Ontario-Michigan Interface PAR Performance Evaluation Report

Final Report

IESO, MISO, PJM

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Executive Summary

Introduction

The Phase Angle Regulator transformers (PARs) on the Ontario-Michigan interface began regulating flow on the interface to schedule on April 5, 2012 after an amended Presidential Permit was approved by the DOE. An IESO-MISO Operating Agreement (IESO-MISO-C02) was developed to specify how IESO and MISO operators should manage flow to schedule on the interface. The agreement states that loop flow across the interface will be considered controlled when actual flow is within ±200 MW of scheduled flow. Because of various outages involving the Ontario-Michigan interface PARs, the interface was not being controlled by a full set of PARs until July 18, 2012. Therefore, data collection used in this analysis began in August 2012. Details on how well loop flow was controlled from August 2012 to August 2013 are provided in this report.

Conclusion

This report shows that PARs were able to keep Lake Erie loop flow within a ±200 MW control band during 73.1% of the 15-minute periods during the one-year study period. The simulated loop flow calculated without PAR control would only have been within the control band for 43.4% of the year. During most of the periods that the loop flow strayed outside the 200 MW bandwidth, the flow was over by a small margin and the flow was expected to return within the 200 MW bandwidth within the next few 15-minute periods. Theoretically, the PARs had the capability to control the loop flow within the 200 MW control bandwidth up to 99.1% of the year, although actual operation of the PARs did not produce a percentage of control that high. Though loop flow spent a portion of the study year outside of the control band, the PARs provided benefit through correction at all times of excessive loop flow. The difference between the actual (73.1%) percent of time the interface was within the control band, and the theoretical capability (99.1%) can be attributed to:

- the interface being in Unregulated mode (PARs not available to fully control the interface) during certain periods of the year due to local congestion, unavailability of taps, or other factors,
- time delays between the time loop flow strays outside the 200 MW bandwidth and a manual tap movement is accomplished,
- operators' decision that a tap movement may not be warranted where Lake Erie loop flow is expected to return within the control band in a future 15 minute interval.

As a result of this success, IESO and MISO will continue to operate the PARs to control loop flow to within a 200 MW bandwidth as stipulated in the IESO-MISO Operating Agreement.

Introduction

The intent of this evaluation report is to recount the actual performance of the Ontario-Michigan (ONT-MI) interface PARs over a one-year period during which the PARs were operational, and to provide insight into the effectiveness of the PARs in controlling Lake Erie Circulation (LEC) flow. This report follows from the Regional Power Control Device Coordination (RPCDC) Study report published in 2011 as a joint effort between IESO, MISO, NYISO, and PJM.

Although the RPCDC Study recommended a follow-up study (Second Study) be performed after the Ontario-Michigan PARs enter service and operational data had been collected for a year, this report should not be considered as meeting that recommendation for three reasons:

- First, one of the Ramapo PARs was out-of-service from February 2013 until late-December 2013. Since the one-year of operating data used in this analysis (8/1/12-7/31/13) contains seven months during which there was not a fully functioning set of PARs on the PJM-NYISO interface, the data does not support an analysis on how the various power control devices around Lake Erie influence LEC or could have their operations coordinated to minimize loop flows.

- Second, rather than defer the study until one year of operating data with a fully functioning set of PARs on the PJM-NYISO interface is available, this study is being performed now to address a Joint and Common Market (JCM) initiative that MISO/PJM evaluate the ability of the Ontario-Michigan PARs to manage LEC by having actual flow equal scheduled flow. If the Ontario-Michigan PARs are effective in managing LEC, the JCM initiative will recommend they be included in the MISO/PJM market flow calculations and in the historic allocation process.
- Third, NYISO elected not to participate in this study but did participate in the first RPCDC Study. NYISO has indicated they are willing to participate in a Second Study at some point in the future, provided that actual operating data includes the impacts of all Ramapo PARs. Therefore, this study should be considered a limited scope study that will address a specific JCM initiative. A Second Study is still planned for the future and is anticipated to include the involvement of all four RTOs/ISOs around Lake Erie.

Lake Erie Circulation (LEC) Flow

LEC flow is the unscheduled flow of energy across the transmission system surrounding Lake Erie. LEC flow mainly affects entities in the IESO, MISO, NYISO, and PJM footprints. Conventionally, clockwise LEC flow is positive, counterclockwise flow is negative. LEC flow can be caused by many factors that are beyond the control of grid operators. A number of devices exist which can affect LEC flow, including PARs. The 2011 RPCDC study found that operation of PARs around Lake Erie affects LEC, along with system topology, generation commitment, and the level of scheduled interchange. The analysis described in this report considered only the operation of PARs, and only those PARs on the ONT-MI interface between IESO and MISO.

Ontario-Michigan Interface

LEC flow is affected by several factors including PARs in multiple locations around Lake Erie (*see Figure 1*). This report considered data only for PARs on the Ontario-Michigan interface.

Figure 1 – PAR Locations Which Impact Lake Erie Circulation Flow

The ONT-MI interface is comprised of four 230 kV lines that connect ITC and IESO. Each line has a PAR device that may be placed in series with the circuit. The ONT-MI interface includes five PARs at three locations. PARs on the interface reside at Lambton (IESO), Keith (IESO), and Bunce Creek (ITC) (*see Figure 2*).

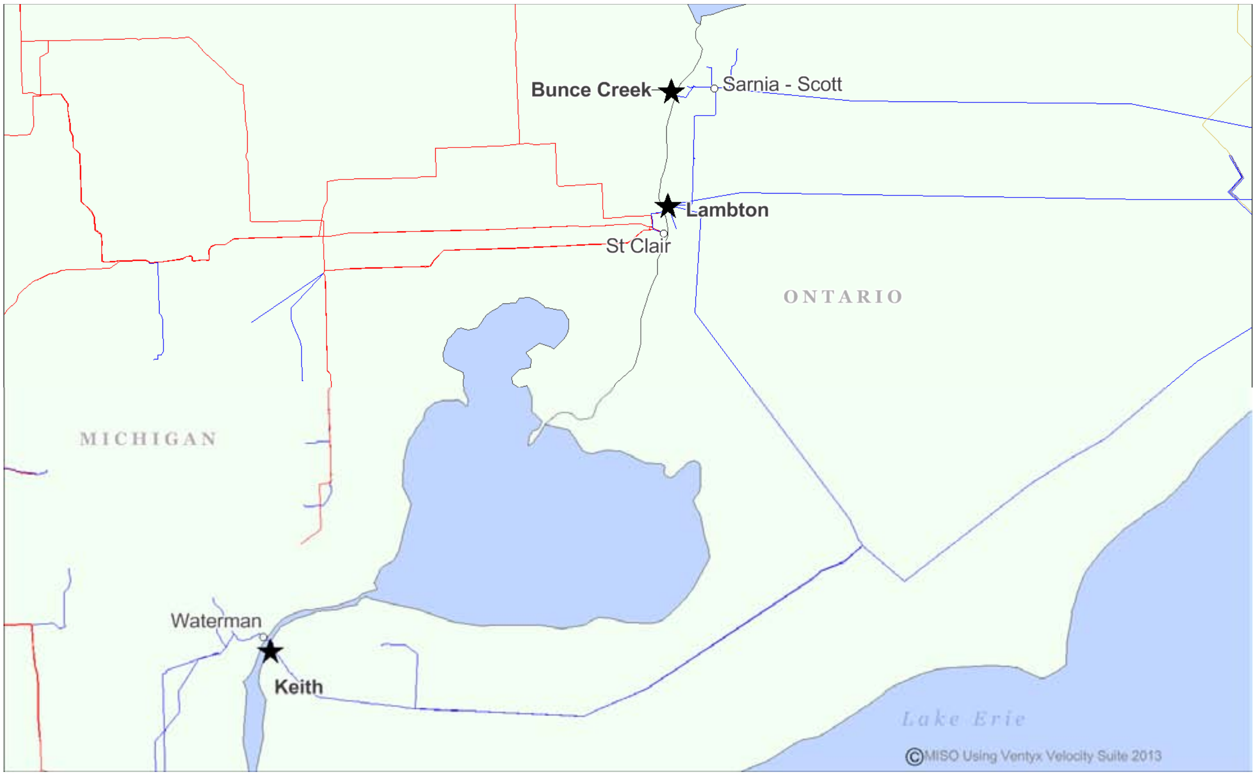

Figure 2 - PAR Locations on the ONT-MI Interface

Ontario-Michigan PARs

The ONT-MI interface PARs were designed to align actual flows with scheduled flows on the IESO-MISO interface. The equipment provides a large number of tap positions, providing for precise control, as well as the ability to adjust the tap positions intra-hour.

Summary of PARs on the ONT-MI interface:

- At Lambton (IESO) *see Figure 3*
  - **PS4** on circuit St. Clair (ITC)-Lambton (IESO) 230 (L4D)
  - **PS51** on circuit St. Clair (ITC)-Lambton (IESO) 230 (L51D)
- At Keith (IESO) *see Figure 4*
  - **PSR5** on circuit Waterman (ITC)-Keith (IESO) 230 (J5D)
- At Bunce Creek (ITC) *see Figure 5*
  - **PST1** and **PST2** in series on circuit Bunce Creek (ITC)-Scott (IESO) 230 (B3N)

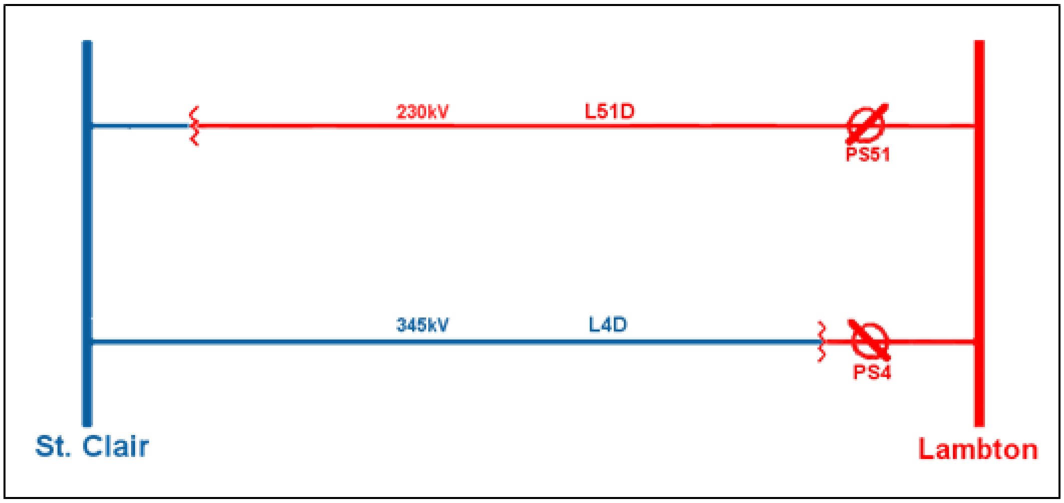

Figure 3 - Lambton PS4 and PS51

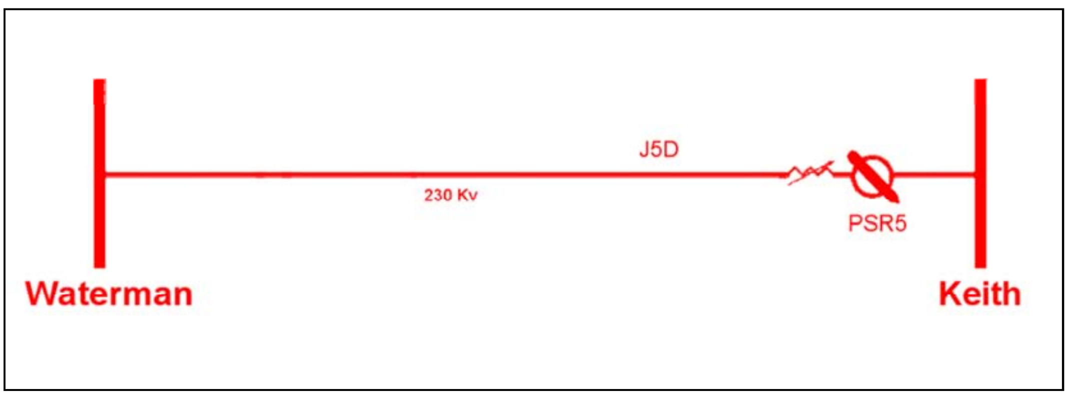

Figure 4 - Keith PSR5

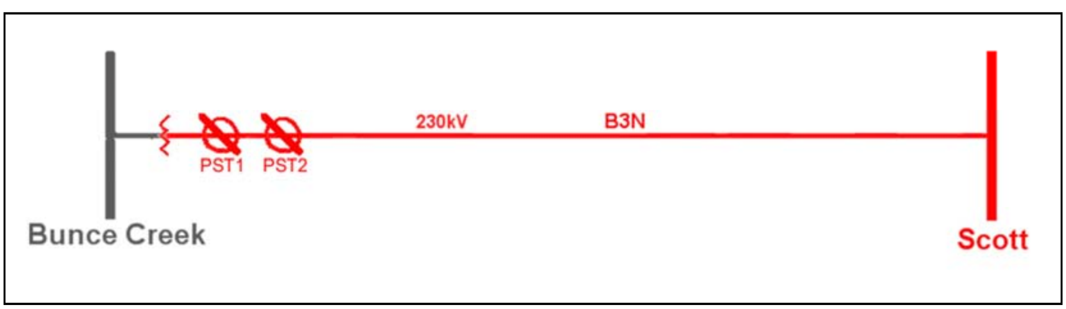

Figure 5 - Bunce Creek PST1 & PST2

Lambton PS4 & PS51 (L4D/L51D)
The PS4 and PS51 PARs at Lambton each have ±32 tap positions from neutral, with the ability to adjust phase angle by approximately ±45°. PS4 is in series with the Lambton (IESO)-St. Clair (ITC) 230 (L4D) circuit, and PS51 is in series with the Lambton (IESO)-St. Clair (ITC) 230 (L51D) circuit. PS4 and PS51 each have a tap change limit of 56 tap changes in a 15-minute period. If that limit is met, the PAR enters a three-hour cool down period during which it may change one tap every two minutes.

Keith PSR5 (J5D)
The PSR5 PAR at Keith has ±18 taps positions from neutral, with the ability to adjust phase angle by approximately ±30°. PSR5 is in series with the Keith (IESO)-Waterman (ITC) 230 (J5D) circuit. No limit is identified for the number of tap changes that may be requested for PSR5 in a given time period.

Bunce Creek PST1 & PST2 (B3N)
The PST1 and PST2 PARs at Bunce Creek in IESO are in a series configuration. Each PAR has ±16 tap positions from neutral, with the combined ability to adjust phase angle by ±45°. No operational limit is identified for the number of taps that PST1 and PST2 may change in a given time period, but these PARs must be within one tap position of each other when both are in service.

Summary of Ontario-Michigan Interface Operations

Ontario-Michigan PARs
Since July 2012, all five Ontario-Michigan PARs have regularly been in service and providing flow control. Operation of the PARs is intended to align actual flow to scheduled flow. As described in this analysis, the combined ONT-MI interface PARs have the ability to offset approximately 800 MW of LEC flow (based on the maximum observed total PAR control capability during the analysis period with all PARs in service).

Modes of Operations
The interface may be operated in Regulated, Unregulated, or Bypass mode. In Regulated mode, the PARs are in service with enough expected capability to control LEC. In Unregulated mode, the PARs are in service but are not expected to be able to control LEC within the control band. This may occur if the devices are at max tap or system conditions preclude the devices from fully controlling the interface. In Bypass mode, the interface has no flow control capability. Bypass mode can be set if all the PARs are physically bypassed or if all the PARs are in service and near neutral tap position without intent to control flow.

Transitions from Regulated to Unregulated Mode
The interface may be move from Regulated to Unregulated mode for a variety of reasons, including local congestion, PARs at max tap, and/or unavailability of one or more PARs. An outage of a PAR may limit loop flow correction, but would not necessarily eliminate loop flow control capability for the entire interface.

Tap Changes
Adjustment of PAR tap positions is not automatic and must be performed manually. Tap adjustment begins with a blast call between IESO, MISO, Hydro One, ITC TO, and ITC LBA (MECS). Mutual agreement from all parties is required to initiate a tap change. Operation of the ONT-MI interface PARs is coordinated under the instruction of document IESO-MISO-C02, “Operation of the Ontario-Michigan Tie Lines and Associated Facilities.”

Using the PARs to Control LEC
Operator action is taken to control LEC flow when unscheduled flow exceeds 200 MW in either direction. When LEC flow exceeds, or is expected to exceed, the control band, operators would initiate a tap change with the intent to bring flow back within the control band. As the operation of the PARs is not automatic, operator judgment plays a

large part in control. Operators may also assess the trajectory of LEC flow to determine the likelihood that flow will return to within the control band without direct intervention.

Data Analysis

Data was analyzed for one full year during which the ONT-MI PARs were in service. The period analyzed was from 8/1/2012 to 7/31/2013. Data included in the analysis is listed in Table 1. Several values were calculated from the data in Table 1. The principal measures used in the analysis are the LEC Flow, and the LEC Flow without PAR Control. A selection of derived values is listed in Table 2. To determine the LEC Flow without PAR Control, a calculation was performed for each 15-minute period based on the MISO Real-Time State Estimator snapshot for that period. Using the snapshot in a PSSe simulation, each PAR was adjusted by one tap, and the impact on the interface was recorded. Using this calculated shift factor for each PAR and the actual interface flow values, the estimated flow on the interface was determined by multiplying the shift factor for one tap position by the number of taps required to return the PAR to neutral position, then summing the result for all PARs and adding to the actual LEC flow. To simplify the calculation, a linear relationship between tap change and MW flow change is assumed. In actual operation, the impact may be reduced as the PAR approaches either end of its tap range.

Table 1 - Data Included in Analysis

Data Value	Description
IESO Total Interface Flow	15 Minute Average
IESO Total Interface Schedule	15 Minute Average
Interface Regulation Status	Manually Entered by IESO Operator
B3N Actual Tap	Tap position of PST1 & PST2 at Bunce Creek
L4D Actual Tap	Tap position of PSR4 at Lambton
L51D Actual Tap	Tap position of PSR41 at Lambton
J5D Actual Tap	Tap position of PSR5 at Keith
B3N Circuit Flow	15 Minute Average
L4D Circuit Flow	15 Minute Average
L51D Circuit Flow	15 Minute Average
J5D Circuit Flow	15 Minute Average
MISO State Estimator Snapshots	15 Minute Snapshot of MISO State Estimator

Table 2 – Selected Calculated Values

Calculated Value	Calculation
Lake Erie Circulation Flow	Total Interface Flow - Total Interface Schedule
Lake Erie Circulation Flow w/o PAR Control	Lake Erie Circulation Flow + $\sum(\text{PAR Shift Factors} * \text{PAR offsets})$
Individual PAR Shift Factors	Move each PAR one tap, calculate $\sum \frac{\text{MW}_{\text{post}} - \text{MW}_{\text{pre}}}{1\ \text{tap}}$ for all circuits

For the one-year period reviewed, a tap change was determined to have taken place if the tap position at time *t* did not equal the tap position at time *t-1*. The initiating operator actions were not available for all occasions and were not considered in the analysis.

Results

The PAR data demonstrated a noticeable improvement in the control of LEC flow when the PARs were being used to control flow. During the one-year period, the calculated loop flow without PAR control would be within the ±200

MW control band for 43.4% of the year. In comparison, the actual loop flow with PAR control was within the ±200 MW control band for 73.1% of the year, an improvement of more than 66% over the calculated value without PAR control. *Figure 6* demonstrates the performance of the PARs on a monthly basis by comparing the magnitude of the actual loop flow to the calculated loop flow without PAR control.

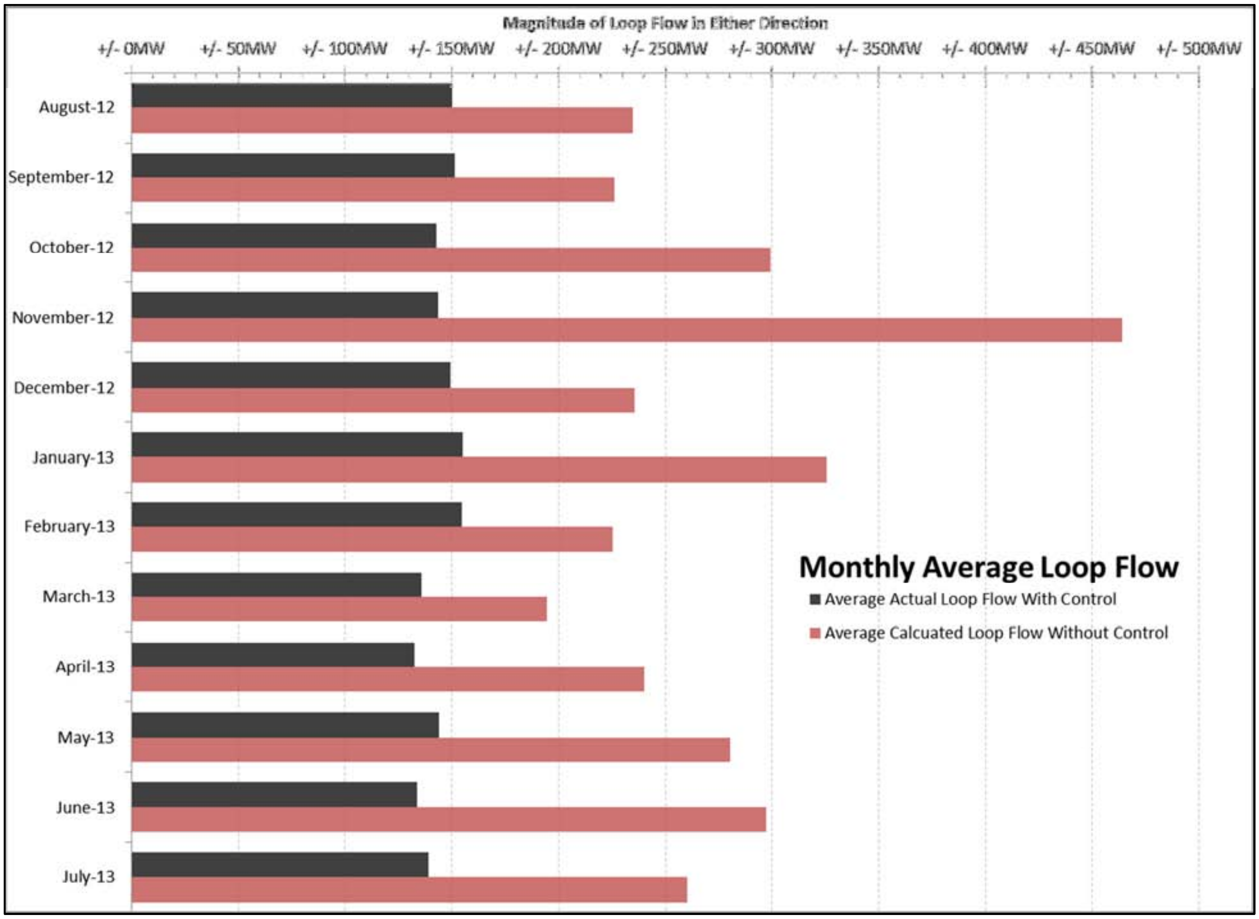

Figure 6 - Monthly Average Loop Flow

As shown in *Figure 6,* the absolute value of LEC flow averaged around 150 MW for each month where the calculated loop flow without PAR control was over 200 MW for every month but one. Although the PARs greatly increased the amount of time that LEC flow was within the control band (73.1%), LEC flow was outside the 200MW bandwidth 26.9% of the year. This time can be further divided into two categories: interface was Unregulated or Regulated.

Of the 26.9% of the time that the interface was outside the 200 MW bandwidth, the interface was listed in the Unregulated mode 1.7% of the time. Of the remaining 25.2% of the time that the interface was outside the bandwidth, the PARs had enough theoretical control capability for a majority (24.8%) of that time, had tap changes been performed. The same can be said for the 1.7% of the time the interface was in Unregulated mode and outside the 200MW bandwidth. Of this time, the PARs had enough theoretical control capability for 1.2% of this time. In total, the PARs had the capability to control loop flow for all but 0.9% ([1.7% - 1.2%] + [25.2% - 24.8%] = 0.9%) of the year; even though MISO and IESO listed the interface as Unregulated for 4.5% of the year. This 4.5% correlates to the periods of time that the operators determined there was not enough PAR control to keep the interface within the 200MW bandwidth.

Based on the observed loop flow and the calculated PAR shift factors, the PARs did not have sufficient capability to control LEC flow to within the control band for 0.9% of the year. This was established by evaluating every 15 minute interval that loop flow exceeded the 200 MW bandwidth, then utilizing the calculated PAR shift factors, all available tap positions on the PARs, and ignoring congestion to determine if enough control was available to bring the interface to within the control band, Of this 0.9%, the interface was listed as Regulated for 0.4% and Unregulated for 0.5% of the year. Therefore, there was enough theoretical capability to control loop flow within 200MW bandwidth 99.1% of the study year.

The 24.8% of the year (25.2% - 0.4% = 24.8%) that the interface was listed as Regulated and still outside of the 200 MW control band is attributed to a combination of reasons. Those include, but are not limited to large schedule changes, local congestion, unavailability of taps, delay time as PAR taps moved, operator judgment that LEC flow will return to within the control band without intervention, and other operational factors. Table 3 lists the portions of the year that LEC flow was in each state.

Table 3 - LEC Flow Within Control Band vs. Outside Control Band

Interface Status	± 200MW Control Band	Percent of Year	
Regulated		95.5%	
	Within Control Band		70.3%
	Outside Control Band		25.2%
Unregulated		4.5%	
	Within Control Band		2.8%
	Outside Control Band		1.7%
		100.0%	100.0%

LEC flow spent more time within the ±200 MW control band with PAR control (73.1%) than was calculated without PAR control (43.4%). The histogram in *Figure 7*~~*Figure 7*~~ shows the number of 15-minute average periods which were spent at each flow magnitude. The tall, narrow shape of the actual loop flow curve (black O's) indicates that the interface spent more time within the ±200 MW control band. The shorter, flatter curve of the calculated loop flow without control (red +'s) indicates that less time would have been spent within the control band and more time would have been spent at higher flow levels without PAR control. The calculated loop flow curve is skewed in the positive direction corresponding to clockwise loop flow, which is consistent with historical observations of LEC. The actual loop flow is symmetric around 0 MW flow, which implies that PAR control was effective to control loop flow in both directions.

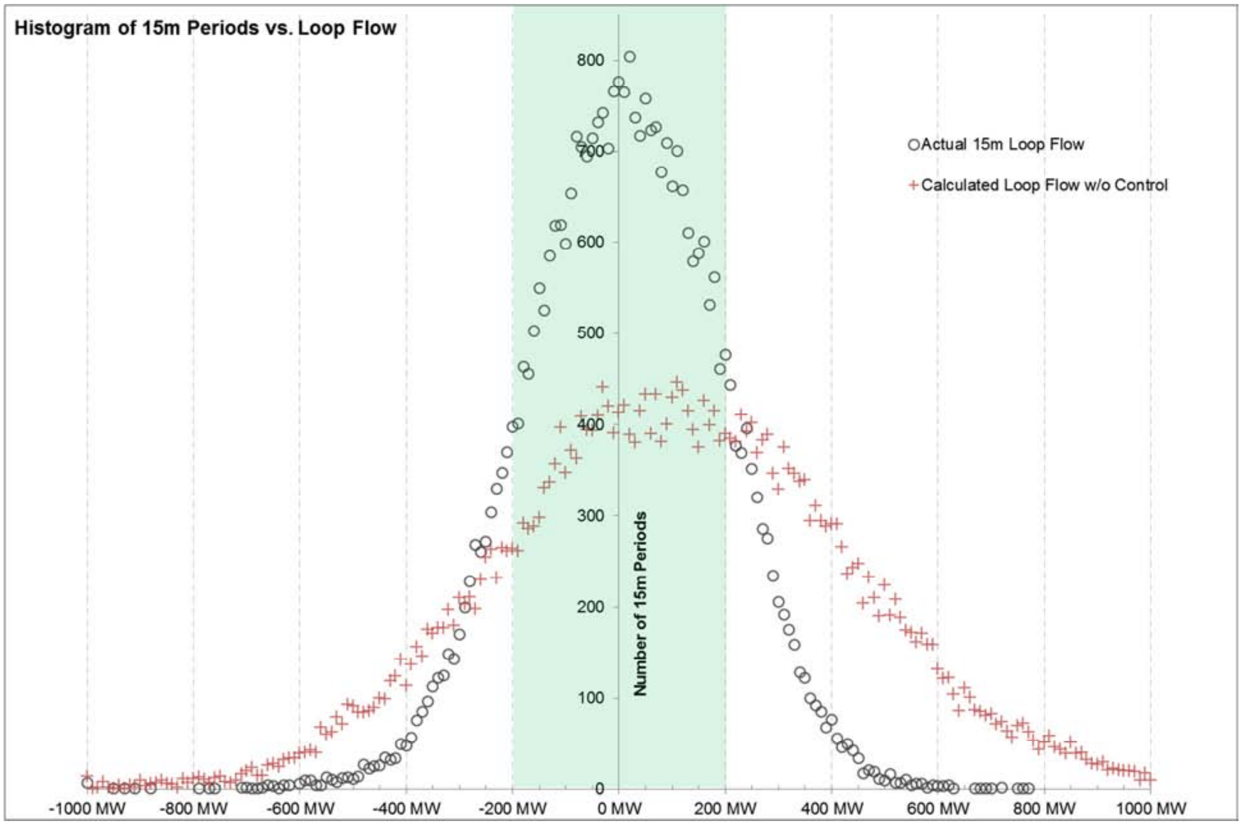

Figure 7 - Histogram of 15 Minute Periods vs Actual and Calculated Loop Flow

The interface exceeded the control band on 2,451 separate occasions during the year, compared to a calculated 1,882 occasions if the PARs had not been controlling flow. For the purposes of analysis, an "occasion" is considered to be a continuous interval of one or more 15-minute periods. Though the number of occasions is greater with PAR control, the duration of each occasion was shorter, and the magnitude of the unscheduled flow was smaller during each occasion. More occasions should be expected when the interface is controlled since the LEC flow will spend more time near the ±200 MW control band and will therefore cross the threshold more often. For comparison of duration and magnitude of occasions, see *Figure 8* through *Figure 11*. These plots show the magnitude of flow at each duration level. While the durations and magnitudes are spread widely without control (*Figure 9*), they are well grouped with control (*Figure 8*) in the region with short duration and low magnitude. Each duration interval of an occasion is plotted as a separate point, so sequential points would be connected to form a time sequence. Most of the high magnitude and long duration points occur within the same occasion, as shown by the set of line plots in *Figure 10*. The two longest occasions are shown by themselves in *Figure 11*. The inverse relationship between duration and magnitude for most points implies that the PARs were operated effectively, whether they were moved to control flow, or not moved in anticipation that flows would return within limits.

The time-series actual LEC flow (*Figure 12*) compared to the calculated LEC flow without PAR control (*Figure 13*) for the same period demonstrates the increase regularity on the interface with PAR control in place. If the time points where the interface was within the ±200 MW control band are removed (*Figure 14* and *Figure 15*), a clearer picture of the PAR contribution is shown. *Figure 14* and *Figure 15* also identify the times when the LEC was outside the control band and available taps were insufficient to bring flow back within the control band. Investigation of the occasions when the PARs were insufficient to control LEC show that most occasions ended with the operator moving the interface to Unregulated status.

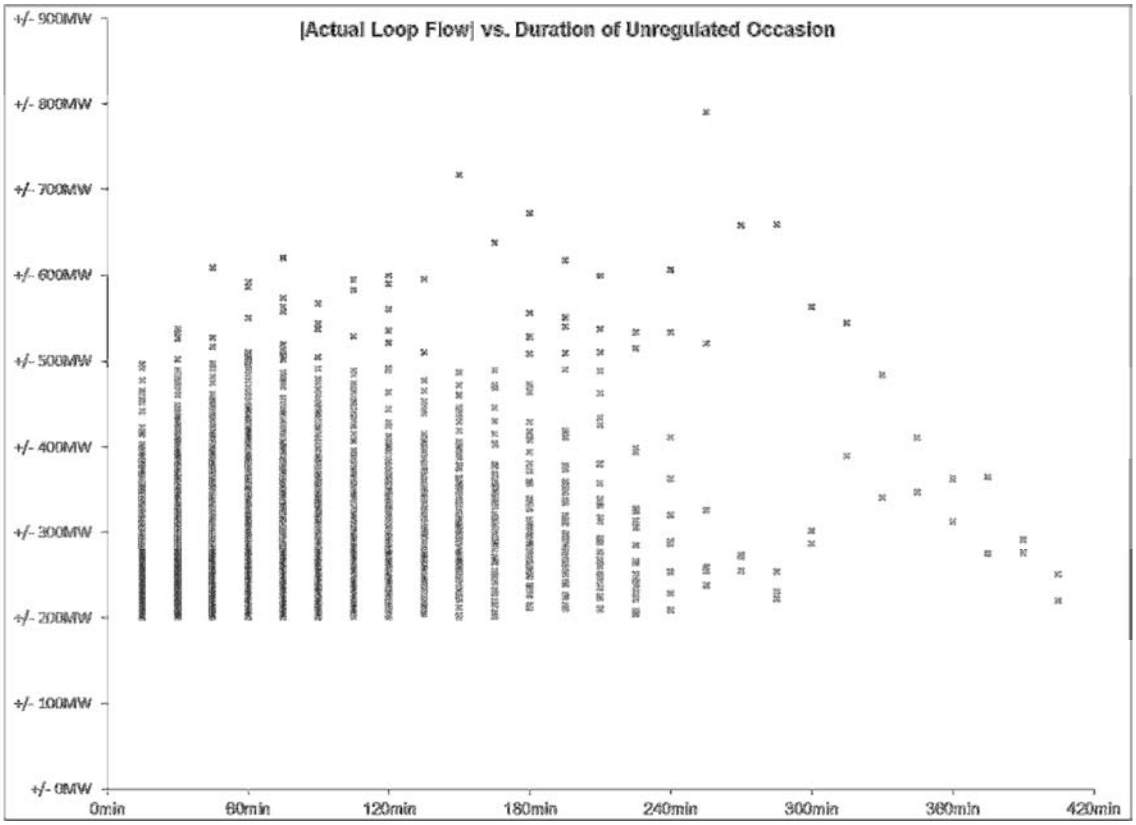

Figure 8 - |Actual Loop Flow| vs. Duration of Unregulated Occasion

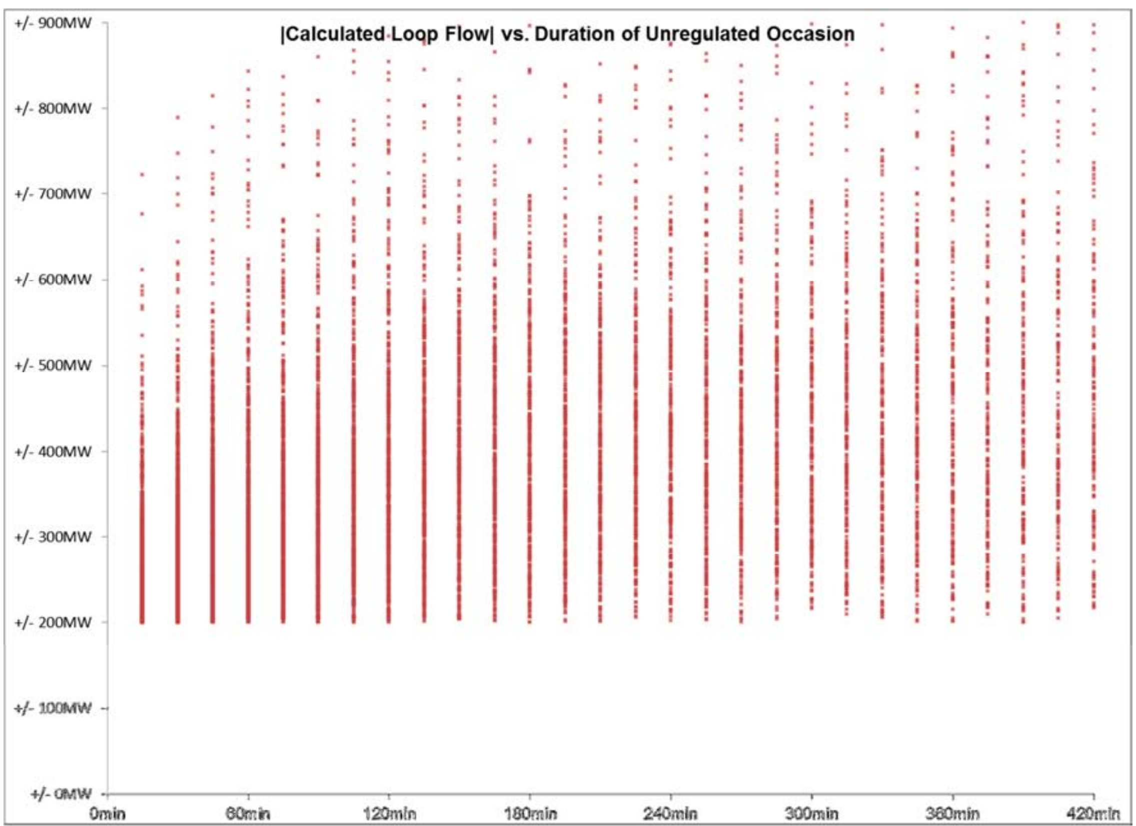

Figure 9 - |Calculated Loop Flow| vs. Duration of Unregulated Occasion

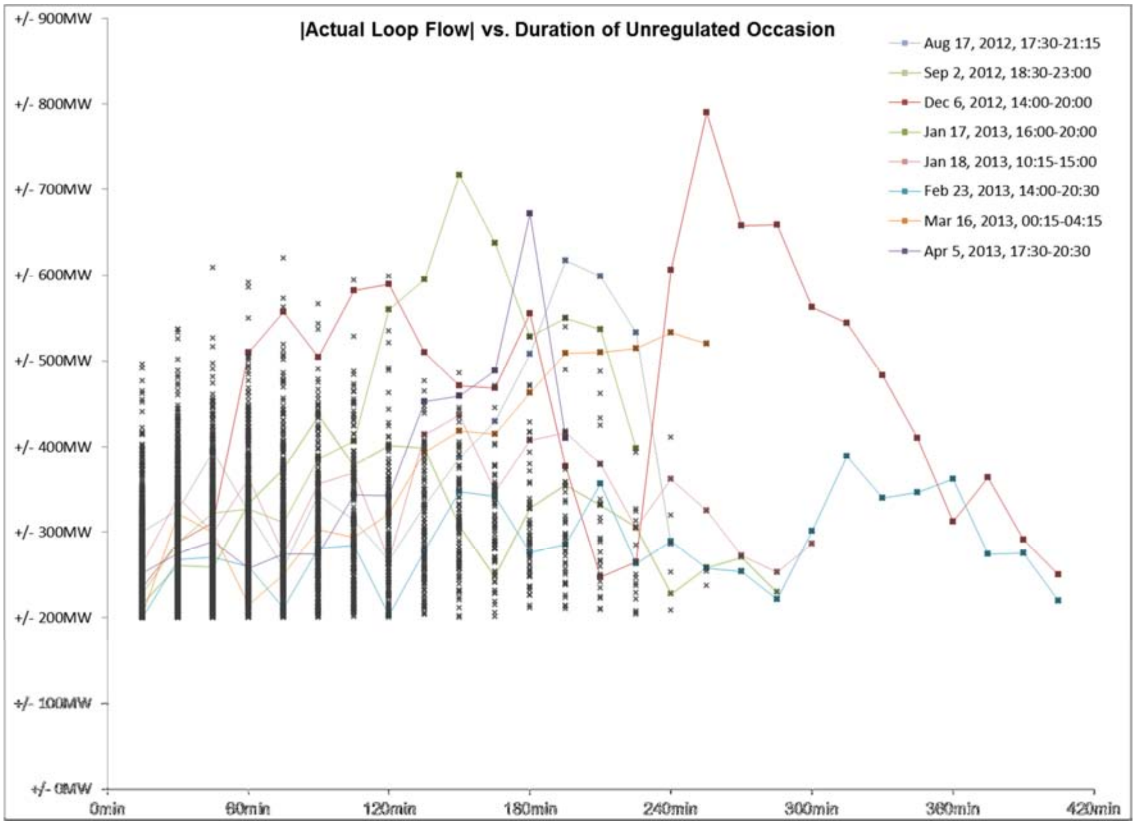

Figure 10 - |Calculated Loop Flow| vs. Duration of Unregulated Occasion, Individual Occasions Demarcated

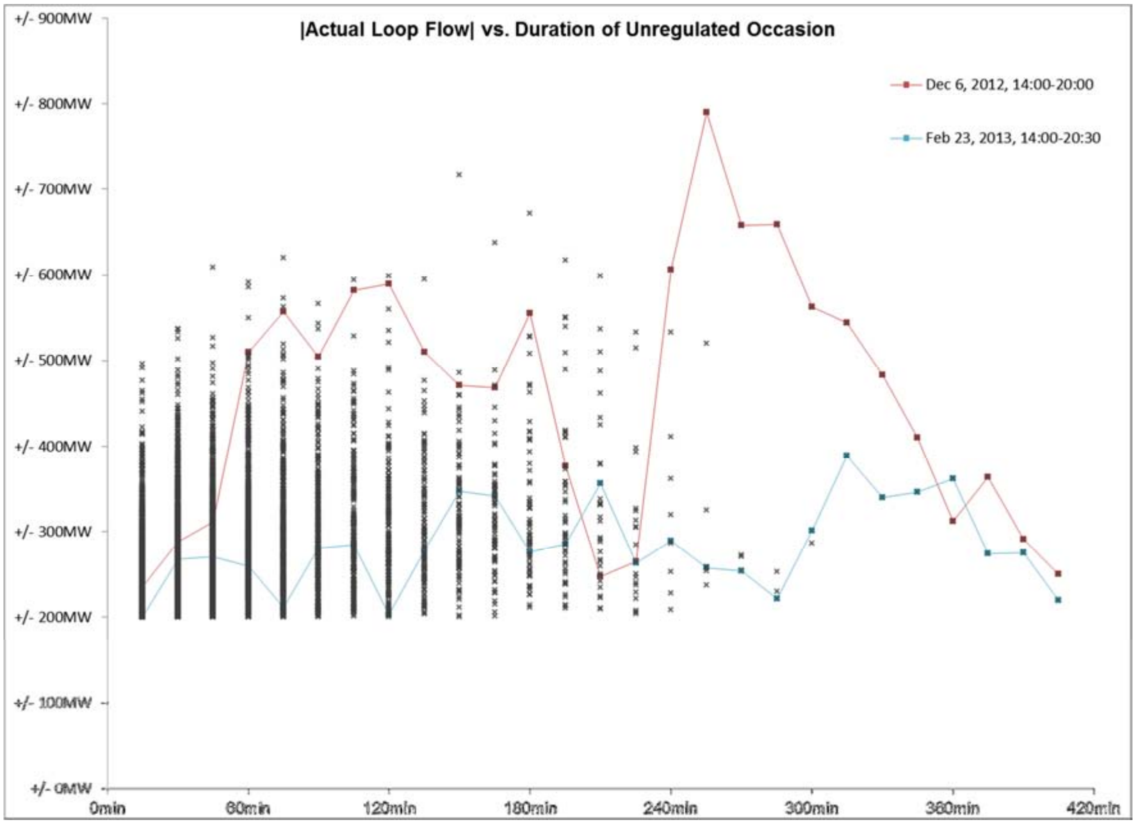

Figure 11 - |Calculated Loop Flow| vs. Duration of Unregulated Occasion, Two Occasions Demarcated

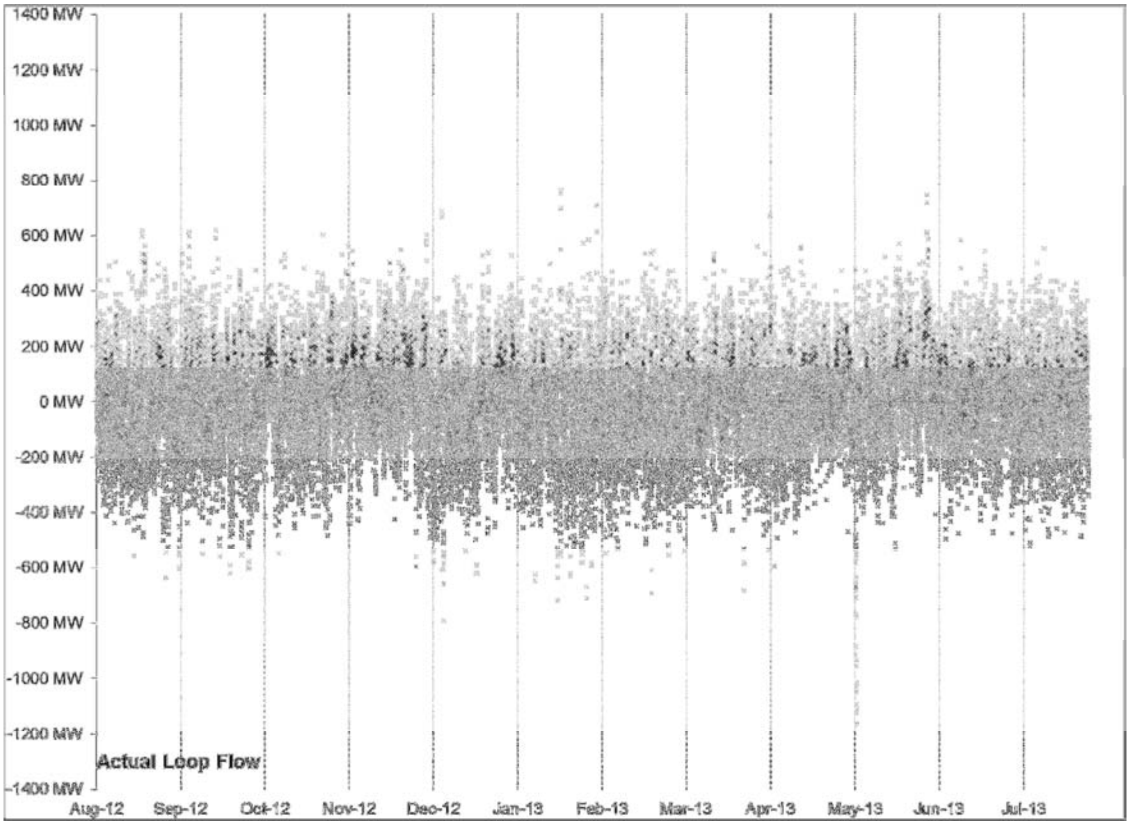

Figure 12 - Actual Loop Flow, 8/1/2012-7/31/2013

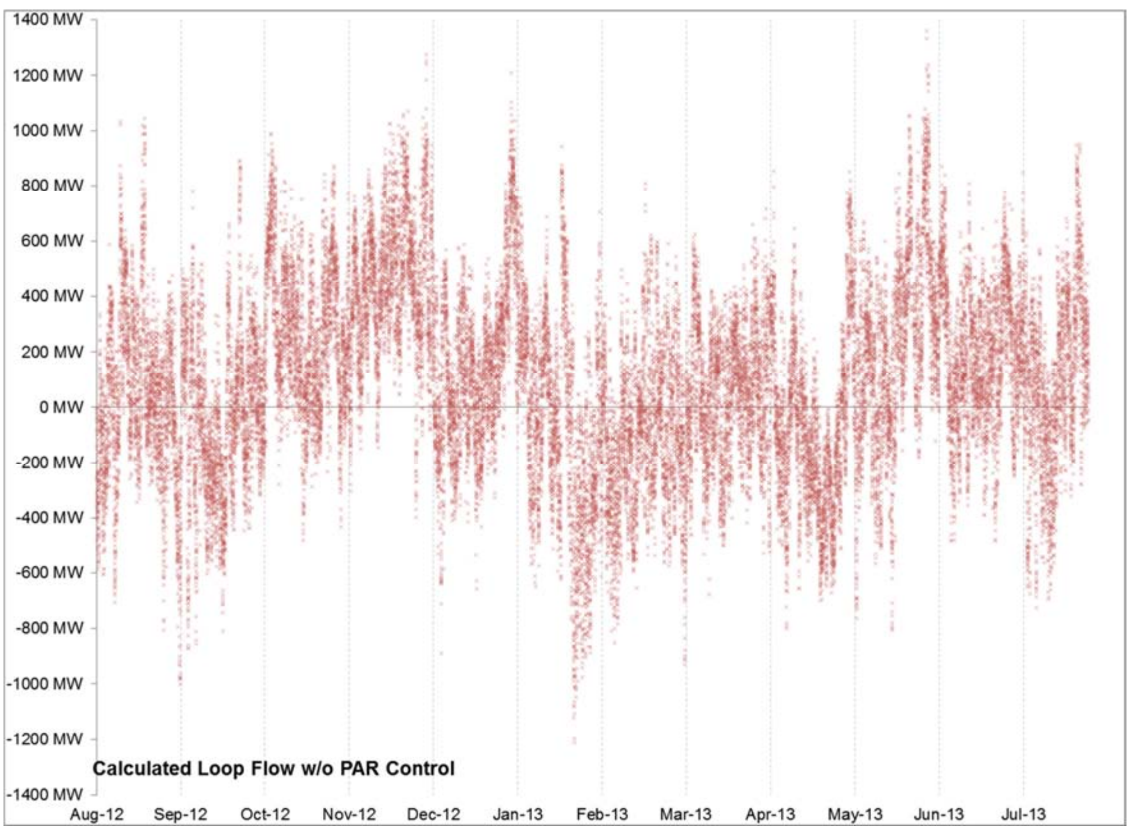

Figure 13 - Calculated Loop Flow without PAR Control, 8/1/2012-7/31/2013

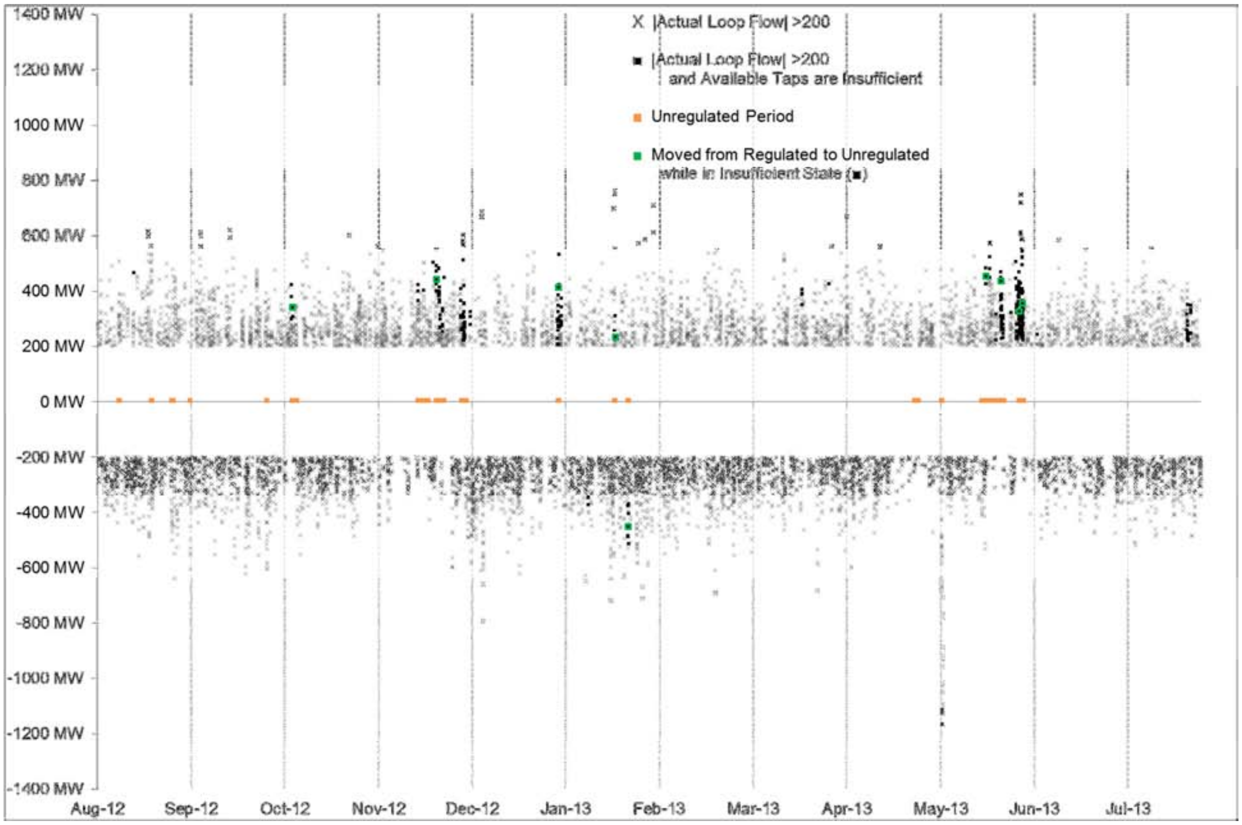

Figure 14 - Actual Loop Flow Outside +/-200MW, 8/1/2012-7/31/2013

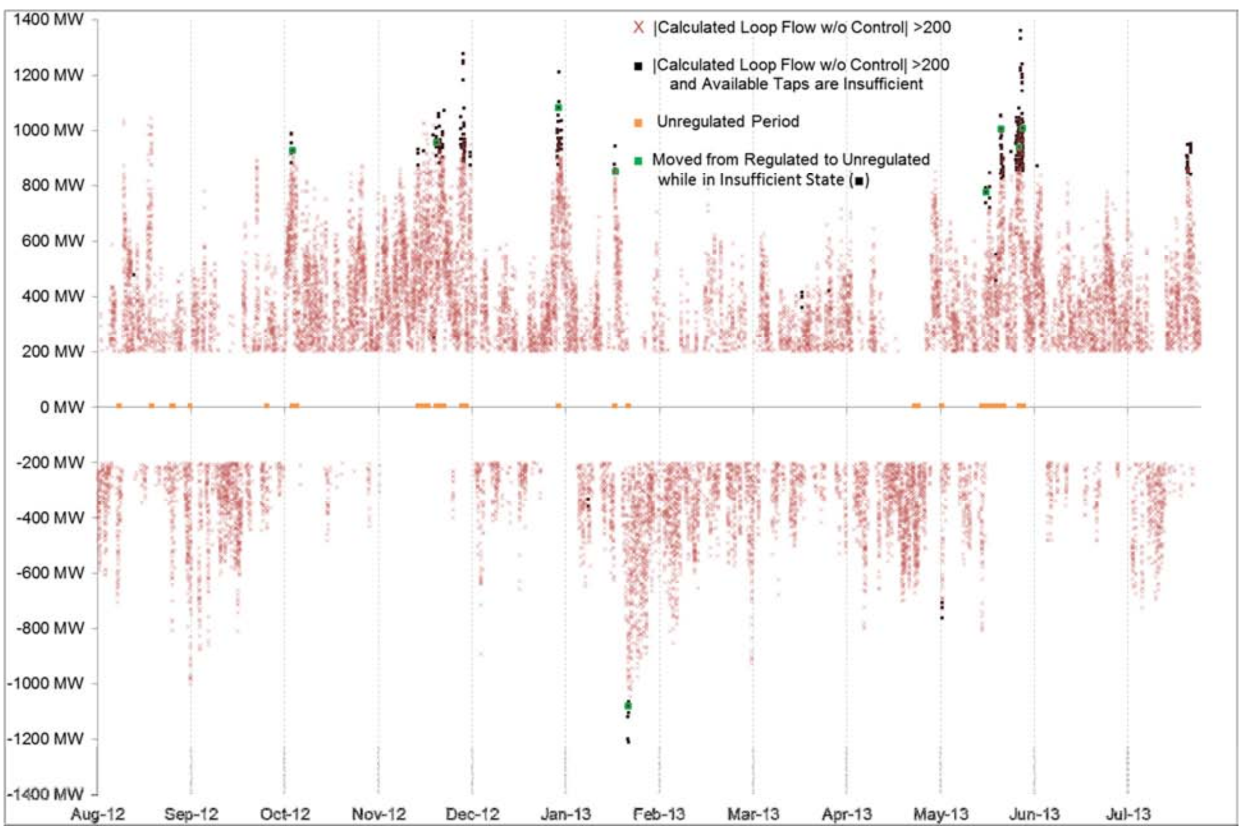

Figure 15 - Calculated Loop Flow without PAR Control Outside +/-200MW, 8/1/2012-7/31/2013