ECE 528 – Understanding Power Quality

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

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Lecture 8

Today…

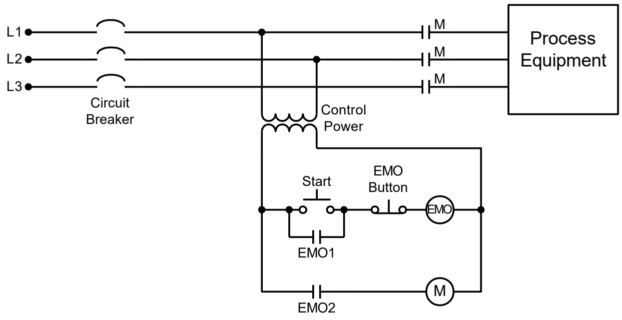
- Sags and short interruptions
  - Finish equipment-level mitigation
  - Whole facility and utility-system mitigation options
  - Summary and a few more important points
- Summary of voltage sags
  - Description
  - Causes
  - Effects
  - Mitigation

Some homework/exam suggestions

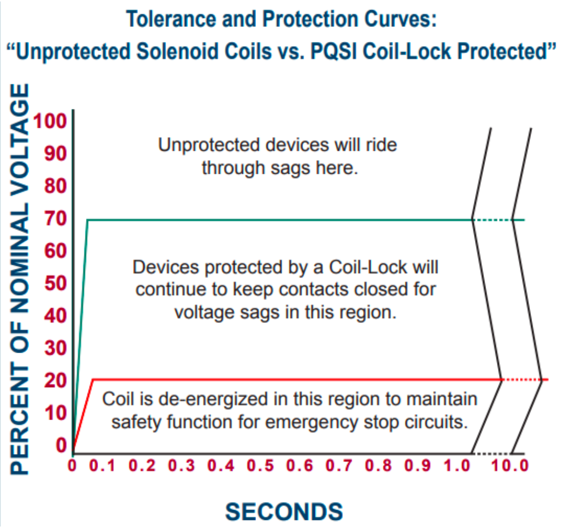
- Send Mathcad or Prime files.
  - Makes it easier to find a small mistake
- Turn in professional, annotated work
  - Helpful if you want to refer to this work later
  - Makes grading easier – you're more likely to get partial credit if needed
- Test your answers
  - It's a necessary engineering skill
  - You'll learn more by experimenting
- Word problem?
  - Be concise but complete
  - Give "most likely" answer(s) and a brief description of your basis

Subsystem voltage sag 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



From PQSI.com – relay coil sag tolerance comparison.

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

Power Quality Mitigation Philosophy

Electrical Disturbance + Path + Vulnerable Equipment = Power Quality Problem

What we know:
Eliminating any of the three components eliminates the problem.

It often makes sense to install some mitigation device here.

Why?

Why mitigate at the vulnerable equipment:

- Maximizes the disturbances that can be mitigated - most benefit
- Minimizes the capacity of mitigation - least cost

What other advantages can we think of?
Are there disadvantages to this approach?

Whole facility mitigation

- Why install whole-facility mitigation?
  - Time constraints
  - Convenient – can turn project over to utility or third party
  - Utility may provide this service for an additional fee
  - Minimal impact to facility's existing electrical system

A few options

- Battery-based systems
  - Multiple large UPSs, or utility-scale battery storage systems
  - May be part of a microgrid
  - May provide other benefits, such as peak shaving
- Motor generator
- Dynamic voltage restorer
- High speed transfer switch
- Some combination of these

Utility-scale battery storage system

- Simply a much larger version of a traditional, on-line or off-line, battery-based UPS.
  - Advantages
    - Can mitigate sags, interruptions, and swells
    - May be installed to work with a generator and will smooth the transition to and from a generator
    - Convenience – one device – external monitoring

Utility-scale battery storage system

- Disadvantages
  - Battery maintenance – typically require periodic replacement.
  - Must be sized to carry the entire downstream load.*
  - Cost: approximately $400/kVA – hardware only.

* Control system may simultaneously disconnect non-essential load.

Motor-Generator

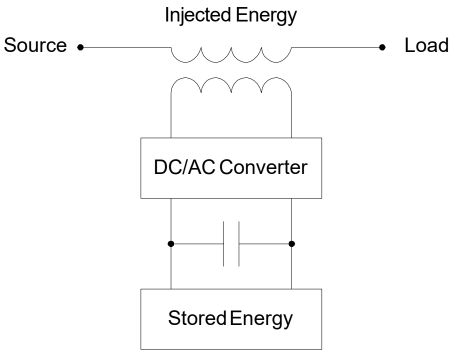
- Motor – turns flywheel – turns generator
  - Advantages
    - Isolation from utility system – protects from transients and harmonics
    - Protection from interruptions
    - May synchronize with a diesel generator
    - Seamless transitions between utility and generator
    - No inherent harmonic generation

Motor-Generator

- Disadvantages
  - Losses – system is always running
  - Must be sized for entire load
  - May limit future load growth
  - Frequency variations as system slows
  - Stored energy in a conventional system may be much higher than useful energy.
    - Frequency variation and energy storage may be addressed with power electronics.

Dynamic Voltage Restorer

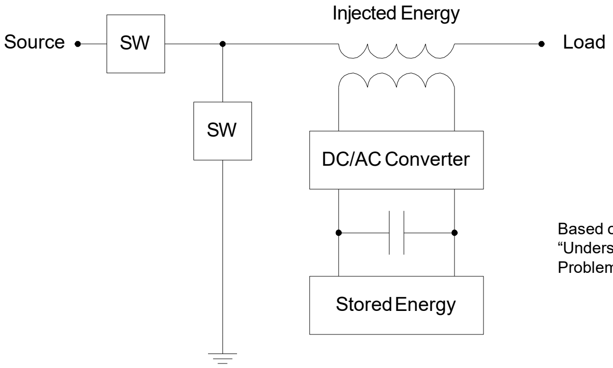
- Uses series connected transformer to “inject” the missing energy during a voltage sag
  - Advantages
    - Energy storage options include batteries, capacitors, flywheels, superconductors, etc.
    - Only the missing energy needs to be stored
    - May also be used for harmonic filtering



Based on figure 7.27 in “Understanding Power Quality Problems” by Math Bollen

Dynamic Voltage Restorer

- Disadvantages - cannot (usually) mitigate interruptions



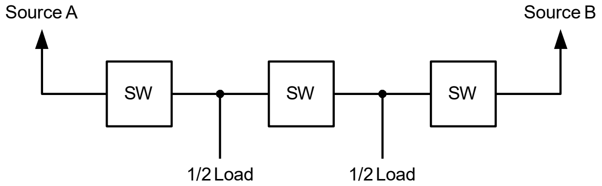
Based on figure 7.53 in “Understanding Power Quality Problems” by Math Bollen

High speed transfer switch

- Solid-state switches used to make or break connections between the load and alternate sources.
  - Advantages
    - No energy storage required
    - Minimal losses
    - Fast response time

High speed transfer switch

- Disadvantages
  - Requires two independent sources (with respect to the typical voltage sags.)
  - No local energy storage
  - Underutilized system capacity and capacity charges



Other utility/whole facility options

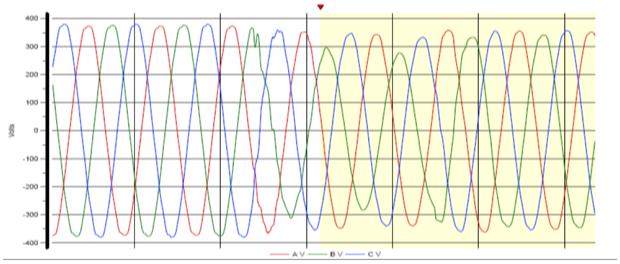
- Protection scheme issues
  - Minimize fuse saving to minimize interruptions
  - Fuse taps to minimize unnecessary interruptions
  - Current-limiting fuses may shorten fault clearing times and reduce the depth of the corresponding voltage sag
  - Prevent the faults in the first place!
    - Line clearing, bird guards, enclosed “dead-front” switchgear, etc.

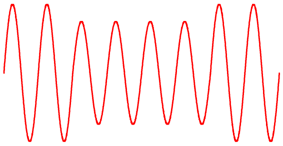
Summary and a few more important points

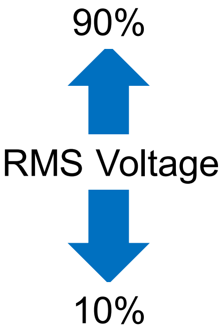
- Although whole-facility protection is possible, it is generally more cost-effective to:
  - Start at the equipment or component and work upstream (slowly).
  - Only protect necessary equipment.
  - Before adding equipment, (UPSs, etc.) evaluate changes to existing equipment.
    - Line-to-line connected control power transformers minimize the impact of Single-line-to-ground (SLG) faults.
    - Operate equipment near the top of any available voltage ranges.

Voltage sags – summary:

What are they?







Voltage Sags - Causes

- Sudden increase in load
  - Some motor starts (FPQ 4.7)
  - Short circuit faults and fault clearing (FPQ 3.4)

Analogy:

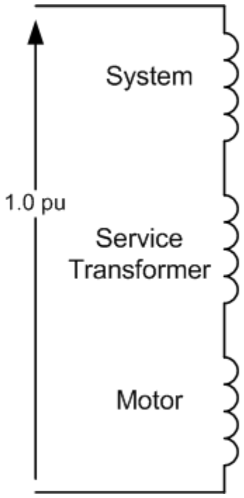
Voltage is analogous to water pressure in a home. Turing on water at one faucet may create a noticeable drop in pressure at another faucet.

Determining factors - depth

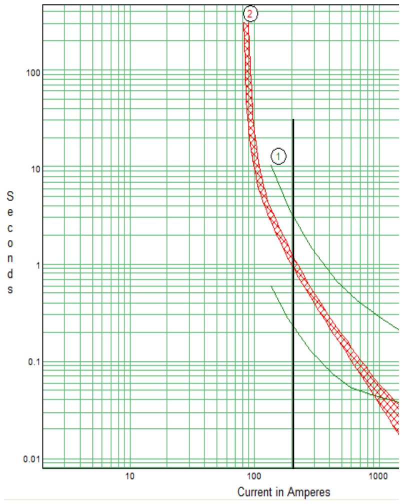
- DEPTH is determined by the relative size of the load or fault compared to the system fault duty.

$$Vmin := \frac{Xm}{Xs + Xt + Xm}$$

What determines system fault duty or capacity?



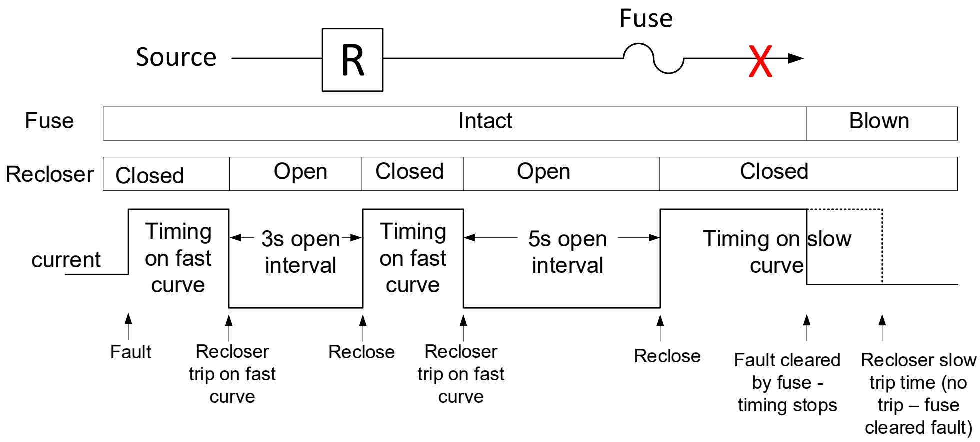
Determining factors - duration



- Duration is determined by the motor start time or the fault clearing time.
- Fault clearing time is determined by the fault current and the corresponding response time of the protective devices (fuse, recloser, circuit breaker)
- TCC curves tell us response times

Reclosers: Fuse saving and trip saving

Permanent fault with fuse saving:



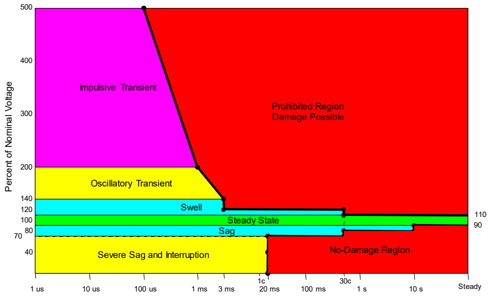
What changes with a trip-saving protection scheme?

Equipment vulnerability

- What determines vulnerability in common devices?
  - Energy storage versus energy use
    - Inertia – spinning loads
    - Capacitance - power supplies

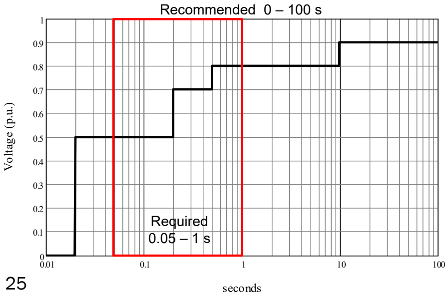
The term “ride through” is often used when describing voltage sag vulnerability. Ride through describes the depth and duration for voltage sags that some device can withstand and continue operating.

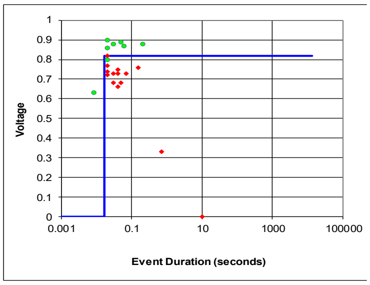
Equipment vulnerability information



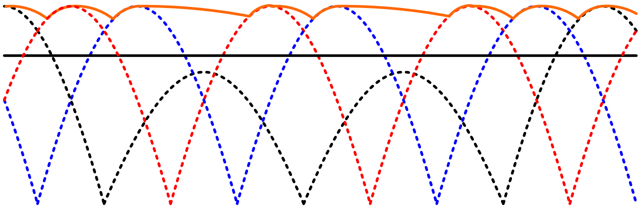
Equipment	Most Vulnerable	Average	Least Vulnerable
PLC	20ms, 75%	260ms,60%	620ms, 45%
PLC I/O card	20ms, 80%	40ms, 55%	40ms, 30%
5hp AC drive	30ms, 80%	50ms, 75%	80ms, 60%
ac control relay	10ms, 75%	20ms, 65%	30ms, 60%
Motor contactor	20ms, 60%	50ms, 50%	80ms, 40%
PC	30ms, 80%	50ms, 60%	70ms, 50%

Better voltage sag performance →

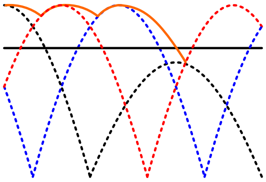




Ride through: Energy storage versus energy use



High energy storage versus energy use: device can “ride through” the single-phase voltage sag.

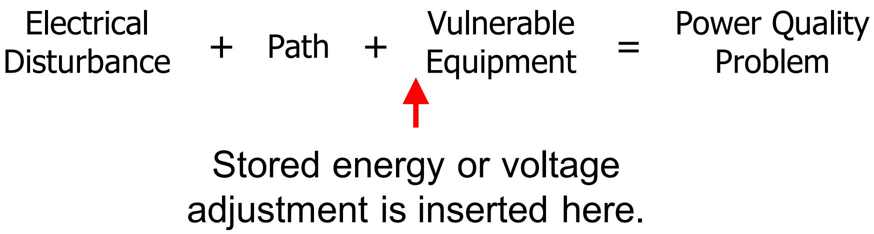


Low energy storage versus energy use: device cannot “ride through” the single-phase voltage sag.

See lecture 6 for more information.

Voltage sag mitigation

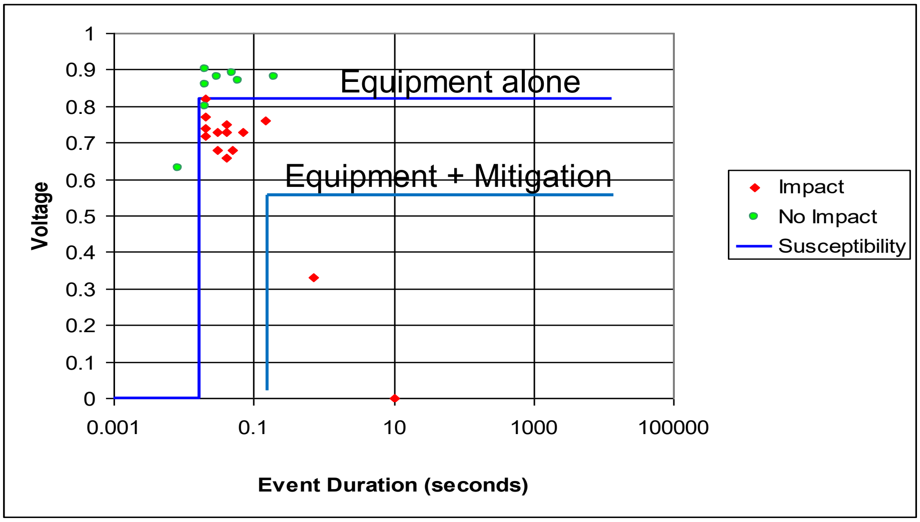
- Two basic approaches
  - Store more energy
  - Adjust the voltage (quickly)



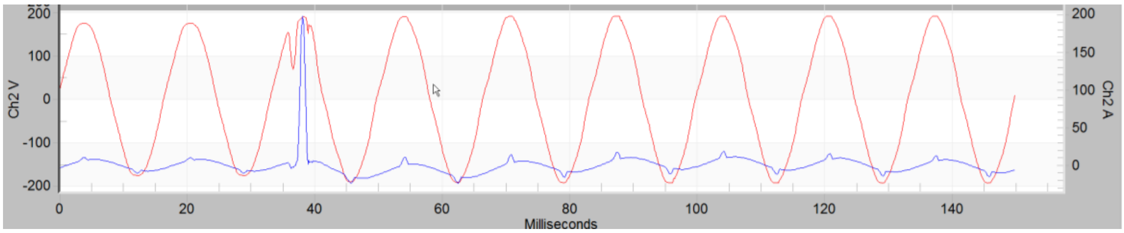
Electrical Disturbance + Path + Vulnerable Equipment = Power Quality Problem

Stored energy or voltage adjustment is inserted here.

Mitigation objective: lower susceptibility



Vulnerability of some rectifier-based loads: I^2t limits and voltage recovery



A large increase in the dV/dt of the voltage applied to a capacitor will cause a large inrush current to flow. This inrush current can damage diodes and similar devices. More on this when we discuss transients.

Some mitigation options

- UPS
- Motor-generator
- Dynamic voltage restorer
- High speed transfer switch
- Dip proofing inverter
- Voltage dip compensator
- Ferroresonant transformer
- DC controls
- Coil hold-in devices

Next time…

- Start harmonics
  - FPQ – chapters 6 and 7
  - PSQ – chapter 5
- Reminder:
  - Download and familiarize yourself with the IEEE standards and papers mentioned in the lectures.
  - Send rough drafts of your homework and exams – I’ll give you feedback you can incorporate to make them better.