DOE/OE Transmission Reliability Program

Eastern Interconnection Phase Angle Base Lining Study

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Topics

- Project Objective
- Study / Analysis Steps
- Major Technical Accomplishments
- Next Steps

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Project Objectives

- Research and apply statistical methods to perform base-lining analysis for four ISOs
- Establish the operating reference ranges for wide area angle differences for guidance to operators
- Identify significant events by using phasor measurement system data
- Research cascading event precursors

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Analysis Process

- **Select Phase Angle Pairs for Analysis**
- **Combine Phasor data from four ISOs (PJM, NYISO, MISO and ISO NE)**
  - *Two months of winter data (12/15/2013-2/15/2014)*
  - *Two months of fall data (09/01/2014-10/31/2014)*
  - *One week of December data (12/01/2014-12/7/2014)*
- **Extract angle pair values**
- **Establish normal ranges based on four months of data**
- **Apply Control Charting Statistical technique for significant events**
- **Validate detected events with NERC data – determine appropriate sigma value for application of statistical methods**
- **Characterize events based on number of angle pairs participating**
  - *Local events – few*
  - *Global events – many*

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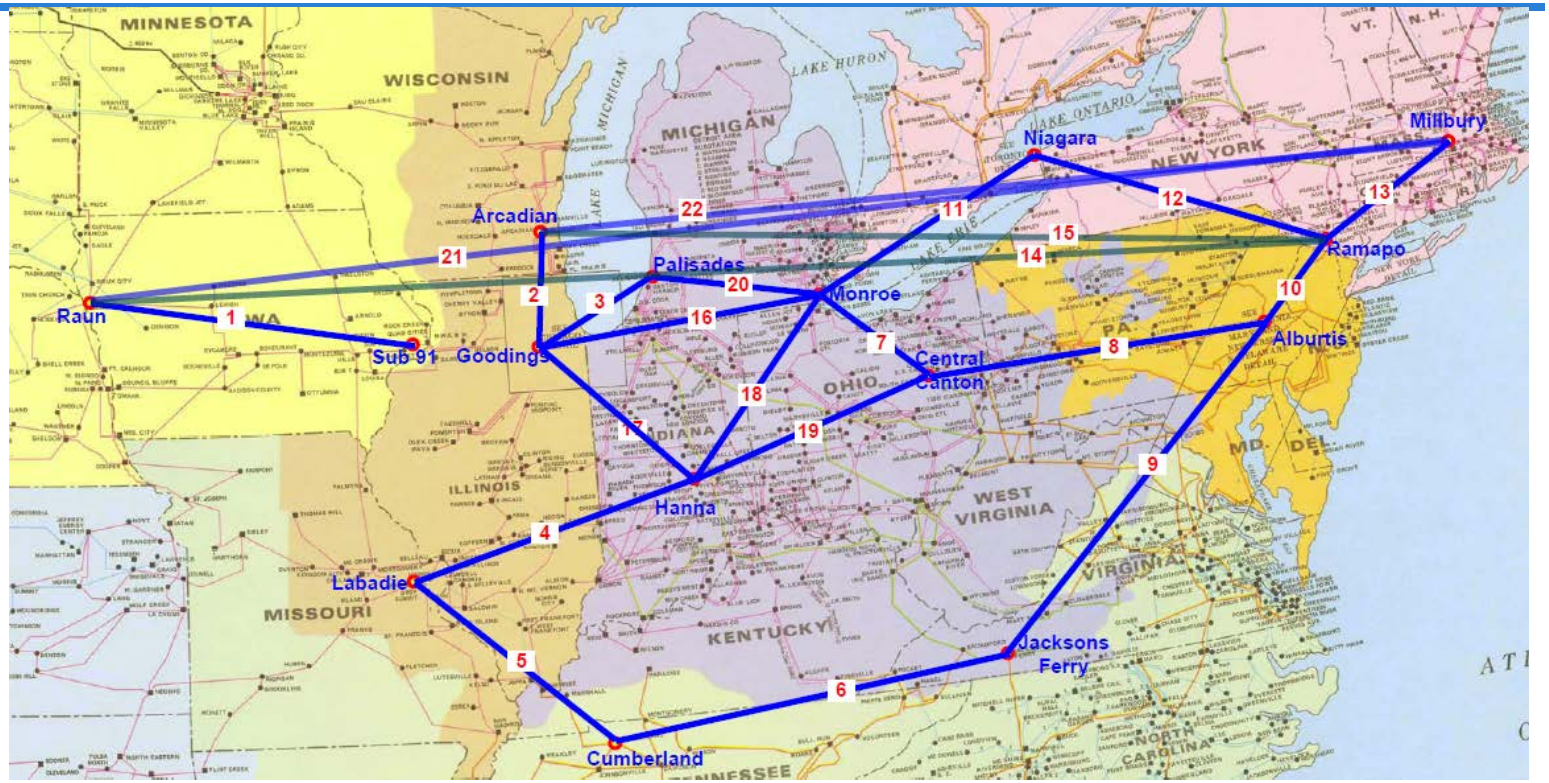
Selected Twenty Two Wide Area Angle Pairs Covering Four ISOs-Inputs from ISOs



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

Extract Angle Pair Values -– Identified Data Quality Issues

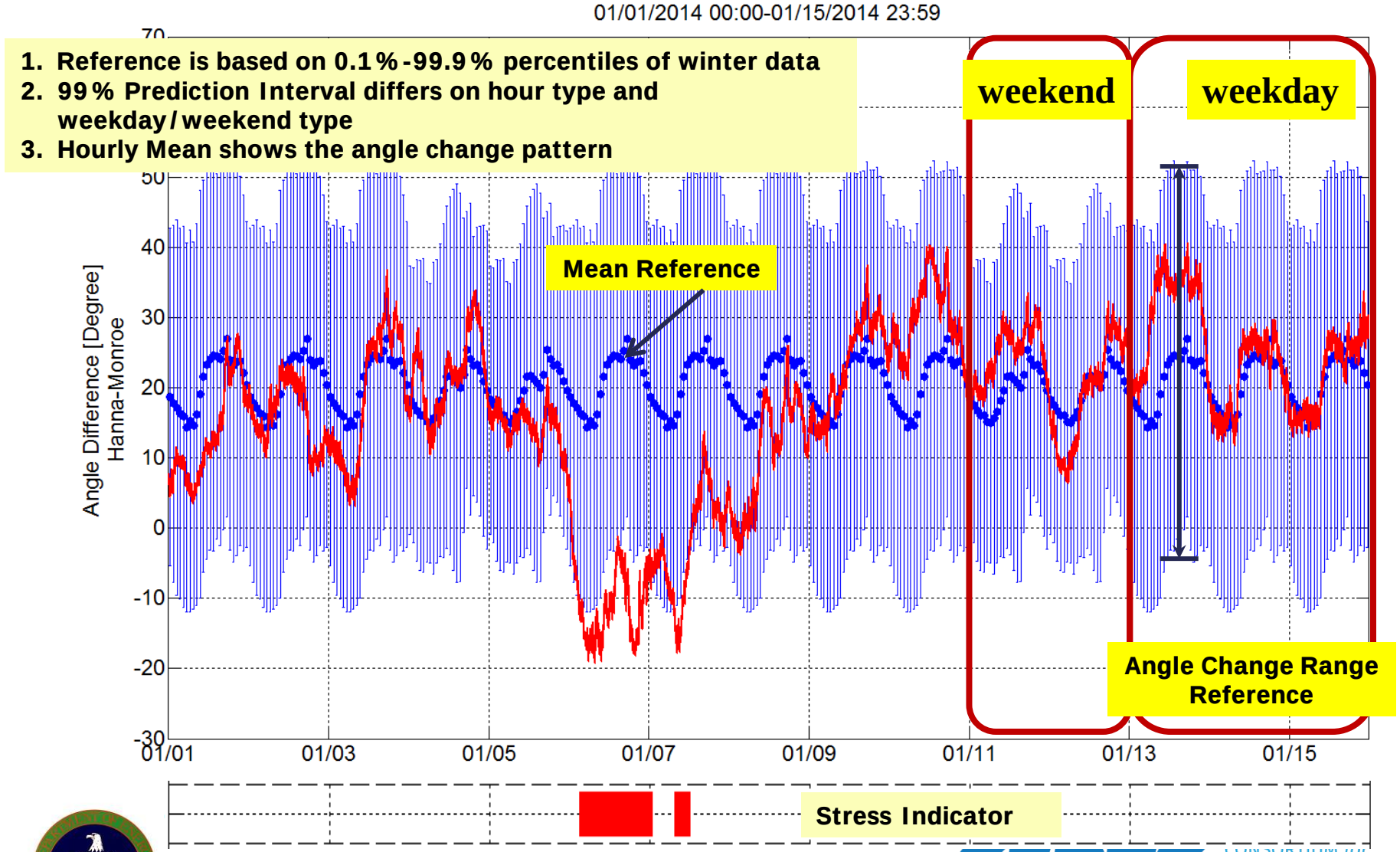
Examples of Bad data got MISO 12/1-12/07/2014 – Values replaced with NA

Status Flag Code	0x00000	0xDE030	0xFF030	0x21000	0x56000	0x56010	0x56020	0x42000	0x88000			
Data Quality Type	Good data	Data Invalid	Data Invalid/ Sync Error	Sort by arrival	PMU Error	PMU Error/ Unlocked time	PMU Error/ Sync Error	Sync Error	Test Mode	Dropout (1)	Missing (2)	Total
Altwrock_Ck 01	594352	71	4	0	0	0	0	0	0	591	9782	604800
Ammojopa_345 01	590716	0	492	3221	0	0	0	0	0	589	9782	604800
Ammolabadie 04	590644	0	491	3297 (3)	0	0	0	0	0	586	9782	604800
Ammomtgy 01	588802	0	2686	2942	0	0	0	0	0	588	9782	604800
Ammorush_Is 01	590543	0	495	3395	0	0	0	0	0	585	9782	604800
Ammosioux 01	590618	0	498	3261	27	28	0	0	0	586	9782	604800
Consargenta 01	594319	108	4	0	0	0	0	5	0	582	9782	604800
Conspalisad2 01	560893	33525 (4)	4	0	0	0	0	7	0	589	9782	604800
Decomonroe4 01	0	594425	4	0	0	0	0	0	0	589	9782	604800
Decoplacid 01	594406	18	4	0	0	0	0	0	0	590	9782	604800
Ipl Guion 01	594222	3	204	0	0	0	0	0	0	589	9782	604800
Ipl Hannaipl 01	594222	3	204	0	0	0	0	0	0	589	9782	604800
Ipl Sunnysid 01	594051	131	204	0	0	0	0	0	43	589	9782	604800
Mec Cbluffs 01	593898	0	53	0	91	386	0	0	0	590	9782	604800
Mec E_Molin 01	594010	0	416	0	0 (5)	0	0	0	0	592	9782	604800
Mec Hills 01	594383	0	47	0 (6)	0	0	0	0	0	588	9782	604800
Mec Lehigh2 01	584039	0	95	0	1333	6265	2700	0	0	586	9782	604800
Mec Raun 01	0	0	594429	0	0	0	0	0	0	589	9782	604800
Mec Raun 02	0	0	594435	0	0	0	0	0	0	583	9782	604800
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	604800

1. **Dropout (missing data) indicates possible failure of PMUs/PDC or the communication in between**
2. **Missing data (missing datetime and data) indicates possible failure of PDC/Database or the communication in between**
3. **PMUs from AMMO have most errors due to Time Sync and Sort by Arrival indicating possible clock/ communication issue**
4. **PMUs from Palisades and Monroe have mostly Data Invalid error indicating possible device failure**
5. **PMU from Lehigh experienced PMU error including configuration error indicating possible device/clock failure**
6. **PMUs from Raun have mostly Data Invalid/Sync error indicating non-operational PMU**

Established Monitoring Range

Values outside range during polar vortex on January 6 and January 7, 2014



http://www.nerc.com/pa/rrm/Pages/January-2014-Polar-Vortex-Review.aspx

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Identifying Significant Events Using Control Charting Technique

- Method commonly used in manufacturing to find samples outside the tolerance band
- Manufacturing tolerance band is typically +/- 3 sigma (99.7%)
- Angle pair angle difference used as input data
- Tested for December 1-7, 2014 period
- Tested alternate Values – 3 sigma results in too many events; 20 sigma identified extreme system events
- Two extreme events detected with 20 sigma – one event missed
- All three events detected using 15 sigma
- Local events detected by few angle pairs (1 to 3 angle pairs)
- Global events detected by large number of angle pairs (seven+ angle pairs) – wide area events

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Validated Three Events with NERC Report for Dec 1 to Dec 7, 2014

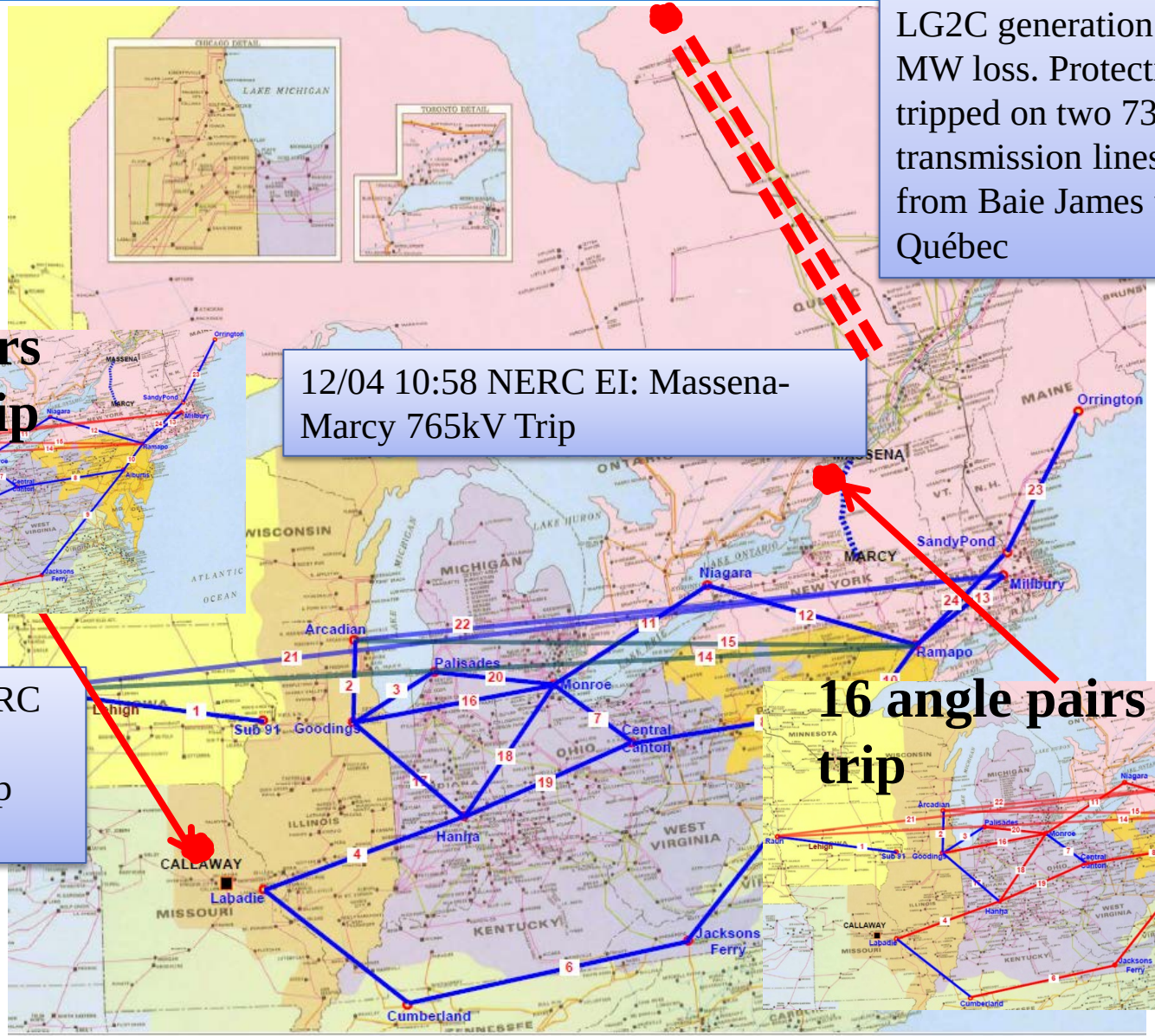
12/04 15:05 NERC Quebec: LG2C generation trip with 1019 MW loss. Protective devices tripped on two 735-kV transmission lines carrying power from Baie James to southern Québec

7 angle pairs detected trip

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

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

16 angle pairs detected trip



Research on Event Precursors

- Background
  - Typical blackouts with initial disturbances or trigger events followed by a sequence of cascading events
  - Major blackouts – WI 1996, EI 2003, PSW 2008 and many others all had event precursors with indication of 10 minutes to hours before blackouts
- Finding
  - **Initial Event** - Precursor is not likely found before trigger/initial events
  - **Trips** - Line and generator trips and single contingencies may have no early warning sign
  - **Cascading Events** – Cascading event precursors do exist and can provide early warning to operators
  - **Research** – Event precursor research is promising – needs more data for analysis to understand precursor patterns and thresholds for use in operations

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Areas for Additional Research – Next Steps

- Baselining Research and analysis of data from 4 ISO's has identified 2 promising research areas:
  - Event Precursor Research
  - Automating phase angle limit determination in real time
- Event Precursor Research – Study patterns to identify precursors that provide lead time for preventive operator action
  - Requires data from ISO's
- Automating phase angle limit determination in real time
  - Methods researched can be implemented to work in real time
  - Application can be designed to integrate with existing synchrophasor deployments
  - Does not require additional data
  - Will need ISO cooperation for testing, validation and demonstration

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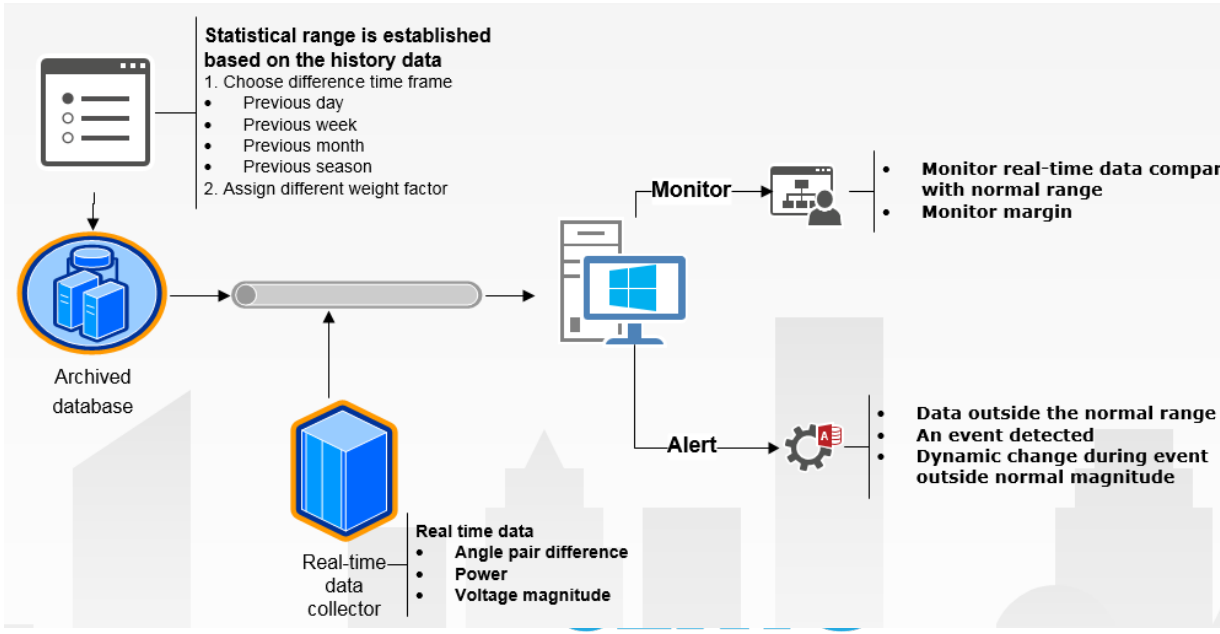
Real time application for establishing and monitoring phase angle limits

- Use archived data to perform statistical analysis and determine limits
- Update limits in real time
  - Normal operating range established by historical data
  - User can set the different time of range to establish the normal operating range
    - *Previous day, previous week, previous month, previous season*
    - *Assign weight function*
  - Range to be monitored can be static or dynamic range based on the hour type of the day or the day type of week (weekday/weekend)
  - Monitor margin based the normal distribution
- Alert the operators if
  - Value is outside the normal operation range
  - Any system disturbance detected
  - Dynamic change outside the normal range



Work Plan and Steps

Design and develop proof of concept real time application for establishing phase angle limits and monitoring

- Collect the requirements from ISOs and design scope of work
- Functional description, design document and specifications prototype
- Collect the feedback from ISOs and modify the documents as necessary
- Design interface to access data from ISO database or historians (PI system, RTDMS…)
- Enable users to specify the type of data to be used in establishing angle limits – duration, season, weighting factors etc.
- Utilize baselining research to date to develop methodology (statistical, algorithms and procedures) to provide phase angle limits in real time
- Use control chart technique to detect vulnerabilities to extreme events and find the critical paths (most sensitive to disturbances)
- Calculate operating margin in real time
- Design application so it is extensible to handle other metrics if warranted
- Validate the prototype for one or more ISO's as a test bed for angle limits, operating points, margins and critical paths in real time

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Thank You.

Any questions ?

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