New Issues and Opportunities for Power Quality

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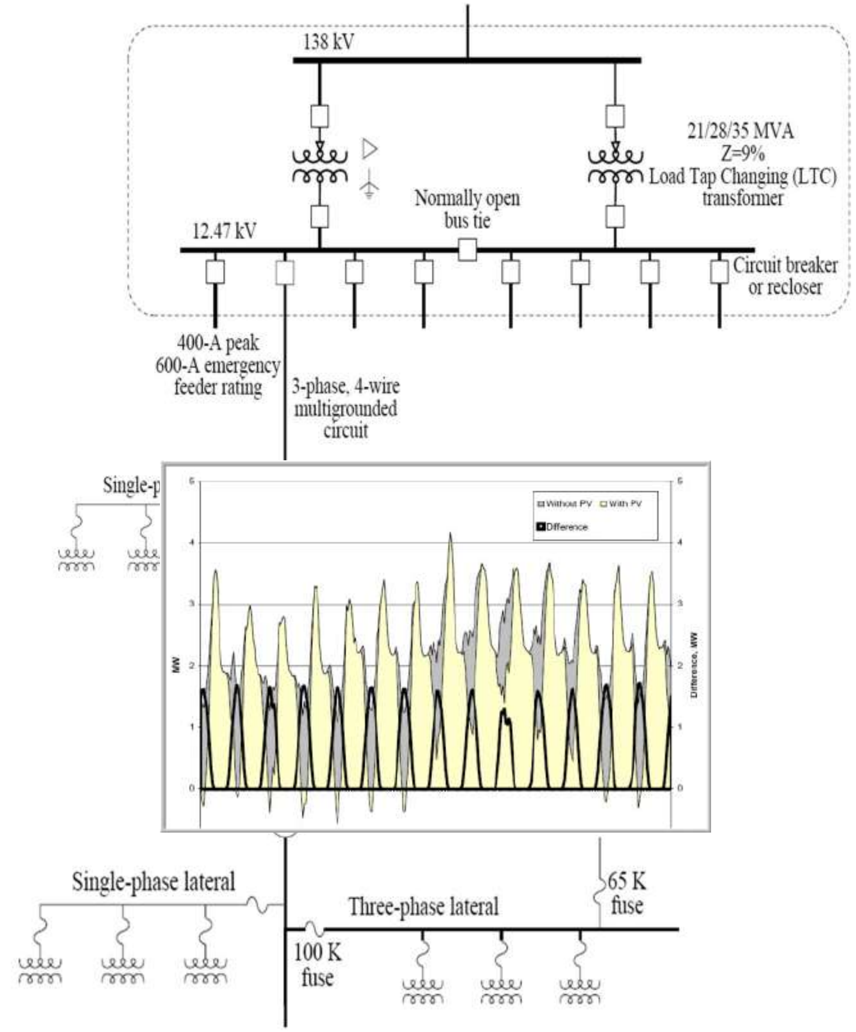
Interesting PQ Opportunities and Challenges

- **Opportunities**
  - Value from PQ data
  - Value of PQ
- **Challenges**
  - Changes to Area of Vulnerability (AoV)
  - DER integration and Increasing Complexity
- Concluding thoughts

Opportunity: Proactive Use of PQ Data

Incipient Failure Detection of Grid-Connected Equipment

- PQ Monitors are an important sensor
  - Strategically located
  - Higher resolution data
- PQ monitoring, however, is NOT just a sensor
  - A dedicated team committed to design, O&M, and application of the data
- Many grid-connected devices can be monitored using PQ data
  - Capacitors
  - Transformers
  - Load Tap Changers
  - Reclosers
  - Etc.



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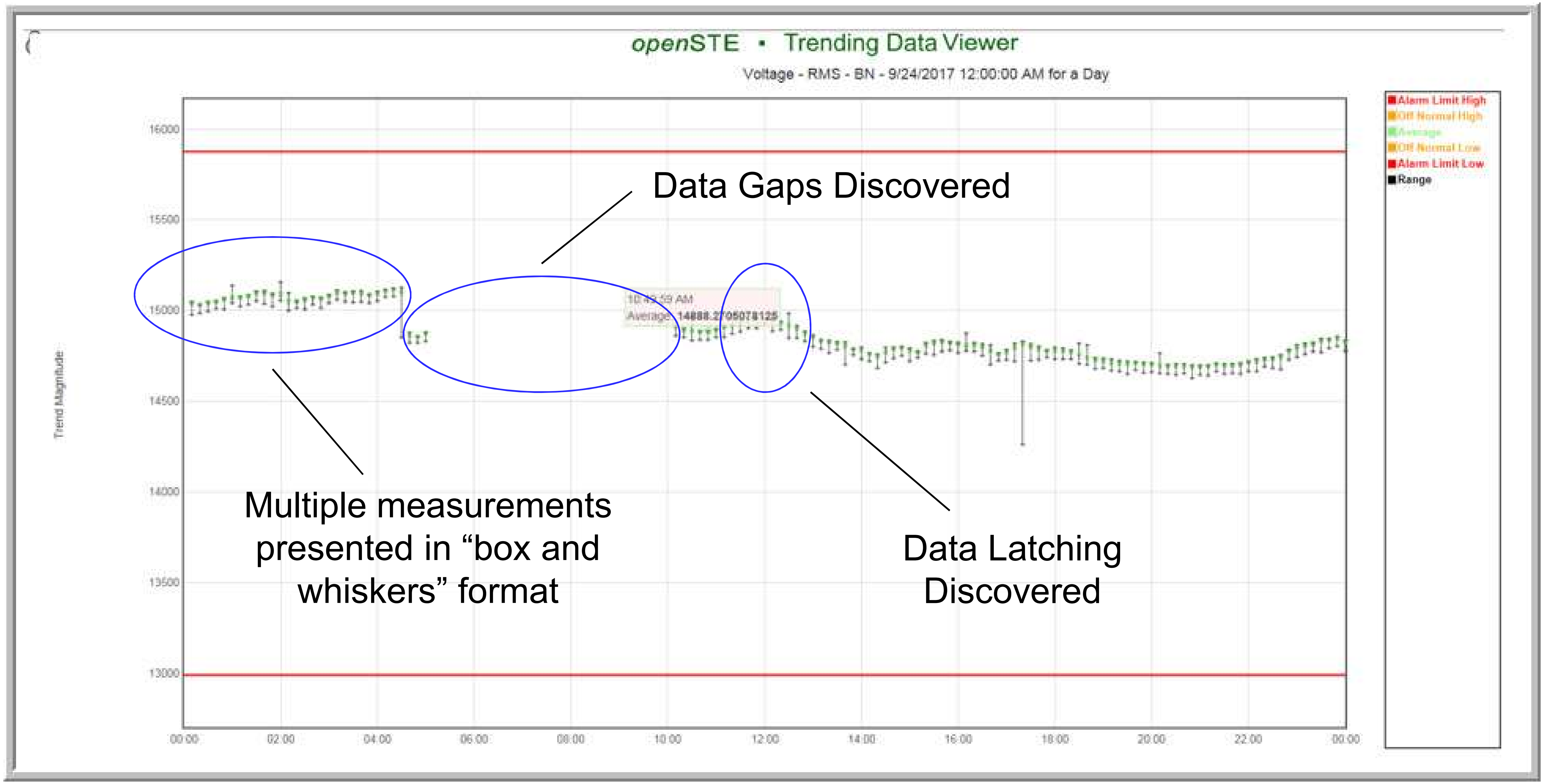
Example: Capacitor Switching Assessment Module

- **Reactive Power Balancing**: Assess the health status of the capacitor units based on change in reactive power balance during switching indicative of capacitor unit failures or blown fuses and the amount of unrealized reactive power based on the reactive power rating of the monitored cap bank**.**
- **Switch restrikes**: Assess the health status of capacitor circuit switchers by identification of switch restrikes, **based on the presence of discontinuities in the monitored currents,** indicative of circuit switcher problems.
- **Synchronous closing control:** Assess performance by estimation of the closing angle deviation from its reference angle**.**
- **Harmonic resonance detection**: Computing the increase in the voltage total harmonic distortion (THD) before and after energizing.
- **Harmonic Changes**: Detect if there is an increase in harmonic distortion immediately upon closing.
- **Cap Energization**: Detect if the capacitor is energized without any closing control or with pre-insertion closing
- **Missing Pole**: Detect if there is a missing pole during closing

- **Report capacitor and system steady state quantities:**
  - **resonance frequency**
  - **instantaneous peak voltage**
  - **RMS voltage before and after capacitor energizing operation, and its associated RMS voltage change**
  - **instantaneous peak current**
  - **RMS current before and after capacitor energizing operation, and its associated RMS current change**
  - **switching frequency during closing**
  - **change in reactive power**
  - **power factor before and after energizing operation**
  - **THD current before and after energizing operation and its associated change**
  - **THD voltage before and after energizing operation and its associated change**
  - **the number of capacitor steps before and after energizing, and**
  - **capacitive reactance before and after energizing operations.**

Employing these techniques and using PQ data, one utility has reported over US$1M in cost savings due to avoided transmission-level cap bank failures

Opportunity: Data Validation (PQ Dashboard)



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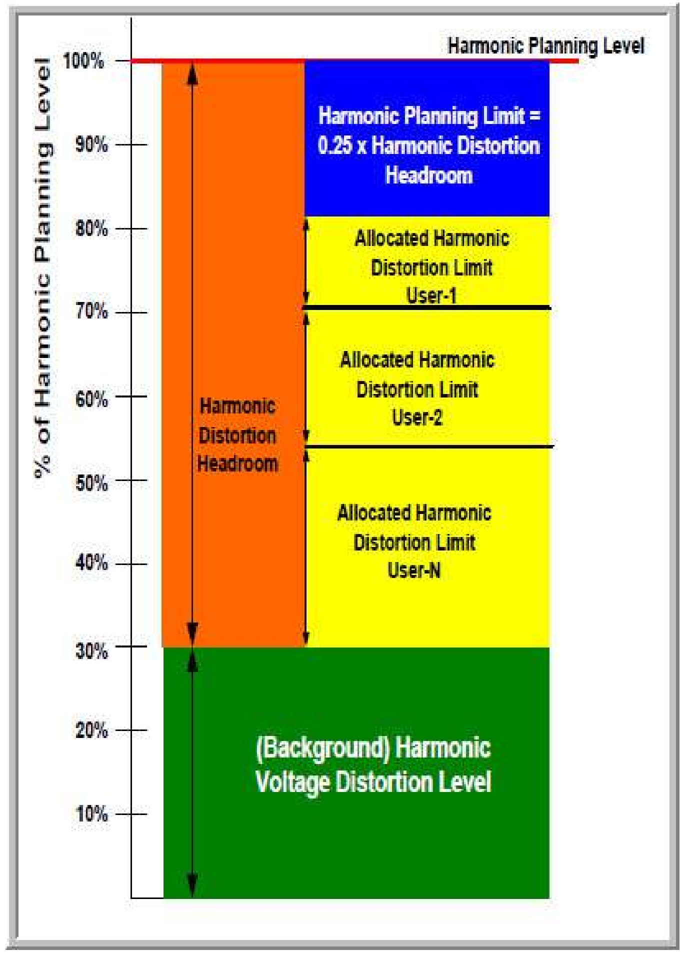
Opportunity: Value of PQ
Today's Approach to "Managing" PQ
Threshold based …

- Harmonics (IEEE 519-2014)

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5[a]

[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.



- Flicker (IEC 61000-3-7)

Table 2 – Indicative values of planning levels for P_{st} and P_{lt} in MV, HV and EHV power systems

	Planning levels	
	MV	HV-EHV
P_{st}	0,9	0,8
P_{lt}	0,7	0,6

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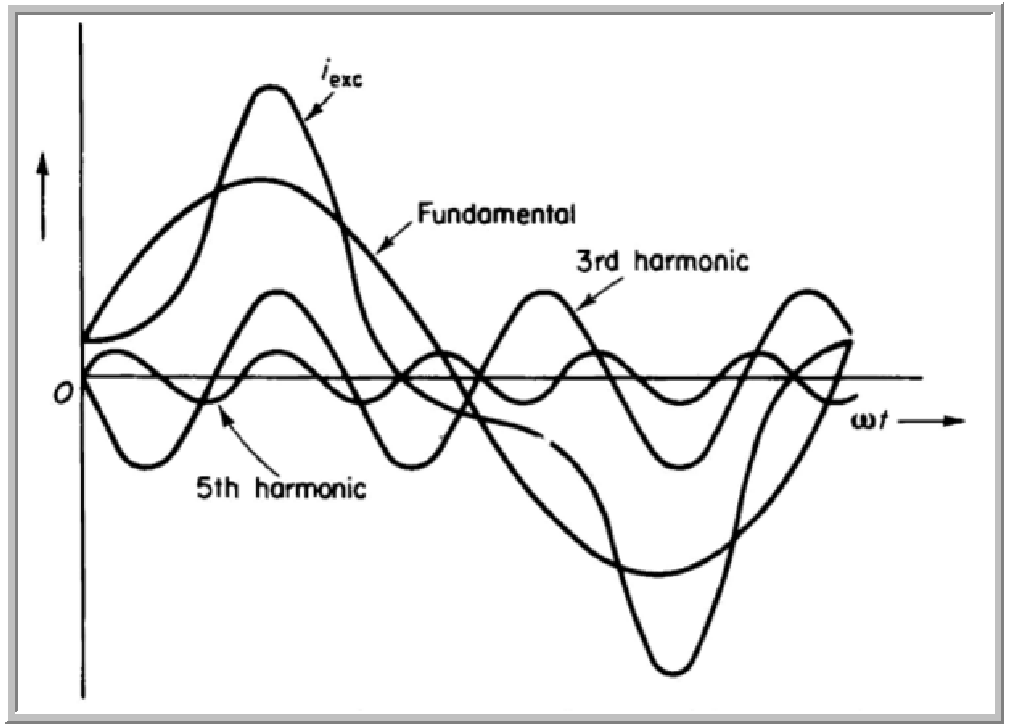
Opportunity: Developing a New Model for Management of PQ

Incorporating Economical Drivers - Harmonics

- Hard costs due to harmonics
  - Additional generation capacity and operational costs
  - Additional I^2R losses in equipment and wiring
  - Damage due to harmonic resonance

- Soft costs due to harmonics
  - Equipment heating / shortened life
  - Increased chance of malfunction
  - Lost system capacity
  - Others



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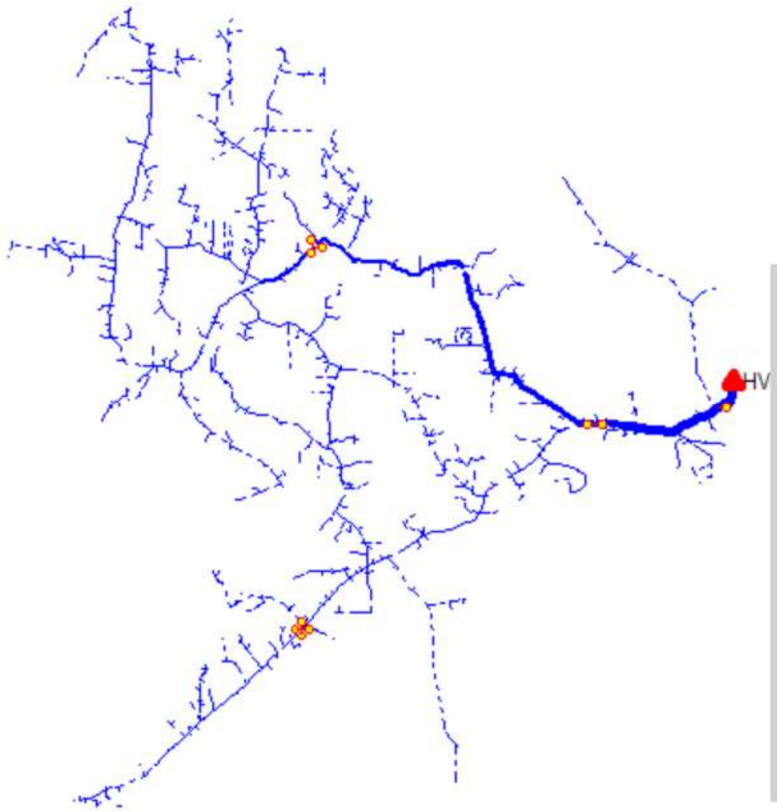
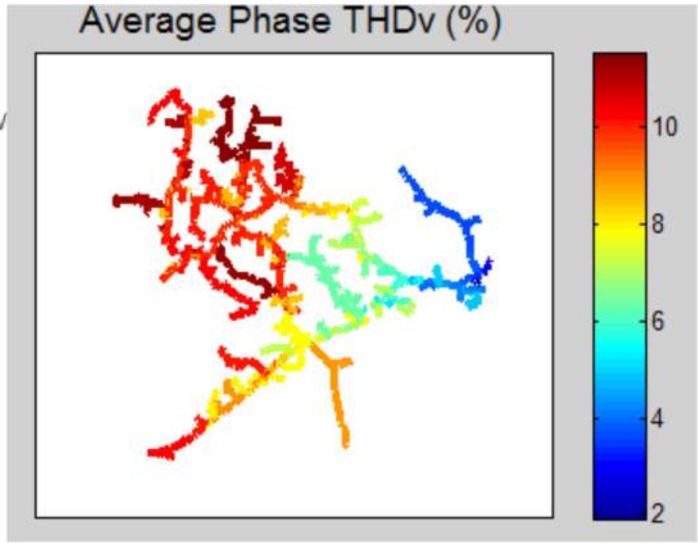
EPRI Scenario Analysis of Cost of Harmonics

- V-thd at the substation: ~2%
- V-thd peaks ~10%





Harmonic Spectrums Used in Analysis

Harmonic Order	Harmonic Magnitude (% of Fundamental)		
	Background Voltage	Base Harmonic Load Current	High Harmonic Load Current
3	1.3	8.6	14
5	1.5	4.7	7.5
7	0.4	2.9	4.5
9	0.2	2.9	4.5
11	0.1	1.1	1.5
13	0.1	0.9	1.4

EPRI Scenario Analysis of Cost of Harmonics Base Case – No filters

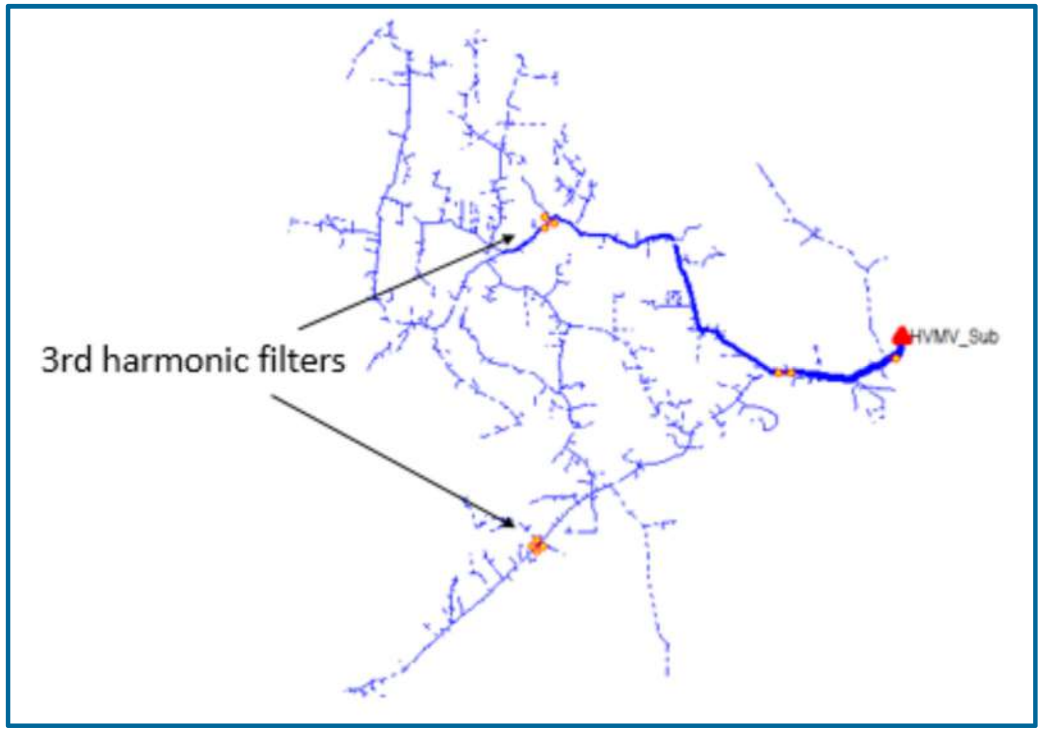
- Percent increase in losses due to harmonics: 2.6%

Losses for Test Case 1—Base Harmonics

Component	Losses (kW)			Percent Increase due to Harmonics
	Fundamental	Harmonics	Combined	
Peak Hour Analysis				
Lines I^2R losses	1034.4	29.2	1063.6	2.8
Transformers I^2R losses	118.8	1.5	120.3	1.3
Transformers no-load losses	56.8		56.8	
Transformer eddy losses	7.1	0.9	8.0	12.7
Capacitor losses		0.5	0.5	
Total losses	1217.1	32.7	1249.2	**2.64**
Annual Analysis				
Losses (kWh)	3,419,784	84,045	3,503,829	
Cost ($1000)	342	8.4	350.4	
Total losses (% of energy)	11.30	0.3	11.6	

EPRI Scenario Analysis of Cost of Harmonics Base Case – 3rd Harmonic Filters Added

- Losses due to harmonics are 1.1% after vs. 2.6% before
- Economic payback based only on these losses: ~11 years



Losses for Test Case 1—Base Harmonics Scenario with Filter Banks

Component	Losses (kW)			% Increase due to Harmonics
	Fundamental	Harmonics	Combined	
Peak Hour Analysis				
Lines I^2R losses	1034.4	11.4	1045.8	1.1
Transformers I^2R losses	118.8	0.8	119.6	0.7
Transformer no-load losses	56.8		56.8	
Transformer eddy losses	7.1	0.5	7.6	7
Capacitors losses		0.2	0.2	
Total losses	1217.1	12.9	1230	**1.06**
Annual Analysis				
Losses (kWh)	3,419,784	33,794	3,502,472	
Cost ($1000)	342	3.4	345.5	
Total losses (% of energy)	11.3	0.12	11.59	

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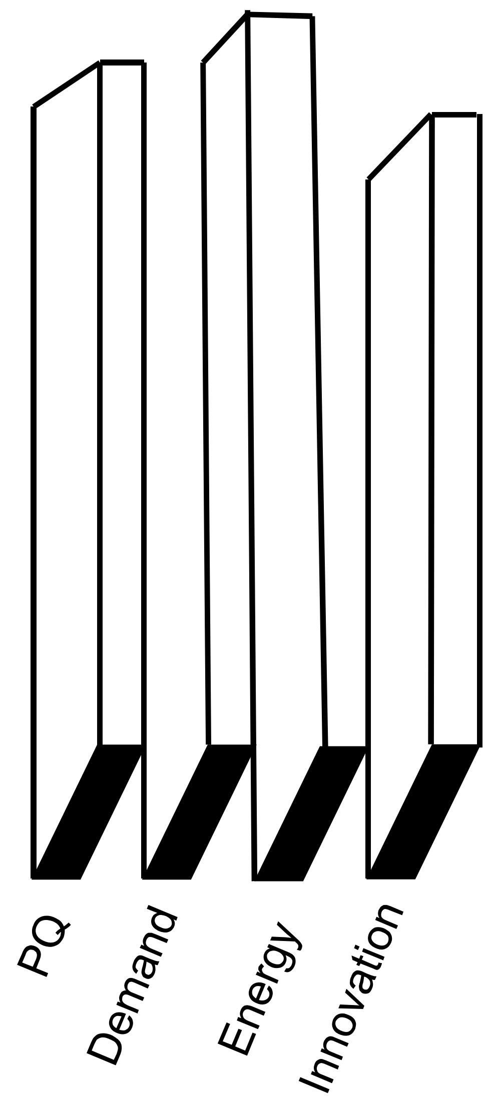
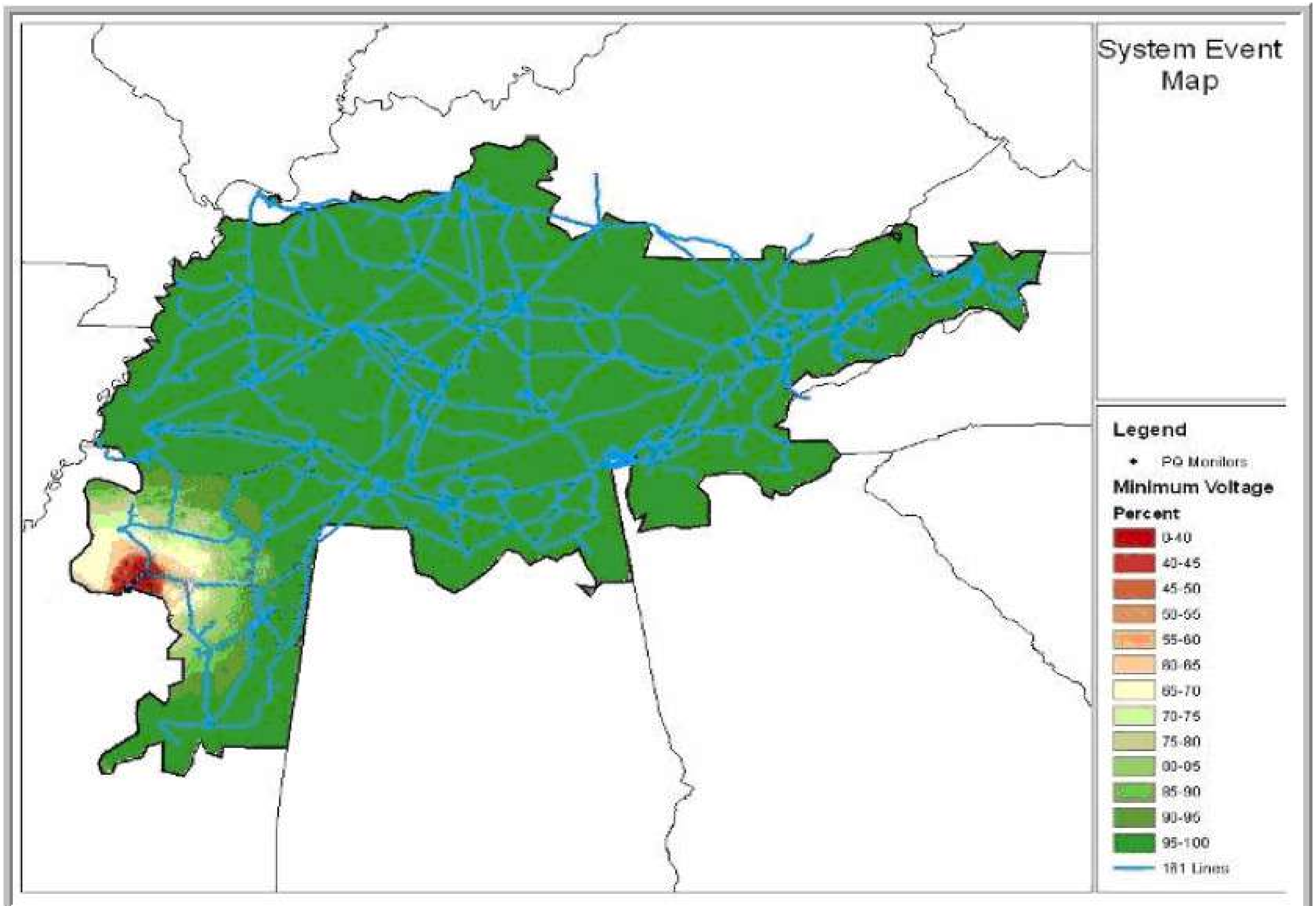
Challenges



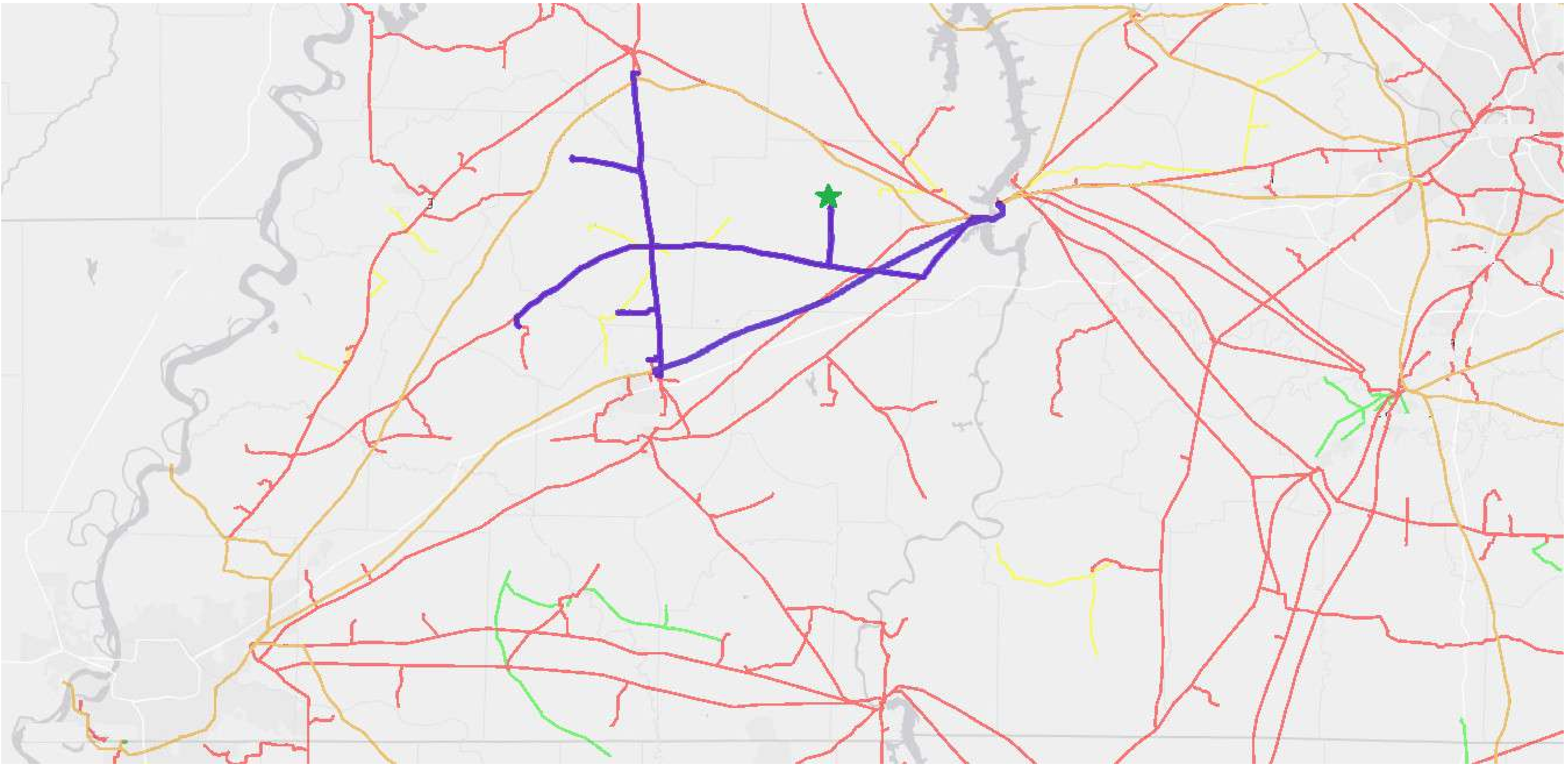
Challenge: Area of Vulnerability
Increasing Voltage Sag Propagation



Impact of Gen Plant closings on AoV - Real-world Example

Before Local Fossil Plant Closing

- Customer (green star) is fed from a 161kV system
- Current exposure to interrupting sag (70%) from any fault on ~200 miles (322 km) of feeder (blue)



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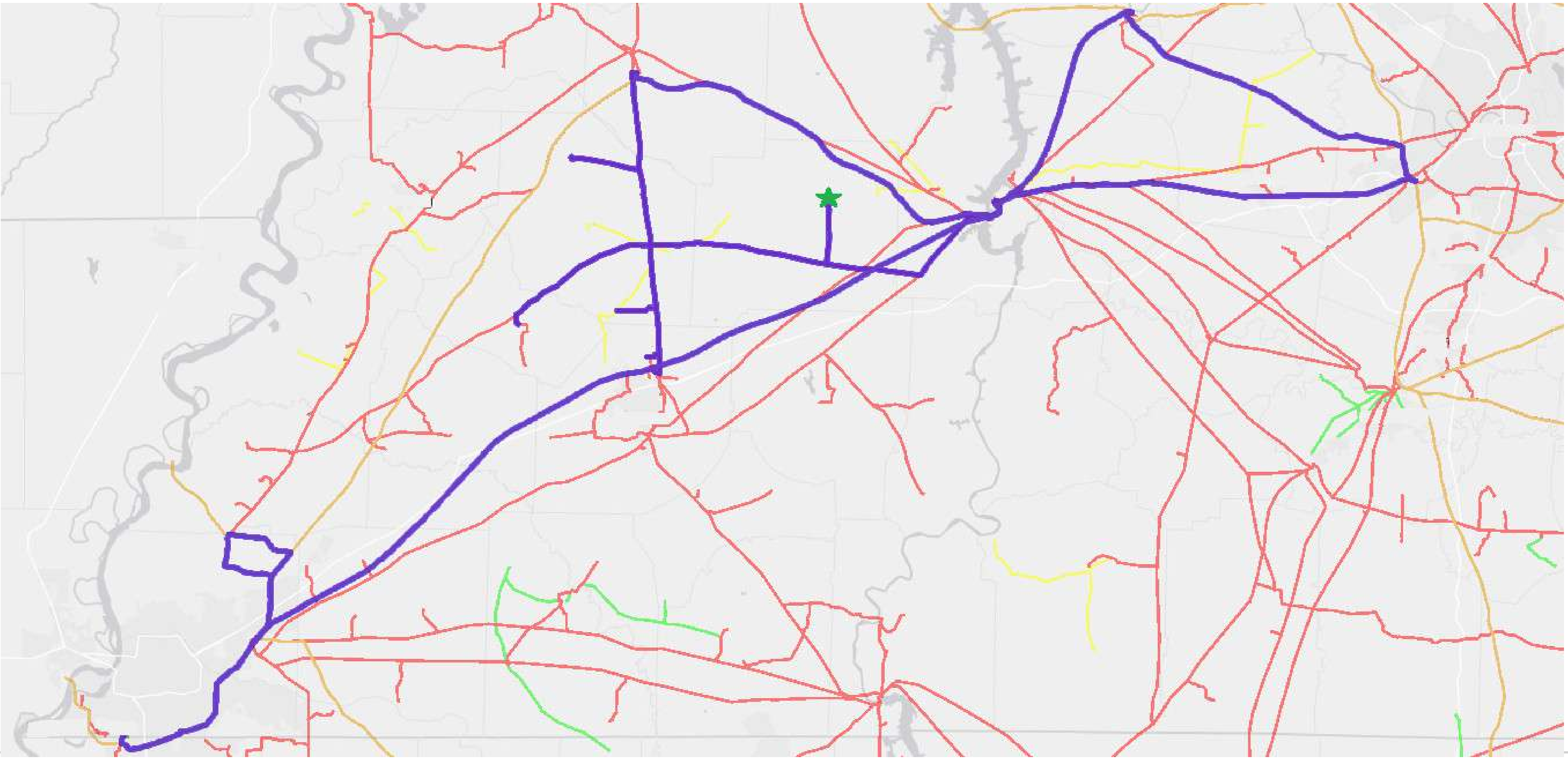
Impact of Gen Plant closings on AoV - Real-world Example

After Local Fossil Plant Closing

- Addition of new inter-tie to 500kV transmission
- New exposure to interrupting sag (70%) from any fault now ~600 miles (966 km) of feeder
- Customer is now 3X more likely to see disturbing sags, (assuming the location of faults is random)



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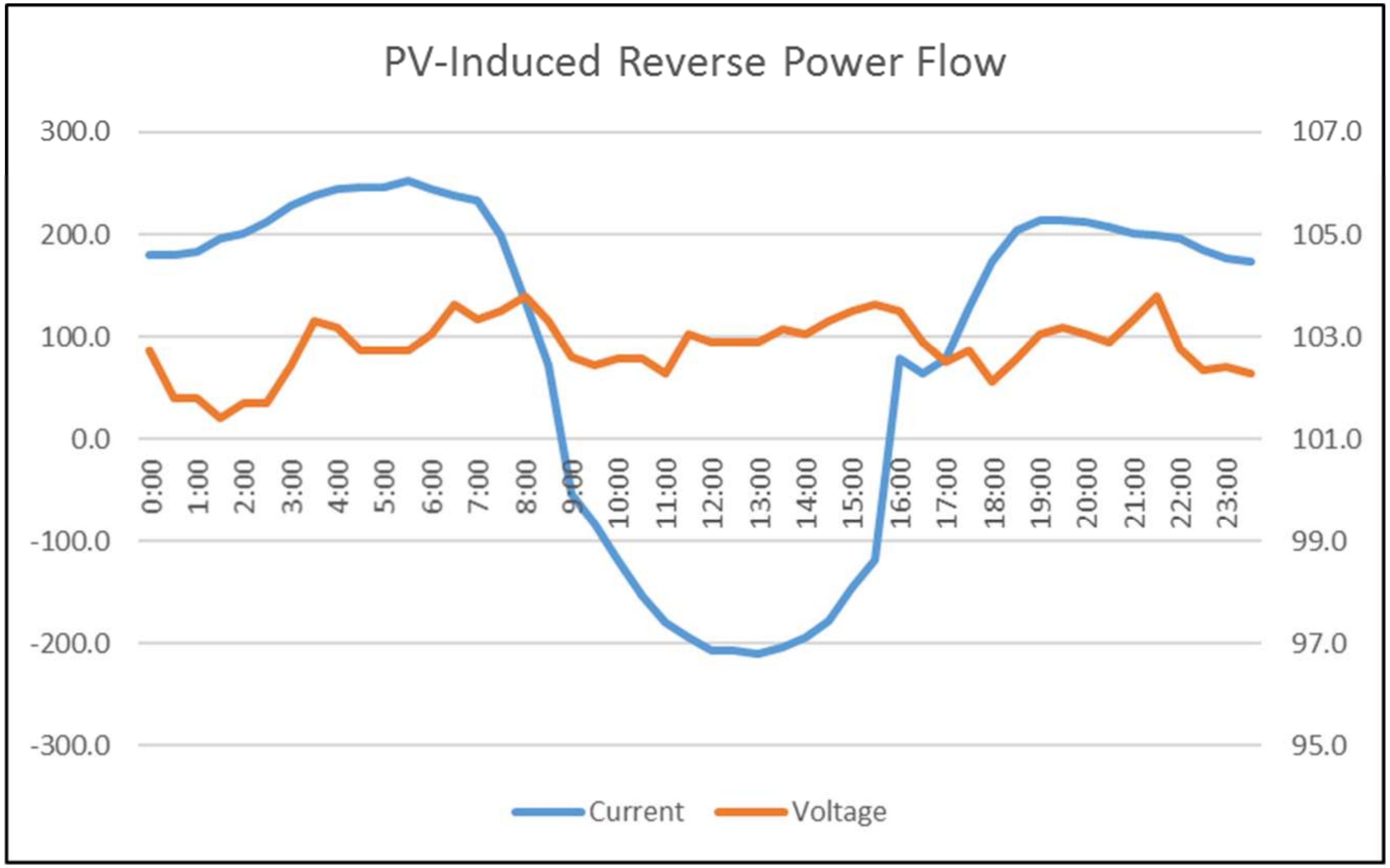
Challenge: Impacts of Distributed Energy Resources (DER) on the Power System

Challenge	Possible Solution
Too much PV: Excess output of Renewable Energy (RE) over demand causes an imbalance due to surplus real power	>> Control of RE output (Challenging) >> Utilization of storage batteries and pumped storage generation (Expensive)
Capacity Limitations: Capacity shortage for transmission, substations, and distribution due to large-quantity interconnection of PV	Upgrade of T&D and substation assetts (Expensive)
Frequency variation: Rapid output fluctuation of PV facilities causes system frequency variatoins	Apply backup power sources such as thermal power and pumped storage power to compensate for output fluctuation (Expensive)
Elevated voltage: System voltage in distribution feeder rises due to reverse power flow from PV facilities to grid	>> Increase distribution system capacity (Expensive) >> Add voltage regulators across the grid, such as: SVR, SVC and STATCOM (Expenive, Complicated)

Challenge: Increasing Grid Complexity from DER
Reverse Power Flow



- Distribution circuit with extensive rooftop PV installations
- During peak sunlight intervals, PV output exceeds loads
- PV output is close to double local load

Utility Survey: DER PQ Phenomenon

Witnessed Issues	Ranking
Elevated voltage (steady-state) related to DER operation	1
Harmonics contributed by DER sites	2
TOV (temporary over voltage) due to operation of DER	3
Flicker associated with DER	4
Voltage unbalance caused by DER	5
Conducted emissions (2 kHz to 150 kHz) from DER on power lines	6

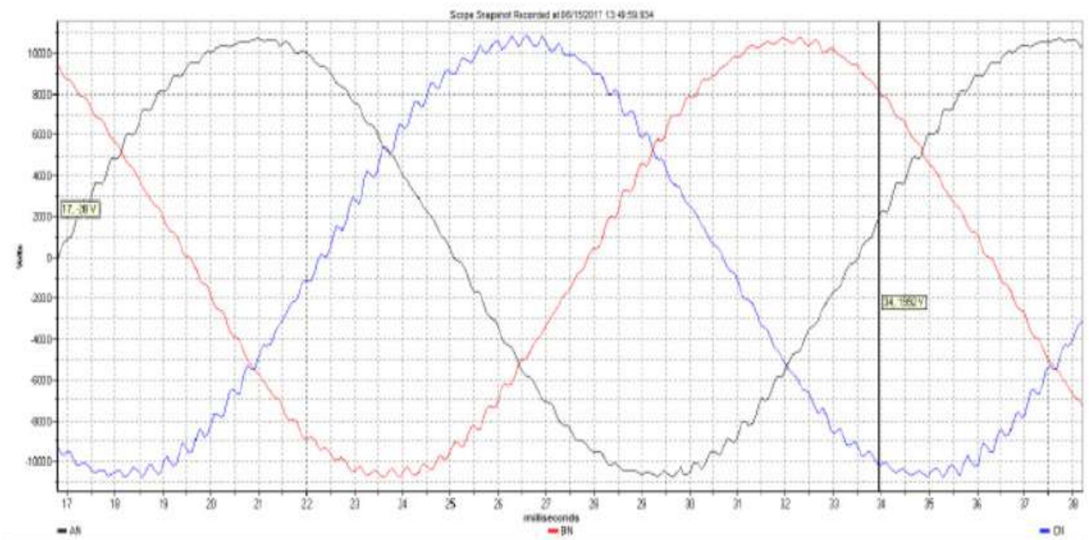
Unintended Consequences!

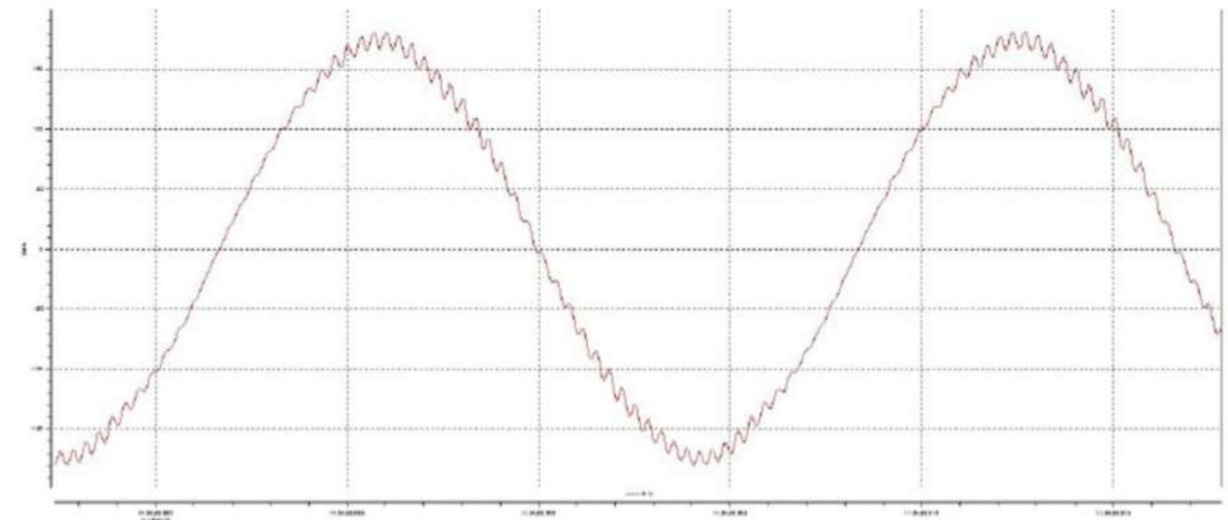
High Order Harmonics from PV

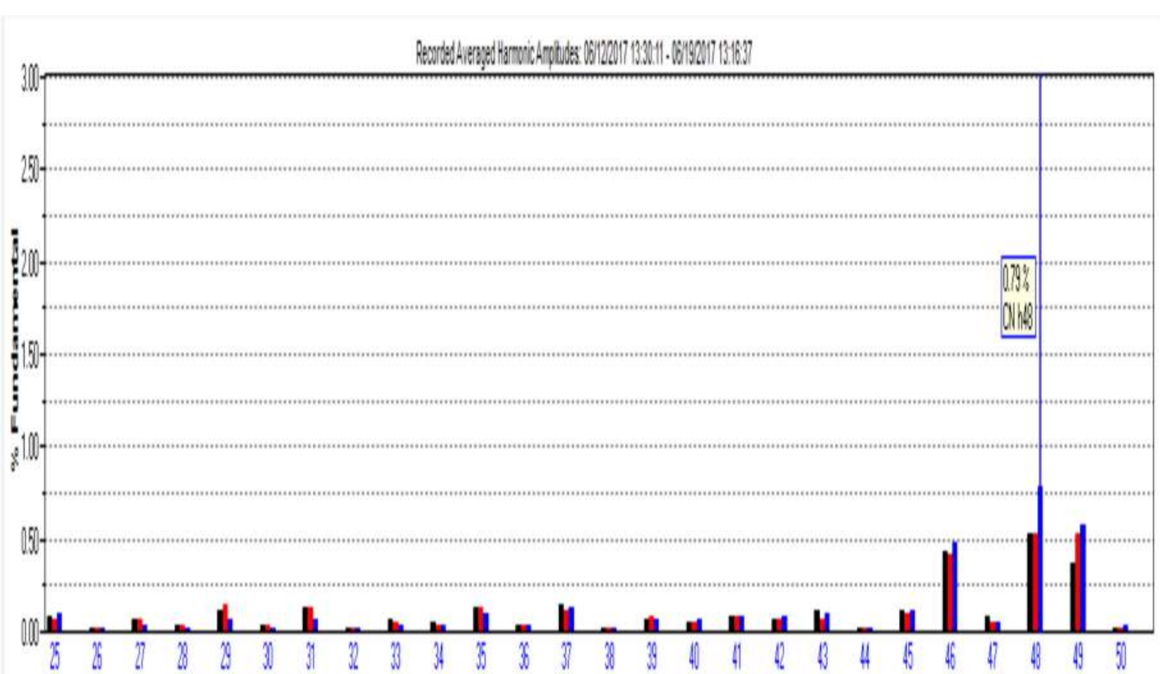
Near Mining Site – No Observed Impact

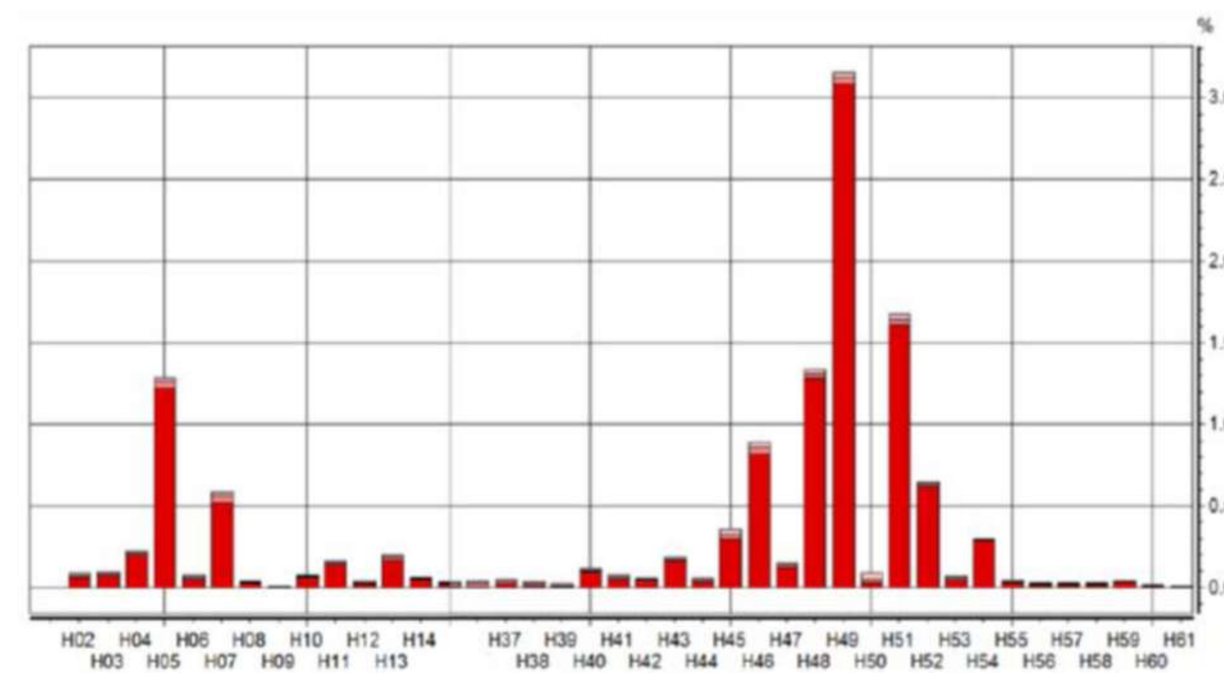
Residential Customer Experienced Nuisance Noise from Appliances

What is the mechanism for the Audible Noise?









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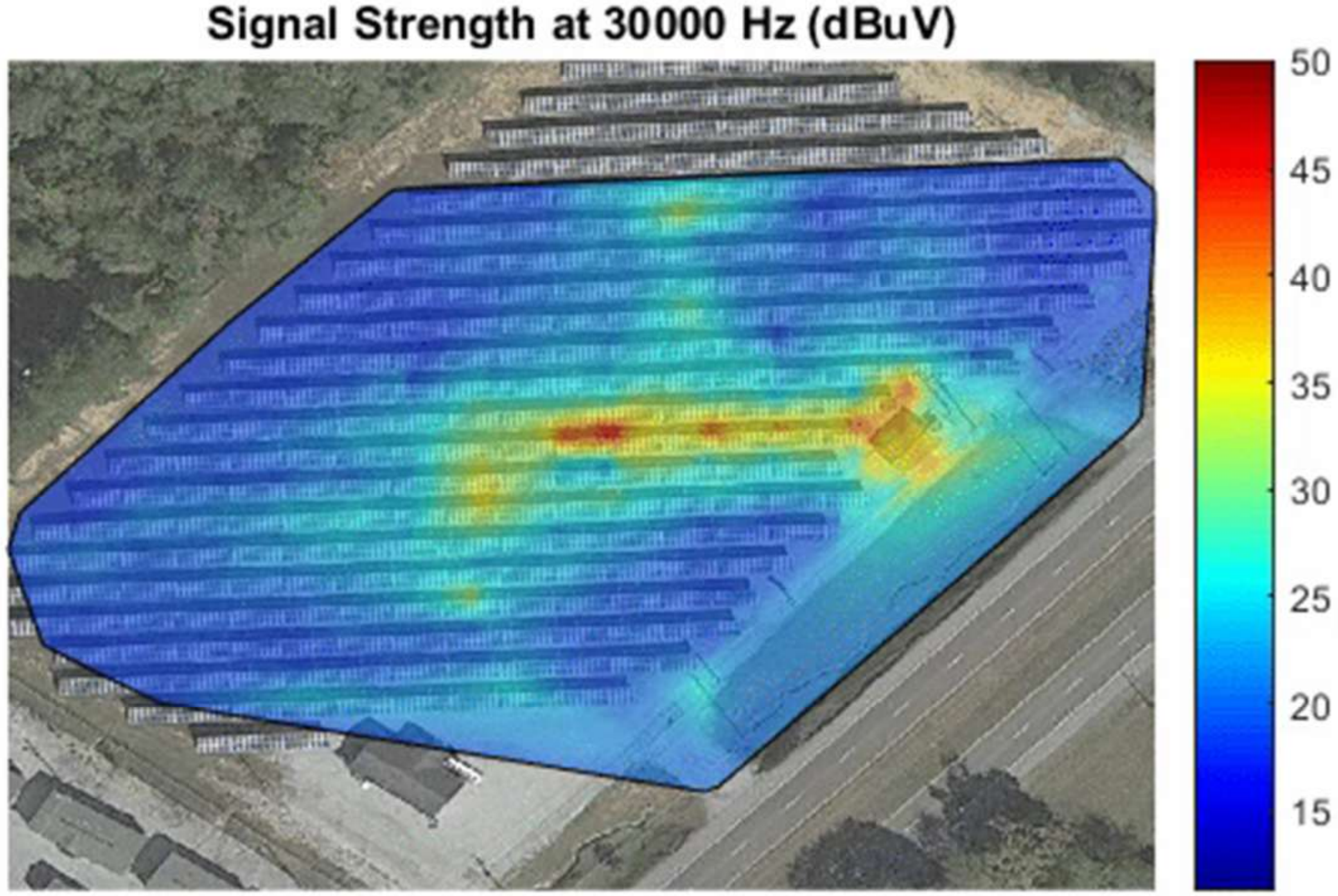
Animated Heatmap (30 kHz to 842 kHz)



Radiated Emissions from this PV Installation:

- **Start: ~30kHz**
- **End: ~180kHz**

Other Broadcast Signals Seen:

AM Longwave:

- **Signal: ~ 76kHz**
- **Signal: ~189 kHz**

AM Medium Wave:

- **WRJZ - AM 620kHz**
- **Talk Radio- AM 760kHz**

- More Interference Near Inverters and Nearby Panels at Lower Frequencies
  - Less Interference Above 240 kHz

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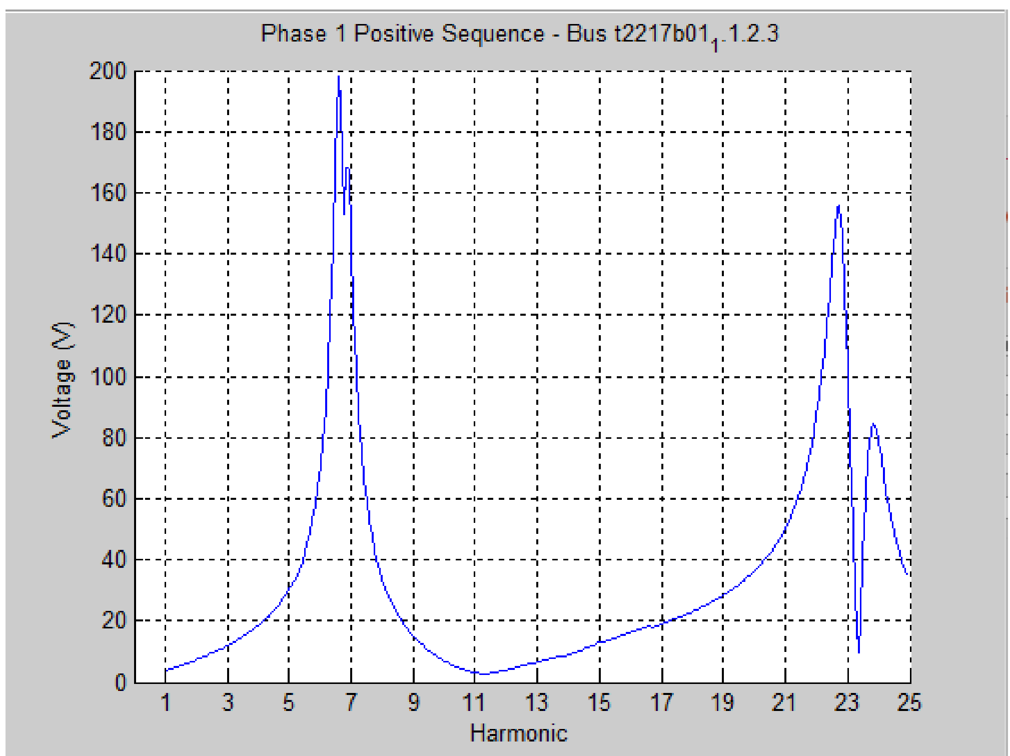
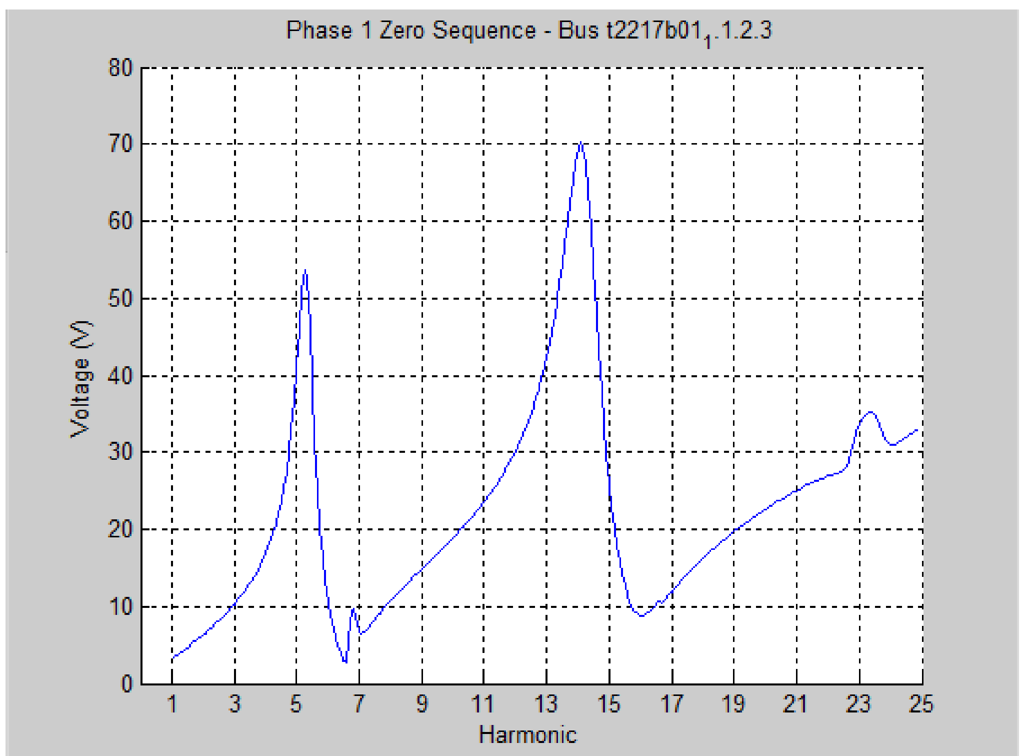
System Resonance measured at first line segment on PV Farm Feeder

BA25H BA60AH AP42AH AG33AH 158780 VLA26 VLA27 VLA28





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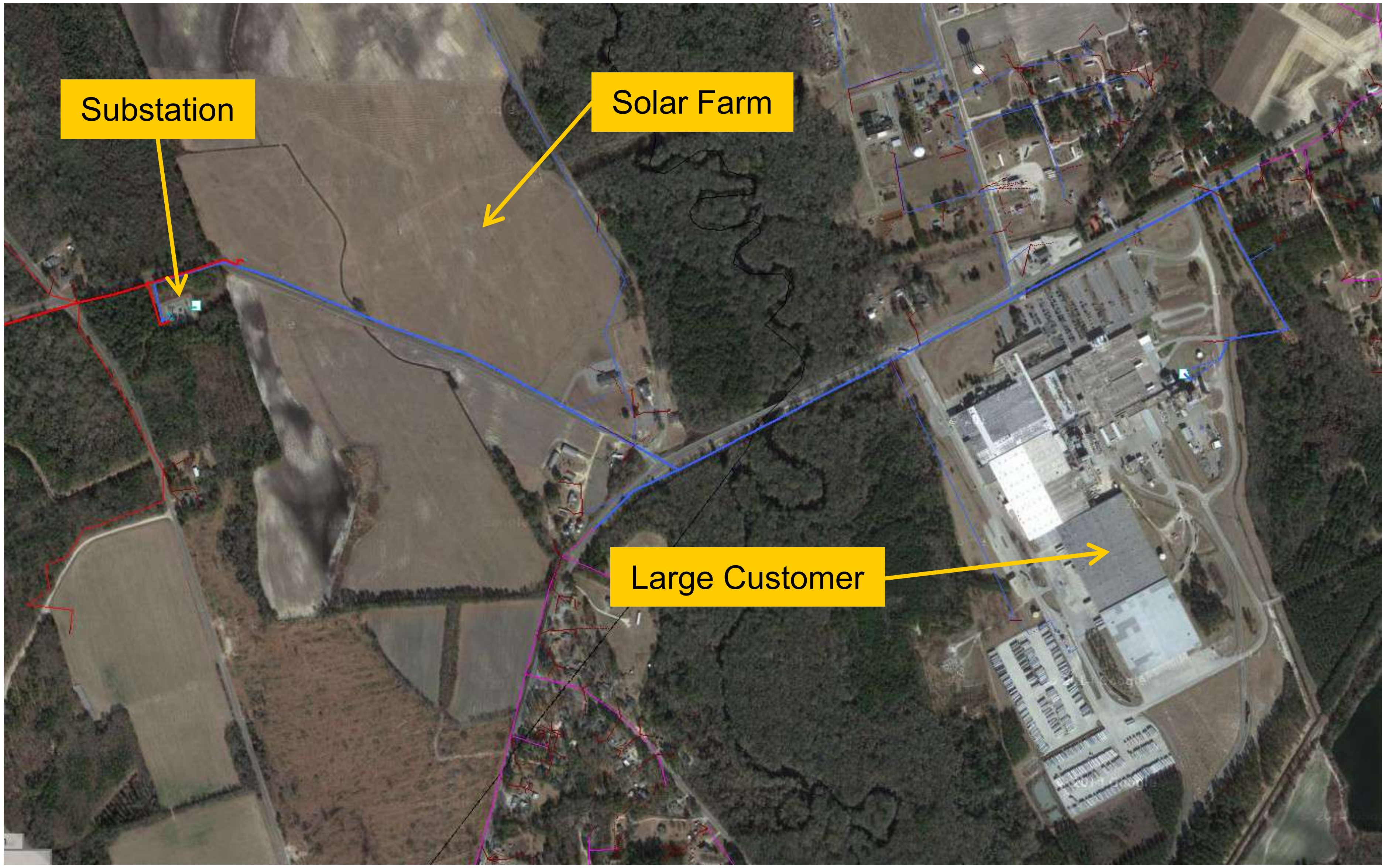
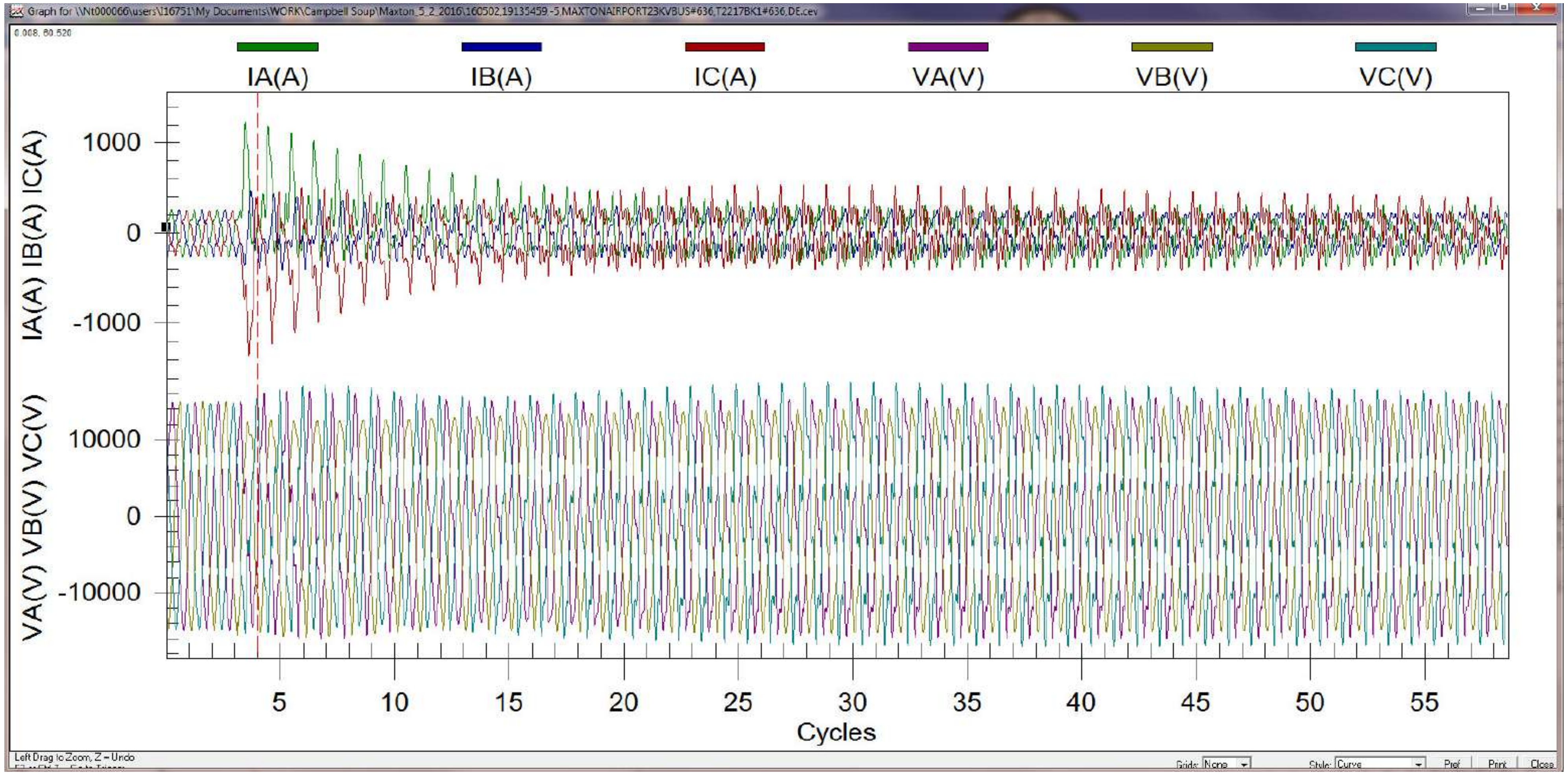
Challenge: PV System Transformer Inrush

Large Customer and Solar Farm



This Magnetizing Inrush Shut Down Plant Equipment – High Harmonics



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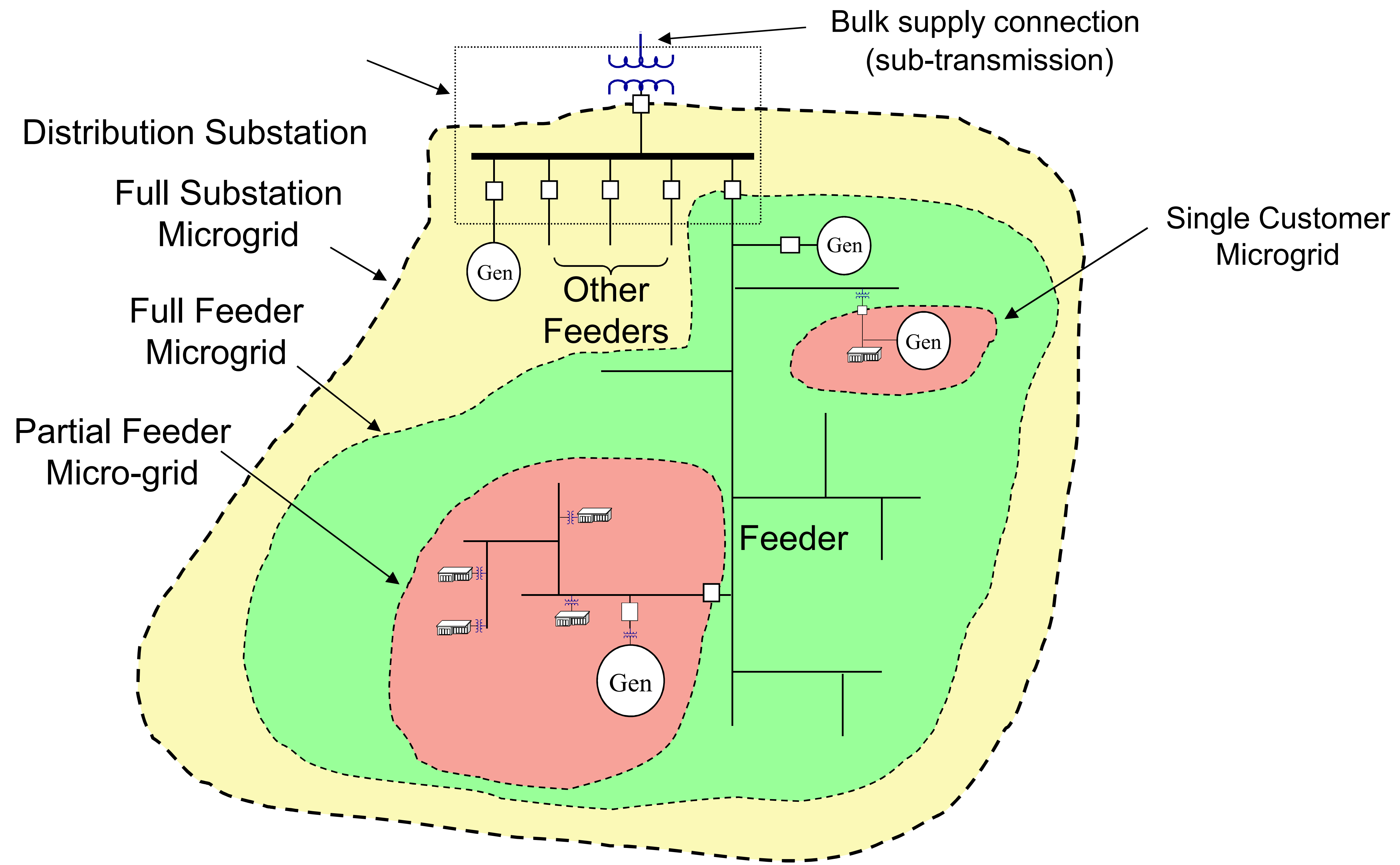
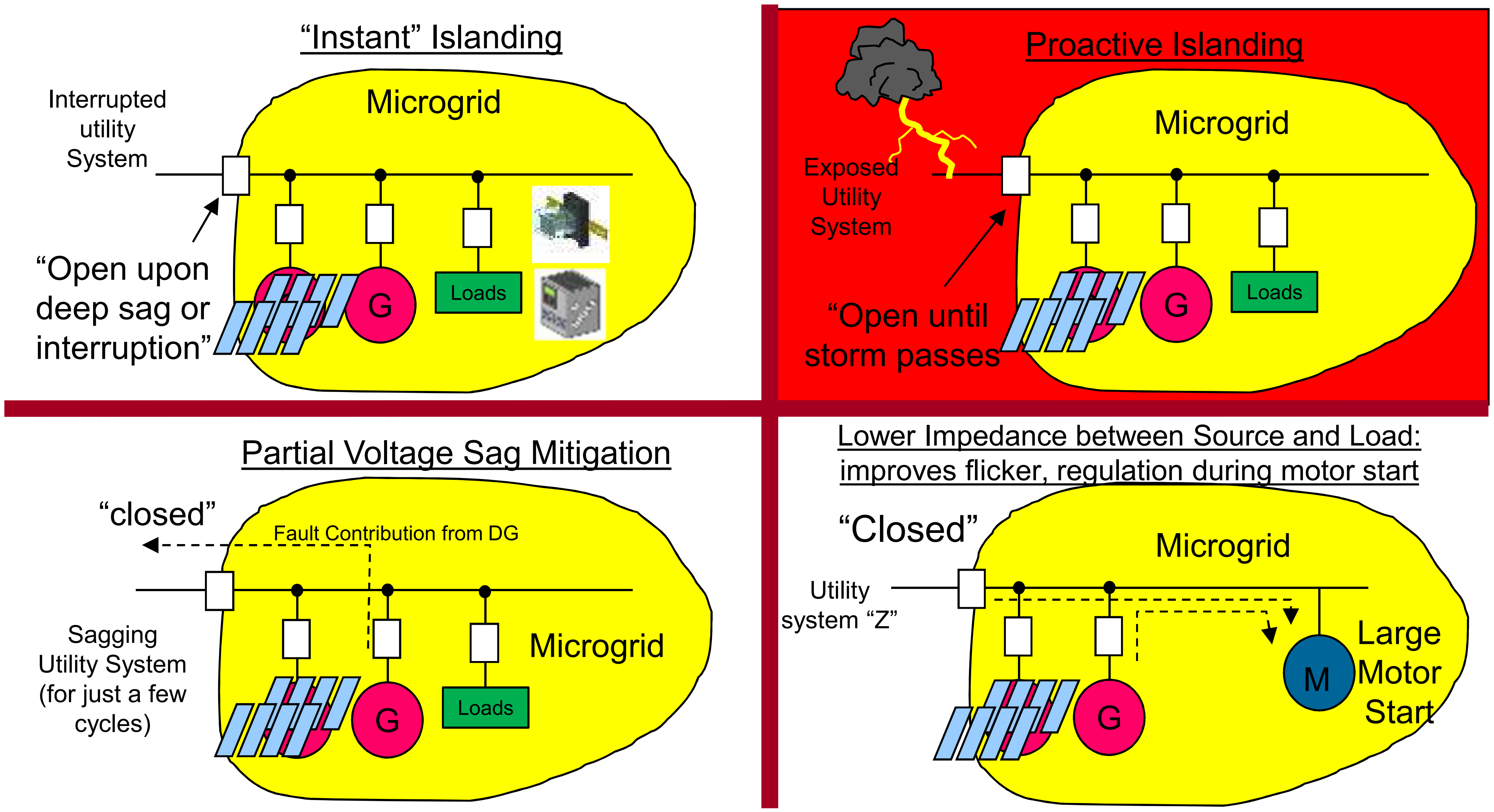
Challenge: MicroGrids
Potential Benefit or Problem?

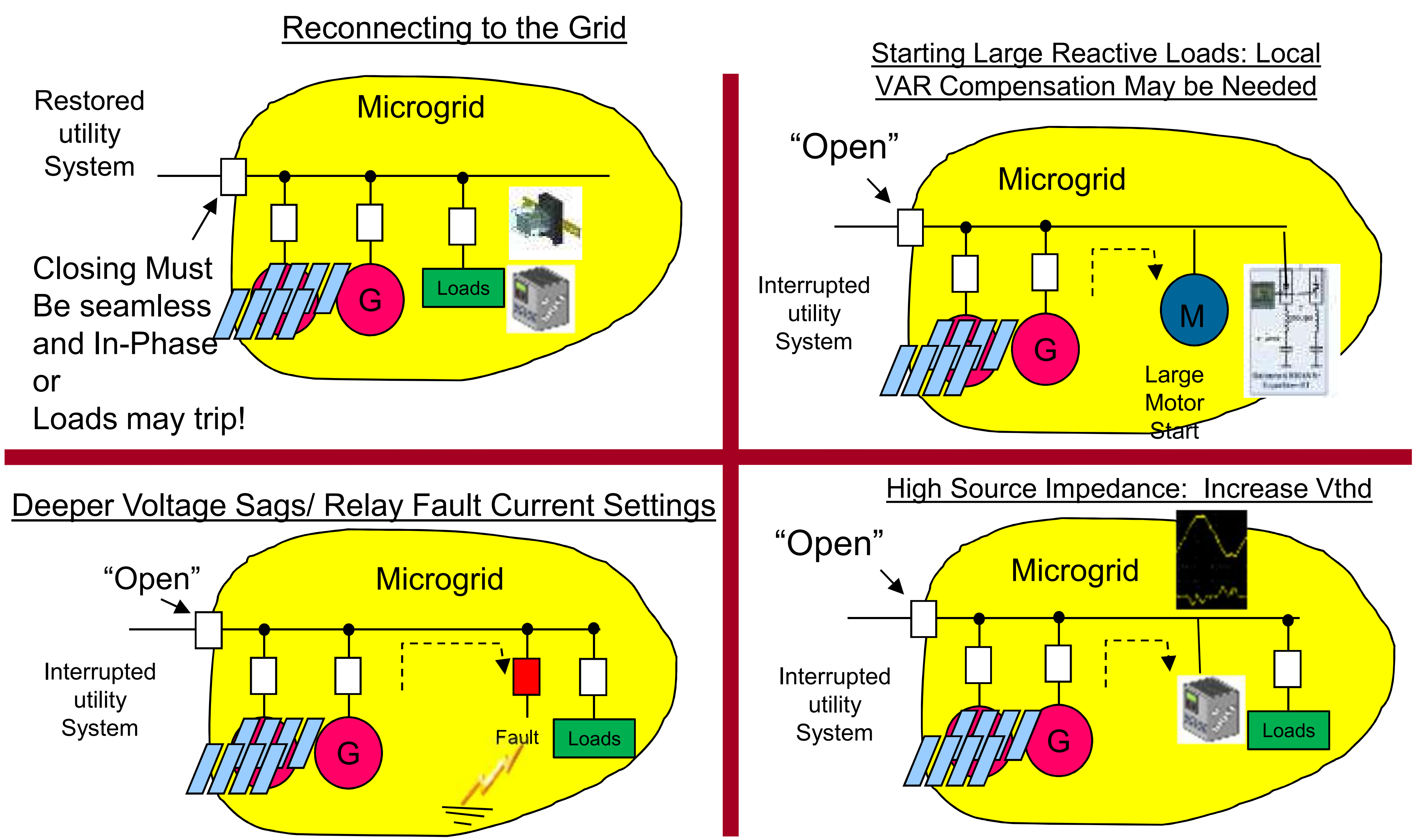


Four Ways that Microgrids *could* Enhance PQ/Reliability



All of our regular PQ standards are for grid-connected systems. We haven't really even begun to develop comparable standards for transitioning to local, islanded generation

The Science of Unintended Consequences:
At Least Four Ways things *could* get worse



Concluding Thoughts - Our Industry's Approach to PQ Challenges

- Our working model of a stiff central grid that can weather any change with out degradation to quality is melting away
- We are easily distracted by jargon that sounds meaningful, but often contains no actual concrete goals
  - Smart Grid
  - Intelligent Grid
  - Automated Grid
  - Big Data
  - Digital Grid
- We treat PQ as an after affect, not as a goal or measure of value
- Utility PQ Teams are usually small, distributed, and underfunded
- The utility industry is one of the few remaining that regularly uses its customers as a PQ department

Concluding Thoughts - Our Industry's Approach to PQ Opportunities

- Power Quality is the best view into operational excellence available to the utility
- PQ teams and their data offer a "fast track" to activing measurable results from Big Data and innovation
- PQ is a valuable measure of operational excellence and can be used as such:
  - What is the value of near-perfect PQ?
  - What is the value of the goal of zero customer interruptions?
  - How can operational excellence be assured in the future despite profound change?
  - How can we know more about the quality of our product than the customer

Together…Shaping the Future of Electricity