Designing and Maintaining a Pollution-Resilient Electric Power System

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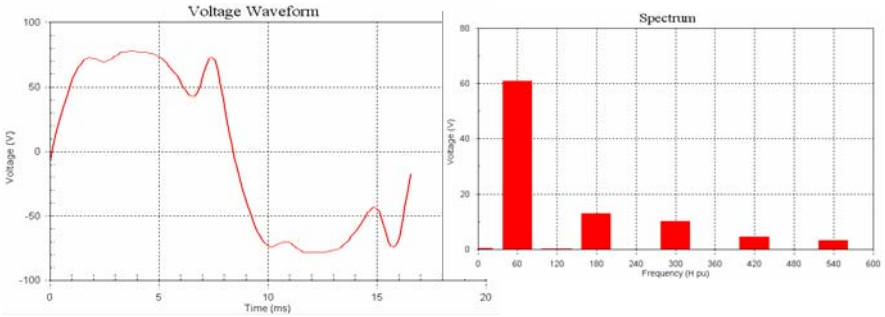
EnerNex CORPORATION

Managing Pollution Issues

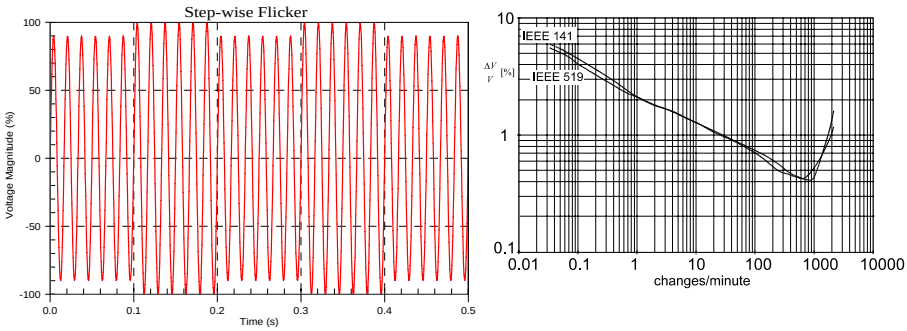
- Define the metrics, and measure them
- Use simulation to compare different designs and maintenance strategies
  - validate with measurements
  - how to value pollution?
- Implement system changes
  - again, validate with measurements

Harmonic Voltage Distortion



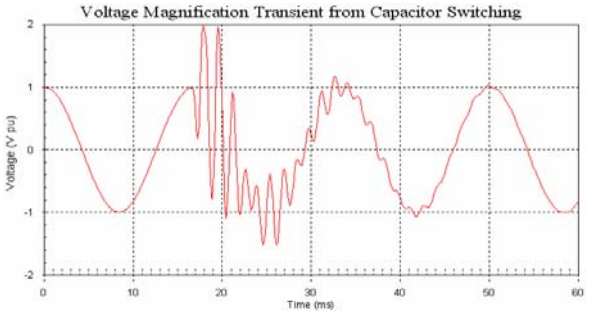
- Pollution Rank #1, PQ Rank #3
- Standard: IEEE 519
- Metric: THD_{95}; level exceeded 5% of time
  - limit at MV is 5.0% total, 3.0% any component

Voltage Flicker



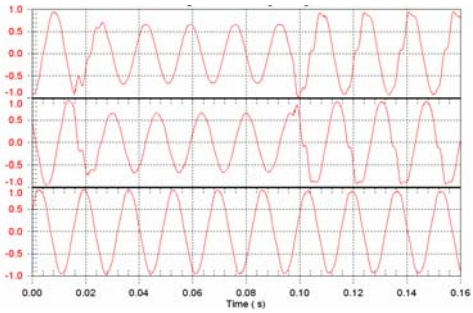
- Pollution Rank #2, PQ Rank #4
- Standard: IEEE 1453
- Metric: P_{ST}; short-term flicker coefficient
  - planning limit is 0.9

Transient Overvoltages



- Pollution Rank #3, PQ Rank #5
- Standard: IEEE 1159 (plus EPRI reports)
- Metric: $SATMORI_{1.7}$; annual frequency of voltage transients at least 1.7 per-unit
  - typical value of 1 per day?

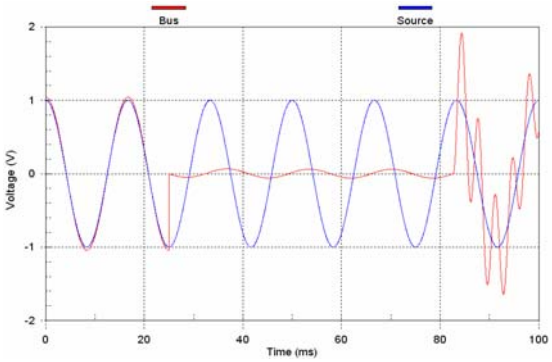
RMS Variations (Sags & Swells)



(Similar to voltage flicker)

- Pollution Rank #4, PQ Rank #2
- Standard: IEEE 1159 (plus EPRI reports)
- Metric: $SARFI_{70}$; annual frequency of sags to 70% voltage or below
  - typical value of 20

Momentary Interruptions



(Sags below 10% voltage; followed by a voltage recovery transient when the fault clears)

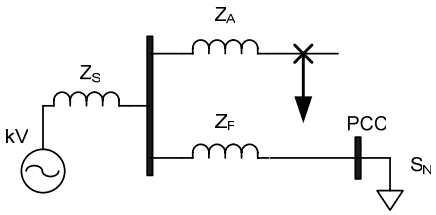
- Pollution Rank #5, PQ Rank #1
- Standard: IEEE 1366
- Metric: MAIFI; frequency of interruptions up to 1 or 5 min
  - typical value of 6 annually

Benefits of Source Strength

- Reduce voltage sag magnitudes
- Absorb more harmonic current injection
- Reduce flicker magnitudes
- Note: these are probably what you think of as “pollution”
  - No inherent effect on interruptions (aka reliability) or transients (another type of pollution)

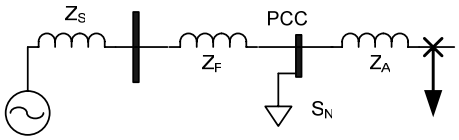
Source Effect on Sags

Fault on Adjacent Feeder



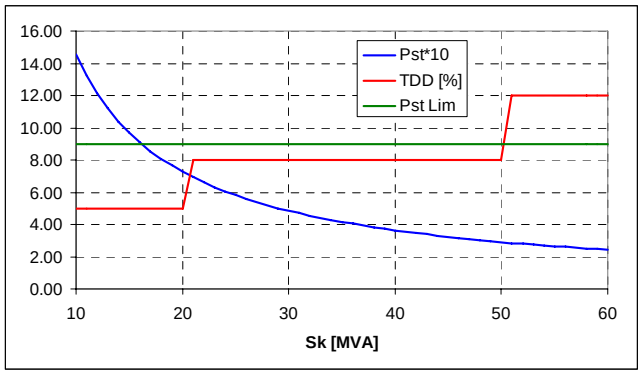
$$\overline{V}_{PCC-1} = \frac{Z_A}{Z_S + Z_A}$$

Downstream Fault



$$\overline{V}_{PCC-2} = \frac{Z_A}{Z_S + Z_F + Z_A}$$

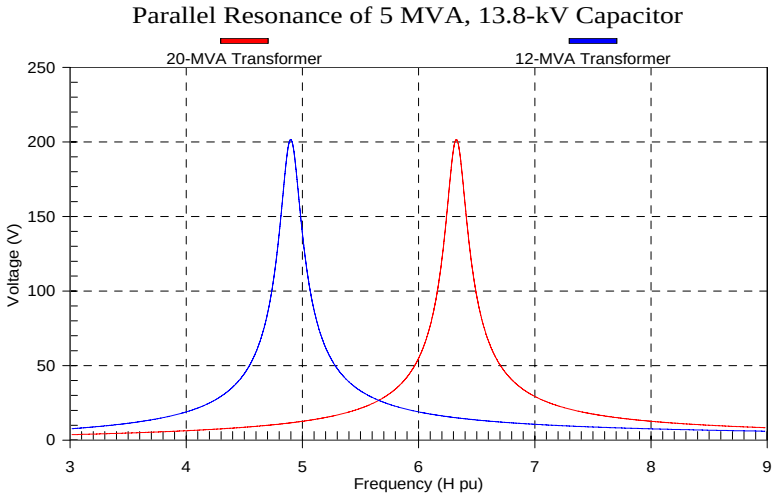
Source Effect on Flicker & Harmonics



$$S_K = \frac{kV^2}{Z_S + Z_F}$$

$$P_{ST} = c_f \frac{S_N}{S_K}$$

Source Effect Parallel Resonance



How To Increase Source Strength

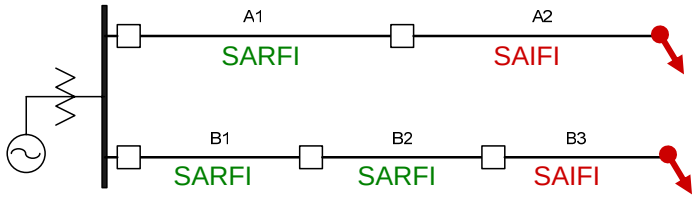
- Increase conductor sizes
- Increase substation transformer capacity
- Add a substation transformer
- Higher transmission voltage service
- Add a transmission line
- Express feeders (isolation from other load)
- Dedicated transformers (more isolation)

Benefits of Sectionalizing

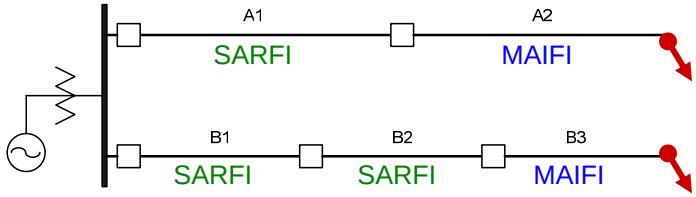
- Better interruption indices
- More RMS variations (they were interruptions before)
- No inherent impact on harmonics, flicker, or transients

Effect of Sectionalizing

Permanent Fault



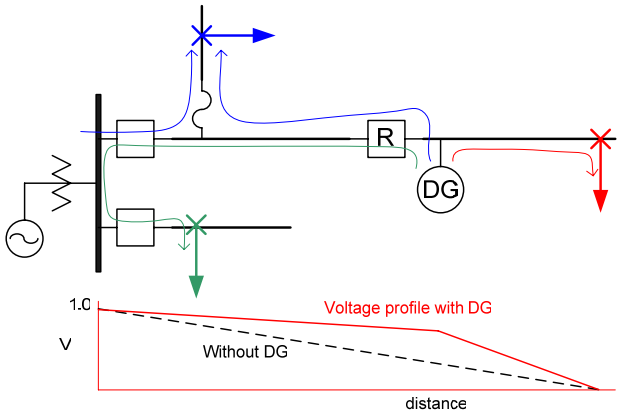
Temporary Fault



Impact of Distributed Resources

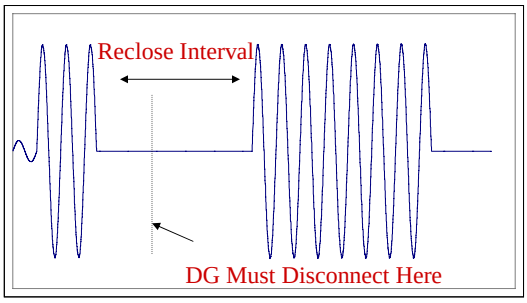
- The effect is mixed, and benefits may accrue primarily to the DG owner
- Good Impacts:
  - Higher source strength? Depends on interconnection
  - Backup source may reduce long-term interruption indices
- Bad Impacts:
  - Higher ground fault voltages on healthy phases
  - May produce more flicker or harmonics

DG Effect on Overcurrent Protection



- No Fuse Saving
- Loss of Sensitivity
- Sympathetic Tripping

DG Impact on Reclosing



- DG has to disconnect early in the reclose interval, may lengthen to 2 – 5 seconds
- Dead time changes from “instantaneous” to “momentary” category of IEEE 1159

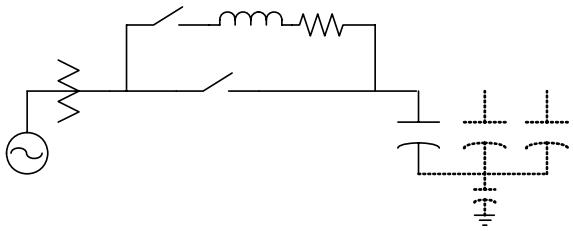
Reducing the Event Rate

- Helps both interruptions and RMS variations
- Upgraded lightning protection
  - Arresters
  - Overhead shield wires, with better grounding
  - More insulation
- Vegetation management

Other Measures

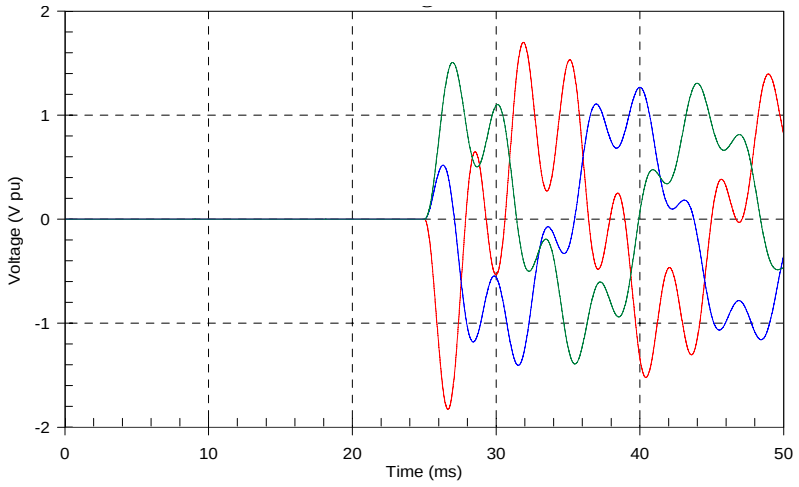
- Capacitor switching surge reduction
  - Synchronous or zero-voltage control
  - Preinsertion resistors
- Power electronic devices to reduce flicker or harmonics (STATCOM, DVAR, etc.)
- Passive harmonic filters
- PWM converters don't inject low-order harmonic currents

Capacitor Switches

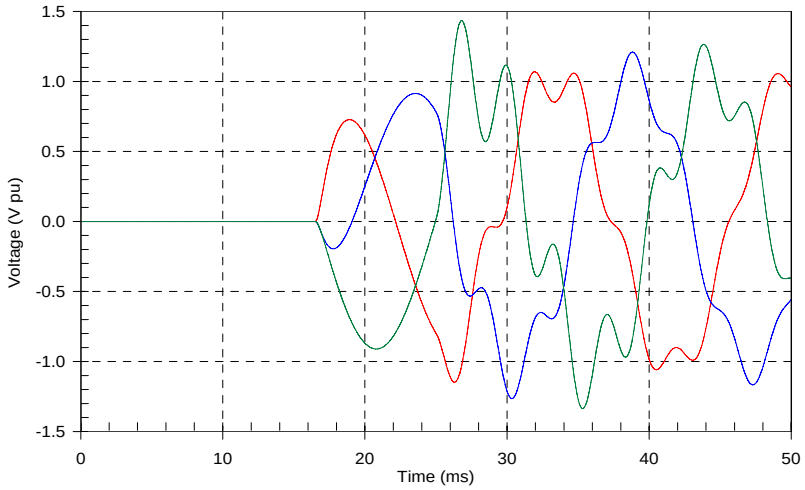


Mitigation	Peak [p.u.]	% >= 1.7 p.u.
None	2.010	94.5
20-Ω Resistor	1.565	0.0
Standard Inductor	2.088	28.0
Enhanced-Duty Ind.	1.897	45.0

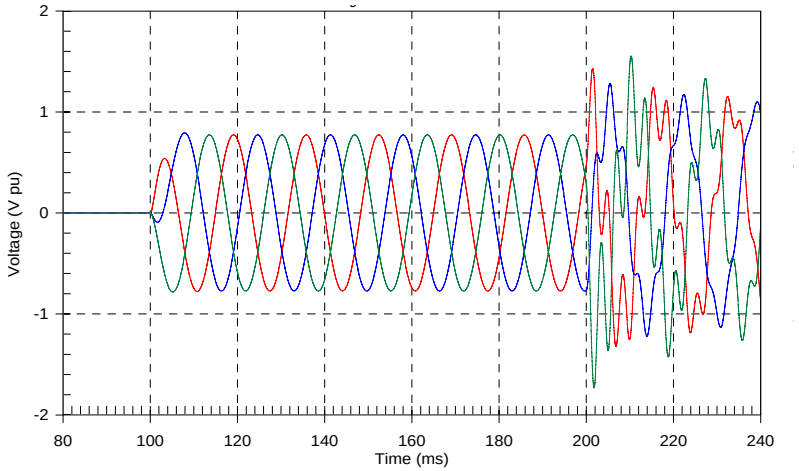
No Mitigation



Pre-insertion Resistor

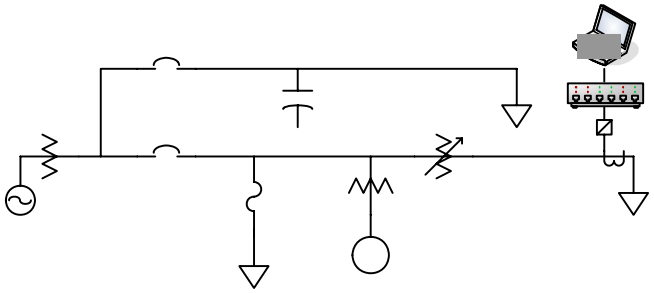


Pre-insertion Inductor



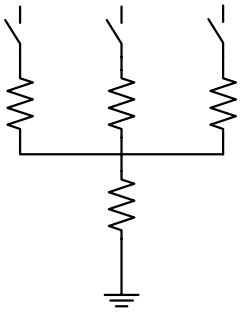
Why Do We Need PQ Simulation?

- Measurements take a long time
- Measurements are after the fact
- Simulation can be a virtual laboratory

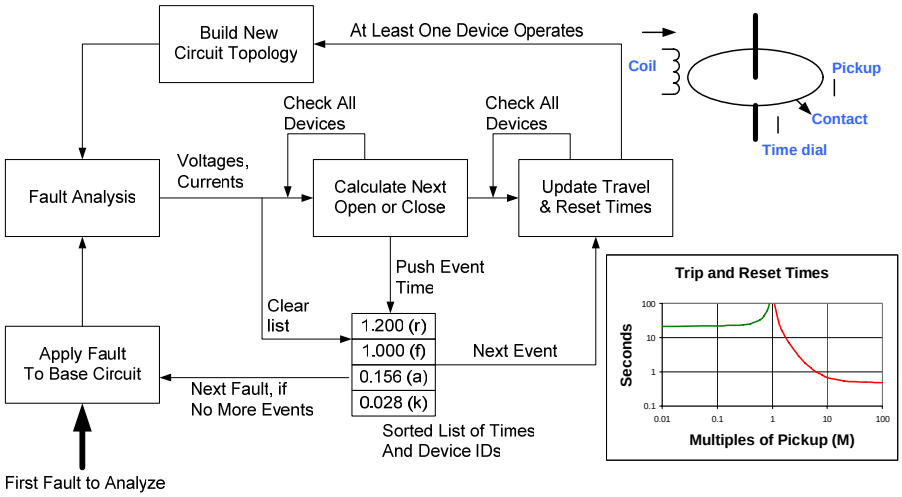


Stochastic Fault Application

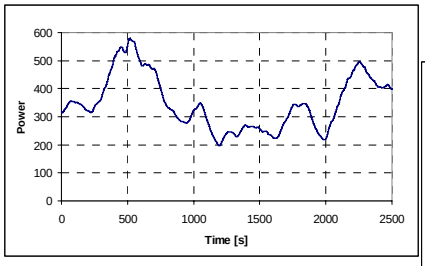
- Rate (0.1 / mile / yr)
- Other Variables:
  - Phases Involved
  - Permanent? (20%)
  - Resistance? (5 Ω)
- *Each type makes a weighted contribution to MAIFI and SARFI*

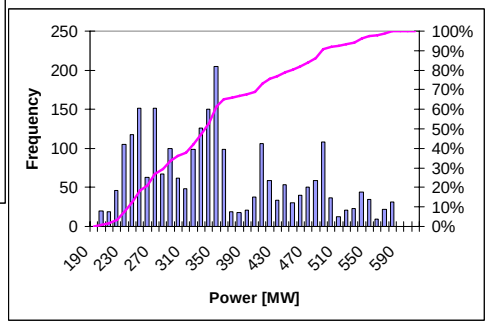


Fault Analysis Flowchart



Stochastic Load Variations





Peak = 579.6 MW

2% Level = 563.6 MW

5% Level = 533.6 MW

How Accurate Can This Be?

- Overcurrent device models are very good
  - Utilities used these for decades
  - They have been essential to protect life and property
- Voltage and current calculations are very good
  - Utilities used these for decades
  - They have been essential for equipment specification
- The greatest uncertainty lies in the number, types, and locations of faults, or the variation of harmonic and flicker injections
  - Utilities do gather some statistics
  - Benchmark over time with PQ measurements

Conclusion

- You can't manage something unless you measure it
- Software tools need to produce figure-of-merit outputs (SARFI, MAIFI, P_{ST}, THD_{95})
- How to assign value to the indices?
- EPRI software tools:
  - PQ Planner (not used much)
  - DSS (***going open source!!***)