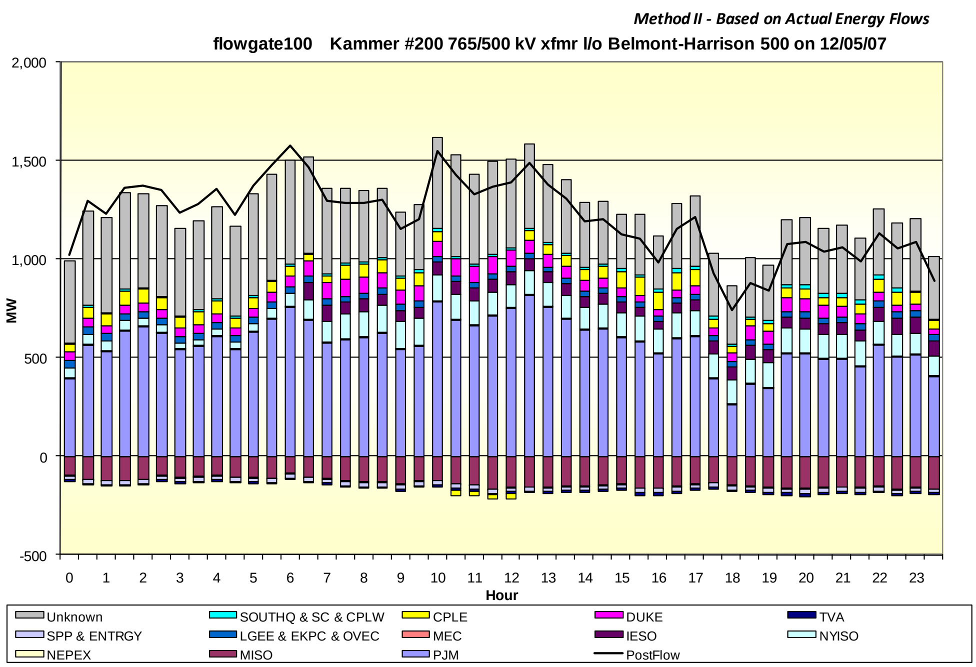


Figure 11: Impact of entities on Flowgate 100 using Method II

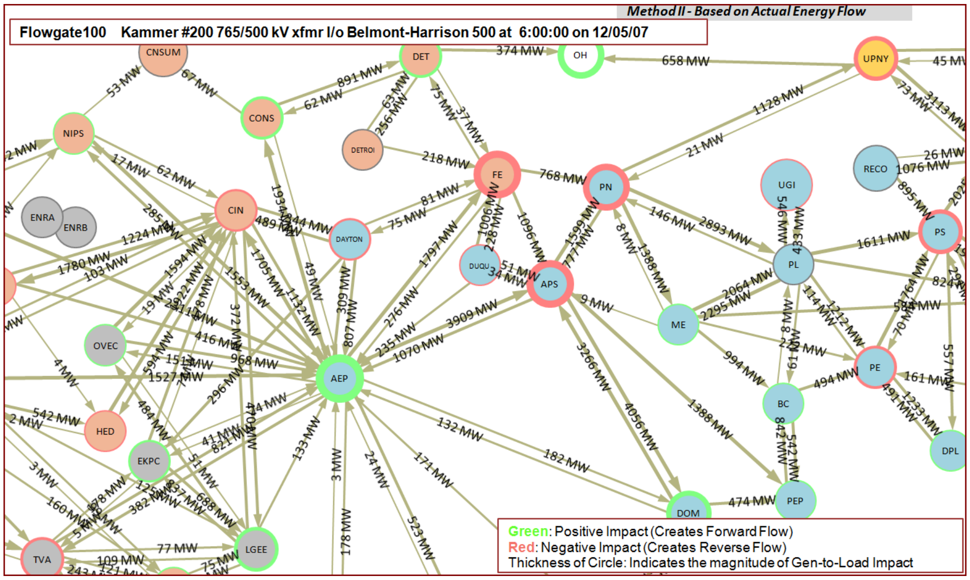


Figure 12: Snapshot of actual energy flow at 6:00 on 12/05/2007

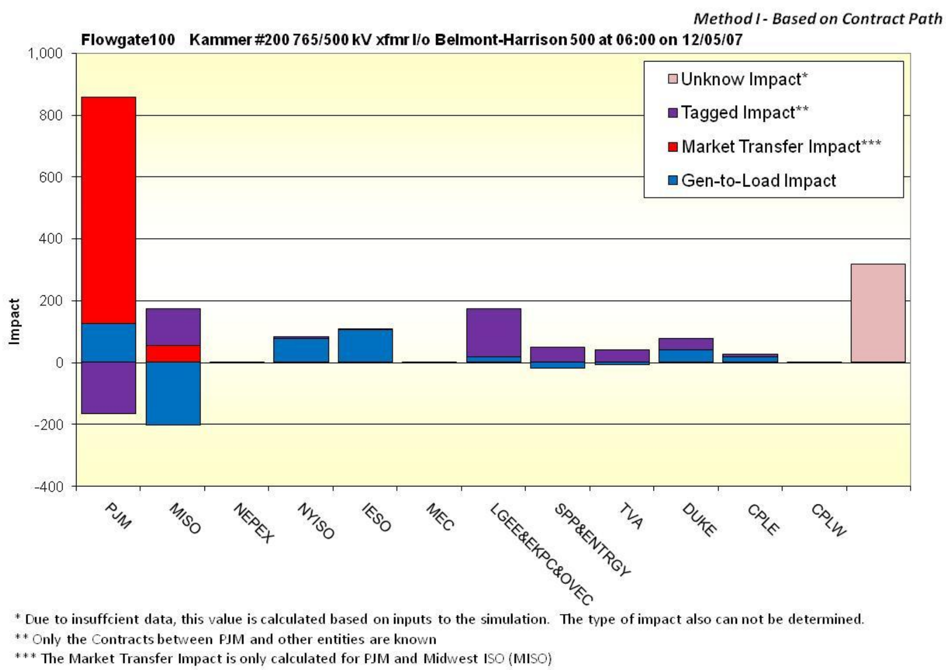


Figure 13: Different types of impact on Flowgate 100 at 6:00 on 12/05/07

Figure 13 indicates that major flowgate impact is from PJM's market transfer flows, which is from ComEd to APS, MIDATL and DOM. Generation-to-load impacts from the Midwest ISO zones have a reverse flow impact of 100 MW. Schedules from OVEC to PJM have a positive flow impact of 157 MW. Schedules from TVA to PJM have a positive flow impact of 41 MW.

## *PJM/Midwest ISO Northwest Seam, PJM*

| | |
|---|---|
| 500 | Pontiac-Wilton Center 345 kV l/o Pontiac-Dresden 345 k |
| 291 | Pierce B 345/138 kV transformer l/o Pierce-Foster 345 |
| 2336 | BentnHrbr-Palisades345/Cook-Palisades345 |
| 2377 | Darwin-Eugene 345 kV l/o Jefferson-Rockport 765 kV |
| 2980 | Dune Acres-Michigan City 138 1&2 (flo) Wilton Center-Dumont 765 |
| 3250 | 155 Nelson-111 Electric Junction (15502) 345 kV l/o Cherry Valley-Silver Lake(15616) 345 kV |

Figures 14 and 15 both show that PJM has a large impact on Flowgate 3250. PJM's impact mainly came from ComEd area with a generation-to-load impact of about 800 MW. Except for serving load (12,000 MW), ComEd generation provided another 3,000 MW of generation to outside areas.

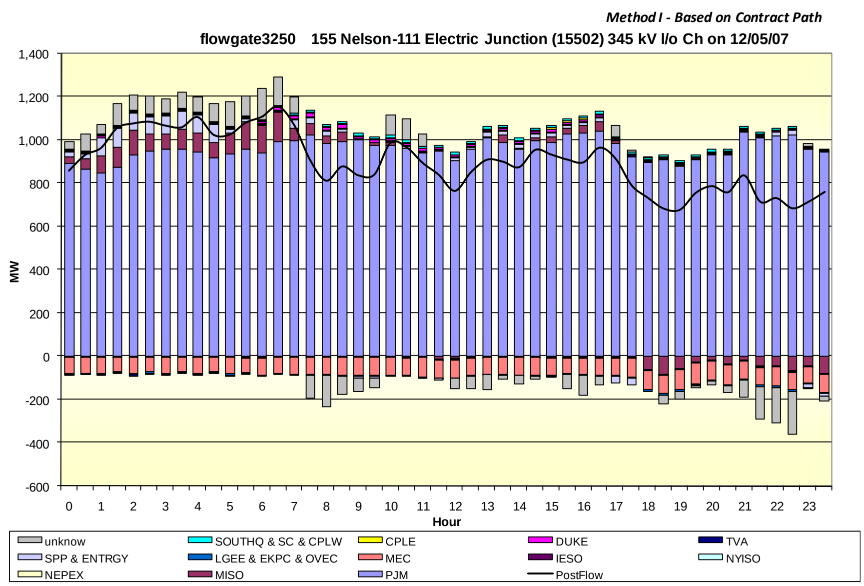


Figure 14: Impact of entities on Flowgate 3250 using Method I

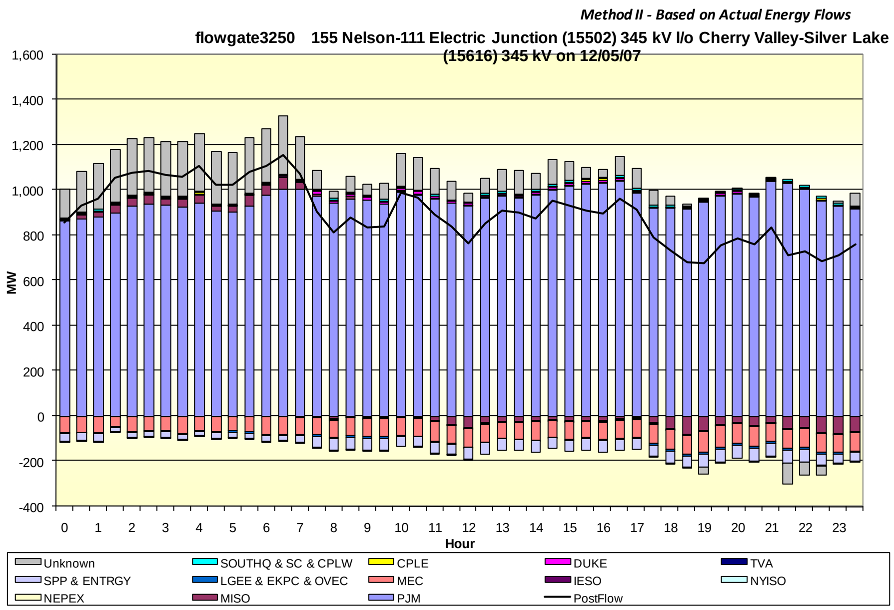


Figure 15: Impact of entities on Flowgate 3250 using Method II

## *PJM/Midwest ISO Northwest Seam, Midwest ISO*

| | |
|---|---|
| 6004 | MWSI (Minnesota Wisconsin Stability Interface) |
| 6007 | GENTLMN3 345 REDWILO3 345 1 |
| 6126 | S1226-Tekamah 161kV flo S3451-Raun 345kV |
| 6164 | Plymouth-Sioux City 161kV flo Raun-Sioux City 345kV |
| 6168 | Hills-Parnell 161kV flo Hills-Montezuma 345kV |
| 14551 | Alma-Elk Mound 161 FLO King-Eau Claire-Arpin 345 |
| 3529 | N. Appleton-Werner W. 345 |
| 3532 | Ellington-Hintz 138 for N.Appleton-Werner West 345 |
| 3706 | Arnold - Hazleton |
| 3006 | EAU CLAIRE-ARPIN 345 KV |
| 2086 | Newtonville 138/161 Xfm T3 flo Newtonville 138/161 Xfm T5 |
| 3012 | Paddock 345/138 Xfm (flo) Wempletown-Rockdale 345 |
| 3145 | PANA XFMR + COFFEEN-COFFEEN NORTH |
| 3167 | St. Francois – Lutesville 345KV |
| 3352 | Lanesville Xfmr 345/138kV (flo) Kinc-Lath-Pont & Kinc-Pawnee |

Figures 16 and 17 show entities other than Midwest ISO may have a large impact on Flowgate 2086. TVA provided around 1,500 MW of extra generation to outside region at 13:30 on August 8, 2007; most of the flows moved to AEP and SOUTH_EQ. Further analysis cannot be completed since PJM does not have enough information about transaction data of TVA and other entities.

At 16:30 on August 8, 2007, the tie-line from Bus GIBSON2 in CIN area to Bus DUFF in SIGE area was open, which increased the reverse flow on Flowgate 2086.

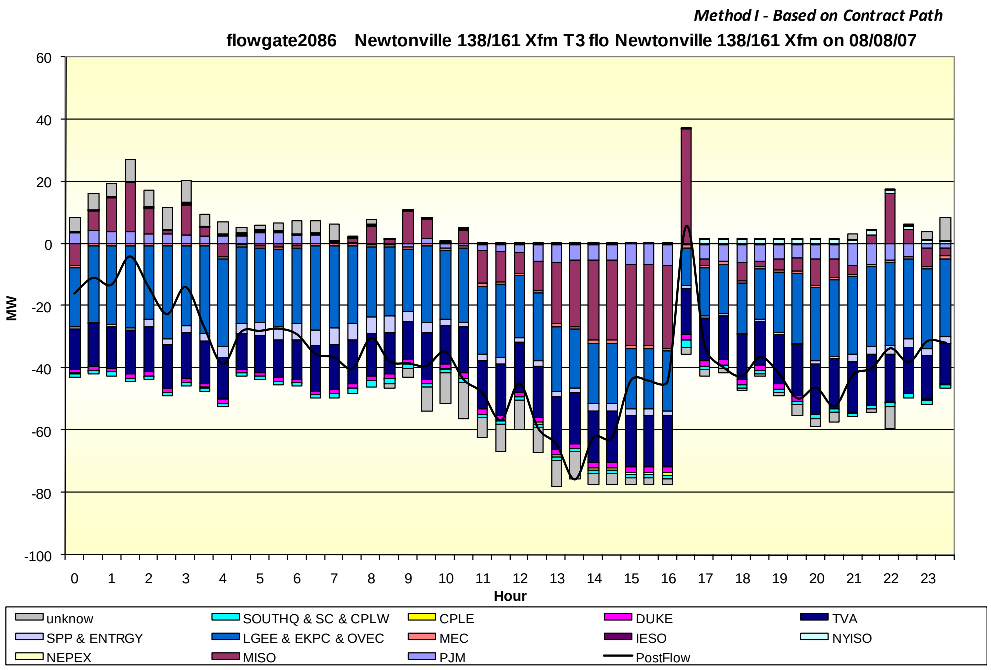


Figure 16: Impact of entities on Flowgate 2086 using Method I

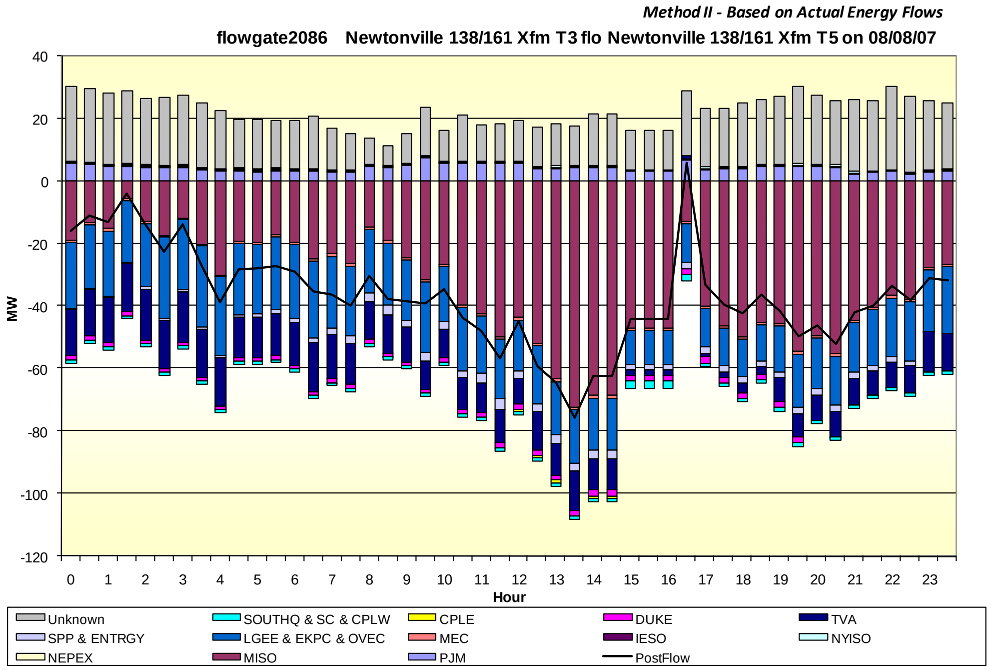


Figure 17: Impact of entities on Flowgate 2086 using Method II

## *Southeast Region*

| | |
|---|---|
| 310 | Person-Halifax 230 kV line l/o Wake-Carson 500 kV |

The Person-Halifax flowgate is on the PJM/Progress Energy interface, which is impacted by large volumes of loop flows. TLRs were unsuccessful in effectively managing loop flows in late August and early December of 2007. August 20, 2007 and December 5, 2007 represent days of extreme opposites for PJM's southeast interface; large amounts of energy flowed from north-to-south on August 20, 2007. December 5, 2007 experienced the opposite, where large amounts of energy flowed from south-to-north. This is demonstrated in Figures 18 and 19.

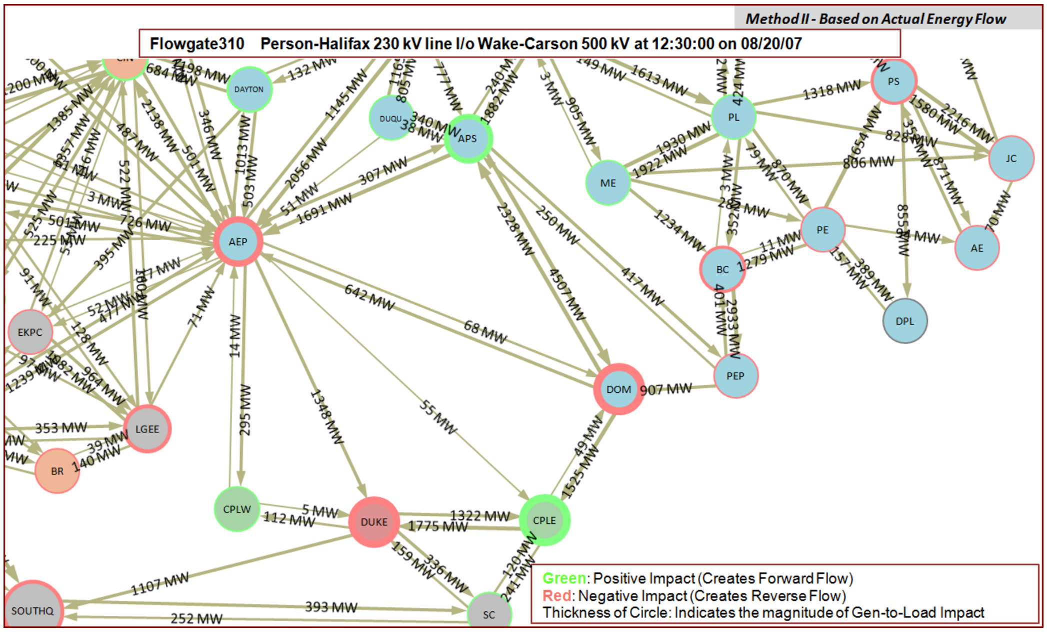


Figure 18: Snapshot of actual energy flow at 12:30 on 8/20/2007

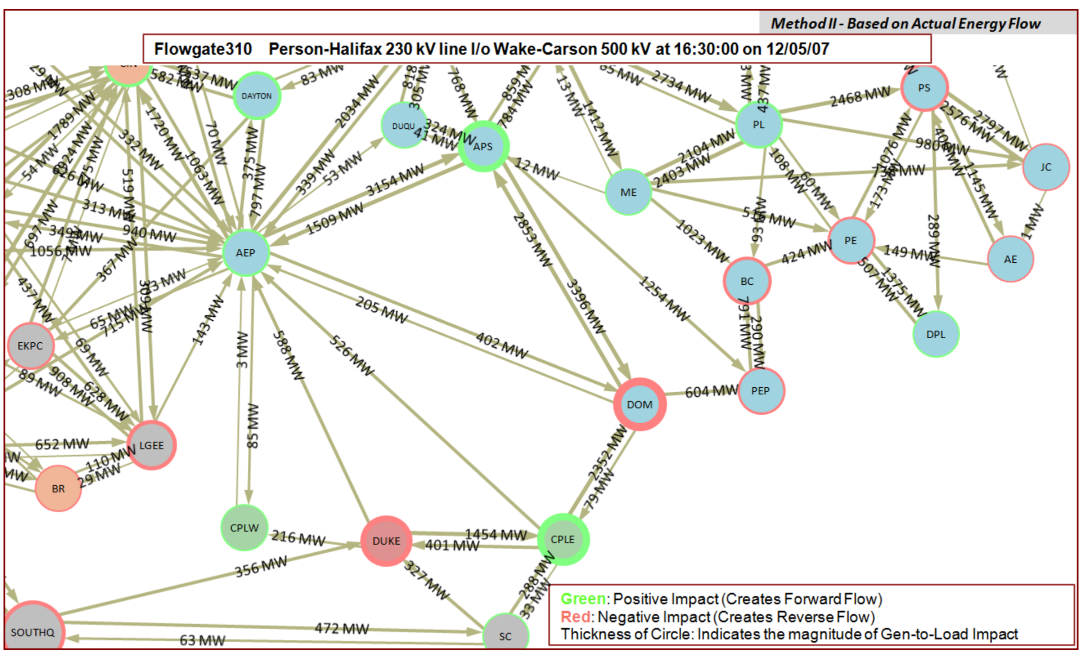


Figure 19: Snapshot of actual energy flow at 16:30 on 12/05/2007

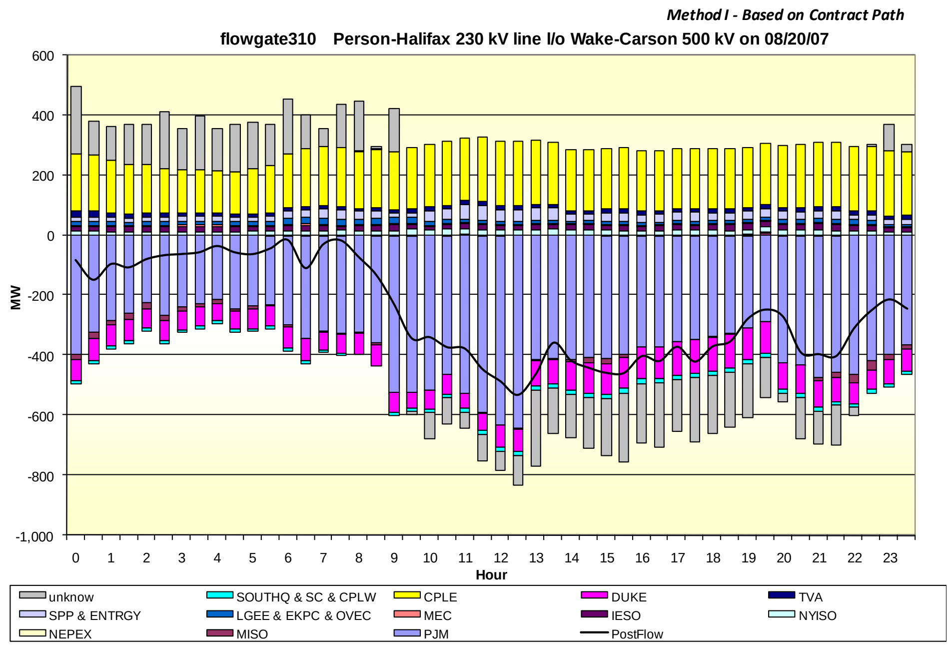


Figure 20: Impact of entities on Flowgate 310 using Method I on 8/20/07

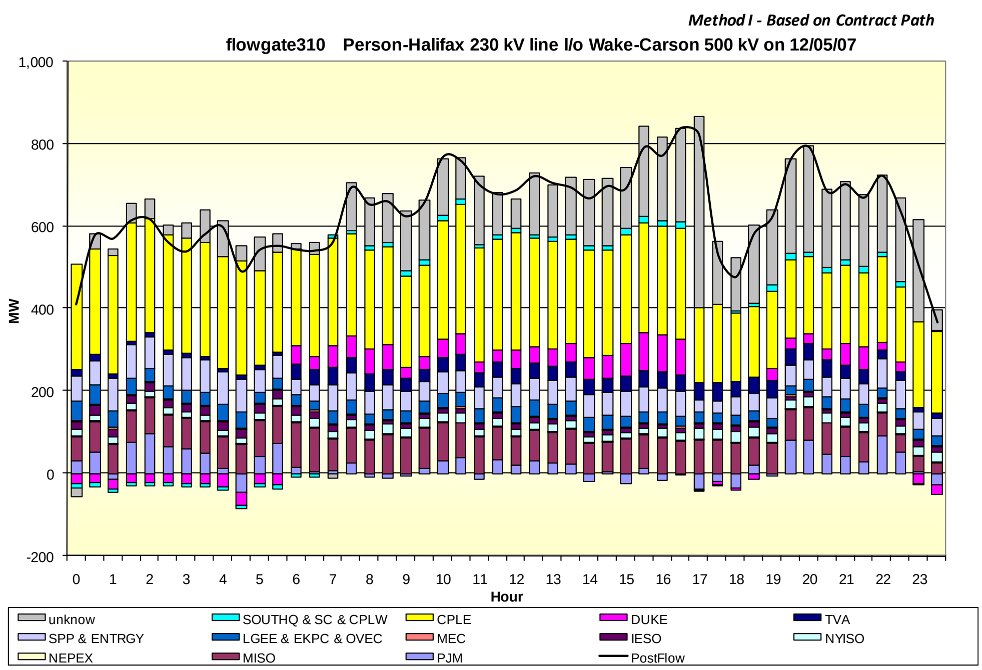


Figure 21: Impact of entities on Flowgate 310 using Method I on 12/05/07

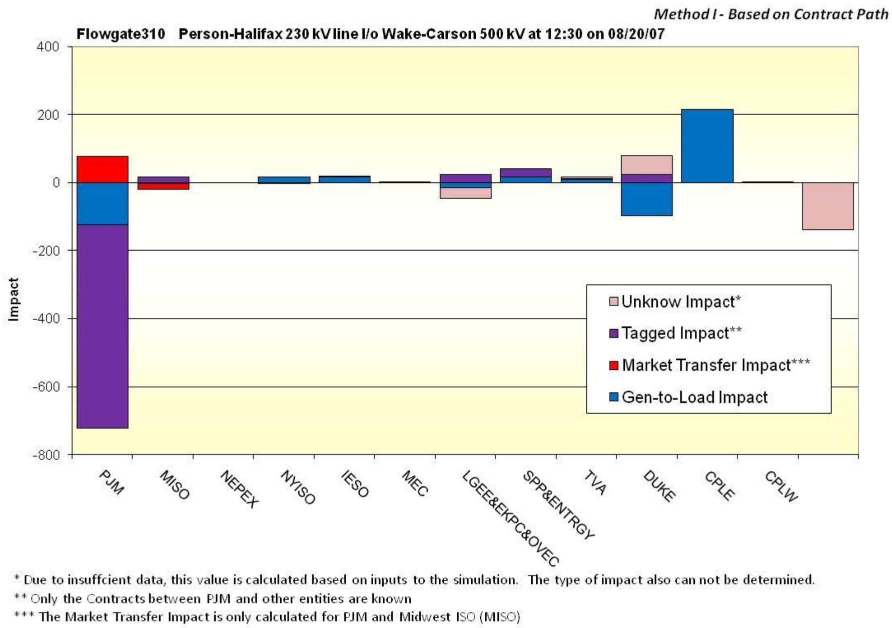


Figure 22: Different types of impact on Flowgate 310 at 12:30 on 8/20/07

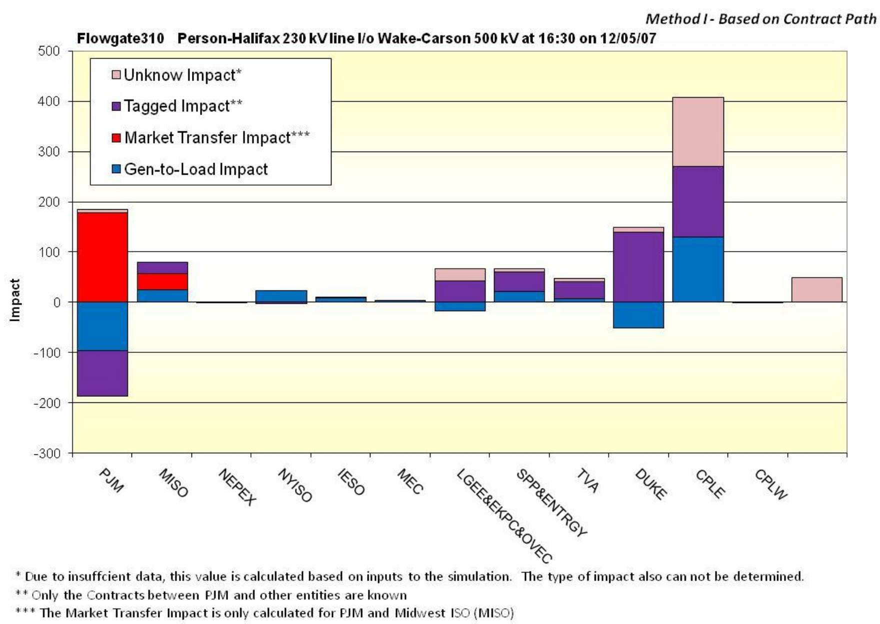


Figure 23: Different types of impact on Flowgate 310 at 16:30 on 12/05/07

Table 5: Generation-to-Load Impact of areas having big impact on Flowgate 310

| Date | Time | Area | Gen | Load | Losses | Export | Import | Dfax | Generation-to-Load Impact |
|---|---|---|---|---|---|---|---|---|---|
| 08/20/07 | 12:30:00 | APS | 7077 | 5882 | 187 | 6893 | -5885 | 0.008 | 46.1 |
| 08/20/07 | 12:30:00 | AEP | 21662 | 19919 | 659 | 9171 | -8087 | -0.003 | -67.9 |
| 08/20/07 | 12:30:00 | DOM | 12905 | 13637 | 303 | 4496 | -5531 | -0.015 | -197.4 |
| 08/20/07 | 12:30:00 | CPLE | 7054 | 7873 | 140 | 2065 | -3022 | 0.030 | 214.5 |
| 08/20/07 | 12:30:00 | DUKE | 16085 | 16189 | 306 | 2877 | -3287 | -0.007 | -104.6 |
| 08/20/07 | 12:30:00 | MIDATL | 40172 | 35586 | 637 | 6210 | 2261 | | 45 |
| 12/05/07 | 16:30:00 | APS | 6489 | 7081 | 244 | 7060 | -7895 | 0.012 | 74.6 |
| 12/05/07 | 16:30:00 | AEP | 19543 | 18947 | 654 | 9516 | -9573 | 0.000 | 3.9 |
| 12/05/07 | 16:30:00 | DOM | 11293 | 13402 | 300 | 3741 | -6150 | -0.022 | -250.7 |
| 12/05/07 | 16:30:00 | CPLE | 6123 | 4467 | 166 | 3311 | -1821 | 0.029 | 133.0 |
| 12/05/07 | 16:30:00 | DUKE | 12398 | 11030 | 194 | 2257 | -1083 | -0.005 | -51.6 |
| 12/05/07 | 16:30:00 | MIDATL | 41082 | 40799 | 885 | 3825 | -4426 | | 24 |

MIDATL had 4,000 MW extra generation and the schedules from PJM to south entities were about the same amount on August 20, 2007, which created 400 MW of north-to-south flow which negatively impacted on Flowgate 310. PJM generation-to-load is north-to-south due to Clover generation location relative to this flowgate. PJM market transfer impact is south-to-north as a result of ComEd and AEP generation looping through CPLE. Duke generation-to-load impacts Flowgate 310 in a north-to-south direction by about 100 MW. CPLE generation-to-load impacts Flowgate 310 in a south-to-north direction by about 200 MW (Figure 22).

CPLE and DUKE had 2,000 MW and 1,000 MW extra generation on December 5, 2007, respectively. Schedules into PJM from southern entities were about 3,000 MW, which negatively impacted Flowgate 310 by 350 MW of south-to-north flow. Same as August 20, 2007, PJM generation-to-load is north-to-south while PJM market transfer impact is south-to-north. Duke generation-to-load impacts flowgate 310 in a north-to-south direction by about 60 MW. CPLE generation-to-load impacts flowgate 310 in a south-to-north direction by about 120 MW (Figure 23).

# Conclusions

The Phase II Study was designed to investigate the source of parallel flow on flowgates. By incorporating transaction, generation, demand and transmission configurations, PJM and Midwest ISO were able to conduct power flow studies to reduce the causes of flow on impacted flowgates to three broad categories: Tagged Impacts from generation serving transactions, Market Transfer Impacts from multi-zonal markets like PJM and Midwest ISO, and Generation-to-Load Impacts from any control area with generation serving internal load.

Over the studied dates, each market and non-market entity studied transferred large amounts of actual energy flows from beyond their immediate area. Many times, the actual flow of energy through the transmission network far exceeded the difference in generation and demand. Table 6 below is based on three days' data (August 8, 2007, August 20, 2007, and December 5, 2007) from PJM's EMS state estimator. These days represent days where significant congestion, parallel path flows and/or TLR activity occurred on the PJM and Midwest ISO systems.

Table 6: Average generation, demand, export and import over study period, in Megawatts

| Area | Generation | Demand | Actual Exports | Actual Imports |
|---|---|---|---|---|
| PJM | 98,127 | 93,786 | 16,841 | 12,499 |
| Midwest ISO | 51,913 | 53,928 | 11,981 | 13,996 |
| NYISO | 9,651 | 10,616 | 2,671 | 3,636 |
| IESO | 12,084 | 12,649 | 509 | 1,076 |
| DUKE | 13,792 | 13,686 | 2,256 | 2,150 |
| CPLE | 6,341 | 6,334 | 1,929 | 1,921 |
| TVA | 7,001 | 7,081 | 2,797 | 2,877 |

One limiting factor in quantifying all flowgate impacts in the Phase II Study was a lack of consistent data. The Phase II Study shows that much of the source of flow on the flowgates cannot be determined with readily available data without using simulation tools.

PJM and Midwest ISO each possess models of their transmission grids within their EMS state estimators, with additional equivalenced representations of external control areas. While these models are extensive, they are not as large a scope as what is used by the IDC. However, the IDC does not publish archives of its historical models, does not publish NERC tag data for the eastern interconnection past a two day window, and does not retain transfer distribution factors except on TLR issuances.

The Phase I Study recommended working with OATI to create a shared archive of historical IDC data for use in historical analysis. The Phase II Study also recommends the creation of an archive to store the contracts used by the IDC, market flows, and transfer distribution factors to aid in data mining.

The purchasing and selling of energy through NERC tags is commonplace on the Eastern Interconnection. The Phase II Study used power flow simulations to show the distribution of tagged schedules and their impacts on the selected flowgates. Entities in the Eastern Interconnection rely on the IDC to calculate the tagged impacts on their behalf, and together use the tool to manage congestion by curtailing schedules that negatively impact constrained flowgates.

However, tagged impacts are not the only cause of flow and thus curtailing schedules is not the only solution. A Congestion Management Process provides a mechanism to calculate and monitor “market flow” impacts on flowgates. The Joint Operating Agreement between PJM and Midwest ISO provides the system operators with market-to-market re-dispatch options to manage loop flows. PJM and Midwest ISO recommend that neighboring control areas, which have not yet done so, implement a Congestion Management Processes similar to the one currently in place between the Midwest ISO and PJM, and are encouraged to enter into joint operating agreements to improve constraint management.

One outcome of the Phase II Study was to show that all control areas, market and non-market alike, have generation-to-load sources of impact on flowgates. The IDC allows the reporting of “market flows”, which are the summation of market transfer impacts and generation-to-load impacts. Currently, only PJM, Midwest ISO and SPP calculate and report market flows, while the impact of the remainder of the eastern interconnection is largely unknown. Using TARA, PJM and Midwest ISO can approximate the impact of neighboring generation, which infers that the IDC power flow model could be used to calculate generation-to-load impacts for entities that choose not to calculate impacts themselves. The Midwest ISO and PJM recommend that all of the entities in the Eastern Interconnect work to improve the transparency of their systems by calculating and reporting their generation-to-load impacts to the IDC.