



PPL Electric Utilities

We Deliver.

Dynamic Line Ratings Strategy

Current PPL Transmission Grid



Star 11052019 13:00, End 12262019 13:00 19-00042 Edit 736195
 REV # 1 Work Order 58252892

To Have: 13869KV Transformer No. 4, 69KV Operating Bus sections No. 2 and 3 and the 69KV Inspection Bus at Wacoaville substation, including the Hoesensack-Wacoaville No. 2 69KV line, Wacoaville sub to 69KV loops 4084/4490/8, and the Wacoaville-South Fogelsville No. 1 69KV line, Wacoaville sub to 69KV loops 6073/6402/5, and the Wacoaville-Brangsville No. 1 69KV line, Wacoaville sub to the Wacoaville No. 1 69KV line. All (1400) 61132644336 out of service to test, commission, and place in service 69KV Bus Tie relay schemes related to 69KV Bus Section 3 in the New Control House. Restore the Bus Sect. 2-3 69KV QGD, Replace the South Fogelsville No. 1 Line, Inspection Bus 69KV Disconnects, Lighting Arrestors, and CBs on the Hoesensack No. 2, to the new control house. Continue 69KV Bus Tie CB replacement and connect new 69KV Bus Tie Pot device. Restore Operating Bus Section 1-3 Sect. 3 QGD, Rebuild Operating Bus Section No. 2, Cutover new Operating Disconnect. Replace 69KV pot devices and associated pot junction boxes for the following terminals: Hoesensack No. 2, South Fogelsville No. 1, Brangsville No. 1. Replace 69KV Bus Tie Ins Bus Disconnects, Close 69KV loops in Bay 1SL to connect 69KV Cap Bank 1 69KV QGD to 69KV Inspection Bus, Replace T4 station service fuse from NK-43 to NK-25, Remove cable between T8 tertiary cabinet and T4 station service transformer.

PERMIT
 Approx Clearing Time
 Day and Date: NOV 03 2019 Time: 14:16 Contact Number: 60-908-6360
 Issued By: [Signature] to: [Signature]

Time	Location	DETAILS OF BLOCKING/SWITCHING
0702	5806643944	CLOSE TRAN 1-2 TIE (1424-N.O.) 69KV MOLBAR VIA SCADA
0705	WESC	OPEN BREI 1 69KV CB VIA SCADA
0817	61132644336	OPEN WESC 1 (1400) 69KV AB & RT
0718	5806643926	CLOSE MIRU TAP 2 (1461-N.O.) 69KV MOLBAR VIA SCADA
0711	WESC	OPEN SFOG 1 69KV CB VIA SCADA

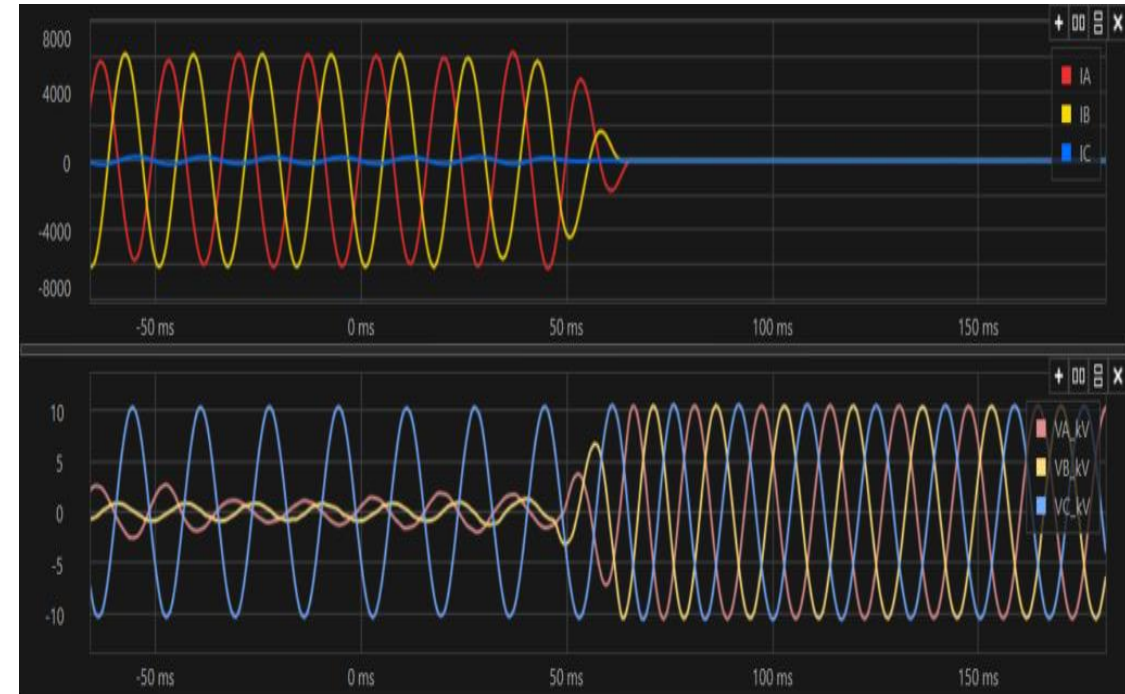
Operator Review:
 Cleared by: [Signature] Closed by: [Signature] Time: 14:18 Date: DEC 2 3 2019
 Also see permits: C19-00483, 19-01654, 19-05258, 19-05259, 19-07274, 19-07278, 18-02504, 19-07272, 46092, 19-07871

- Heavily rebuilt & strengthened physical plant
- ~50% penetration of microprocessor relays
- Primitive “smart” devices
- No automation
- People-dependent
 - Manual switching / paper permits
 - Reactive to failed equipment
 - Engineer calculated fault locations
 - Isolated voltage control



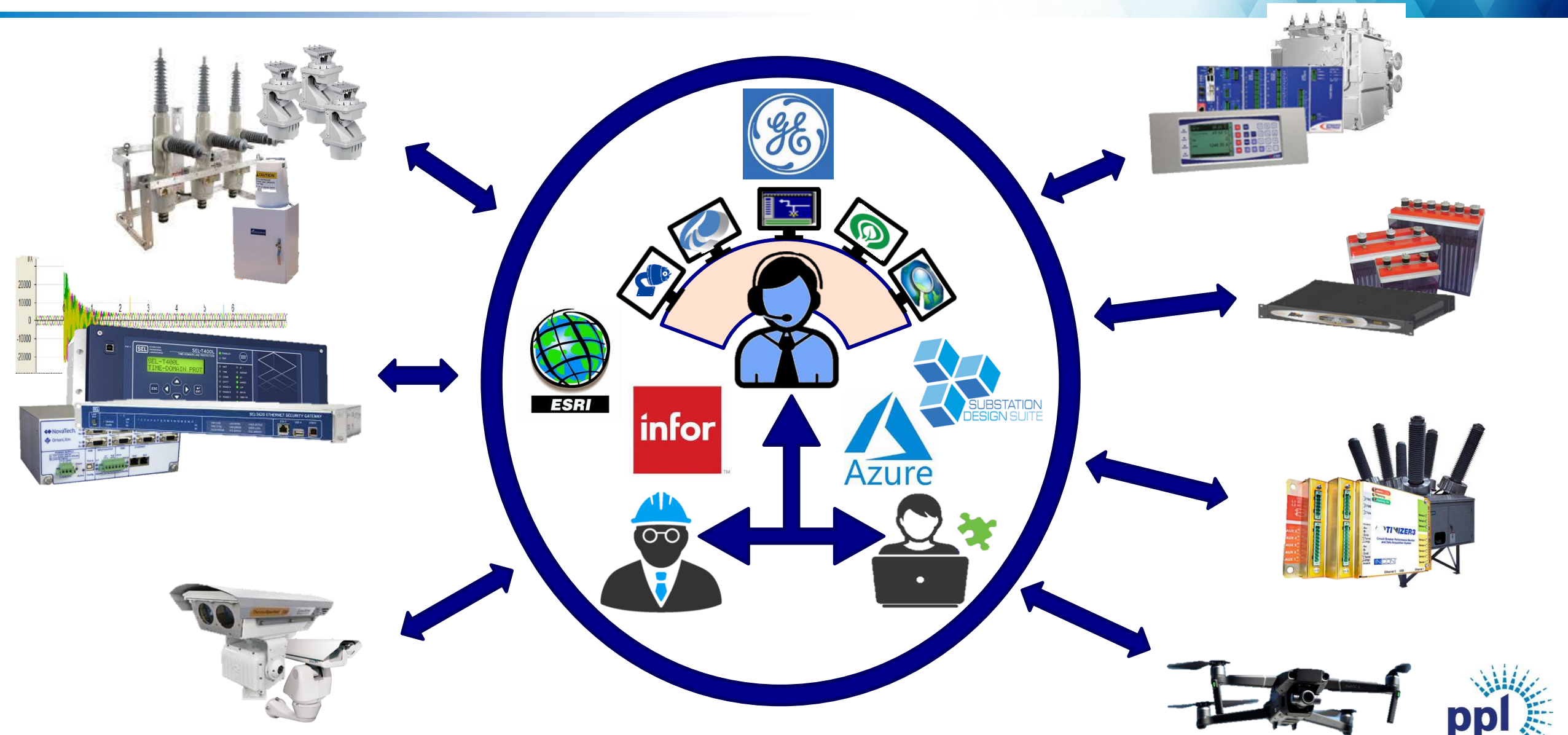
Elements of the Future Transmission Grid

- 100% smart relays & devices
- Single connectivity, geo-spatial, & engineering model
- Predict all failures before they occur
- Automated operations based on real-time data feeds into TMS
- Grid-enhancing technologies
 - Smart Wires
 - Asset Health Monitoring on every asset class
 - *Dynamic Line Monitoring*
 - Traveling Wave Relays



High Resolution Waveform Data

Enabler: Centralized Platforms



What is DLR?

System of line sensors installed to measure conductor and environmental real time data. The data can then be used for asset health algorithms and real-time operation for determining a real time rating for the line.

■ Static Line Ratings

Assumes:

- Wind speed
- Ambient Temp
- Solar Radiation
- 2 Seasons (Planning)
- Ambient Adjusted Ratings (Operating)

Conservatively Calculates Ratings

No way to trend field conditions or health

■ Dynamic Line Ratings

Measures:

- Wind Speed
- Ambient Temp
- Conductor Temp
- Conductor Sag

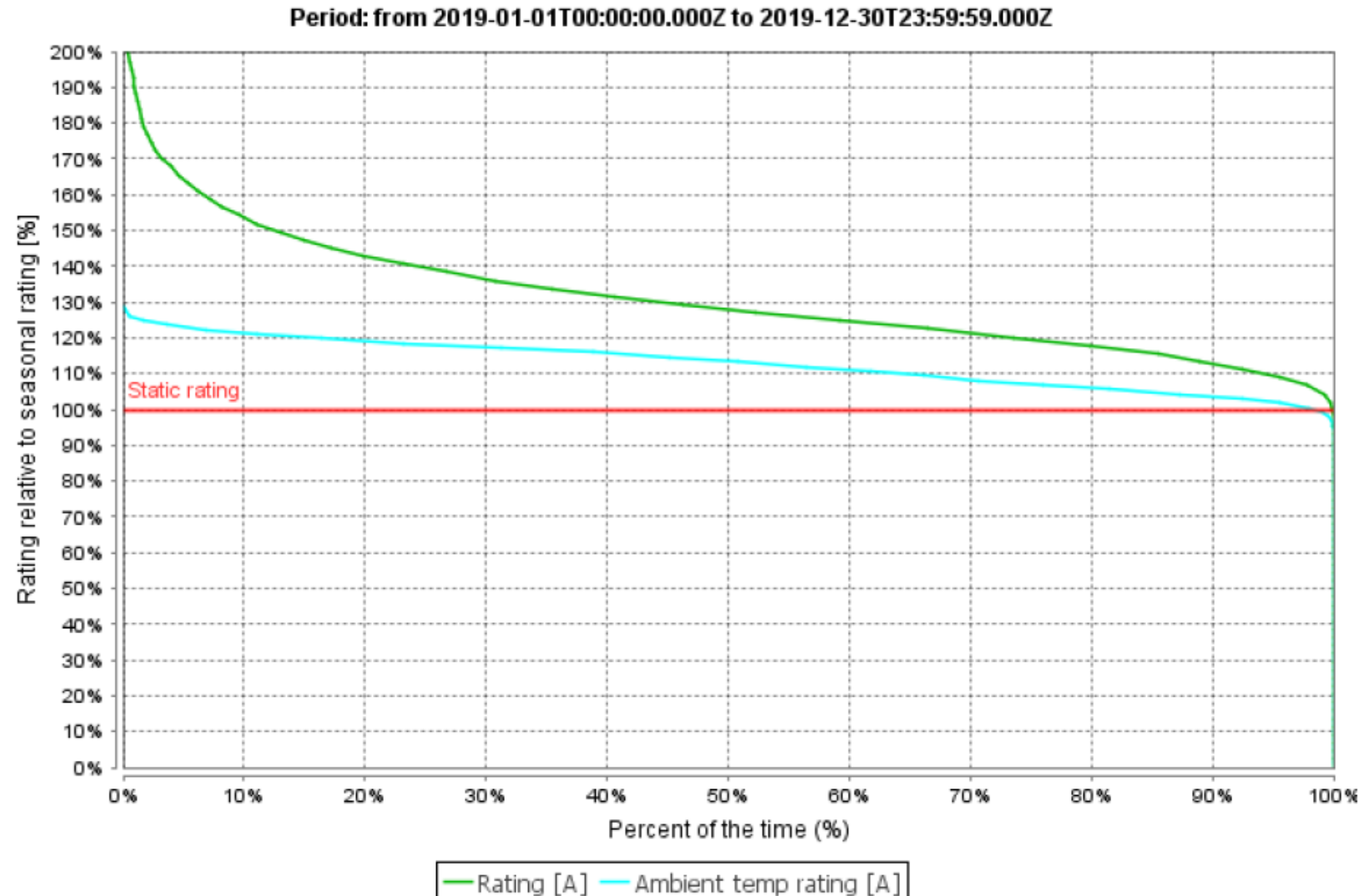
Provides Accurate Real Time and Forecasted Ratings

Measures Conductor Health

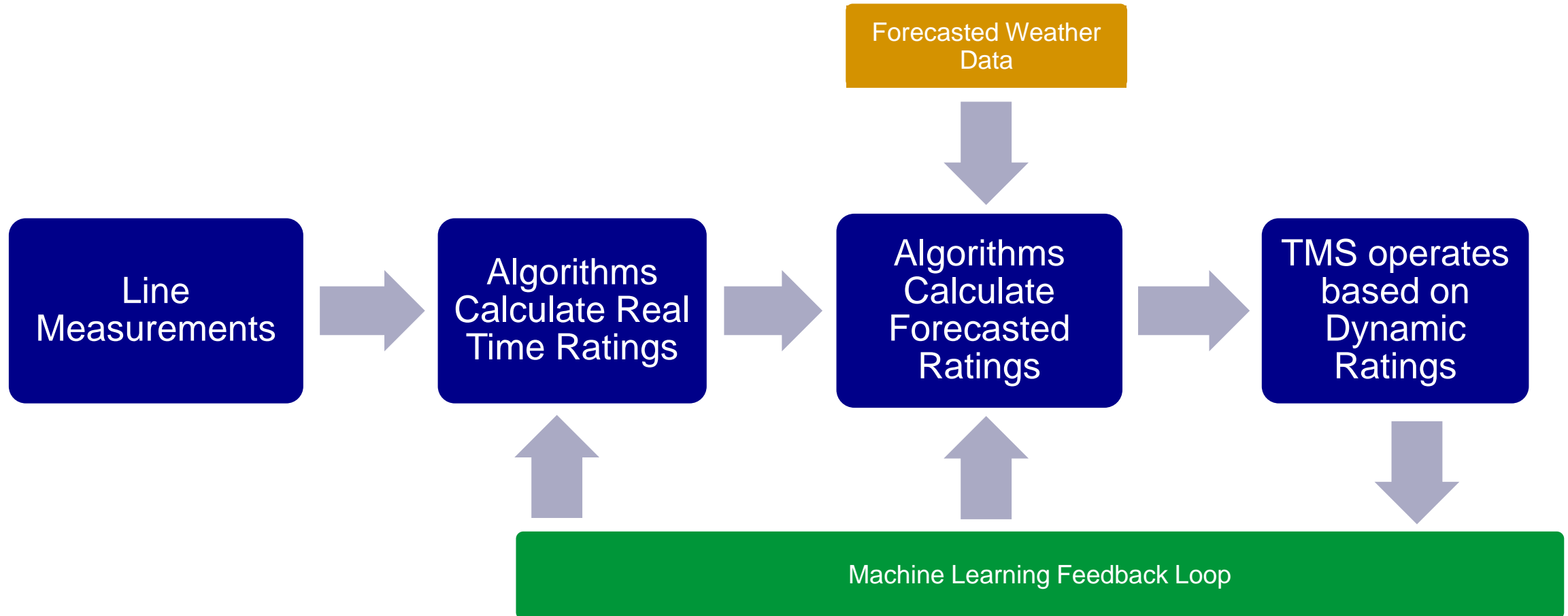


Potential Ratings Gain

- Used historical temperature and wind speed to estimate the impact of the dynamic lines ratings system
- Based on calculated conductor temperature
- Expected average ratings gain of almost 30%
- Actual rating increase incorporating the real time conductor data is expected to be greater than the estimated ratings using historical data



Dynamic Line Ratings Process



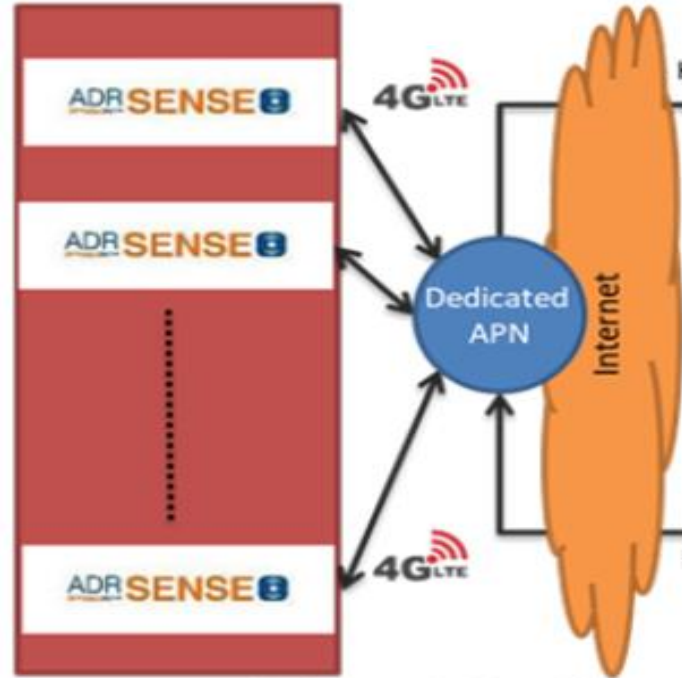
Dynamic Line Rating Next Steps



- Establishing a data stream from the sensors installed on Juniata-Cumberland & Harwood-Susquehanna lines to PPL Operations.
- Work with PJM to fully utilize available line capacity, by operating to real-time ratings and using forecasted ratings in the day ahead market.
- Continue to seek additional lines to install the technology on
- Looking at using accumulated historical DLR over time to justify improving static line ratings methodology

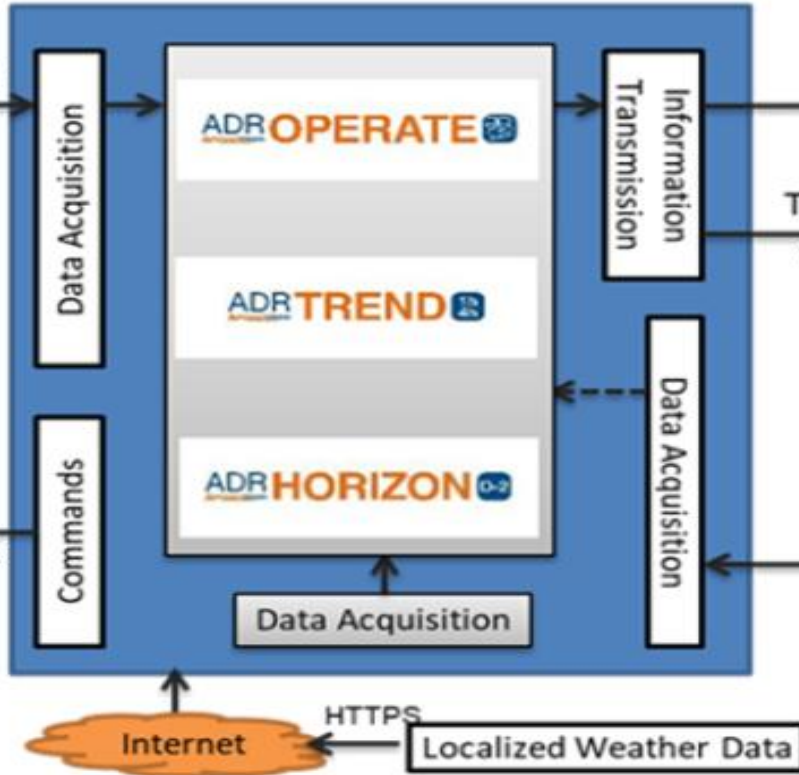
System Overview

Ampacimon
Smart solutions for a dynamic grid
Sensors on T-lines

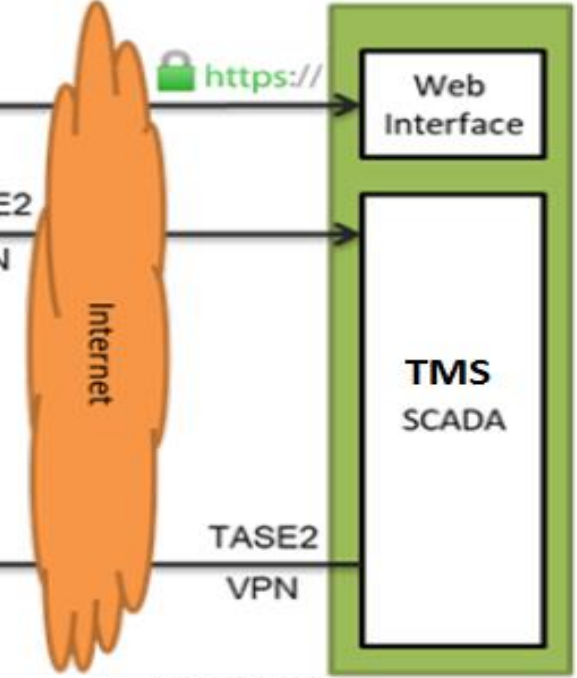


- List of all non-critical data which are encrypted in communication are:
- Raw acceleration
 - Sensor internal board temperature
 - Sensor's power supply voltage
 - Sensor's diagnostic data
 - RMS Current
 - Tension
 - Each data package also contains the Sensor ID

Virtual Server in Cloud Environment



- Sag, Effective Wind speed
- State Change Equations
- IEEE / Cigré thermal modelling
- Ruling span
- Line capacity based on the true limits (Amp, MVA, MW, & MVAR)
- Fault Detection
- Galloping and Ice Accretion
- Storing historical data
- Statistics and reporting
- Forecasting applications



- Dynamic Line Rating:
- Real-time
 - Intra-day
 - Days-ahead forecast
 - MVA, MW & MVAR
- Fault Detection:
- Momentary
 - Permanent
- Galloping & Ice Accretion:
- Conductor Twisting
 - Galloping
 - Ice Accretion