DOE/OE Transmission Reliability Program

Eastern Interconnection Phase Angle Base Lining Study

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Consortium for Electric Reliability Technology Solutions

Topics

- Project Objective
- Study / Analysis Steps
- Major Technical Accomplishments
- Deliverables and schedule for activities to be completed under FY15 funding
- Risk factors affecting timely completion of planned activities as well as movement through RD&D cycle
- Early thoughts on follow-on work that should be considered for funding in FY16

Project Objective

- Conduct wide area angle pair analysis using Phasor Measurement System data from four ISOs
  - December 15, 2013 to February 14, 2015
  - September 1, 2014 to October 31, 2015
- Identify Phase Angle Pairs – Based on Data and Inputs from ISOs
  - Selected 22 inter-ISO angle pairs
- Investigate correlation between LMP and high stress system conditions
- Evaluate changes in angle differences to identify significant system events (December 1, 2014 to December 7, 2014)

Study / Analysis Steps

- **Data Collection**
  - Define Time period for data extraction / collection from ISOs
  - Obtain data from ISOs for 12/15/2013 to 2/15/2014, 9/01/2014 to 10/31/2014 and 12/01/2014 to 12/07/2014
- **Data Checking - evaluate data quality and other attributes**
  - Data Availability and data quality
  - Time synchronization and offset correction
  - Time stamp alignment
  - Data formats
- **Data Aggregation and synchronizing checks for Wide Area Analysis**
  - Combine data from different ISOs
    - Data conversion to a common format and Time alignment
  - Data extraction for selected/alternate angle pairs
- **Perform Statistical Analysis**
  - Box – Whisker and Time Duration Analysis
  - Correlation with Power Flow and Bus Voltage
  - Establish Typical Ranges for Selected Angle Pairs
  - Significant event analysis

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Major Technical Accomplishments

- **Analysis completed for twenty two wide area angle pairs using 2013-2014 phasor system data**
- **Angle pair selection based on the input from ISOs/TAG**
  - Selected twenty two Angle pairs
  - Data required from fifteen substations to analyze the above 22 angle pairs
- **Problems in analyzing wide area angle pairs using PMU data**
  - Poor data quality – data quality needs improvement
  - Data synchronization
  - Offset errors – required adjustments to some PMU data
- **Draft Report for winter (December 15, 2013-February 15, 2014-and fall (September 1,2014 to October 31, 2014) completed and submitted**
  - Analysis of twenty-two wide Internal angle pairs
  - Wide Area Angle pair analysis and its correlation with LMP
- **Phasor System data can provide good results and information for Wide area angle pairs across ISOs. Using phasor system data, ISOs can monitor**
  - System stress conditions
  - Pre-cursors and high stress locations and event identification
  - Data checking and analysis

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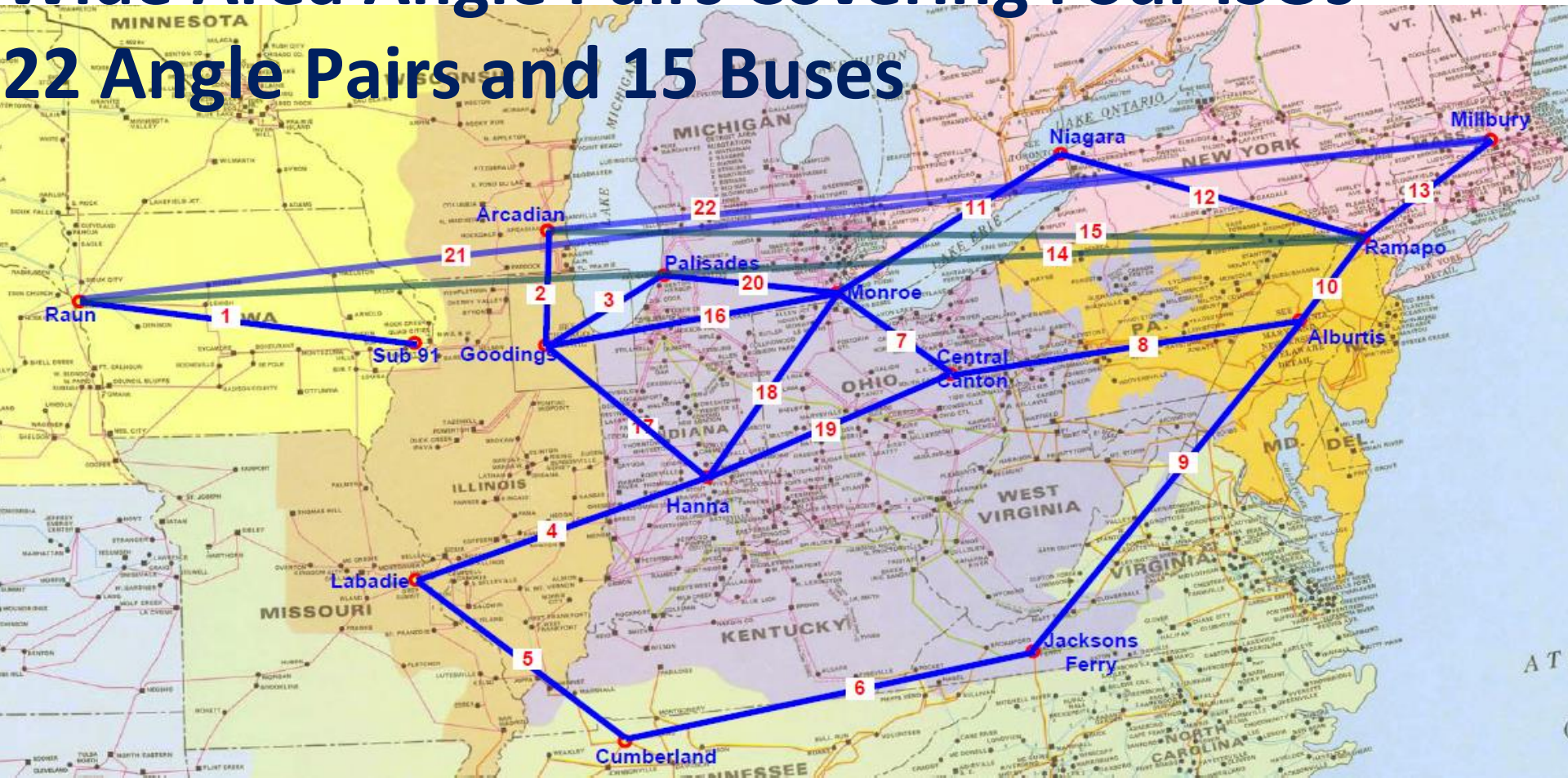
Wide Area Angle Pairs Covering Four ISOs

22 Angle Pairs and 15 Buses



Index	From bus	To bus	Reason
1	Raun	Sub 91	IA Wind Transfers
2	Goodings	Arcadian	Wi-Chi Transfers
3	Goodings	Palisades	Chi-MI Transfers
4	Labadie	Hanna	West to East Transfers
5	Labadie	Cumberland	St Louis South Transfers
6	Jacksons Ferry	Cumberland	TVA to PJM (Southwest) Transfers
7	Canton Centr.	Monroe	SE MI Transfers
8	Alburtis	Canton Centr.	West to East Transfers (Lake Erie Loop)
9	Alburtis	Jacksons Ferry	Southwest to East Transfers
10	Alburtis	Ramapo	PJM to NYISO
11	Niagara	Monroe	NYISO to MISO
12	Niagara	Ramapo	West to Southeast Transfers

Index	From bus	To bus	Reason
13	Ramapo	Millbury	NYISO to ISONE
14	Raun	Ramapo	MISO to NYISO
15	Arcadian	Ramapo	MISO to NYISO
16	Goodings	Monroe	Close the loop
17	Goodings	Hanna	Close the loop
18	Hanna	Monroe	Close the loop
19	Hanna	Canton Centr.	Close the loop
20	Palisades	Monroe	Close the loop
21	Raun	Millbury	MISO to ISONE
22	Arcadian	Millbury	MISO to ISONE

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Results of Comparison for Different Time Periods - High[1] and Low[1] Values

Index	From bus	To bus	SE Data March 2011		PMU Data (1) 12/15/2013-2/15/2014		PMU Data (2) 9/1/2014-10/31/2014		PMU Data (3) 12/1/2014-12/7/2014	
			Low	High	Low	High	Low	High	Low	High
1	Raun 345kV (*Lehigh**)	Sub 91 345kV	-13	48	-30	30	-9	28	-10	25
2	Goodings 345kV	Arcadian 345kV	-8	14	-14	18	-12	15	-8	10
3	Goodings 345kV	Palisades 345kV	7	29	-6	28	-5	23	3	25
4	Labadie 345kV (*Montgomery^*)	Hanna 345kV	23	57	12	63	0	48	22	56
5	Labadie 345kV (*Montgomery^*)	Cumberland 500kV (*Ammojopa^*)	9	35	-11	47	-4	22	-4	20
6	Jacksons Ferry 765kV (*Broadford^*)	Cumberland 500kV (*Ammojopa^*)	-47	-19	-54	-4	-47	-4	-52	-26
7	Canton Centr. 345kV	Monroe 345kV (*Decoplacid^*)	-10	12	-34	17	-9	27	3	29
8	Alburtis 500kV	Canton Centr. 345kV	-46	-10	-61	8	-52	20	-23	5
9	Alburtis 500kV	Jacksons Ferry 765kV (*Broadford^*)	-60	-12	-76	11	-63	29	-33	11
10	Alburtis 500kV	Ramapo 500kV (*Buchanan**)	2	18	-3	49	-2	26	-1	35
11	Niagara 345kV	Monroe 345kV (*Decoplacid^*)	-26	12	-49	50	-7	62	1	51
12	Niagara 345kV	Ramapo 500kV (*Buchanan**)	9	57	22	88	15	69	22	55
13	Ramapo 500kV (*Buchanan**)	Millbury 345kV	-26	17	-36	24	-25	11	-10	19
14	Raun 345kV (*Lehigh**)	Ramapo 500kV (*Buchanan**)	66	154	19	208	7	142	33	128
15	Arcadian 345kV	Ramapo 500kV (*Buchanan**)	39	109	19	159	43	168	15	88
16	Goodings 345kV	Monroe 345kV (*Decoplacid^*)	22	54	-6	51	-1	46	20	55
17	Goodings 345kV	Hanna 345kV	0	23	-21	27	-16	22	-3	29
18	Hanna 345kV	Monroe 345kV (*Decoplacid^*)	11	46	-18	46	-1	40	10	45
19	Hanna 345kV	Canton Centr. 345kV	13	42	-5	48	-11	30	-1	30
20	Palisades 345kV	Monroe 345kV (*Decoplacid^*)	8	29	-3	27	0	27	14	36
21	Raun 345kV (*Lehigh**)	Millbury 345kV	26	117	8	213	0	128	34	148
22	Arcadian 345kV	Millbury 345kV	51	159	2	165	27	154	11	101

[1] High and Low values are determined after eliminating top and bottom 0.5% of data to account for outliers *^ Alternative data sources used due to poor data availability for some primary signals

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Methodology to Identify Significant Events

- Control Chart analysis technique used to identify significant events
  - Method is commonly used in manufacturing to find samples outside the tolerance band
  - Three step method – find max and min values in one minute time window; calculate range; compare with range control value
  - Used angle pair angle difference values for selected angle pairs
  - Typical tolerance band for normal distributions is +/- 3 sigma (99.76 percent). For extreme events used high sigma values
  - Use of 20 sigma identified 2 extreme events; use of 15 sigma identified 3 major events – same as actual number of events
- Methodology can be used to extract significant events From large amount of data

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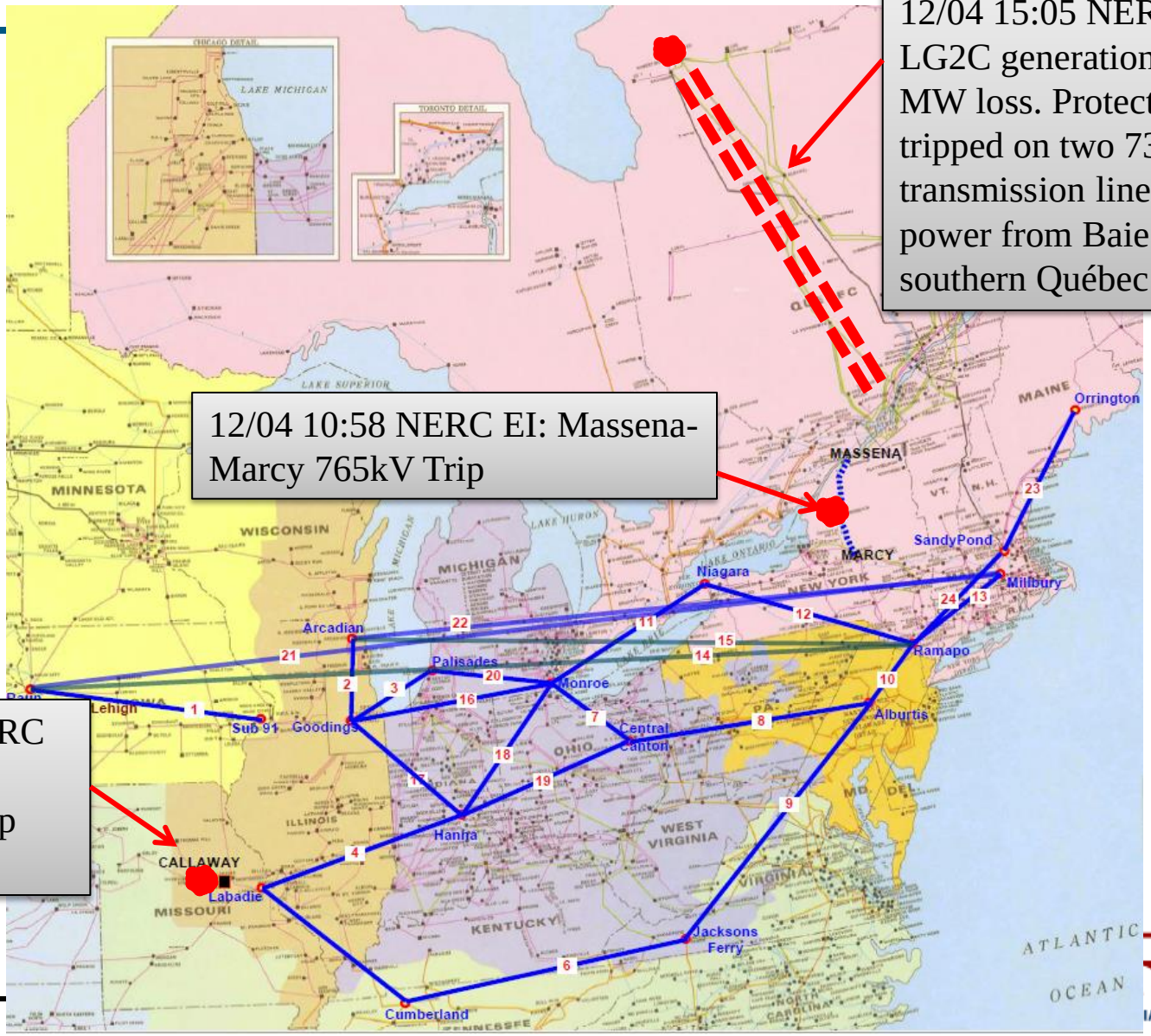
Dec 1 to Dec 7, 2014 – 3 Major Events Identified

12/04 15:05 NERC Quebec: LG2C generation trip with 1019 MW loss. Protective devices tripped on two 735-kV transmission lines carrying power from Baie James to southern Québec

12/04 10:58 NERC EI: Massena-Marcy 765kV Trip

12/03 1:22 NERC EI: MISO Callaway 1 Trip 1287MW Loss



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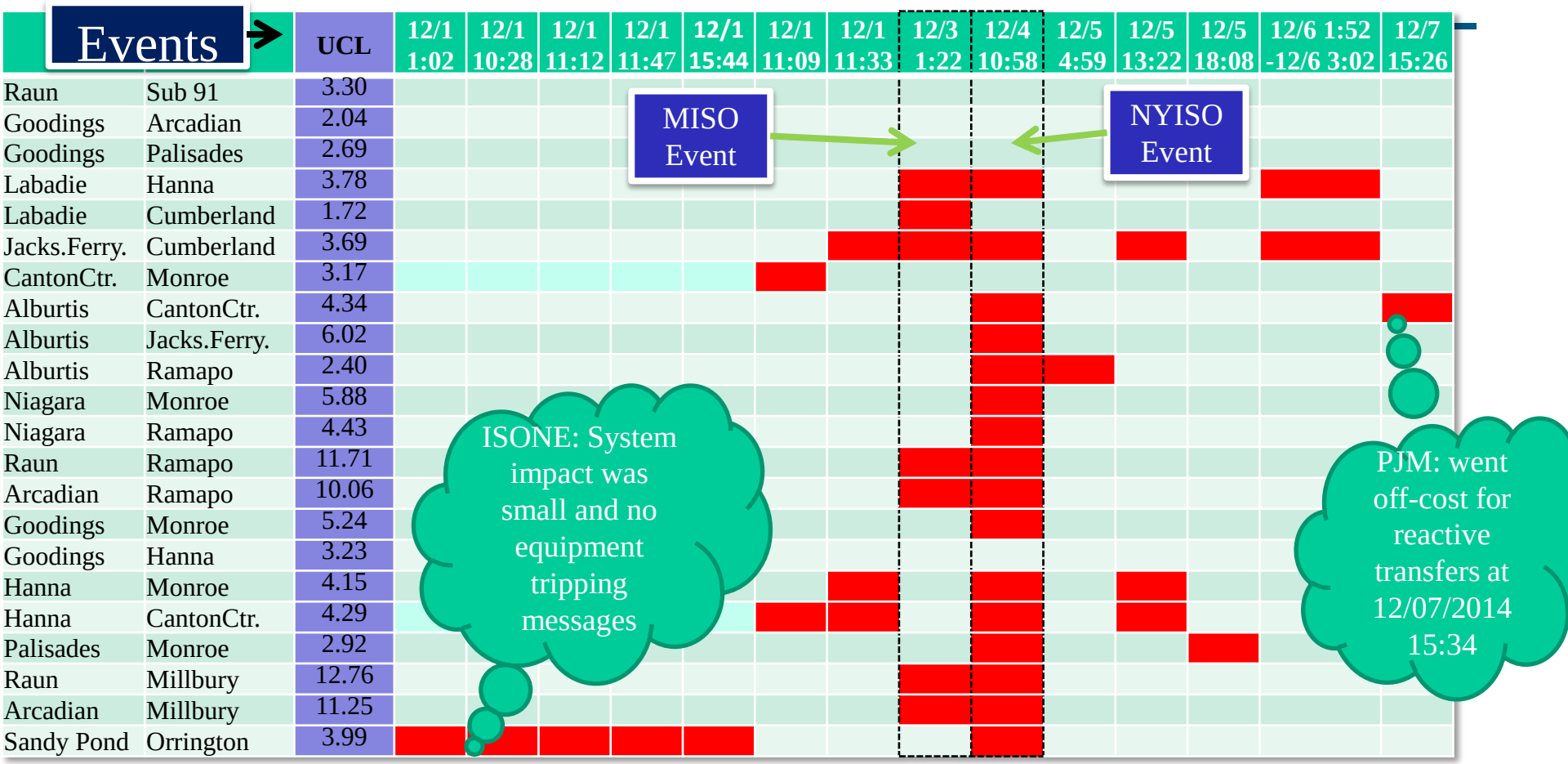
Detected Events Summary (nSigma=20)

Dec 1 to Dec 7, 2014: 14 events identified



		UCL	12/1 1:02	12/1 10:28	12/1 11:12	12/1 11:47	12/1 15:44	12/1 11:09	12/1 11:33	12/3 1:22	12/4 10:58	12/5 4:59	12/5 13:22	12/5 18:08	12/6 1:52 -12/6 3:02	12/7 15:26
Raun	Sub 91	3.30														
Goodings	Arcadian	2.04														
Goodings	Palisades	2.69														
Labadie	Hanna	3.78														
Labadie	Cumberland	1.72														
Jacks.Ferry.	Cumberland	3.69														
CantonCtr.	Monroe	3.17														
Alburtis	CantonCtr.	4.34														
Alburtis	Jacks.Ferry.	6.02														
Alburtis	Ramapo	2.40														
Niagara	Monroe	5.88														
Niagara	Ramapo	4.43														
Raun	Ramapo	11.71														
Arcadian	Ramapo	10.06														
Goodings	Monroe	5.24														
Goodings	Hanna	3.23														
Hanna	Monroe	4.15														
Hanna	CantonCtr.	4.29														
Palisades	Monroe	2.92														
Raun	Millbury	12.76														
Arcadian	Millbury	11.25														
Sandy Pond	Orrington	3.99														

		UCL	12/1 15:44	12/2 5:06	12/2 23:17	12/3 3:56	12/3 4:55	12/4 2:01	12/4 5:45	12/4 6:03	12/4 6:07	12/4 10:58	12/4 16:09	12/4 16:12	12/4 16:47	12/5 1:17	12/5 16:16	12/6 7:41
Ramapo*	Millbury	2.93																
Ramapo*	Sandy Pond	3.09																

*Phase angle regulator on Ramapo

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Deliverables and Schedules

- **Analysis of ISO-internal angle pairs using SE data - Completed**
- **Report summarizing analysis process and analysis results using Phasor system data - Completed**
- **Periodic TAG meetings to report and discuss results (Three in-person meetings during FY15)**
- **Analysis of wide area angle pairs for event detection and as pre-cursors of significant events using one week (December 1-7, 2014) data – in progress**
  - Data received and analyzed
  - Report presented and discussed with ISOs/TAG members
- Complete Report of Analysis – June 30, 2015

Risk Factors Affecting Timely Completion

- Data quality and data availability
  - Data quality needs improvement for some selected locations
  - Data availability for selected angle pairs from ISOs
- Data Synchronization
  - PMU data is well synchronized unlike State Estimator system data
  - Some phase angle adjustments are required –offset errors
- Additional Data
  - Power flow data and some voltage measurements will help in identification and analysis of pre-cursors

Summary and Next Steps

Summary:

- Received and collected Dec 1-7, 2014 phasor data from four ISOs;
- Extracted Dec 1-7, 2014 phasor data, cleaned and combined data for four ISOs;
- **Angle change range can be used to identify system event;**
- **Angle difference value is related to system stress level;**
- Angle pairs close to the event location can detect the event. Angle pairs that are far away from the event location can't detect the event.

Next Steps:

- **Prepare technical report**
- **Conduct Research to Identify event precursors that could lead to early warning and a new approach to alarming and system monitoring to allow operators time to react**
  - **Currently, alarms are based on thresholds.**
  - **Investigate whether for dynamic metrics**
    - **Phase angles**
    - **Oscillations**
    - **Sensitivities**
  - **Trend, duration and rate of change can be used to identify vulnerability to events**

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Thank You.

Any questions ?

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