Data and Analytics for Distribution

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Outline – Questions to Frame the Session

- Data from advanced grid technologies – Emma Stewart (LLNL), Kevin Schneider (PNNL)
- What data do advanced grid technologies provide?
- What data can we collect and track?
- What can be done with data?

- Extra Info:
- GMLC Sensors and Measurement Roadmap
- Synchrophasors and Distribution synchrophasors
- Further reading

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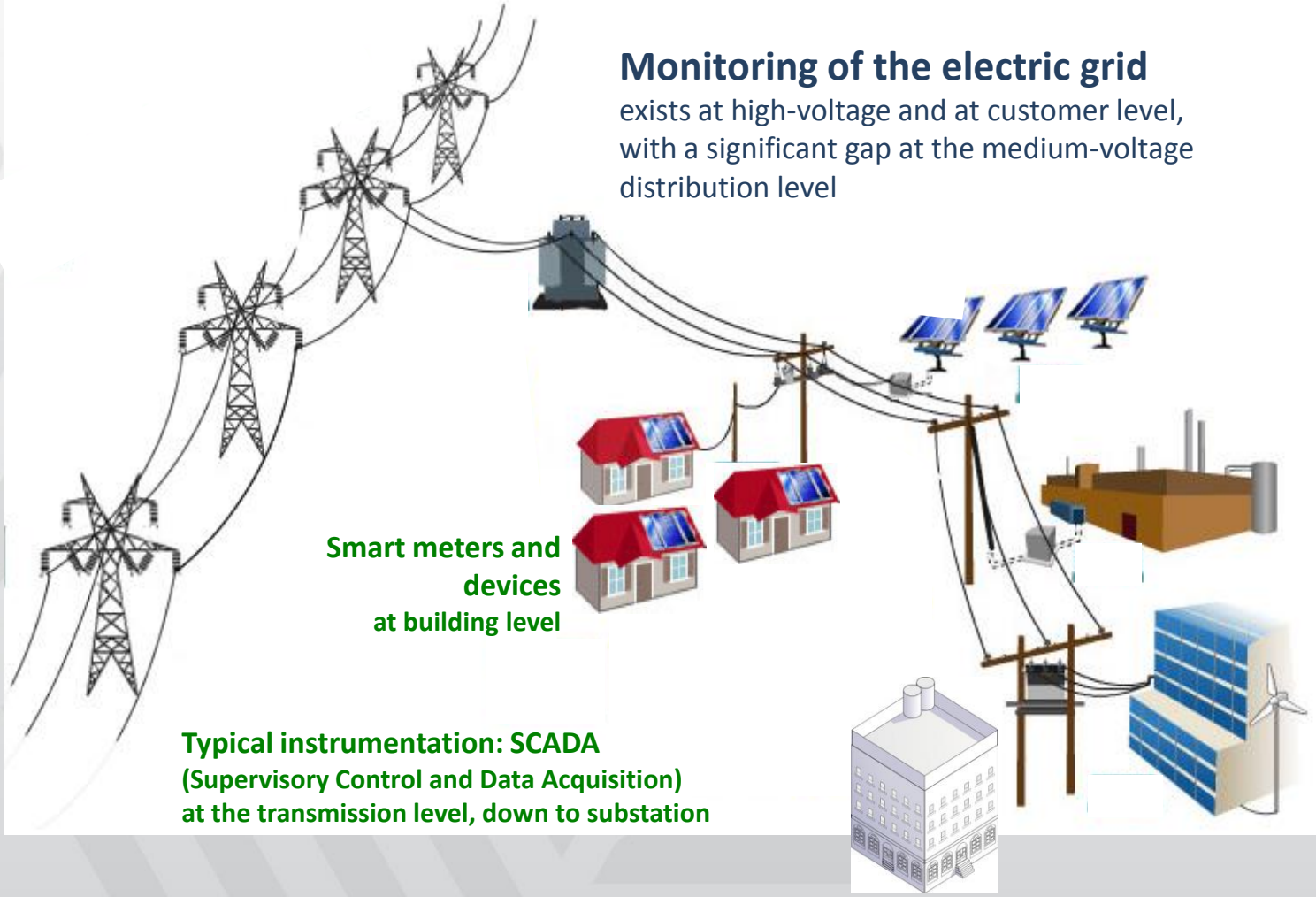
Introduction to Advanced Grid Measurement Technologies

Monitoring of the electric grid

exists at high-voltage and at customer level, with a significant gap at the medium-voltage distribution level



Smart meters and devices
at building level

Typical instrumentation: SCADA
(Supervisory Control and Data Acquisition)
at the transmission level, down to substation

Time scales of measurement and operations are diverse

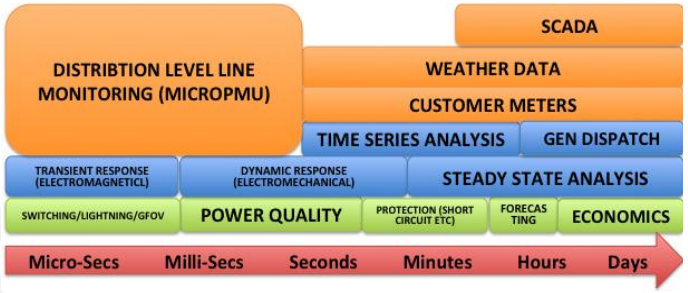
Key questions for both research and industry

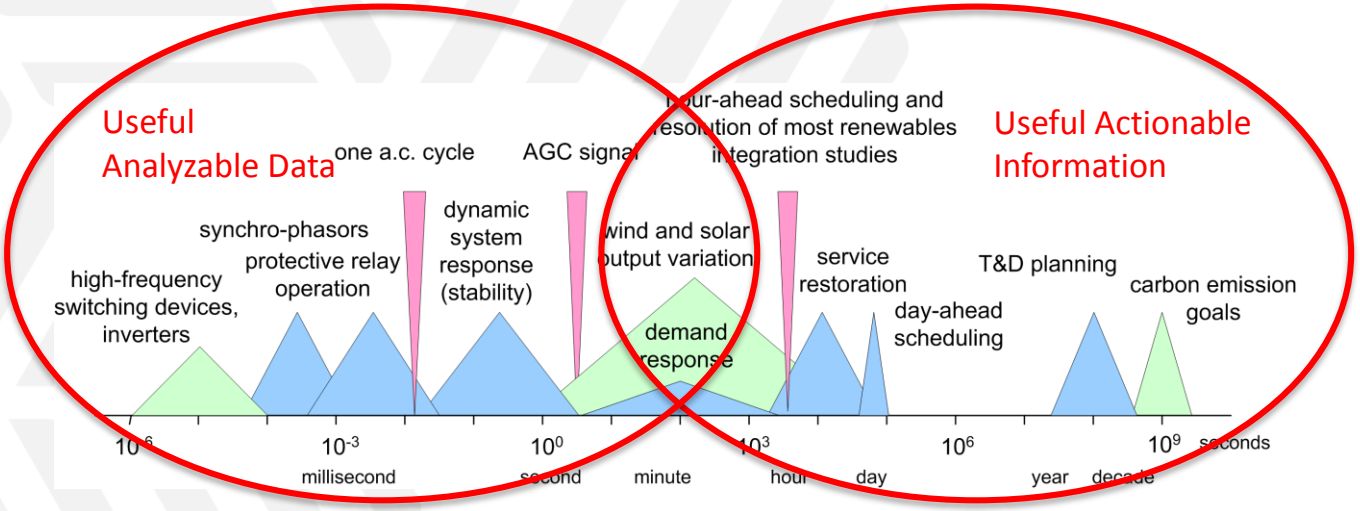
What measurements do we need?

Where do we need the measurement and analytics?

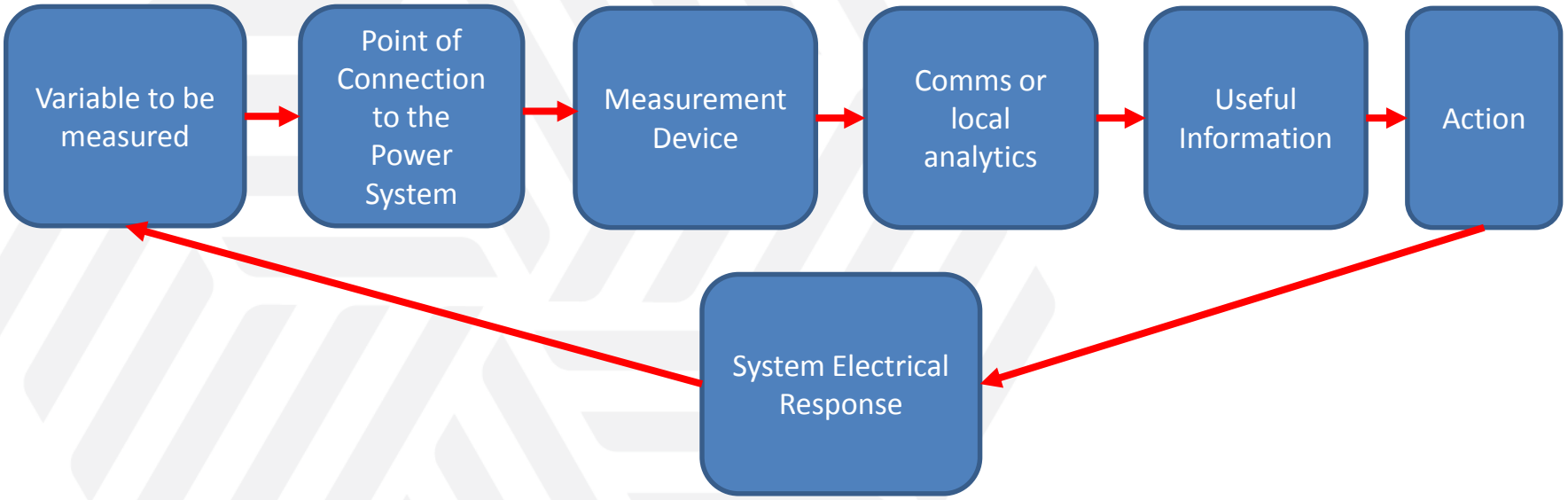
Who needs the information?

When and How do they need it?

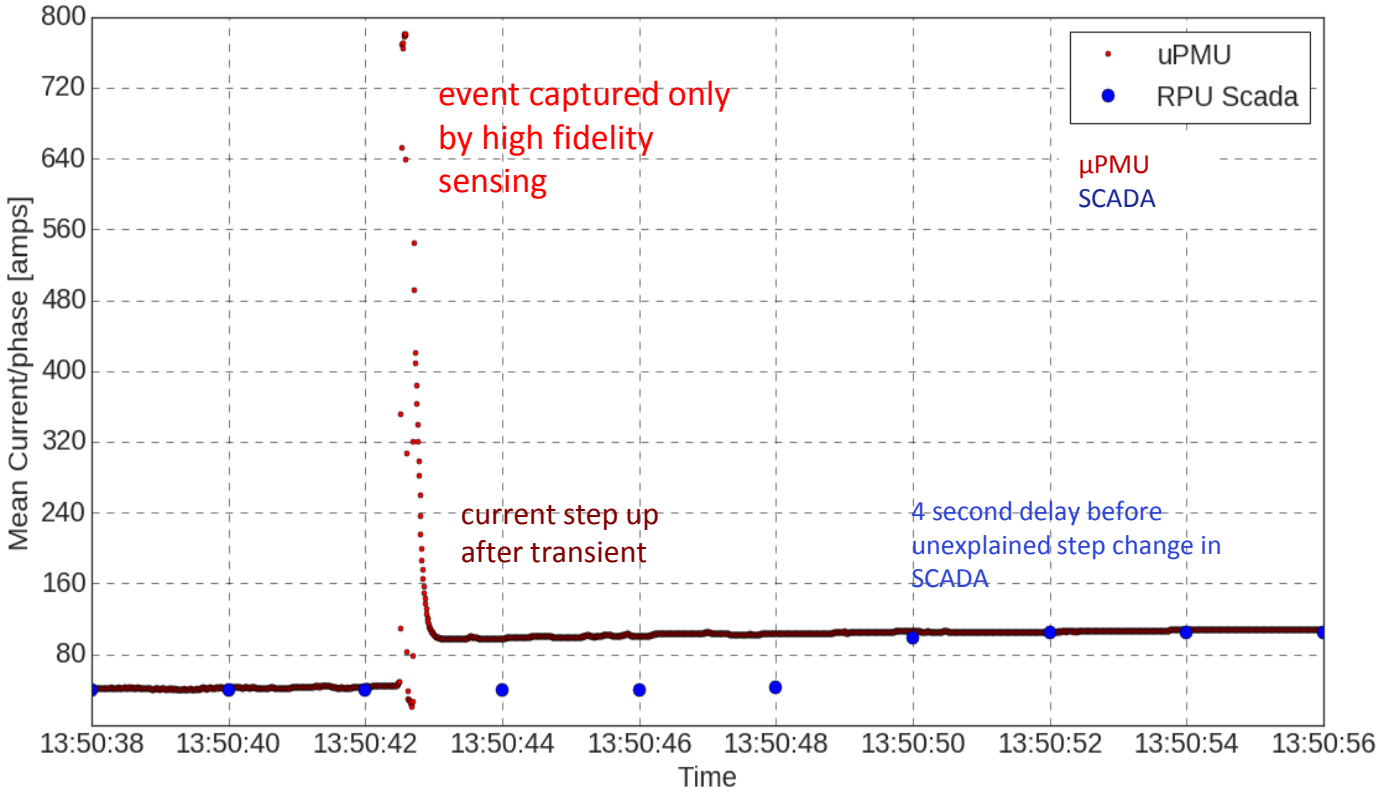




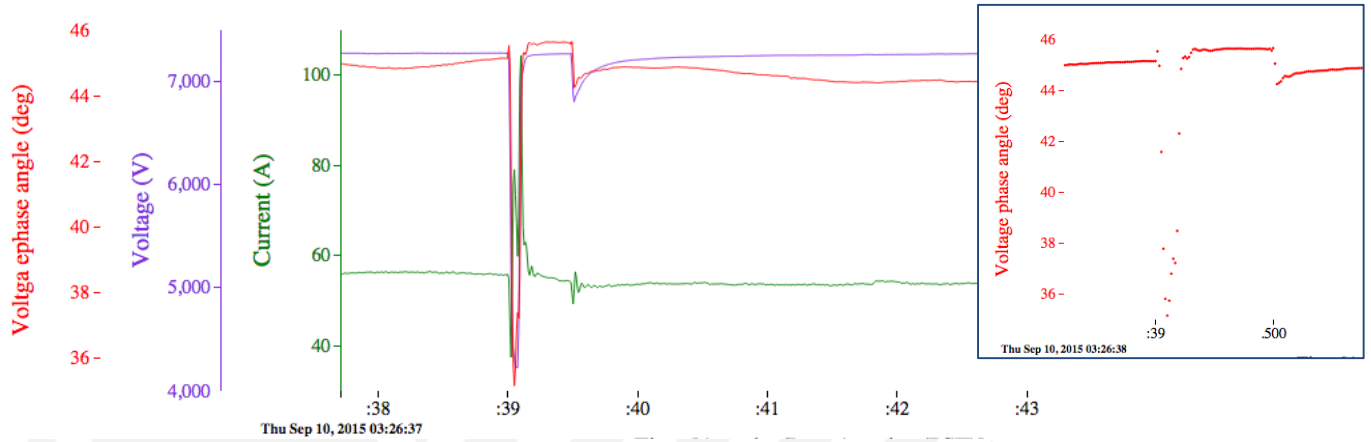
Sensing and Measurement - Intro



SCADA and PMUs – opposite ends of the data spectrum



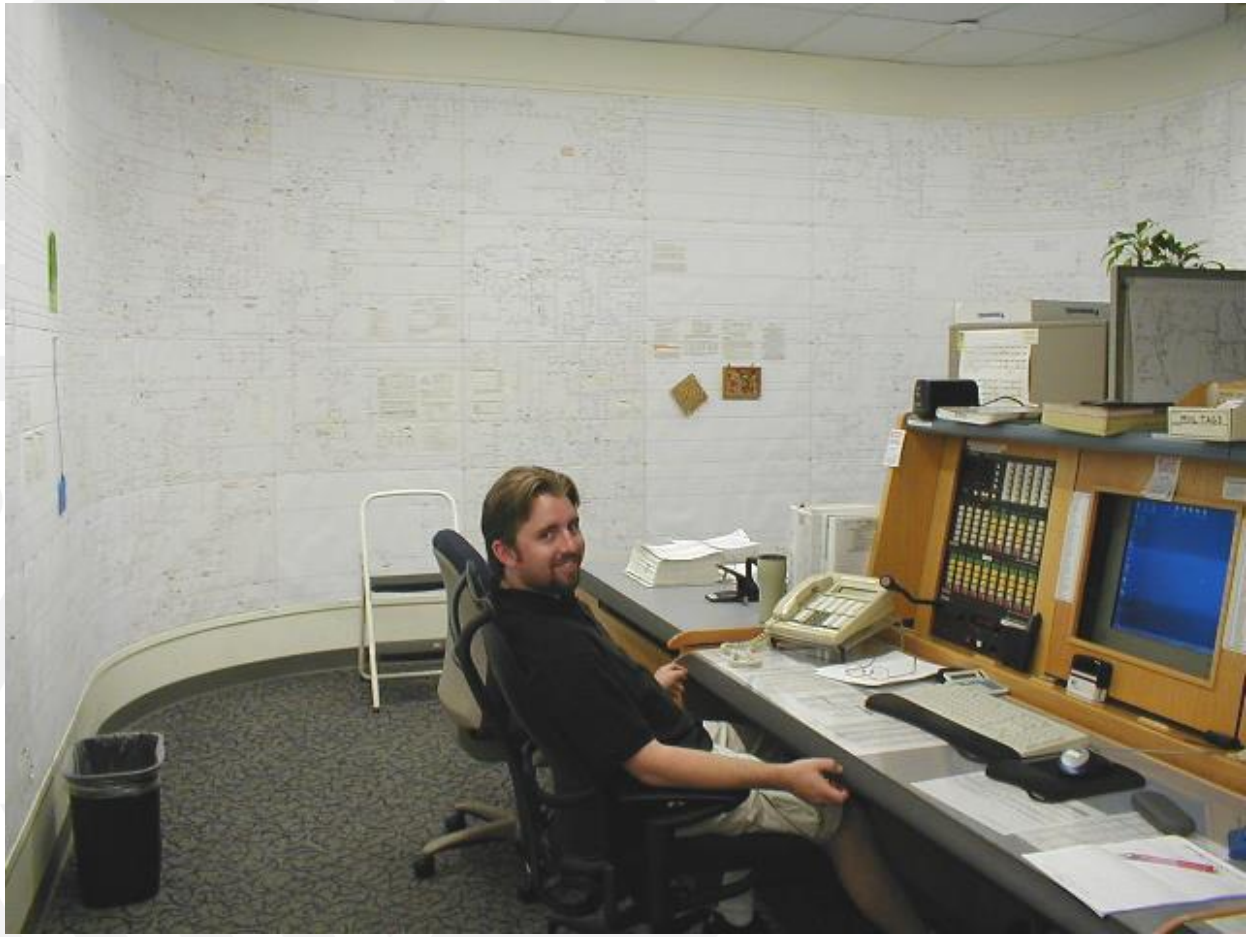
Use Case Example: High Impedance Fault Detection



High-precision measurements capture small events that do not trip protection

Cross-referencing of time-aligned data streams supports diagnostics

Expectation versus Reality

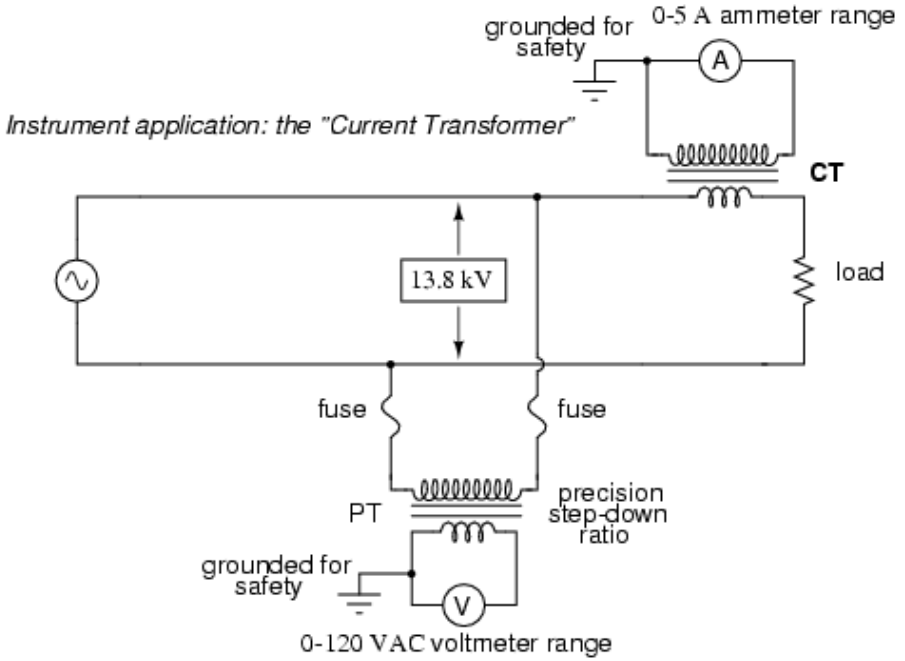


Back to Basics – point of connections to the distribution system

Voltage and current sensing

use instrument transformers
potential transformers (PTs), current transformers (CTs)

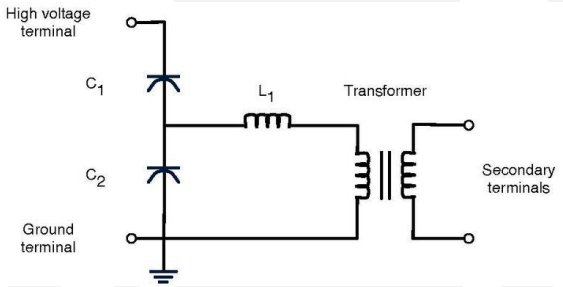
Pt's and CT's



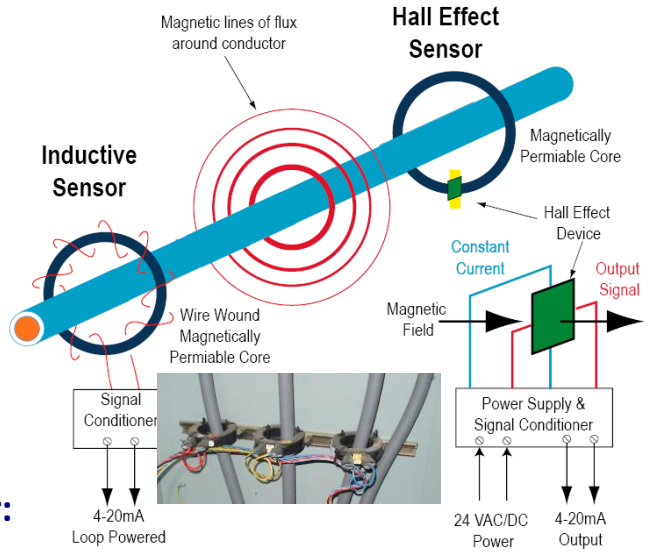
Points of connection

Potential transformers (PTs)

may use resistive or capacitive voltage divider

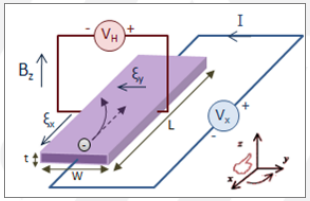


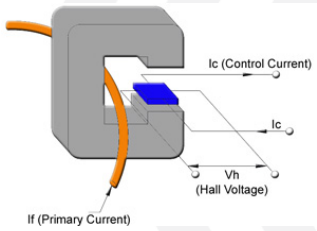
Current transformers (CTs)



Rogowski Coil:

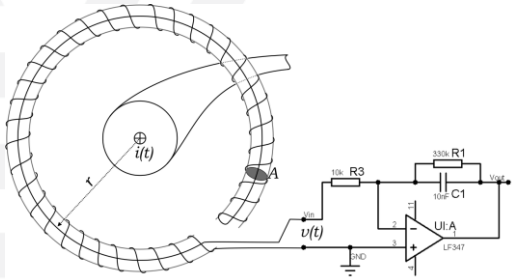
rate of change of primary current produces output voltage; integrate to find original current
no iron core needed, fast response





Hall effect current sensor:

magnetic field in gap (due to primary current) exerts Lorentz force **F** = q**v** x **B**
on moving charges in control current
deflection of these charges produces the Hall voltage
which is measured



"Rogowsky coil" by Luque alfredo - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Rogowsky_coil.png#/media/File:Rogowsky_coil.png

Deeper dive into sensing types

- SCADA
- Smart Meters
- PMUs
- Others

Supervisory Control and Data Acquisition (SCADA) Components

Sensors: instruments measuring physical quantities (current, voltage)

Remote terminal units (**RTUs**): perform analog-to-digital "A to D" conversion of sensor signals; may include basic control capability

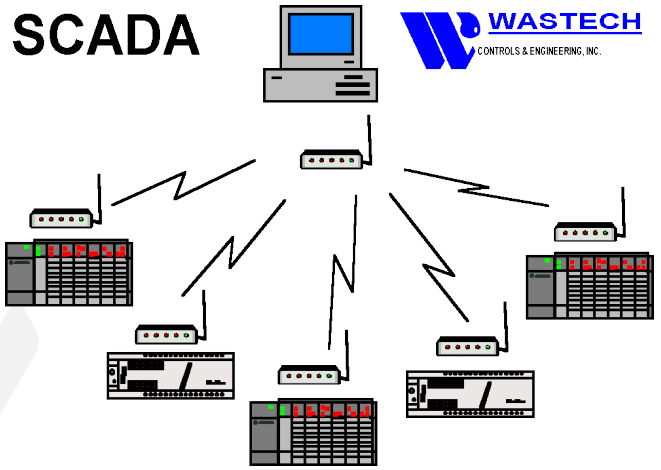
Programmable Logic Controllers (**PLCs**): similar to RTUs, more sophisticated controls

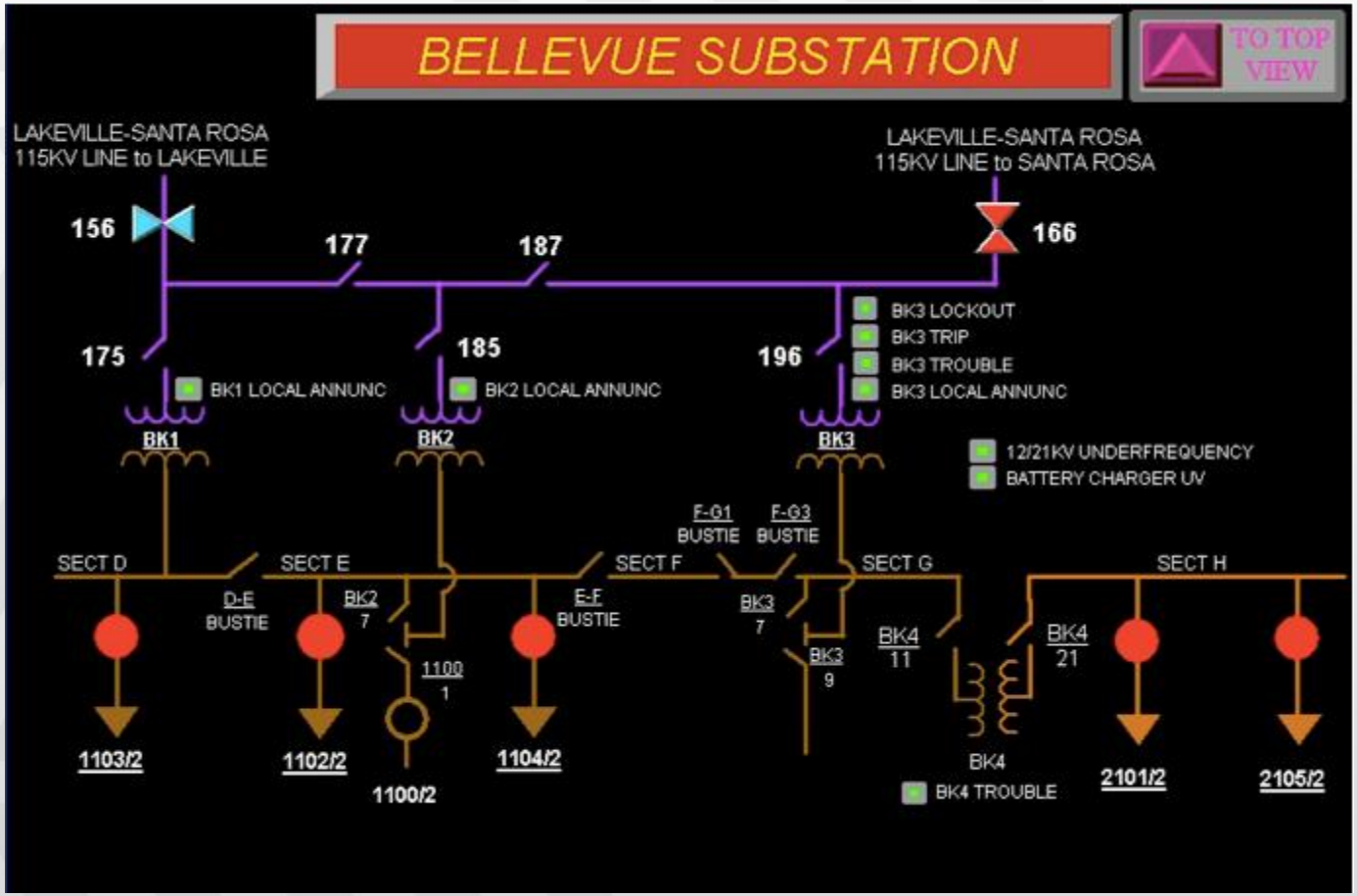
Telemetry: provides connection for signals between field devices and control center, using some **physical communication layers** (telephone wires, radio, satellite, microwave, 3G wireless)

Data Acquisition Server: manages data from field devices

Data Historian: stores data

Human-machine interface (HMI): client for data from server; presents to operator; may receive control inputs from human operator




BELLEVUE SUBSTATION
TO TOP VIEW
LAKEVILLE-SANTA ROSA
115KV LINE to LAKEVILLE
LAKEVILLE-SANTA ROSA
115KV LINE to SANTA ROSA
156
177
187
166
175
185
196
BK3 LOCKOUT
BK3 TRIP
BK3 TROUBLE
BK3 LOCAL ANNUNC
BK1 LOCAL ANNUNC
BK2 LOCAL ANNUNC
BK1
BK2
BK3
12/21KV UNDERFREQUENCY
BATTERY CHARGER UV
F-G1 BUSTIE
F-G3 BUSTIE
SECT D
SECT E
SECT F
SECT G
SECT H
D-E BUSTIE
BK2 7
E-F BUSTIE
BK3 7
BK4 11
BK4 21
1100 1
BK3 9
1103/2
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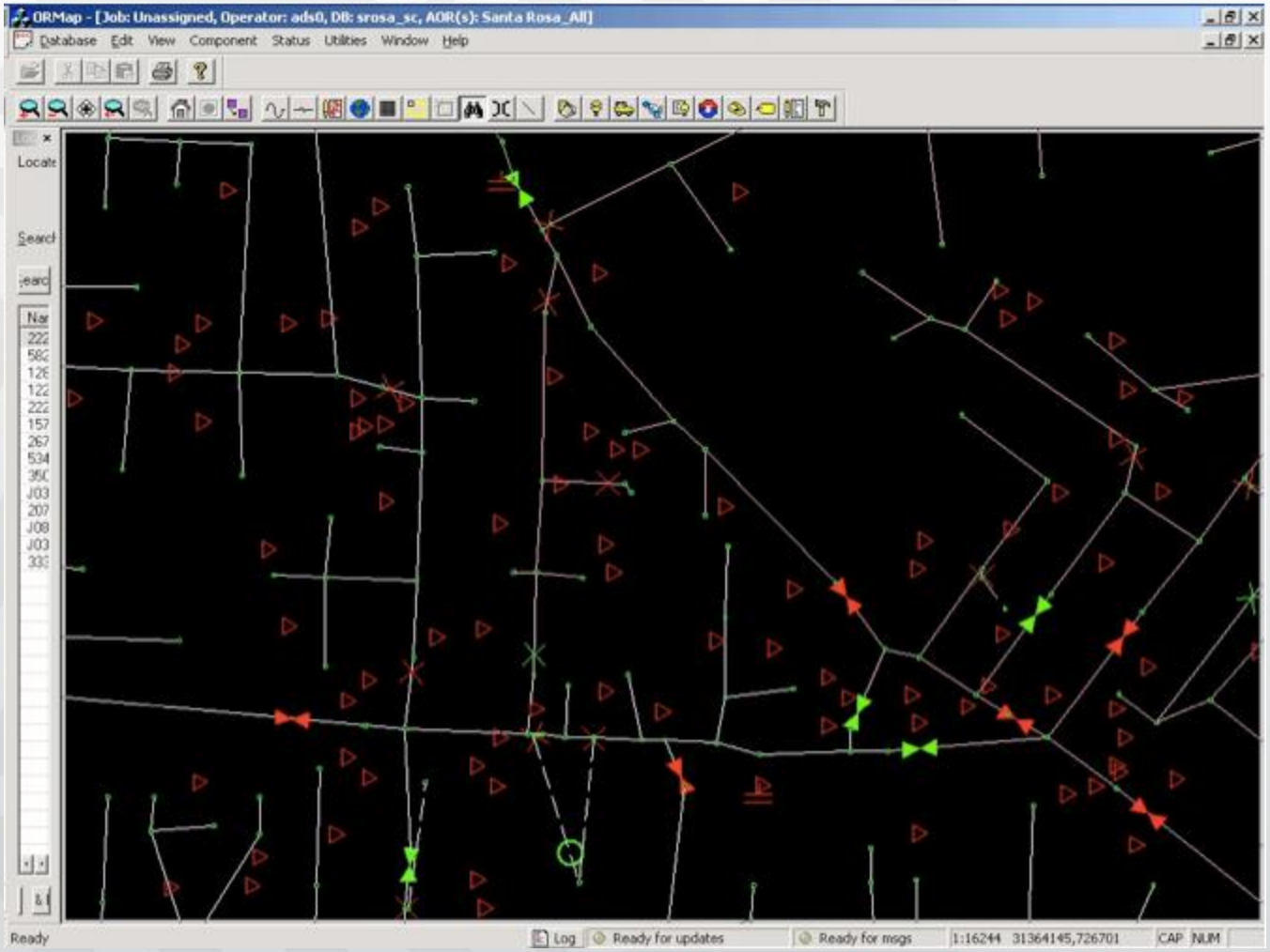
BK4
BK4 TROUBLE
2101/2
2105/2



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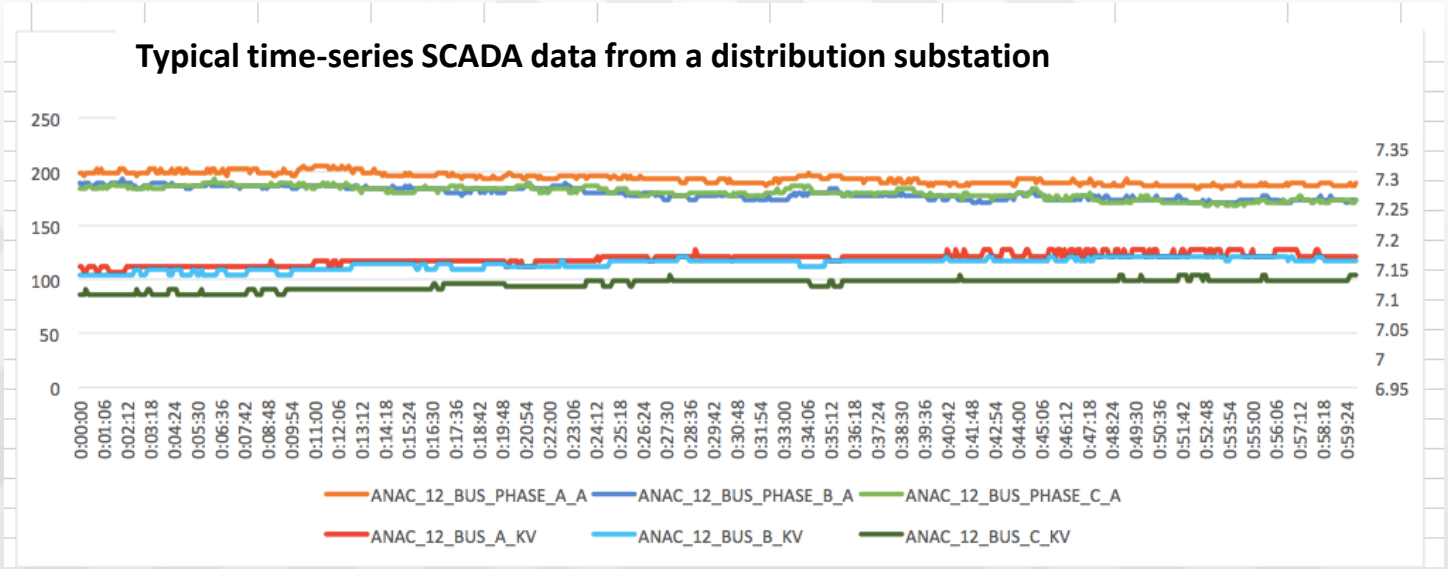


One problem: time synchronization among locations!

Smart Meters

Primary purpose: Settlement
(time-differentiated meter reading)

Secondary purpose:
identify outages
other operations support

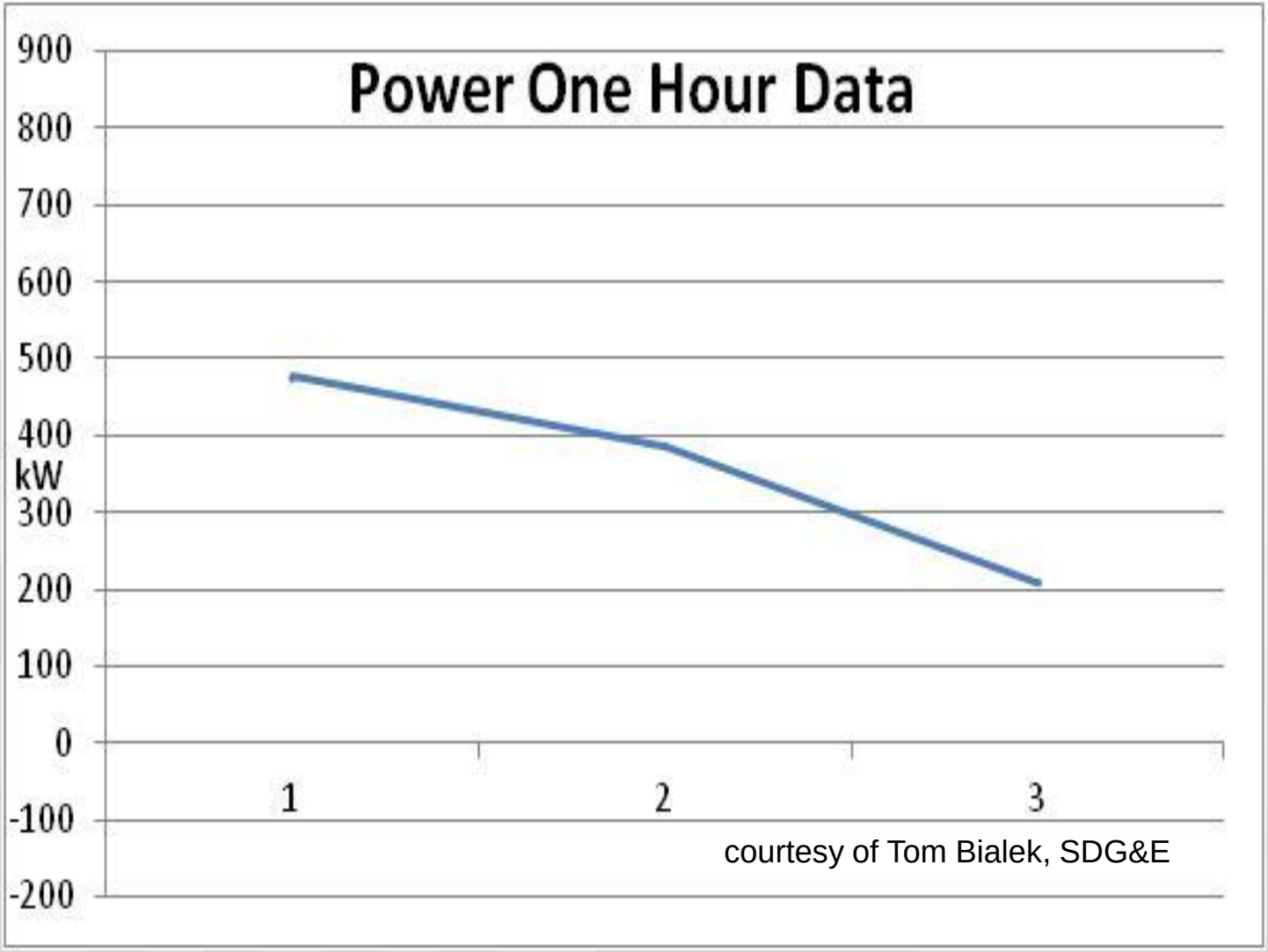
Typical activity:

record kWh usage, voltage at 15-min intervals
report 8 hrs worth of 15-min kWh data to access point 3x per day
send “death chirp” in case of outage

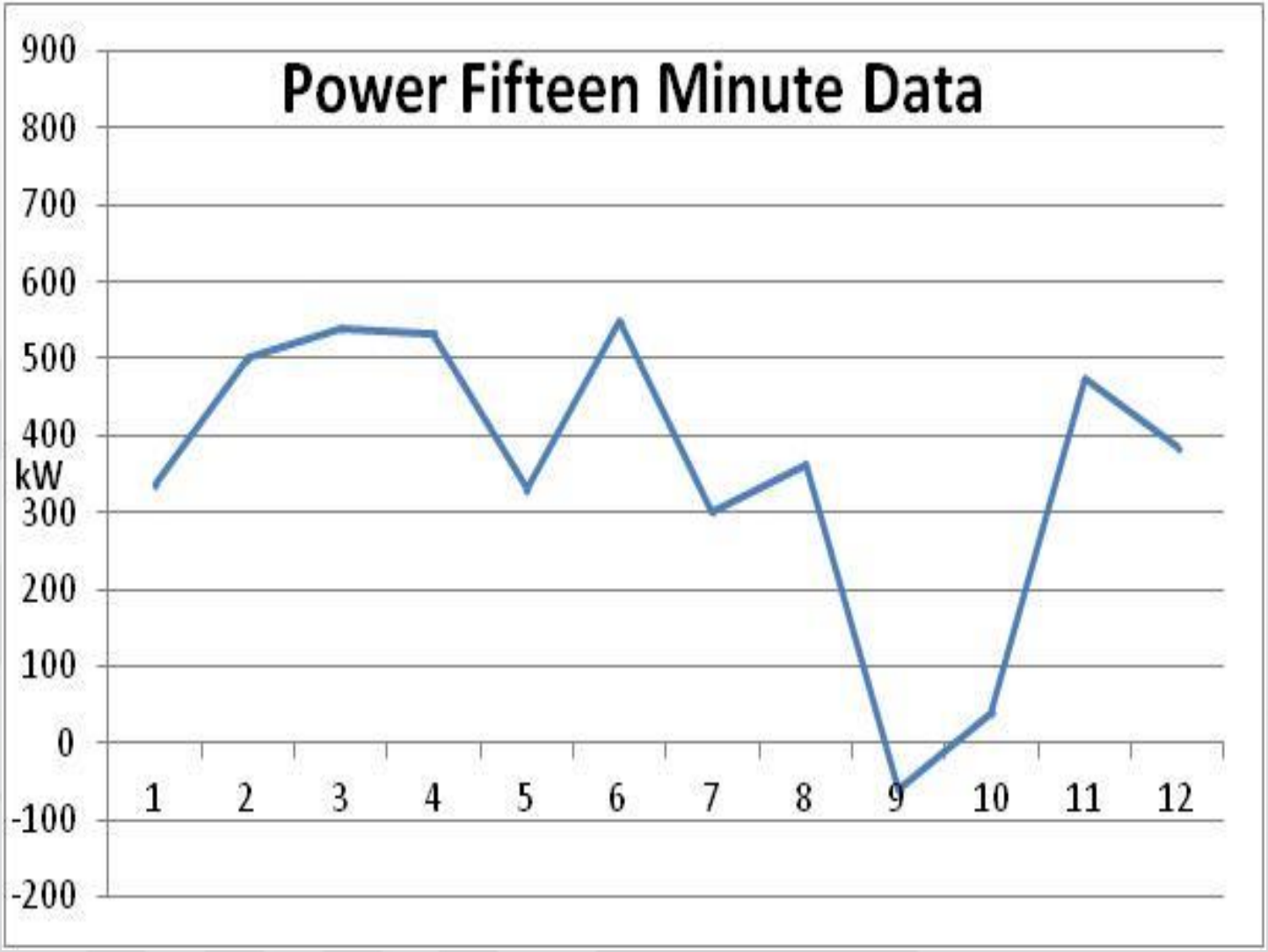
Headroom on communications network allows querying subset of meters for some additional data, reported within minutes

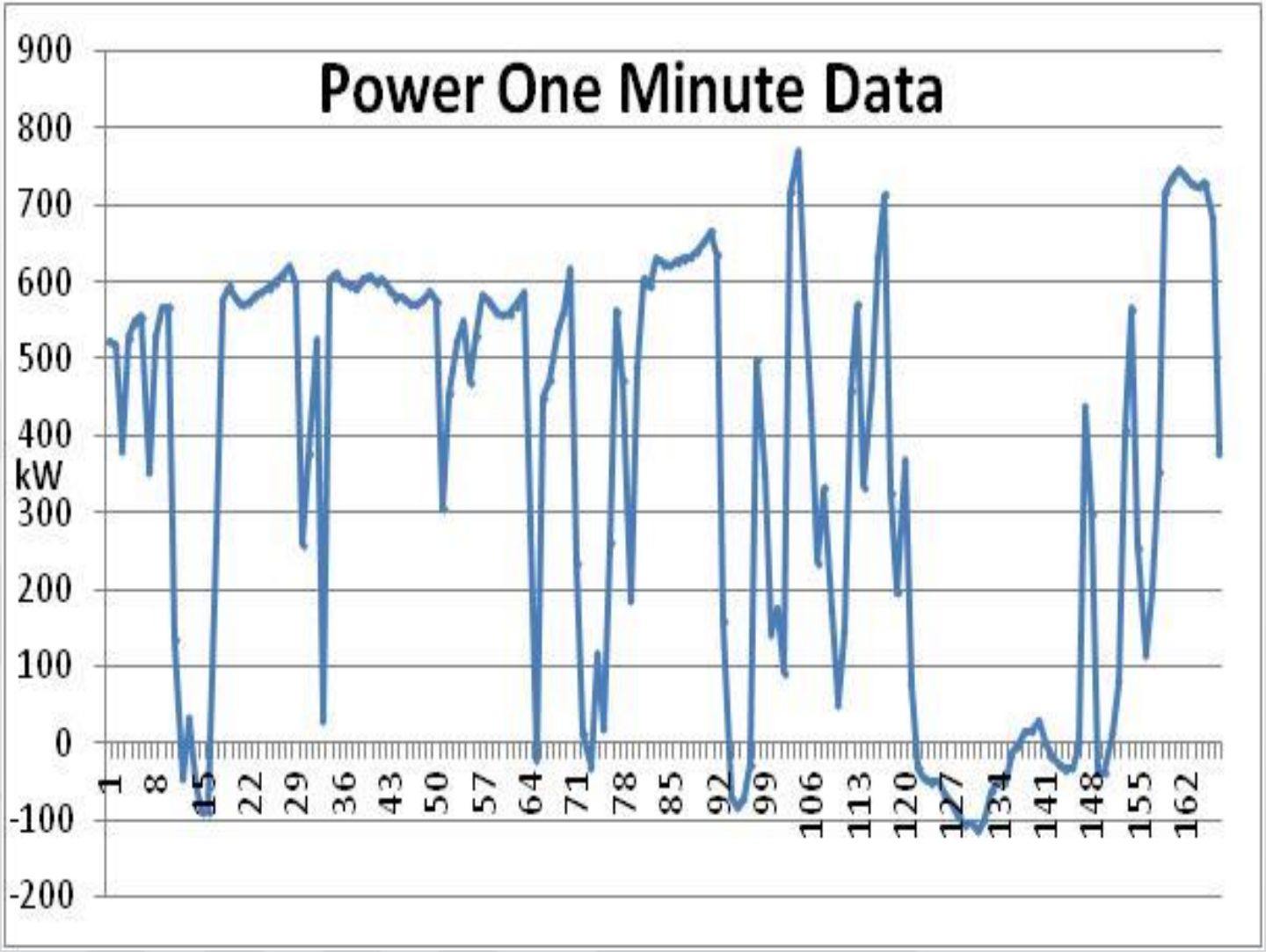
Automated Meter Reading (AMR): one-way communication
Advanced Metering Infrastructure (AMI): two-way communication

- not enough resolution to observe short-term power variations
- typically do not report voltage (although it is sensed)
- data may not provided in real-time
- data may be provided only to billing department, not operations
- most likely early operational application: fault location, isolation and service restoration (FLISR)



courtesy of Tom Bialek, SDG&E


Power Fifteen Minute Data
900
800
700
600
500
400
kW
300
200
100
0
-100
-200
1
2
3
4
5
6
7
8
9
10
11
12


Power One Minute Data
900
800
700
600
500
400
kW
300
200
100
0
-100
-200
1
8
15
22
29
36
43
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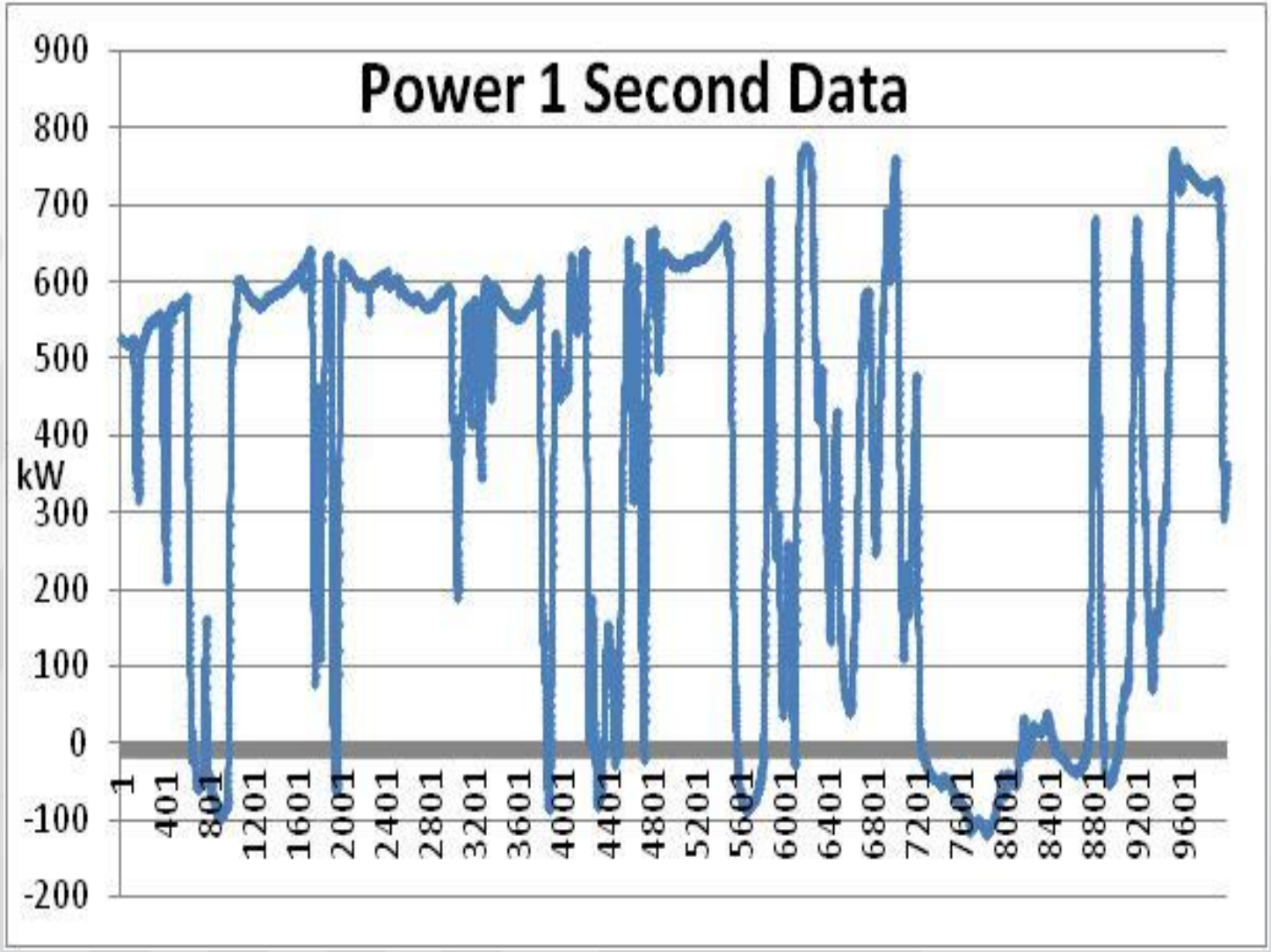
Power 1 Second Data
900
800
700
600
500
400
kW
300
200
100
0
-100
-200
1
401
801
1201
1601
2001
2401
2801
3201
3601
4001
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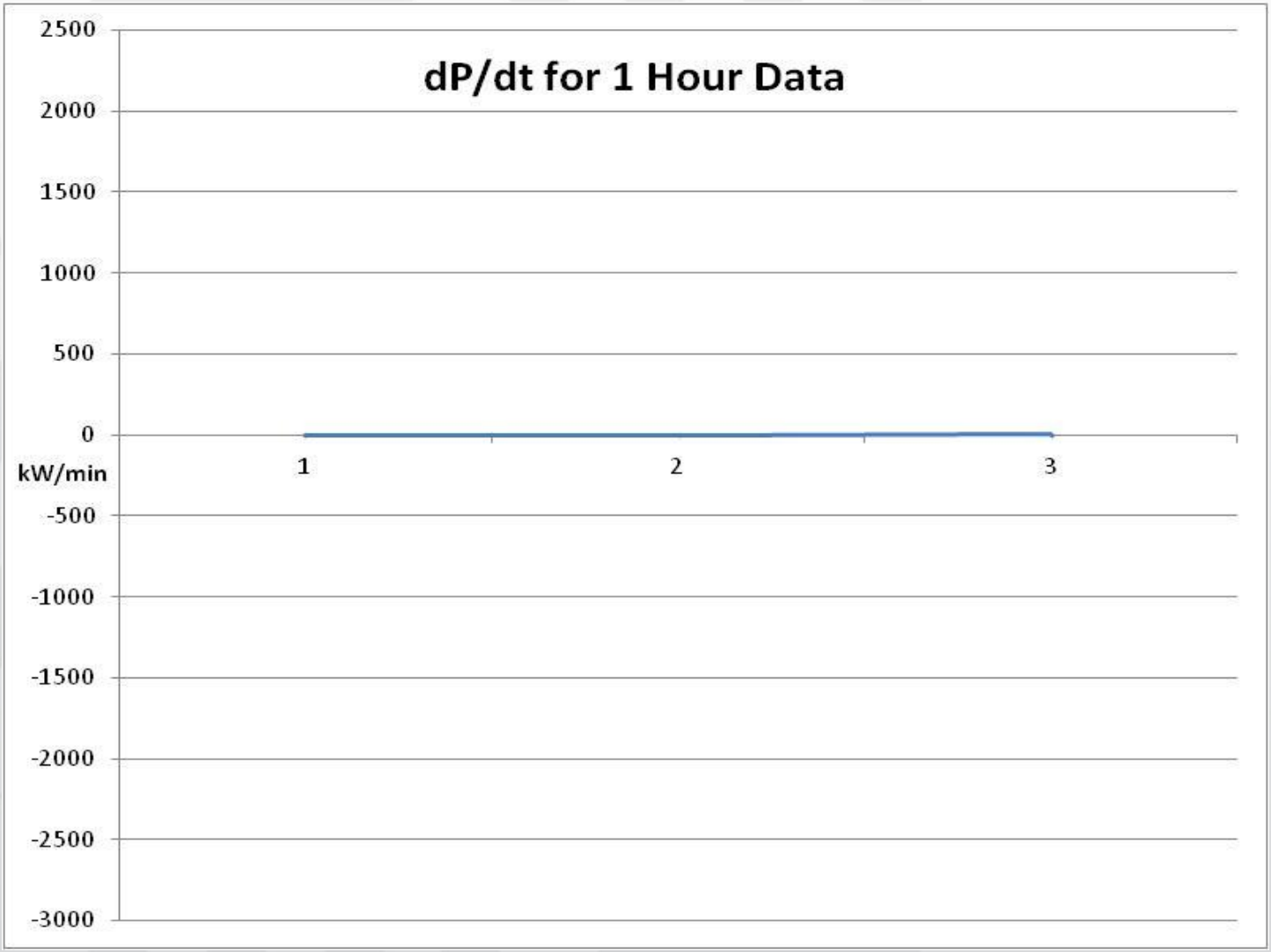
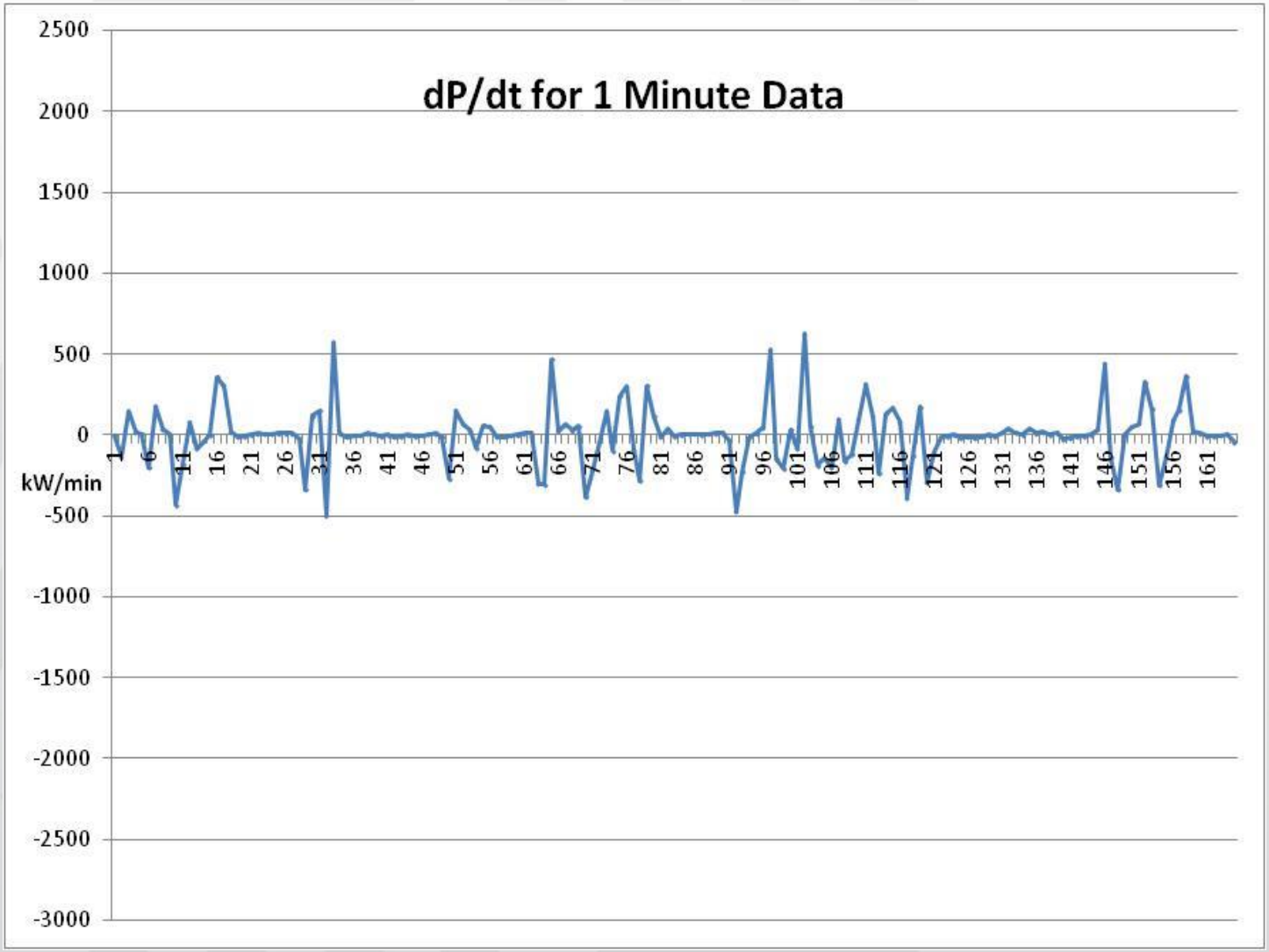
7201
7601
8001
8401
8801
9201
9601


dP/dt for 1 Hour Data
2500
2000
1500
1000
500
0
kW/min
-500
-1000
-1500
-2000
-2500
-3000
1
2
3


dP/dt for 1 Minute Data
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
kW/min
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
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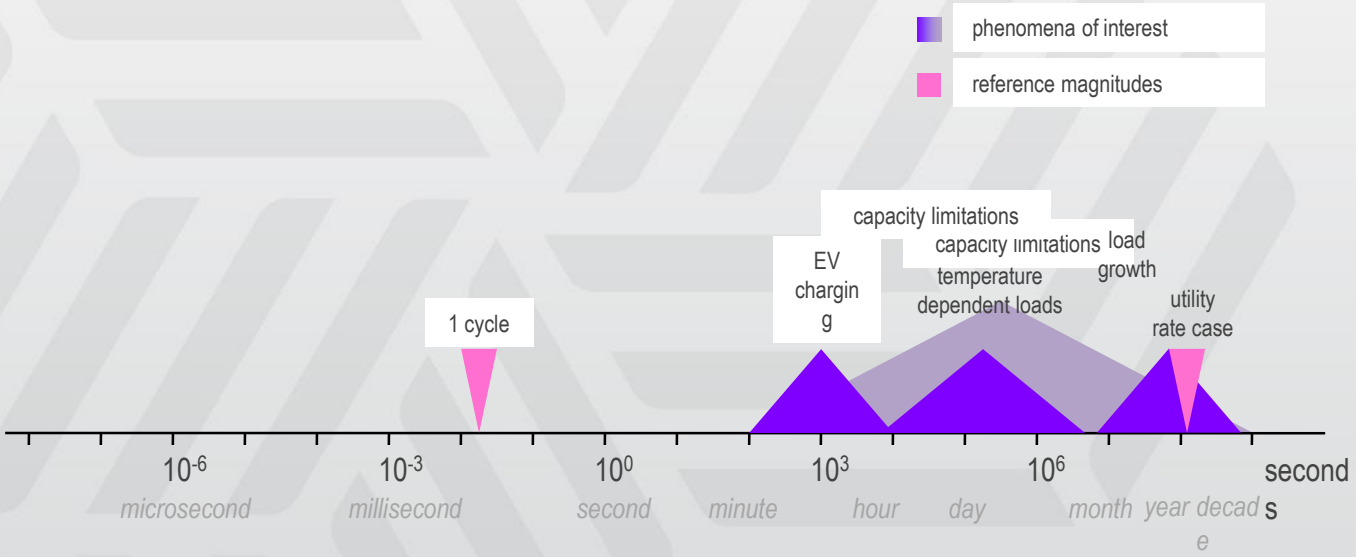
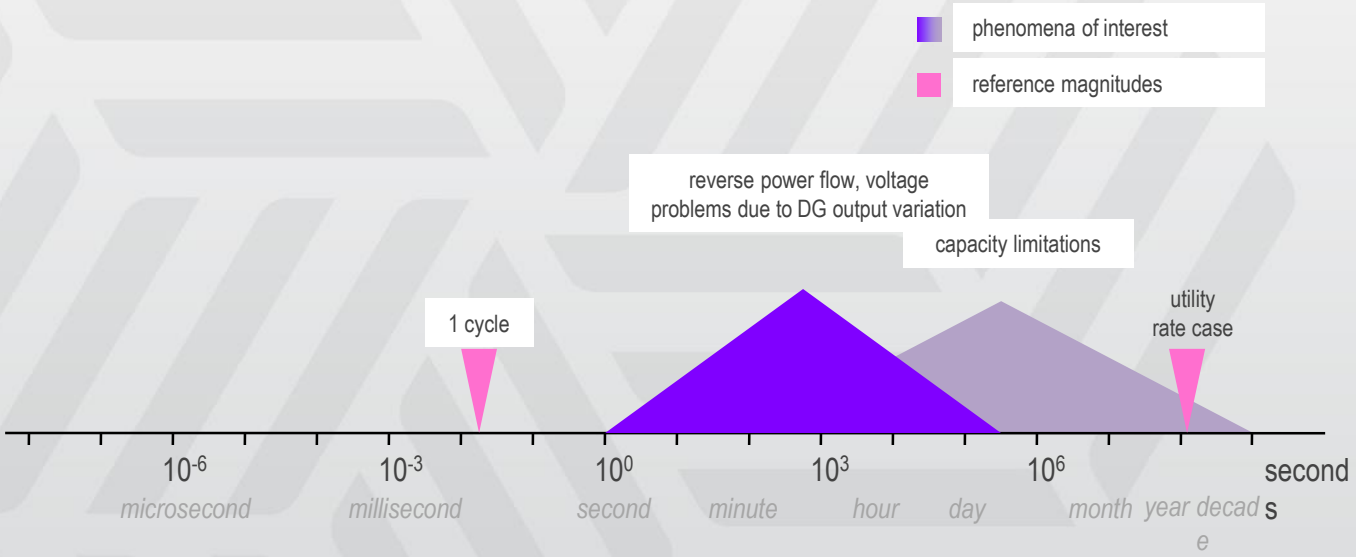
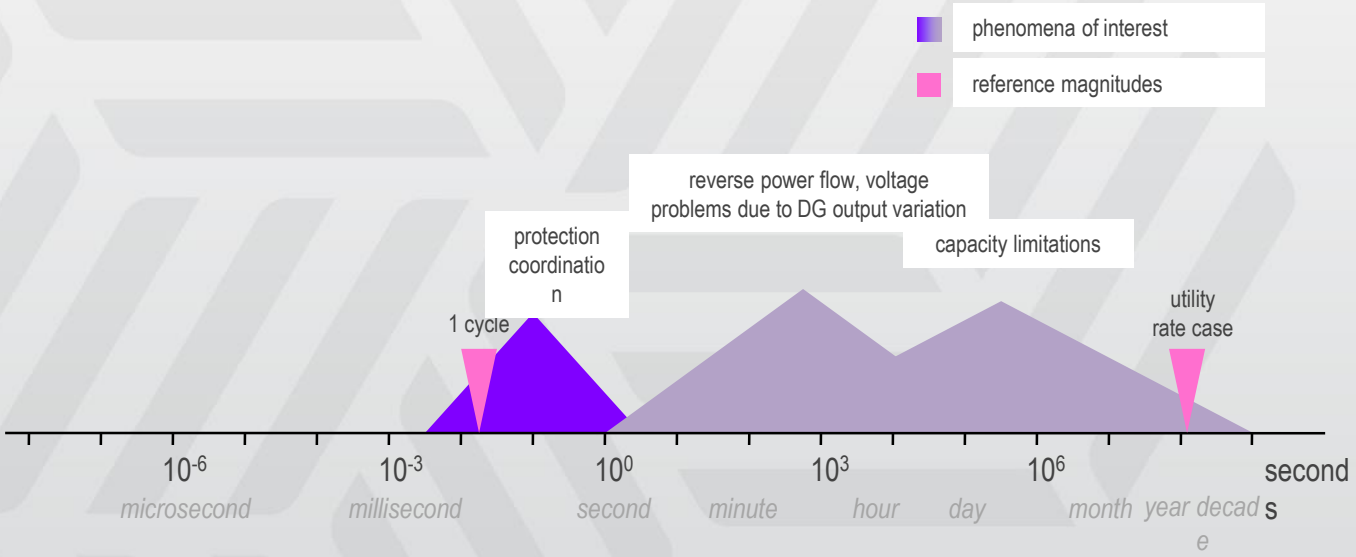
Distribution system issues on different time scales



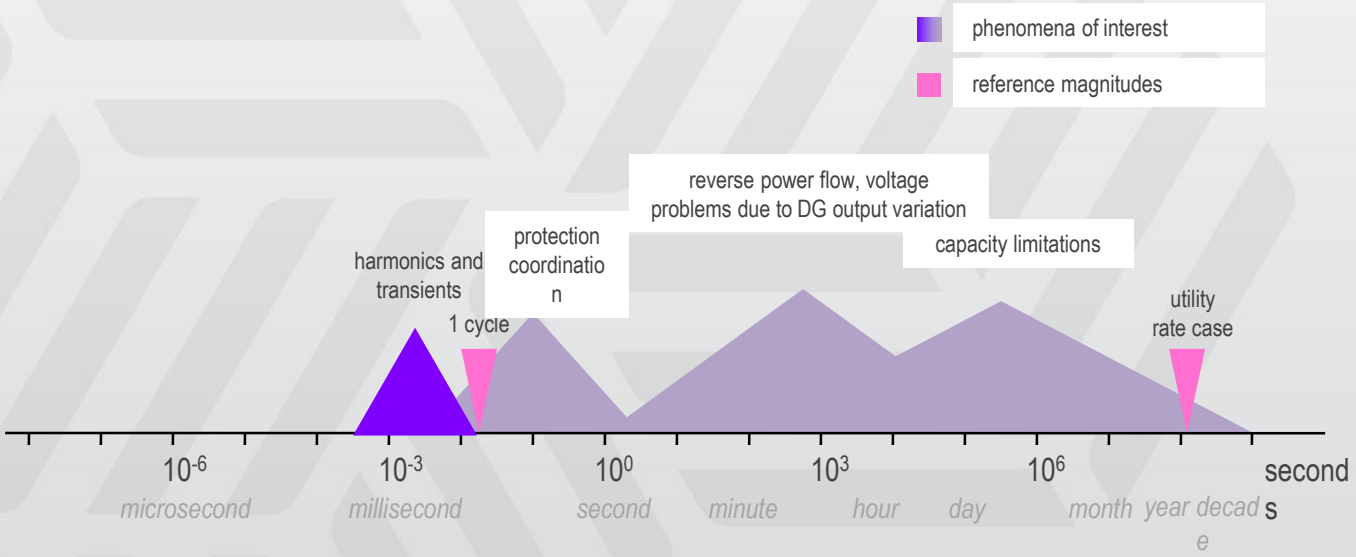
Distribution system issues on different time scales



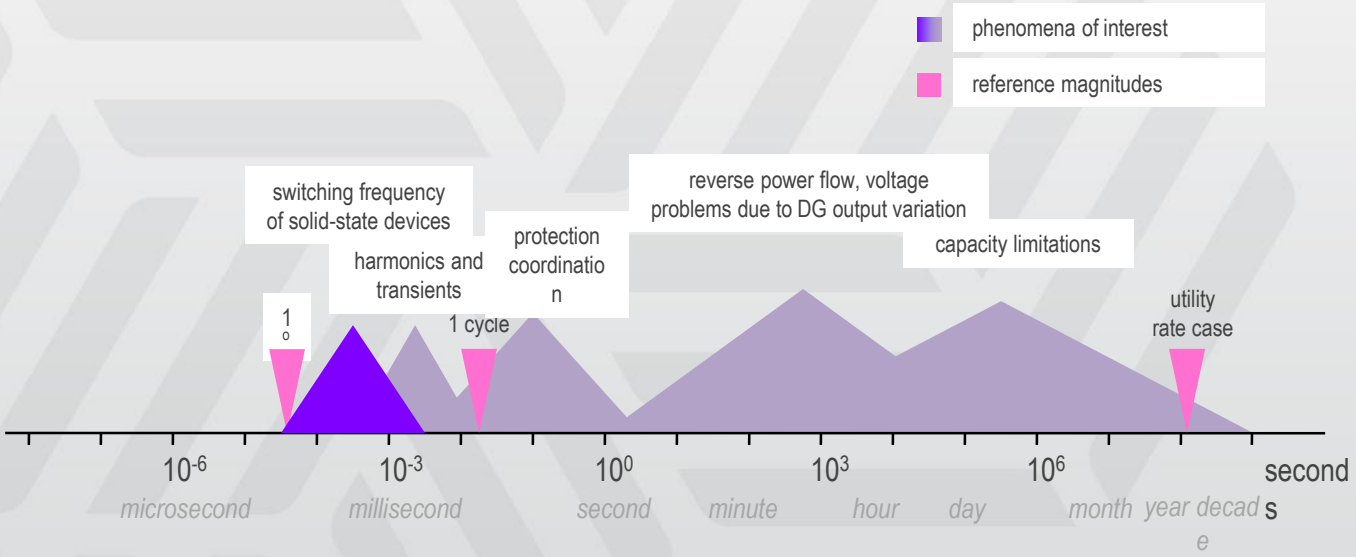
Distribution system issues on different time scales



Distribution system issues on different time scales

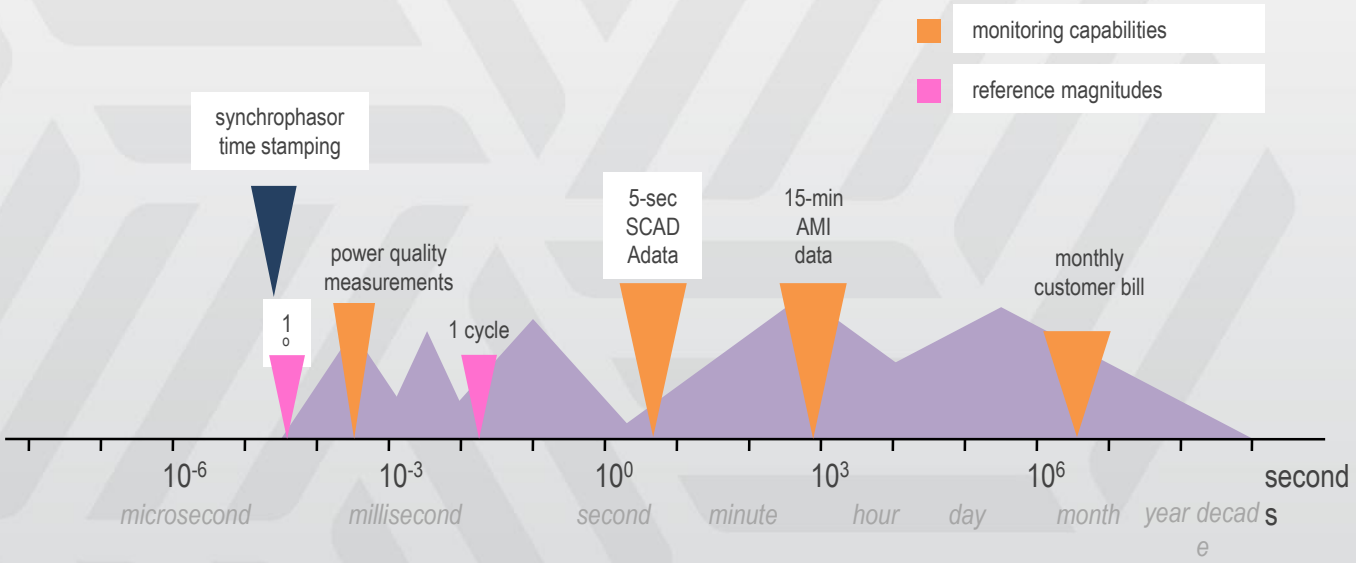


Distribution system issues on different time scales

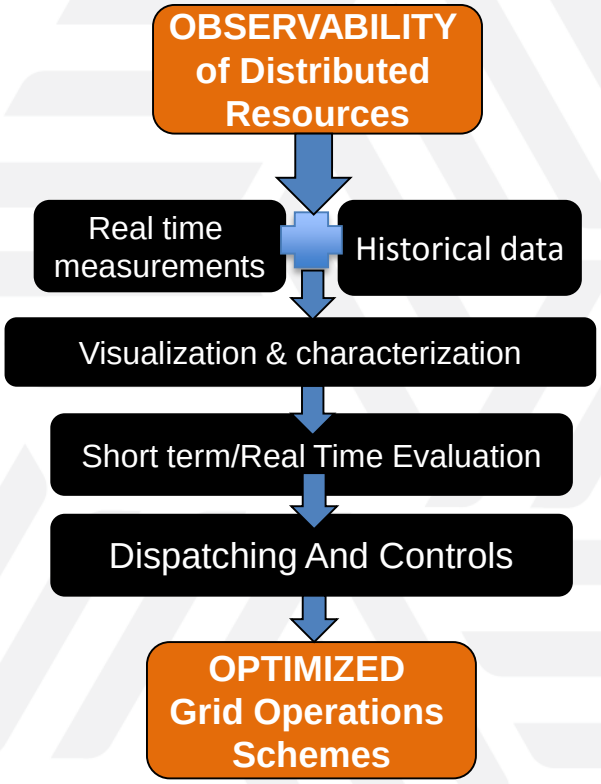


Monitoring capabilities on different time scales

Not a given: time synchronization among multiple locations, even at high measurement resolution



Summary



- Current issues in the distribution system
  - Volume of unknowns
  - Lack of control and visibility
  - Inaccurate and un-validated modeling
- Actionable intelligence for distributed resource could improve integration and acceptance into the distribution grid
- There are big challenges in distribution systems simulation and analysis
  - Observeability – if we cannot see a resource how can we get the most benefit from it?
  - Appropriate accurate analysis – validated models and using the correct tools and applications
- Putting the tools together: Transmission + distribution + customers + resources + communication + control

Common Sensor Types

Sensor Type	Description
faulted circuit indicator	Provides a binary indication of the passage of a fault current (based on magnitude) past the sensing point.
line sensor	Typically sample voltage and/or current and provide various derived quantities, such as RMS volts and/or amps, real and reactive power, power factor, a small number of harmonics of voltage or current, and THD. Transducers may be electrical, magnetic, or optical.
PMU	Phasor measurement unit – provides voltage and current synchrophasors; may also provide line frequency and power flows.
partial discharge	Detects and counts arcing partial discharges in power transformers
cable tan delta	Measures phase shift on cable insulation
line temperature	Measures temperature distributions on power lines - typically done with fiber optics.
residential meter	In addition to usage (energy), may measure secondary voltage; may record data on voltage sags as measured on the secondary at the premise; a few also record real and reactive power and power quality measures such as voltage Total Harmonic Distortion (THD)
Commercial and Industrial (C&I) meter	In addition to usage (energy), measures secondary voltage and current, computes real and reactive power, THD and a variety of other configurable quantities; may capture power waveforms on a trigger basis for later retrieval
feeder meter	Provides meter quality measurement of feeder primary quantities, including voltage, current; real and reactive power

Courtesy of Jeff Taft - PNNL

Common Grid Devices with Sensing Capability

Device	Sensing capability
switch controller	Measure voltage, may record peak fault currents
capacitor controller	Measure voltage, may record peak fault currents, may compute real and reactive power
recloser controller	Measure voltage, may record peak fault currents
voltage regulator	Measures line voltage
substation IED's (microprocessor relays)	Can take transducer inputs for voltage and current directly; can compute many derived values, including real and reactive power, phasors, THD, power factor, etc; also act as a gateway for other kinds of measurements, such as oil temperature, partial discharge data, etc

Courtesy of Jeff Taft - PNNL

Relevant Building Sensors

Device	Sensing capability
Smart Metering	RMS voltage and current and power flow at whole building level
Solar	Irradiance and kWh generated
Thermal Comfort	Dry bulb air temperature
Occupancy	Measures presence and number of people based on IR or sound or both

Courtesy of Jeff Taft - PNNL

Further Reading

- http://gridarchitecture.pnnl.gov/media/advanced/Sensor%20Networks%20for%20Electric%20Power%20Systems.pdf
- https://gridmod.labworks.org/sites/default/files/resources/1.4.09_Integrated%20Multiscale%20Data%20Analytics%20and%20Machine%20Learning%20for%20the%20Grid_Fact%20Sheet_rev2.pdf
- https://www.osti.gov/scitech/biblio/1353149
- https://esdr.lbl.gov/sites/default/files/lbnl_6665e_final.pdf
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