Distribution Systems 101

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Slide credits: Sascha von Meier, UCB
Definitions and Introductions
“Smart grid” generally refers to a class of technology … to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation.

These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries.

They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses.

They offer many benefits to utilities and consumers – mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users’ homes and offices.”

http://energy.gov/oe/technology-development/smart-grid
What a “Smart Grid” should provide, according to the U.S. Department of Energy

- attack resistance
- self-healing
- consumer motivation
- power quality
- generation and storage accommodation
- enabling markets
- asset optimization
Beware the buzz words

popularity of the term “smart grid”

understanding what a “smart grid” is
1 picture > $10^3$ words?
Question: What don’t these diagrams tell you?
A “smart grid” (according to von meier & stewart)

► ...affords the capability to observe and control components at finer resolution in time and space, while supporting large-scale objectives

► ...introduces opportunities for new and different actors to participate in observing and controlling various grid components

► ...allows for better optimization, if it works as intended

► ...also introduces new options and ambiguities about who can and should do what
Components and Functionality
How distribution systems are different than transmission systems


Standard transmission system design:  
**Network**

Standard distribution system design:  
**Radial** with one-way flow
115kV Transmission network

Distribution substations

How distribution systems are different than transmission systems

► Some distribution feeder attributes:

• underground vs. overhead
• topology (e.g. radial, loop, network), sectionalizing options
• circuit length, load density
• load characteristics (time profile, load factor, predictability)
• anticipated load growth, EV, DG
• sensitivity of loads to power quality
• phase imbalance
• extent of SCADA capabilities in place
• type of voltage regulation equipment in place
• type of protective equipment and protection scheme used
Less help from statistics → Irregularities play a greater role

- load (real power)
- power factor (reactive power)
- voltage drop
- phase imbalance
- generation

Source: Richard Brown, IEEE 2007
How distribution systems are different than transmission systems

External influences are always nearby:
- weather
- trees
- animals
- vehicles
- people
- ...

Note: 80-90% of customer outages originate in the distribution system
How distribution systems are different than transmission systems

► Monitoring and control technology has not historically been cost-effective to install, in many cases
► SCADA* typically available at substation level,
► but not on 100% of distribution circuits
► Many distribution circuits are without sensing beyond substation
► → Operators usually can’t see what’s going on

* Supervisory Control and Data Acquisition
Eyes & ears in the field
Substations
Important Equipment

- Transformers
- Conductors
- Protective devices
- Switches
- Voltage control devices
- Sensors and meters
Substation Transformers
Substation Transformers

- Substation transformers can perform various functions:
  - Step voltage up from generation to transmission levels
  - Convert between voltages between transmission lines
  - Step voltage down for use at the distribution level

- Power ratings can be from several MVA at the distribution level to greater than 1,000 MVA at the transmission level.

- These transformers are generally very efficient, greater than 98%.

- Even with high efficiencies, thermal losses must be addressed
  - Passive cooling
  - Passive cooling with a radiator
  - Forced air cooling with a radiator
  - Spray cooling with a radiator
  - Circulated oil cooling with a radiator
Service Transformers
Overhead Lines

Much more common than underground cables ($$)

Usually aluminum and steel, not copper ($$)

Usually bare conductors, not insulated

Faults will occur when the conductor comes into contact with the ground, vegetation, animals, or people...
Underground Cables

Underground cables may be used in a number of situations:

- In areas where there are numerous momentary faults, e.g. wind storms.
- In urban areas where overhead lines may not be practical or desirable.
- In communities where there is a desire to not have visible infrastructure.

Cables can be directly buried or laid into conduit or a vault.

Underground cables have some desirable characteristics but they can be up to ten times the cost of overhead lines.

When faults do occur, it can be difficult to locate and fix the fault. It may be necessary to dig the cable up to fix the fault.
Triplex Cables

- Triplex cables connect the service transformer to the end use customer.
- Utilities generally have guidelines for how long these cables can be...
- The voltage drop across these cables is often unknown
- Multiple customers can be serviced from a single service transformer via independent triplex cables.
Switchgear

Distinguish:

switches – safe to open under normal load current only

protective devices – safe to open under fault current
  • fuses
  • circuit breakers
  • reclosers
Switches

- The primary function of a switch is to provide electrical isolation.
- Switches are not protective devices, unlike breakers they cannot interrupt current.
- Switches at a substation can transfer load between substation transformers.
- At the distribution level switches are used to reconfigure a feeder.
- Switches can be used to transfer load from one feeder to another.
- Switches can also be used as part of a system repair strategy in order to isolate portions of the system while repairs are conducted.
- Switches may be remotely controllable (SCADA) or require manual operation.
Loop System

Primary Feeders
# 1    # 2

Each load can be served from either feeder

Normally Open (N.O.) Switch
Sectionalizing a Loop System: Before

Feeder 1

N.C.

Loads

N.C.

N.C.

Feeder 2

N.C.

N.C.

N.O.

N.C.

N.C.

N.C.

N.O.

N.C.

N.C.

N.C.

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N.C.

N.O.
Sectionalizing a Loop System: After

N.C. = Normally Closed Switch
N.O. = Normally Open Switch

Fault
Isolated section
Primary Selective System

Load can switch to either feeder without affecting other loads
Spot networks are much more expensive and used only in high-stakes settings such as downtown business districts of big cities.
Present State of Utilities

► Distribution Ops and Planning
Distribution Operator’s control room, 2003
newer DO control room at SDG&E
Existing & Emerging Technologies

► All to be covered in later sessions
► DER
► ADMS
► Data & analytics
► Automation
► Modeling
► Communications