ECE 528 – Understanding Power Quality

http://www.ece.uidaho.edu/ee/power/ECE528/

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Lecture 7

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Today…

- Sags, swells, and short interruptions
  - Some Homework 2 pointers
  - Evaluating voltage sag performance
  - Power Quality and reliability indices
  - Economic impacts
  - Mitigating voltage sags and short interruptions
  - General mitigation principles
  - End user mitigation examples

2 Lecture 7

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Some homework 2 questions and answers

1. Give the most likely cause of the variation in the power supply's vulnerability based on the lectures. Assume the sags all start and end at the same point on the waveform.
2. The fault is the same in both parts. Only the protection scheme changes. Pay attention to the locations of the fuse, recloser, and customers. "Fast" or "slow" operation refers to the recloser's curves. "Reclose interval" refers to how long the recloser stays open before re-closing. Clearly describe what each customer experiences; i.e. two voltage sags, each 0.42 seconds long, five seconds apart.

Some common Q & As on homework 2

3. Remember, it's a voltage division problem. MVA values, reactances, or current can be used but using reactances is probably easiest. In 3b, I recommend finding the per-unit current through the system impedance that satisfies the problem, then convert that to amps at 460V. Don't forget it's a 3-phase system. See the examples in lecture 6 and FPQ pgs 113-121.
5. You can check your calculations against the values given in the paper before introducing new values from the problem statement. **T_{60} is the period for one 60Hz cycle.**

Evaluating voltage sag performance

- Voltage sag performance
  - Refers to the voltage sags a facility experiences and the impact of those voltage sags on the facility.
  - IEEE standard 1346 – "Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment" *(Get this standard and skim it.)*

Evaluating voltage sag performance

- Objectives of the evaluation
  - Determine the expected number, depth, and duration of voltage sags
  - Determine equipment vulnerability to voltage sags
  - Identify and address incompatibilities

Electrical Disturbance + **Path** + **Vulnerable Equipment** = **Power Quality Problem**

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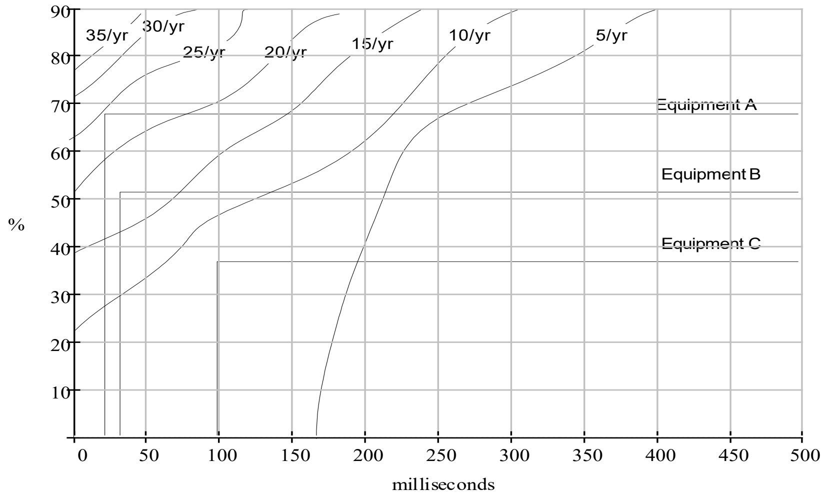
A “compatibility template” (see IEEE Std. 1346)



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Building the compatibility template

- Power system data
  - Sources
    - Long term or permanent monitoring
    - Computer models and system records
  - Issues
    - System behavior may change with upgrades/modifications
    - Long term monitoring takes a long time – customers want data quickly
  - Work-around – dealing with the issues
    - Use typical data from similar systems
      - Urban or rural, industrial or commercial, overhead or underground, etc.

Electrical Disturbance + Path + Vulnerable Equipment = Power Quality Problem

Building the compatibility template

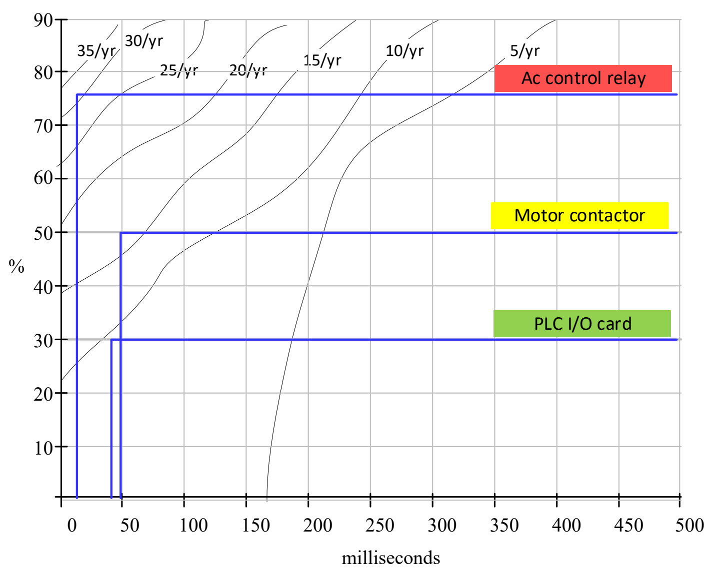
Electrical Disturbance + Path + **Vulnerable Equipment** = Power Quality Problem

- Equipment data sources
  - Manufacturer data or typical industry data
    - Example: Table from IEEE 1346
  - Customer Logs
  - Monitoring at the equipment
  - Sag generators
- Issues
  - Similar sags may have different impacts – phase shift, point-on-wave, phase unbalance
  - Equipment availability for testing
  - Facility is not built yet – no history
  - Time

Equipment	Most Vulnerable	Average	Least Vulnerable
PLC	20ms, 75%	260ms,60%	620ms, 45%
PLC I/O card	20ms, 80%	40ms, 55%	40ms, 30%
5hp AC drive	30ms, 80%	50ms, 75%	80ms, 60%
ac control relay	10ms, 75%	20ms, 65%	30ms, 60%
Motor contactor	20ms, 60%	50ms, 50%	80ms, 40%
PC	30ms, 80%	50ms, 60%	70ms, 50%

Better voltage sag performance →

Example: Building and using the compatibility template



Now it's easy to see which devices in this process have the most impact on process continuity.

The AC control relay's vulnerability to voltage sags determines the vulnerability of the entire process to voltage sags.

The compatibility template helps us decide where to focus our voltage sag mitigation efforts for this process.

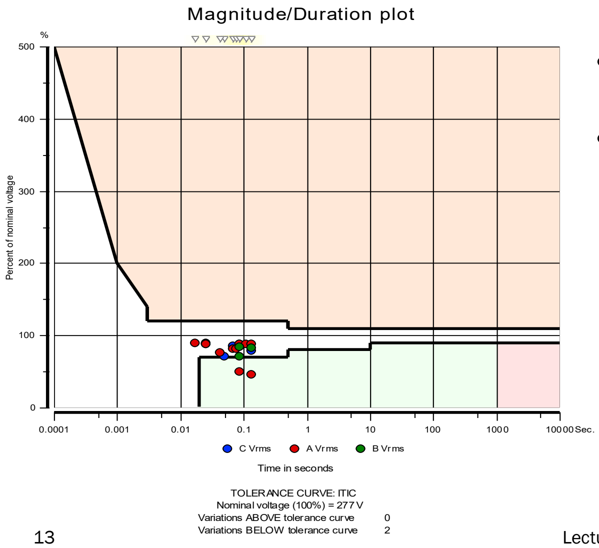
A practical approach with limited data

- Use any applicable monitoring data available
  - Past monitoring for other issues
  - Monitoring at other locations in the area
- Use customer's impact-frequency data
  - Customer logs
- Correlate customer data with system logs
- Use system logs to estimate long-term impact frequency
- Use system logs and computer models to estimate voltage sag depth and duration
- Preventing impact from one or a few events may justify the cost of mitigation

Other ways to specify sag performance

- SARFIx – (PSQ pg. 365) System Average RMS variation Frequency Index. The "x" is a specified voltage level, such as $SARFI_{70}$
- Standard voltage thresholds are 140, 120, 110, 90, 80, 70, 50, and 10% of nominal
- May be specified as a curve; $SARFI_{ITIC,}$ $SARFI_{SEMI}$
- Standard time period is one year, so these indices are an estimate of the number of events per year that satisfy a particular criteria
- See IEEE Guide for Voltage Sag Indices: IEEE Std. 1564-2014.

Voltage variation data on the ITI curve



- How many events would you expect to affect unprotected IT equipment?
- If this data represents 1 month, what would we estimate for $SARFI_{ITI?}$

Reliability indexes

See IEEE Guide for Electric Power Distribution Reliability Indices: IEEE Std 1366

- Used to evaluate interruptions, (Utility definition of "Interruption" may not match IEEE definition for SAIFI and SAIDI
  - SAIFI – System Average Interruption Frequency Index
    - number of times an average customer is interrupted per year
  - SAIDI - System Average Interruption Duration Index
    - total time that an average customer is interrupted per year
  - MAIFI – (not in texts) – Momentary Average Interruption Frequency Index (for trip-close events)

$$MAIFI = \frac{total\ customer\ momentary\ interuptions}{total\ customers\ served}$$

- **See more: PSQ pg. 101, 364-336, FPQ pg. 130-134**

The costs of voltage sag events

- How can a voltage sag lasting only a few cycles result in losses of several million dollars?
  - Lost work – idled labor – starved processes
  - Lost production – makeup production - overtime
  - Repairs
  - Increased buffer inventories
  - Product quality issues
  - Customer satisfaction – lost business
  - Fines, disposal fees

Mitigation principles

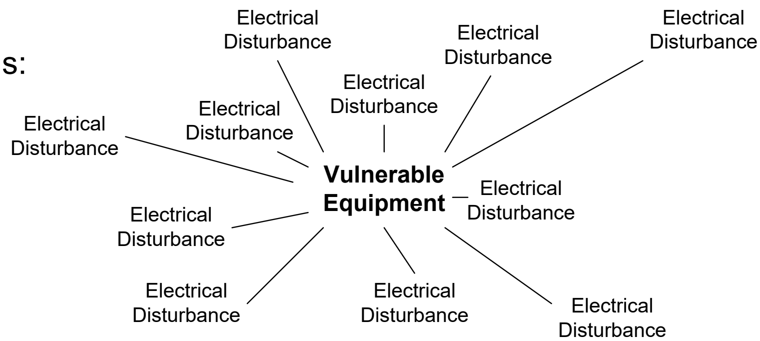
- Mitigation is <u>any</u> equipment or modification that sufficiently resolves a voltage sag incompatibility issue.
- "Perfect Power" is not necessary.
- Mitigation should be "the simplest thing that could possibly work" – a concept from software development and other fields

Work on disturbance or vulnerability?

The model:

Electrical Disturbance + Path + Vulnerable Equipment = Power Quality Problem

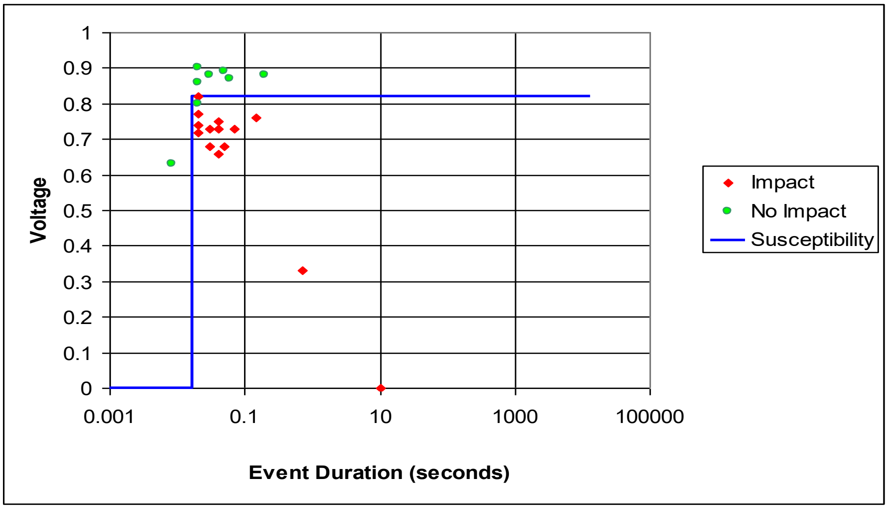
Reality for voltage sags:



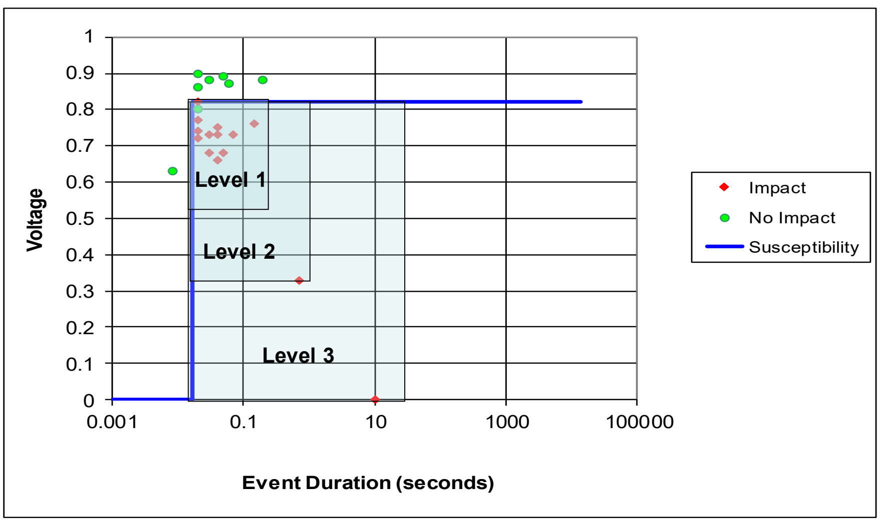
Mitigation principles

- Work as close to the vulnerable equipment as possible.
  - Establish a “Perimeter of Protection”
    - castle and moat analogy
    - *The environment is everything that isn’t me.* – Albert Einstein
  - Minimizes impact from sags regardless of what causes them
  - Tends to minimize costs
  - Important for transient protection too
  - Equipment objective
    - Push the corner of the equipment susceptibility profile down to lower voltages, and out to longer durations, to provide an acceptable level of “ride-through”.

Example – recorded voltage and impact data



Objective – eliminate impact of typical sags



Giving customers options

1. Level 1: sags to 50% lasting up to 30 cycles. – 85% of recorded events.
2. Level 2: sags to 30% lasting up to 60 cycles. – 93% of recorded events.
3. Level 3: interruptions lasting up to 1 minute - 100% of recorded events.*

* *We didn't record everything that might happen, system is still vulnerable to longer interruptions.*

Mitigation options – Level 1
(Load is a PLC that draws up to 1kVA)

- Option 1: Dynamic Sag Corrector (DySC) (PSQ p. 73, fig 3.24)
  (Active series compensator: two back-to-back DC boost converters; one for each half cycle)
  - Adds missing voltage by boosting the supply voltage
  - Sag protection for sags to 50% for up to 2 seconds
  - Cost: about $250
  - Solid-state electronics
- Option 2: Ferroresonant Transformer (PSQ p. 69, fig 3.18)
  - Must be oversized. For sags to 50% load may be up to 60% of rating.
  - Cost: about $1,800
  - No moving parts – no electronics
- Note: this mitigation inserts a device in the 'path'.

Electrical Disturbance + Path + Vulnerable Equipment = Power Quality Problem

Mitigation options – Level 2

- Option 1: Ferroresonant Transformer
  - For sags to 30% load may be up to 25% of rating. Cost: about $4,000.
- Option 2: UPS
  - Typical unit provides 14 minutes of ride-through for 1000 VA for about $550. Batteries are approximately $200 and should be replaced every 3 years. There will be a labor charge to replace them.

Mitigation options – Level 3

- Option 1: UPS
  - Same as level 2, option 2 – Cost: about $550 + $200 + labor to install new batteries every three years.
- Additional considerations for all options:
  - Ferroresonant transformer is “hard-wired” (installation costs) but has no electronic controls or batteries – very reliable, maintenance free, no switching disturbance.
  - UPS and DySC have similar electronics. Lower (worse) MTBF than Ferroresonant transformer. Both may be plug and cord connected – minimal installation time and cost.
  - UPS battery replacement requires technician and downtime or bypass.

Some other devices

- Dip-proofing inverter
  - A UPS that uses capacitors instead of batteries for energy storage.
  - Small footprint – low or no maintenance
  - Can handle complete interruptions for about 3 seconds
- Voltage Dip Compensator
  - A multi-tap transformer with solid-state switching between taps
  - Can handle sags to about 50%

Bigger loads

- Our load is four 15kVA industrial machines
- Level 1 options: (cost per machine)
  - UPS: $7,500
  - DySC: $3,000
  - Motor-Generator: $25k
  - PSQ text mentions flywheel-based systems too.

Bigger loads

- Level 2 and 3 options:
  - UPS: $7,500/machine
  - Motor Generator: $25k/machine
  - Note that as the power requirements increase, technologies such as the flywheel-based systems may become cost effective.
  - We also may have opportunities for subsystem protection.

Subsystem protection

- Remember the EMO circuit?
- In general, if we keep the controls "alive", motors, heaters, and other "high inertia" loads will continue to operate through a sag with no mitigation.
- Many industrial machines are simply assemblies of smaller machines that we may be able to address individually.
- This approach can significantly reduce costs.

More mitigation examples

- DC contactors – stay closed longer, and may use inherent energy storage in power supply
- Coil hold-in devices – *(Coil-Locks)* will keep relays and contactors closed for sags to 25% of nominal voltage.

- Next time
  - Whole facility and utility options.
- To do:
  - **Quiz 2 is posted**
  - Read PSQ Chapter 3
  - Read FPQ Chapter 3 and 4
  - **Work on homework 2 – you have everything you need**
  - Remember to use your online access to IEEE papers and standards through the university library website to download the papers and standards mentioned in the lectures. (See Lecture 1 for instructions.)