ECE 528 – Understanding Power Quality

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

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Lecture 21

Today…

- Some homework 5 clarifications
- Event durations for SARFI and SAIFI calculations
- Homework 6 discussion
- Distributed Generation, Power Quality, and Reliability
  - What is it
  - Some general, “big picture” issues

Homework 5 clarifications

- Problem 1 – Regulator settings
  - You should end up with an Ohm's Law calculation: I x R = V

Example from lecture 17:

3.9 miles to regulation point, R=0.481 ohms/mi, CT = 200:5, PT = 7200:120.

$$R_{setting\_volts} = R_{line\_ohms} \cdot \left(\frac{CT_{rating}}{PT_{ratio}} \right)$$

The calculation from Lecture 17, with units:

$$R := 200\ A \cdot \frac{120\ V}{7200\ V} \cdot 0.481\ \frac{\Omega}{mi} \cdot 3.9\ mi = 6.253\ V$$

Invert and multiply…

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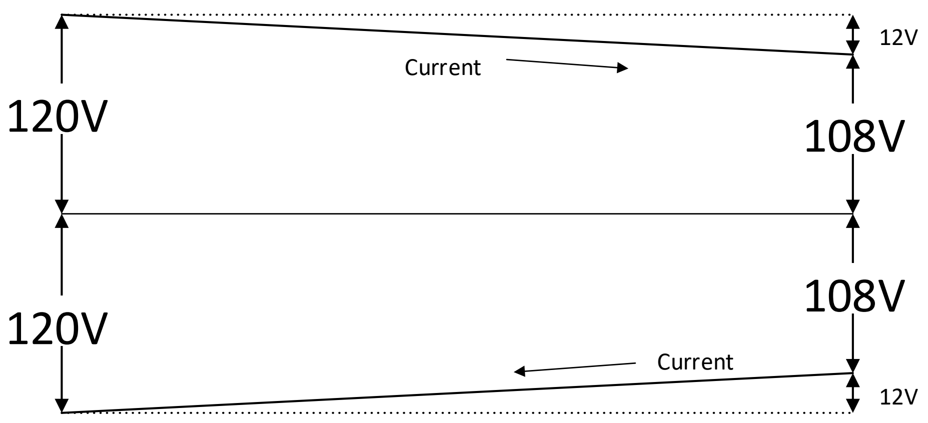
Homework 5 clarifications

- Problem 5 – flicker/voltage drop – impact on 120V loads



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A note on SARFI-X calculation (useful for HW6)

- Per IEEE Std 1564-2014, section 6.2.1:

  "The SARFI-X indices are meant to assess short-duration rms variation events only, meaning that the only events included in its computation are those with durations less than the minimum duration of a sustained interruption as defined by IEEE Std 1159, which is 1 min."

- Use 1-minute as the minimum "sustained" interruption duration (for SAIFI) and the maximum "short-duration" rms variation duration (for SARFI-X)

Homework 6 discussion

Some clarifications and suggestions…

Definitions

- Distributed Energy Resources (DER)
  - Sources of electric power including generators AND energy storage systems, that are not directly connected to a bulk power transmission system
- Distributed Generation (DG)
  - A subset of DER
  - Electric generators connected to a distribution system through a PoC
- EPS – Electric Power System
- Area EPS – An EPS that serves Local EPSs.
- PoC – Point of DER connection to the local EPS – where connection standards apply.

(See IEEE 1547 for more)

IEEE 1547 – 2018

- 1547-2018: *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*
  - 1547.1 IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.
  - 1547.2 IEEE Application Guide for IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.
  - 1547.3 IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems.
  - 1547.4 IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.
  - 1547.6 IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks.
  - 1547.7 IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection.

What is it? – Common technologies

- Reciprocating Engine Genset
  - Uses gas engine with synchronous or induction generator
  - Used to produce electrical energy and heat from methane produced in landfills and anaerobic digesters
  - Waste heat can be used for onsite space and water heating, and for heating the digester
  - Methane containing Hydrogen Sulfide is corrosive to metals commonly used in these engines, shortening their life and increasing maintenance requirements.

Common technologies

- Gas turbines
  - Used as “peaking” generators
  - Popular where heat is needed
    - Generating both electrical energy and heat increases efficiency
  - Connected through synchronous generator to the distribution system
  - Microturbines
    - Generally 25kW to a few hundred kW
    - Replacement for reciprocating engine
    - Connected through an inverter to the distribution system

Common technologies

- Fuel cells
  - Expensive, but clean and quiet
    - Can be used indoors
    - Operation is similar to batteries – hydrogen (anode) combines with Oxygen (cathode) in an electrochemical reaction, producing water and electrical energy
  - Popular for remote locations with small, critical loads

Common technologies

- Wind turbines
  - Cost-competitive in some areas – other economic factors may help
  - Requires an inverter interface to power system
  - Generally requires remote locations and transmission lines
  - Non-dispatchable
  - Requires energy storage for stand-alone operation

Common technologies - Solar

- Solar-Thermal (less common)
  - Produces steam for electric generator

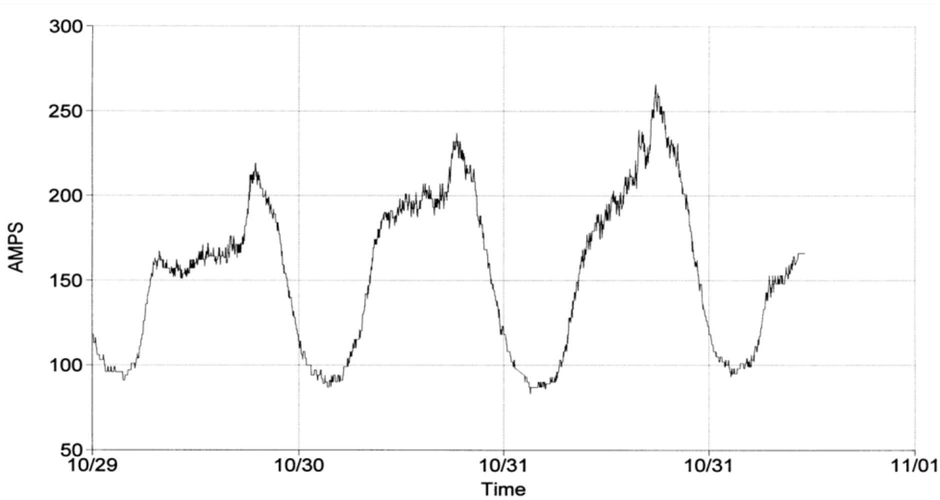
Public domain

- Photovoltaic (more common)
  - More economical with time
  - Requires inverter interface
  - Requires energy storage for stand-alone operation
  - Non-dispatchable

Energy storage

- Storage offers a way to “bank” generation for emergencies or flatten the daily load profile
- Allows generators to run at maximum efficiency
- Similar to hybrid vehicles, but for the power system
- May reduce generation and transmission requirements

Typical daily load profile



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Energy storage technologies

- Batteries
- Compressed Air
- Pumped hydro
- Flywheels
- Capacitors
- Heated fluids
- Superconducting Magnetic Energy Storage (SMES)
- Saved fuels*

Storage technologies (except for Saved Fuels), are Distributed Energy Resources (DER) that are not Distributed Generators (DG) because they first use electrical energy to "charge," then later return most of that energy to the system.

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The DG / DER / distribution system interface

- Synchronous machine
  - May support "islands"
  - May interfere with protection systems
  - High source impedance changes system response when operating "off grid"
    - Reduced fault current
    - Increased harmonic voltage distortion
    - Increased severity of voltage sags

The DG / DER / distribution system interface

- Induction machine
  - Reduced islanding risk
  - Simpler synchronizing with the power system
  - Often requires capacitors
    - Capacitors may create resonance problems
    - May self-excite if islanded
    - May feed faults and interfere with protection systems

The DG / DER / distribution system interface

- Electronic inverter
  - Harmonics in newer PWM inverters is less of a concern than in older inverters
    - IEEE 519, 1547, and 2800 describe the limits

Table 26 from IEEE 1547-2018.

Individual odd harmonic order *h*	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h < 50$[109]	Total rated current distortion (TRD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I_{rated} = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

    - See IEEE 1547 Table 27, and IEEE 2800 Tables 17 and 18 for additional limits.

RPA – reference point of applicability – where the standards apply

The DG / DER / distribution system interface

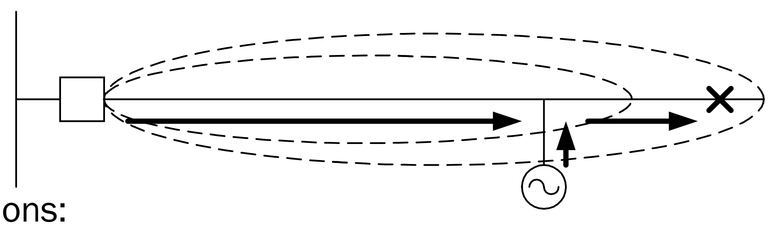
- Electronic inverter – continued
  - Islanding is less of an issue
    - Inverter can quickly detect and separate from the system
  - May feed faults - briefly
    - Electronic controls can quickly detect abnormal conditions and disconnect the inverter from the system

Operating challenges

- Distribution systems are normally designed for radial, single-source operation
  - Remember recloser/fuse coordination
- DER may change the direction of power flow, and impact the response of the distribution system to faults
  - May require reclosers to be able to determine power flow direction
- Reverse power flow may impact the operation of voltage regulators
  - May require more sophisticated control schemes
  - May still impact volage regulation
- Variability – DG/DER is usually not a constant source
  - Operating conditions may change quickly and dramatically
    - Clouds, wind gusts

Operating challenges: Interference with relaying

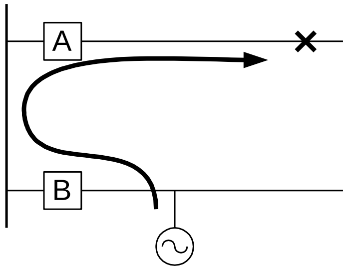
- Reduction of "reach"



  - Solutions:
    - Adjust relay to increase reach
    - Add recloser to add another protection zone
    - Minimize DG contribution to ground faults

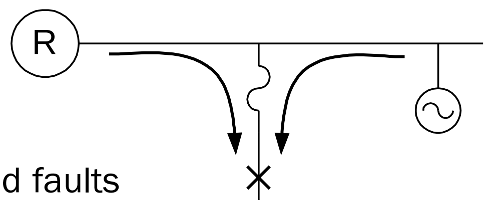
Operating challenges: Interference with relaying

- "Sympathetic tripping"
  - Issues
    - May make finding faults difficult
    - Increases area affected by fault
  - Solutions
    - Directional relays
    - Changes to circuit breaker settings



Operating challenges: Interference with relaying

- Defeat of fuse saving
  - Fuse coordination with recloser fast-trip varies with DG operation
- Solutions
  - Larger fuses
  - Do without fuse saving
  - Minimize DG contribution to ground faults



Operating challenges: System stability

"Traditional" power systems

- Large rotating generators at relatively few generating stations
  - High inertia
  - High short-circuit duty
  - High stability

Systems with high DG/DER penetration

- Many smaller, dispersed sources
  - Inverter-based; low inertia
  - Low short-circuit duty
  - Stability impact – difficult to predict

As the penetration of DG/DER continues to increase, having the DG/DER trip off during system disturbances may be undesirable. "Smart" inverters may help.

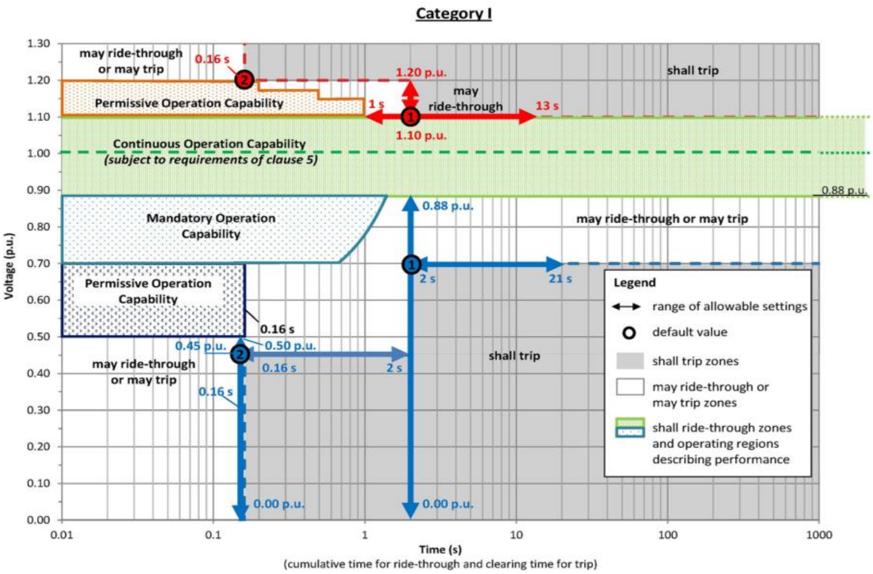
Operating challenges: Reclosing

- Reclosing on rotating generators can damage them
- DER can feed a fault and prevent it from clearing
- Solution – coordinate voltage and clearing time trip settings

Table 11—DER response (shall trip) to abnormal voltages for DER of abnormal operating performance Category I (see Figure H.7)

Shall trip—Category I				
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
OV2	1.20	0.16	fixed at 1.20	fixed at 0.16
OV1	1.10	2.0	1.10–1.20	1.0–13.0
UV1	0.70	2.0	0.0–0.88	2.0–21.0
UV2	0.45	0.16	0.0–0.50	0.16–2.0

Operating challenges – Voltage (IEEE 1547 chapter 6)



DER interruption requirements per IEEE-1547

(voltage at the PoC):

Next time…

- More on distributed resources
  - Power Quality issues with distributed resources
  - Islanding
  - Transformer configurations for interconnection