Distribution Systems 101

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Distribution Systems and Planning Training
for New England Conference of Public Utility Commissioners, Sept. 27-29, 2017

Slide credits: Sascha von Meier, UCB

Definitions and Introductions

An official definition of a "Smart Grid" by the U.S. Department of Energy

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- "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

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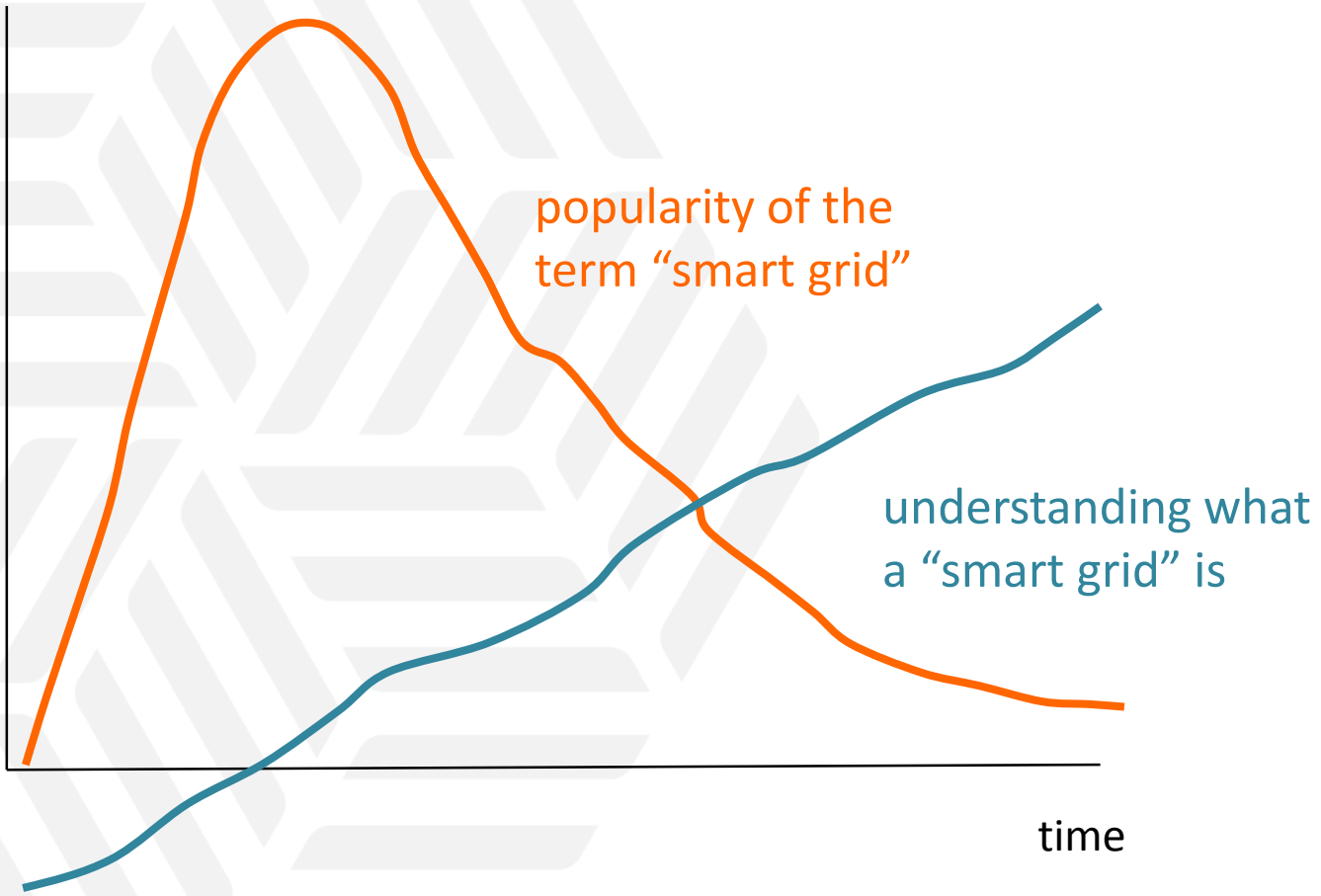
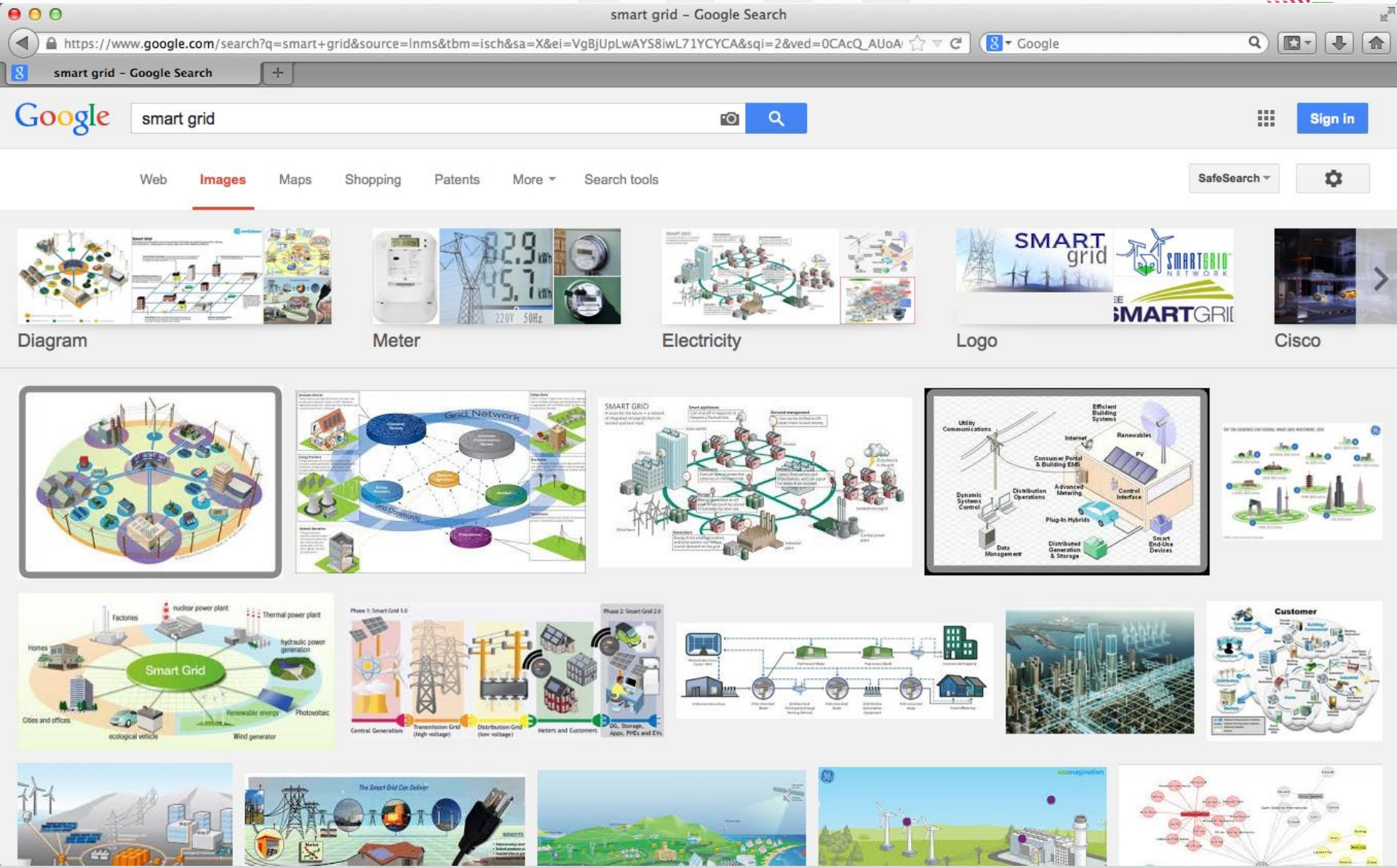
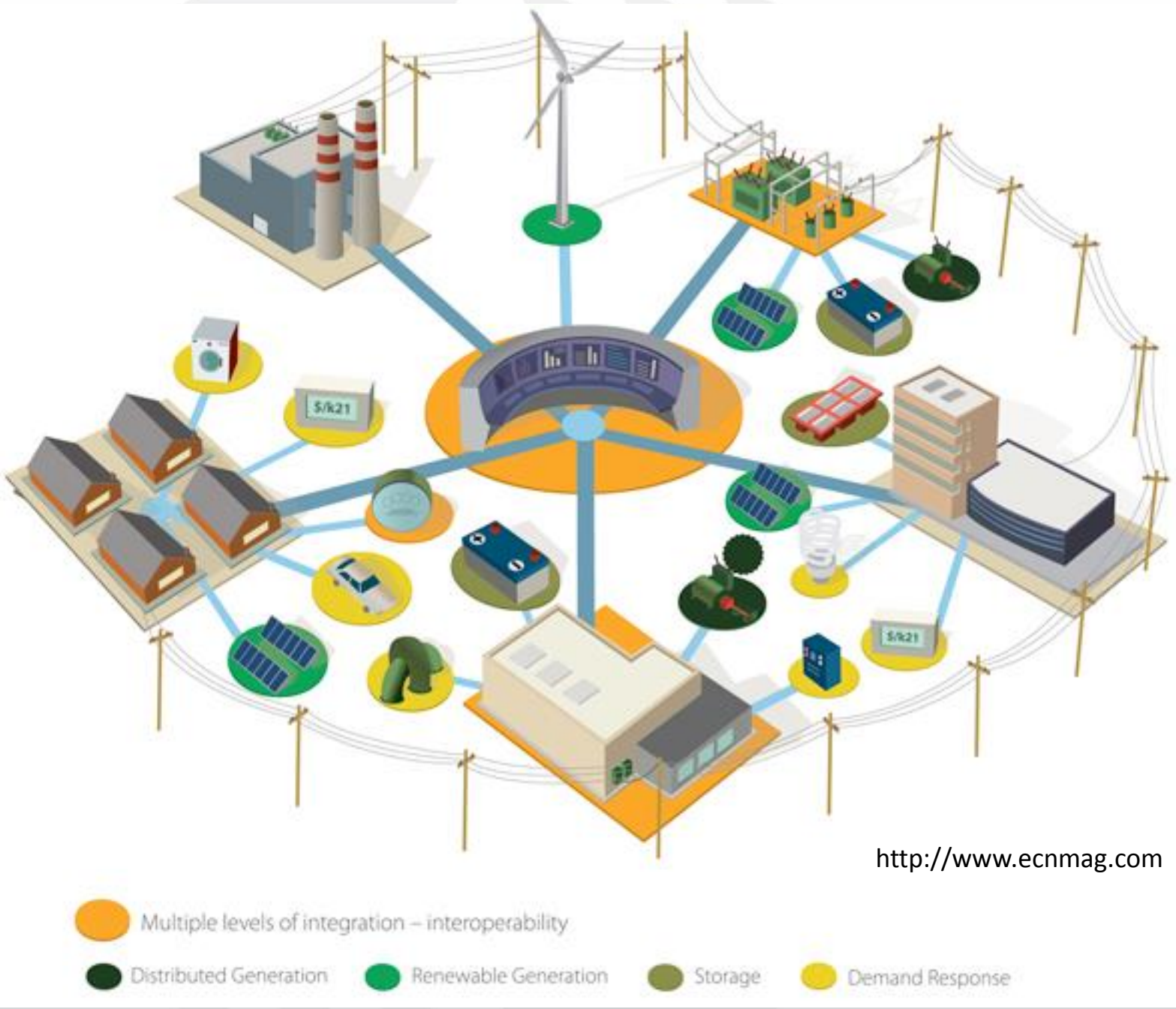
- attack resistance
- self-healing
- consumer motivation
- power quality
- generation and storage accommodation
- enabling markets
- asset optimization

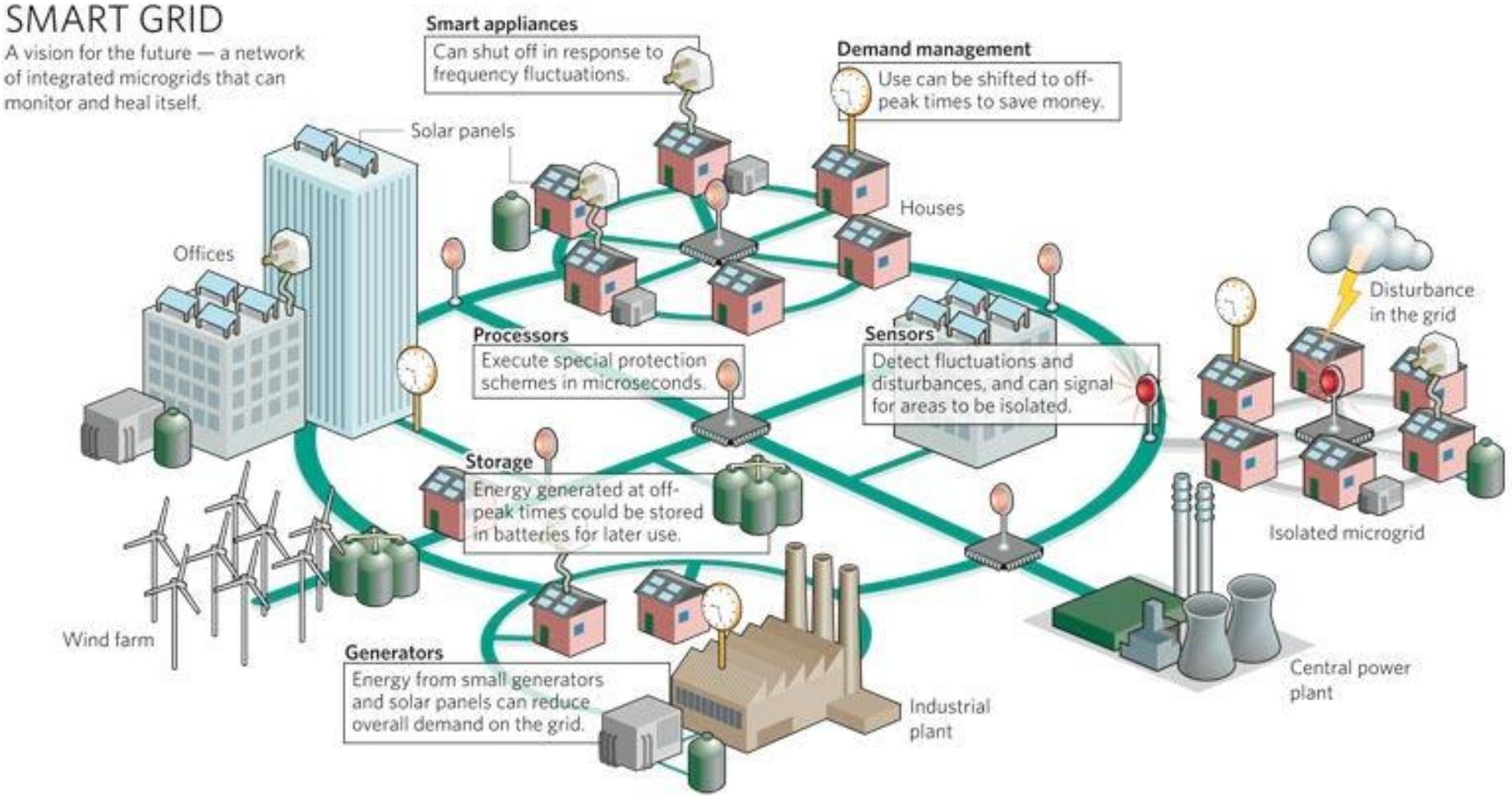
Beware the buzz words



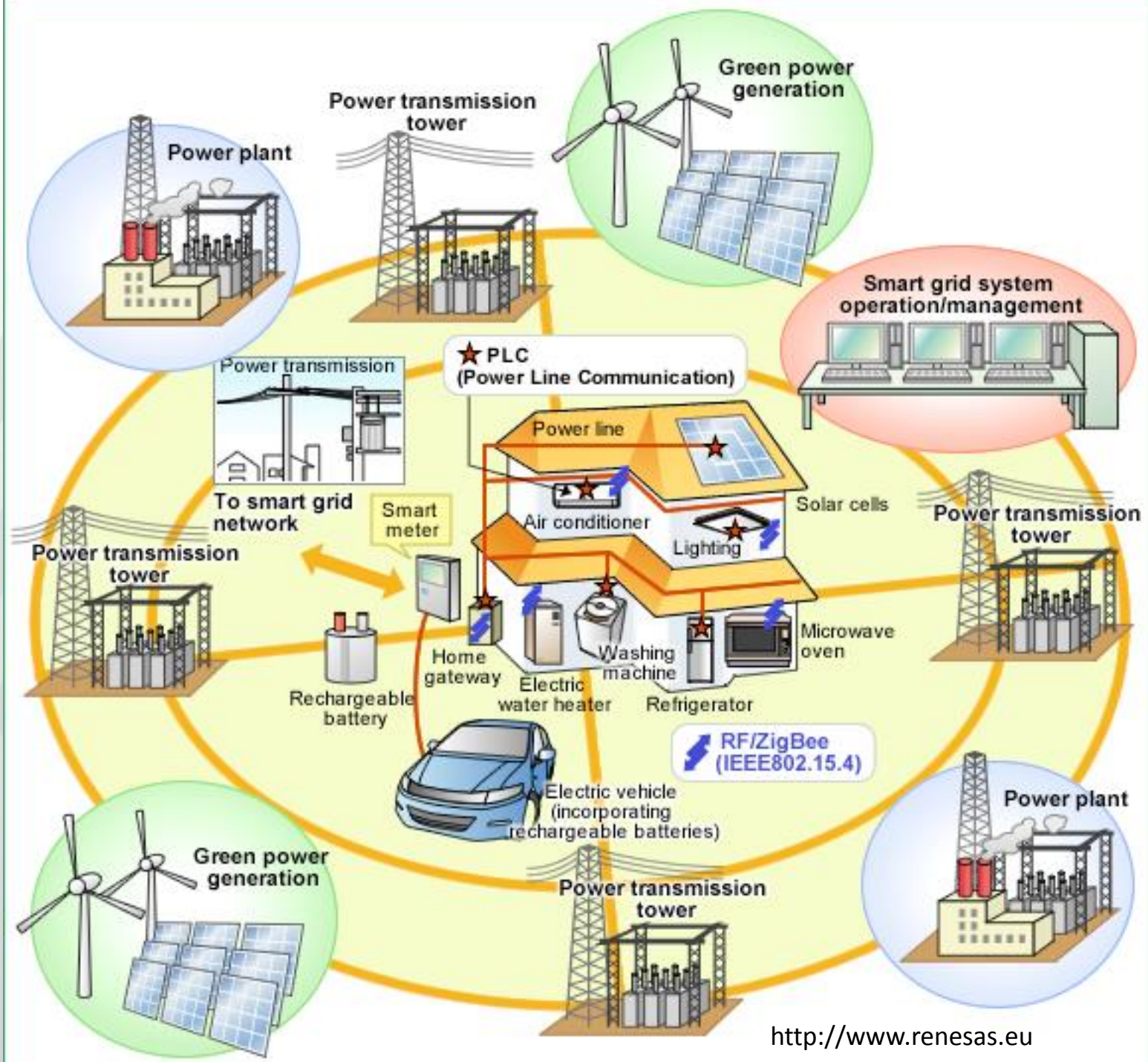
1 picture > 10^3 words?



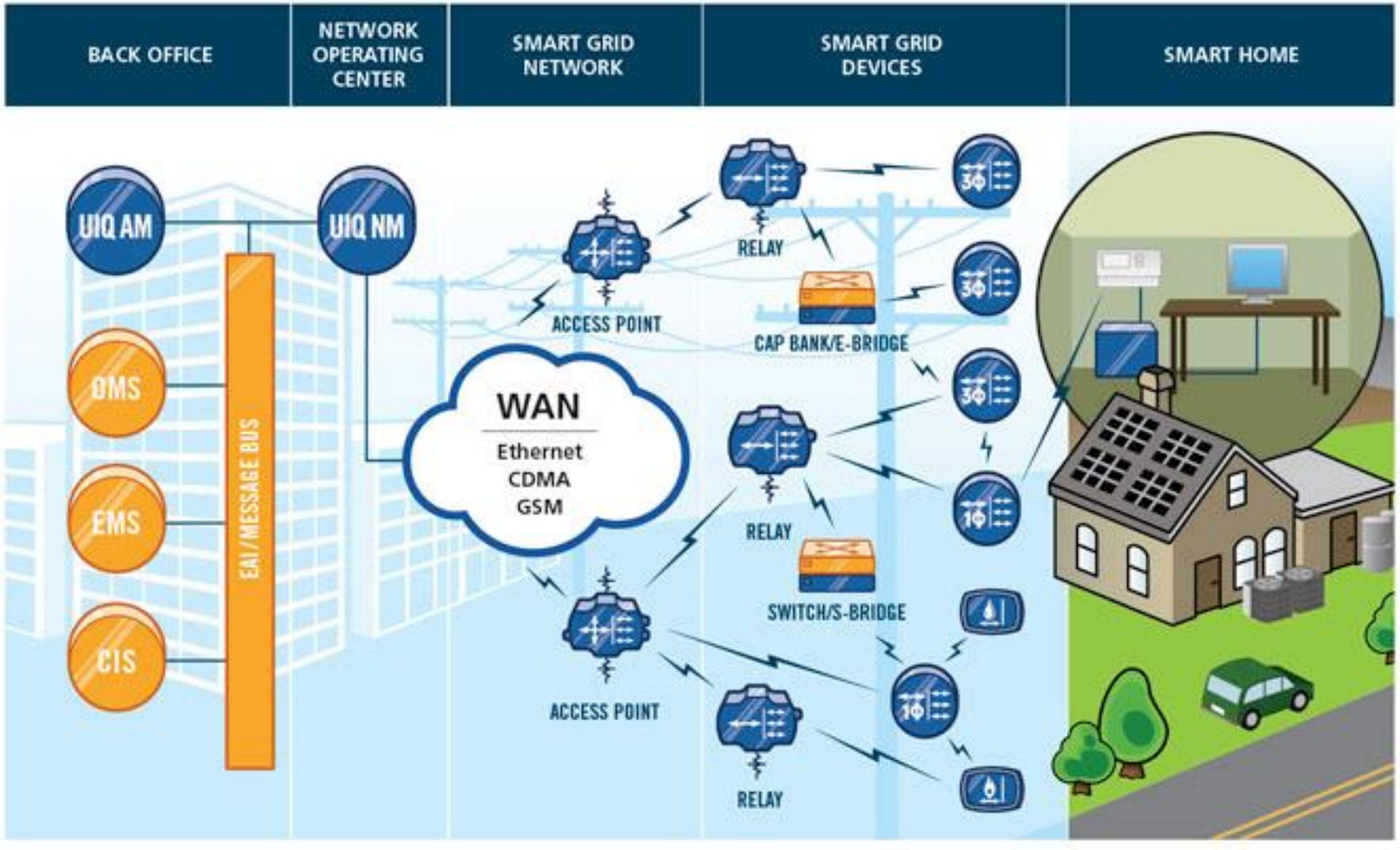

$/k21
$/k21
http://www.ecnmag.com
Multiple levels of integration – interoperability
Distributed Generation
Renewable Generation
Storage
Demand Response



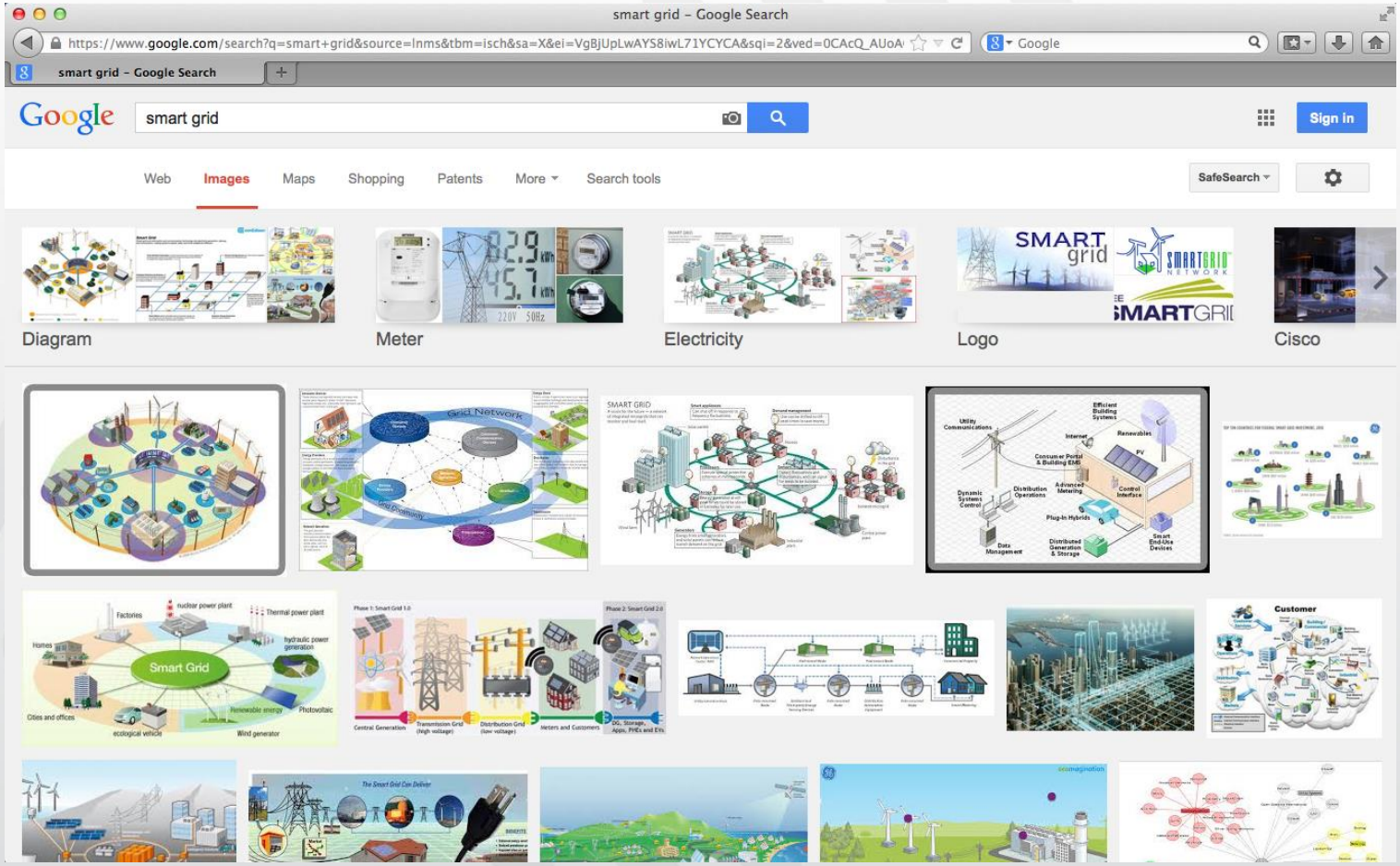
http://smartgridtech.wordpress.com



http://www.renesas.eu



spydergrid.com



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

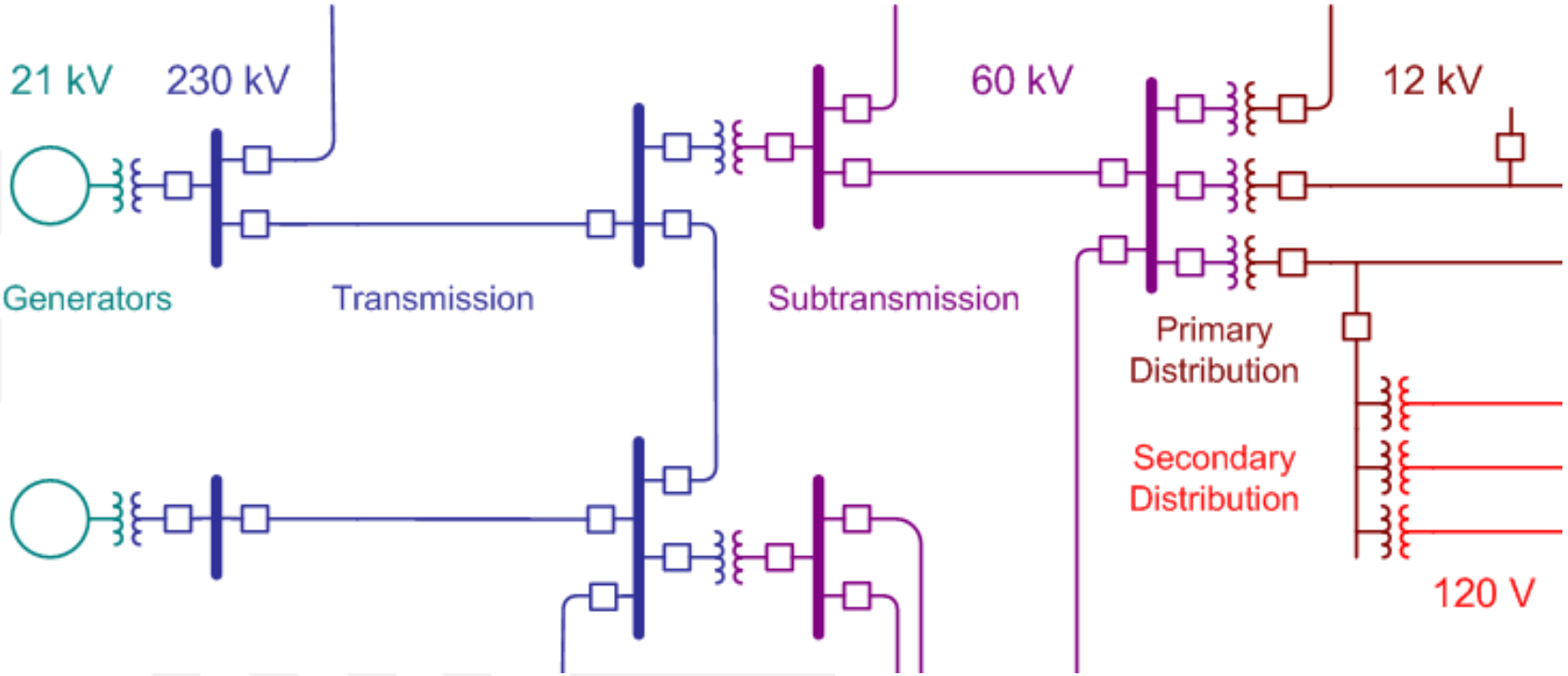
Components and Functionality

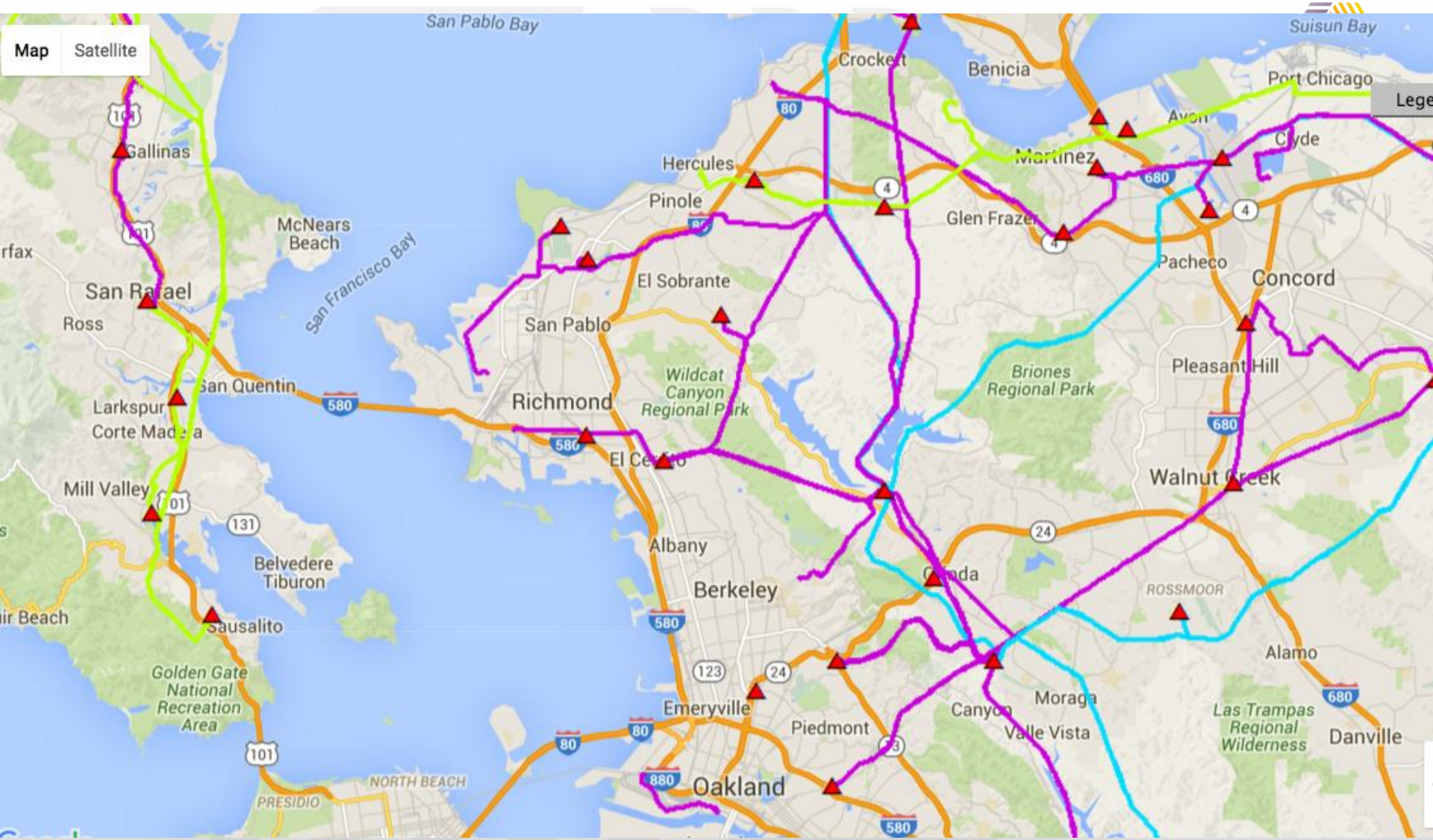
How distribution systems are different than transmission systems

1. Architecture 2. Diversity 3. Variation 4. Vulnerability 5. Opacity

Standard transmission system design:
Network

Standard distribution system design:
Radial with one-way flow

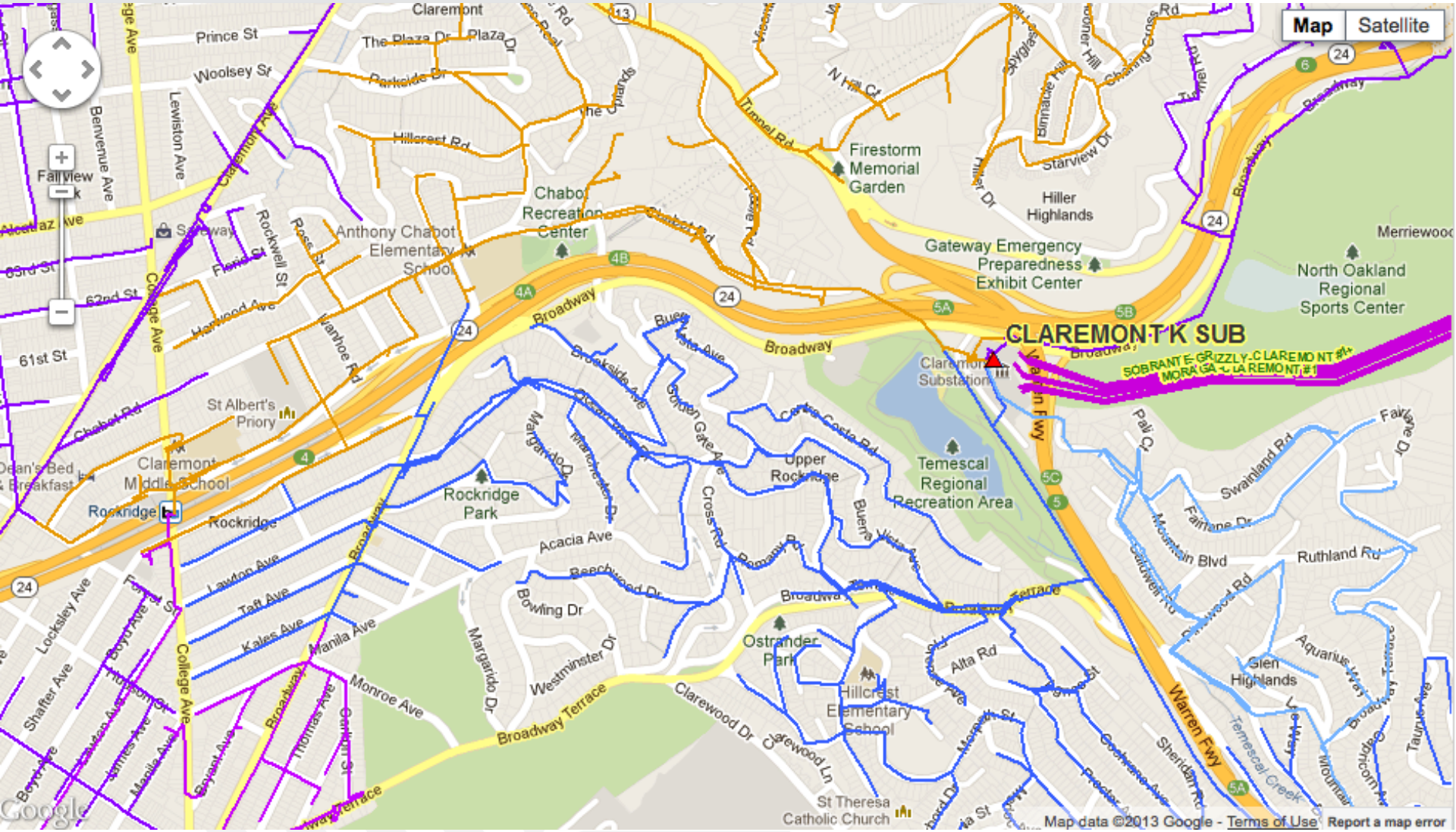




115kV Transmission network

Distribution substations

https://www.pge.com/b2b/energysupply/wholesaleelectricsuppliersolicitation/PVRFO/PVRAMMap/index.shtml


CLAREMONT K SUB
SOBRANTE-GRIZZLY-CLAREMONT #1
MORAGA-CLAREMONT #1
Claremont
Prince St
Woolsey St
Hillcrest Rd
Chabot Recreation Center
Anthony Chabot Elementary School
Firestorm Memorial Garden
Hiller Highlands
Gateway Emergency Preparedness Exhibit Center
North Oakland Regional Sports Center
Broadway
College Ave
Claremont Middle School
St Albert's Priory
Rockridge
Rockridge Park
Upper Rockridge
Temescal Regional Recreation Area
Claremont Substation
Warren Fwy
Ostrander Park
Hillcrest Elementary School
St Theresa Catholic Church
Glen Highlands
Ruthland Rd
Swainland Rd
Acacia Ave
Broadway Terrace
Clarewood Dr
Monroe Ave
Manila Ave
Taft Ave
Lawton Ave
Alta Rd
Westminster Dr
Bowling Dr
Map
Satellite
Map data ©2013 Google - Terms of Use
Report a map error

How distribution systems are different than transmission systems

1. Architecture 2. Diversity 3. Variation 4. Vulnerability 5. Opacity

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► **Some distribution feeder attributes:**

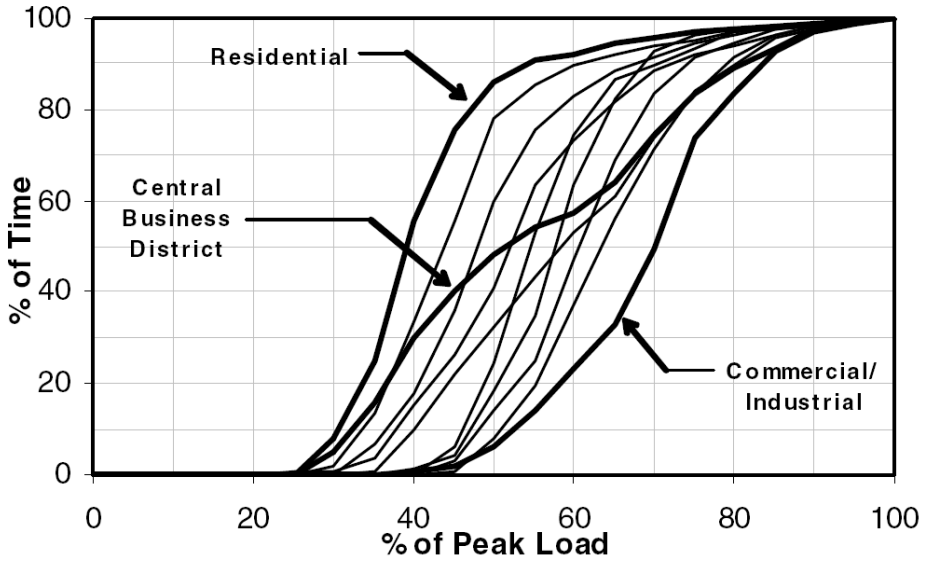
- underground vs. overhead
- topology (e.g. radial, loop, network), sectionalizing options
- circuit length, load density
- load characteristics (time profile, load factor, predictability)
- anticipated load growth, EV, DG
- sensitivity of loads to power quality
- phase imbalance
- extent of SCADA capabilities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

How distribution systems are different than transmission systems

1. Architecture 2. Diversity 3. Variation 4. Vulnerability 5. Opacity

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

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External influences are always nearby:

- weather
- trees
- animals
- vehicles
- people
- …?

Note: 80-90% of customer outages originate in the distribution system


CAUSEWAY

How distribution systems are different than transmission systems
1. Architecture 2. Diversity 3. Variation 4. Vulnerability 5. Opacity

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- 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*

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CONSORTIUM
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Eyes & ears in the field

Substations

Important Equipment

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

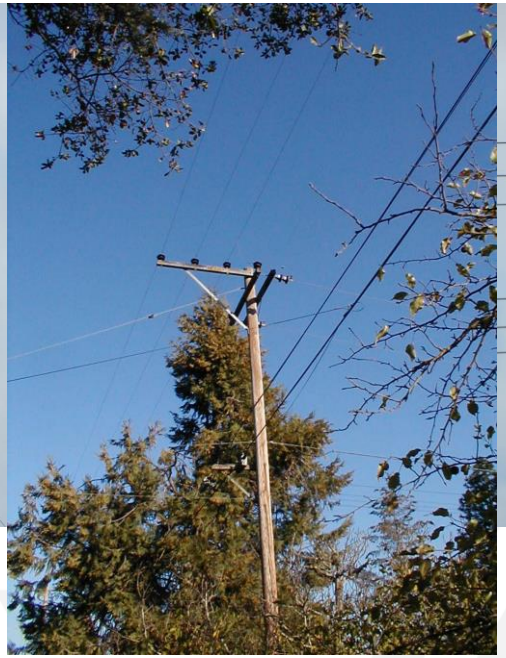
Substation Transformers

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

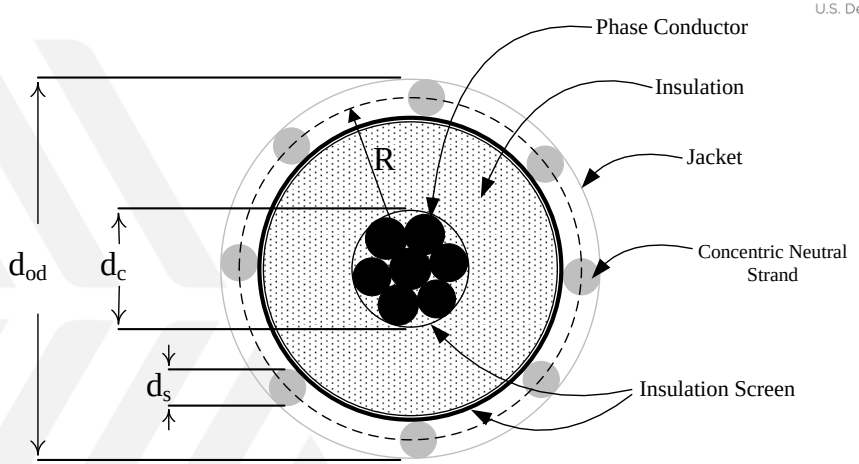
Service Transformers

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.

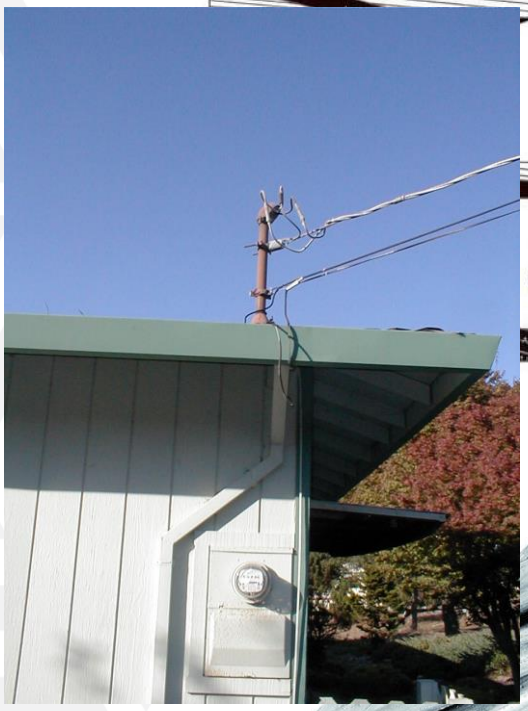
Cables can be directly buried or laid into conduit or a vault.

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.



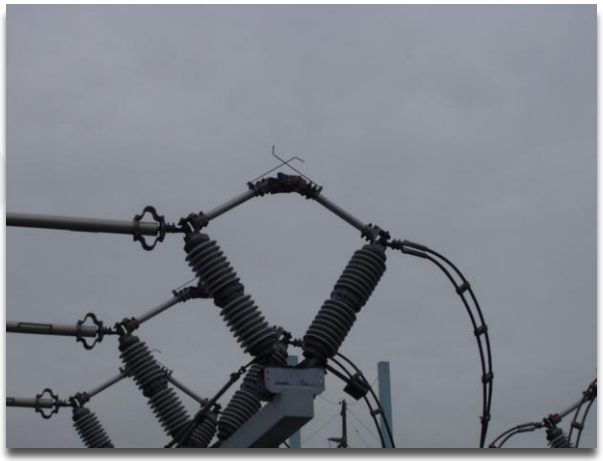
Switchgear

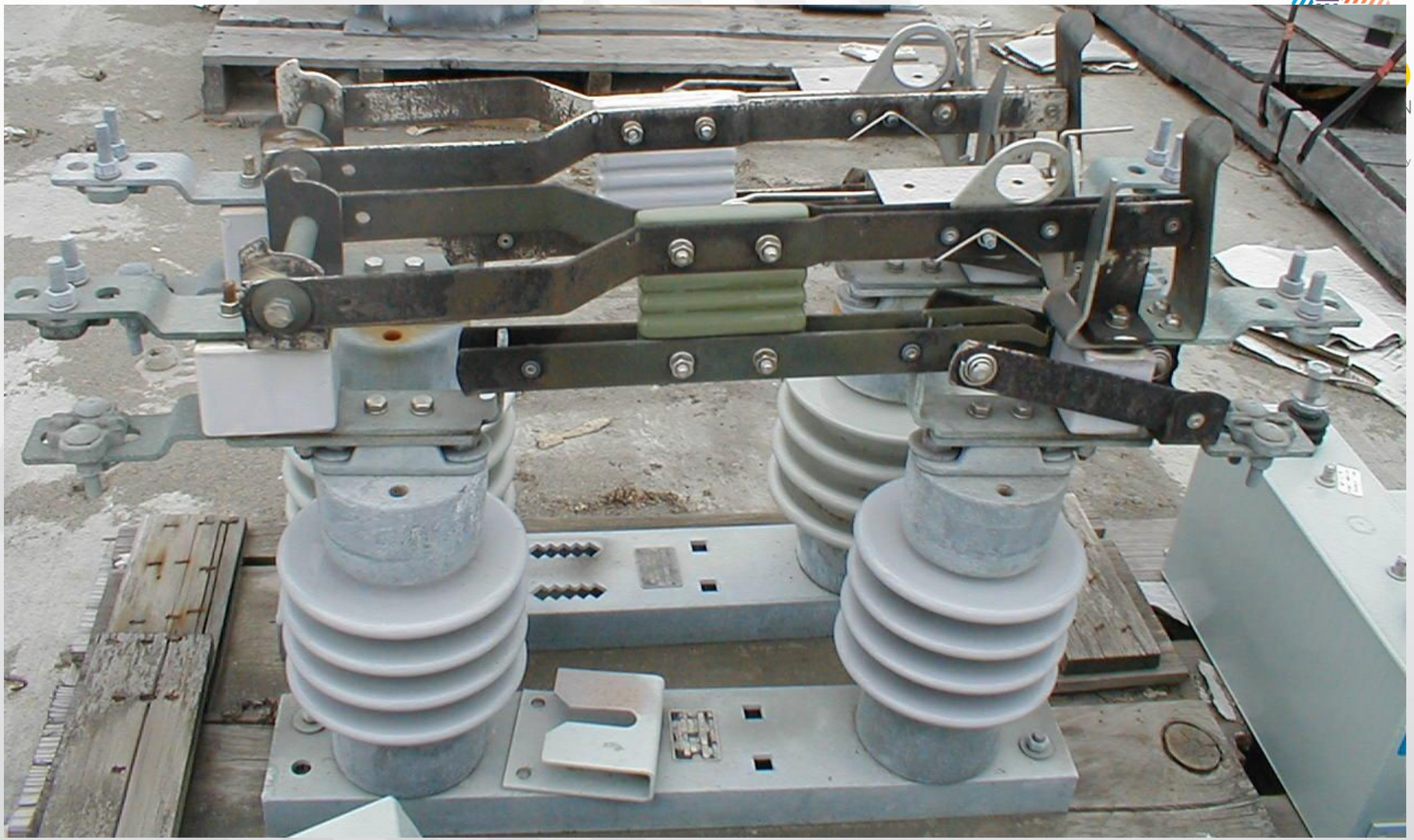
Distinguish:

switches – safe to open under normal load current only

protective devices – safe to open under fault current

- fuses
- circuit breakers
- reclosers





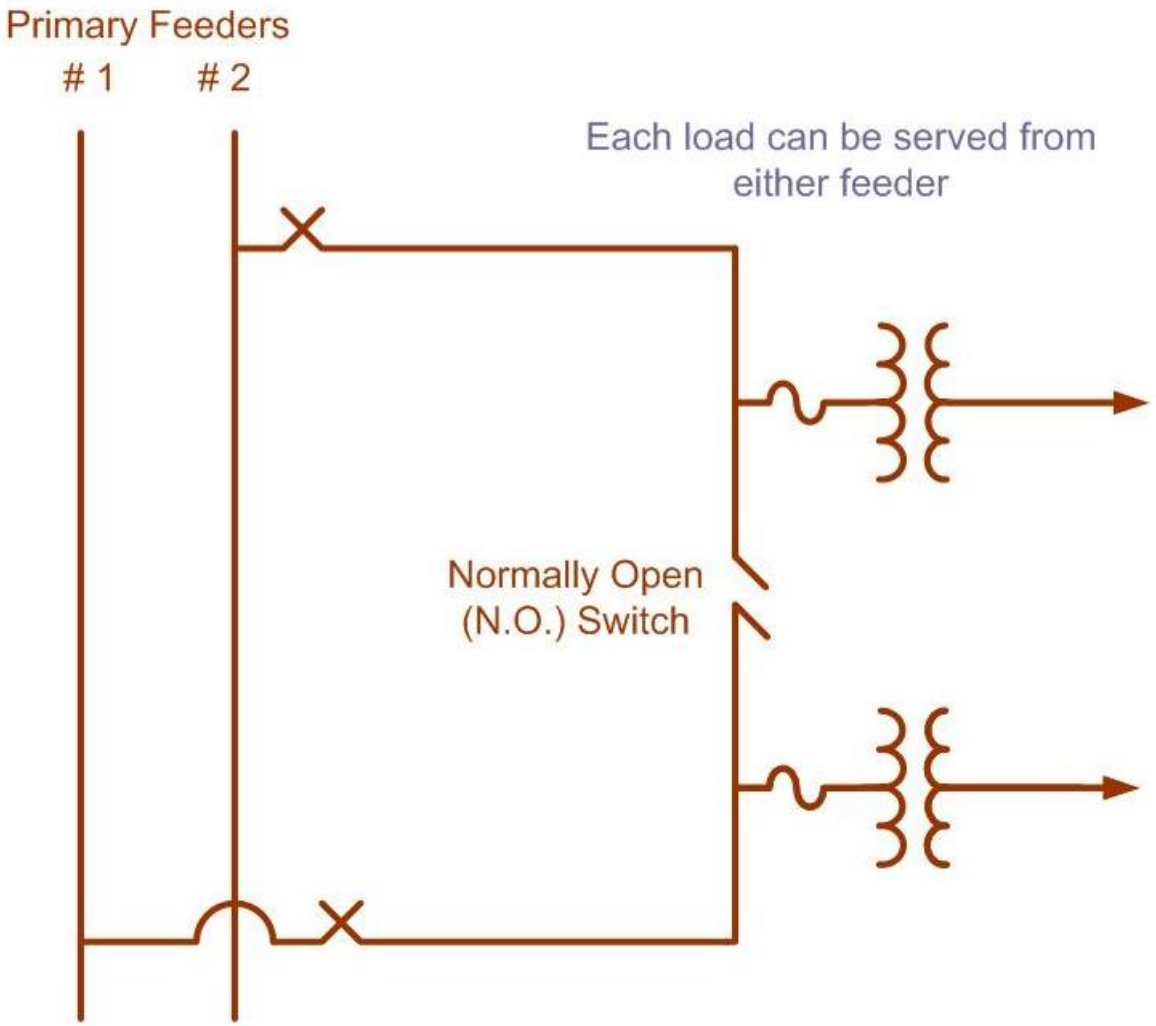
Knife Switch


FLORIDA HOSPITAL
Waterman

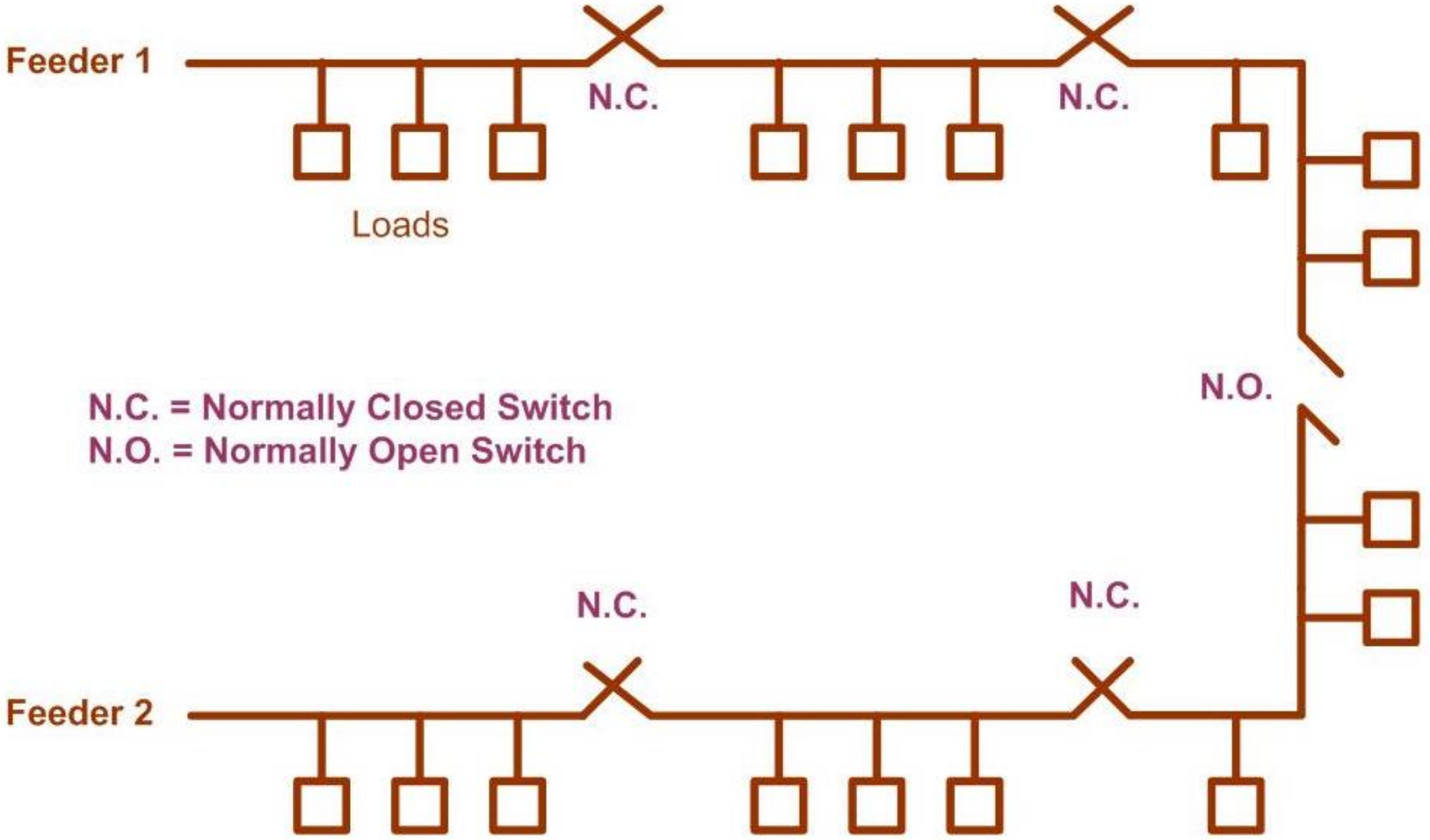
Switches

- 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.

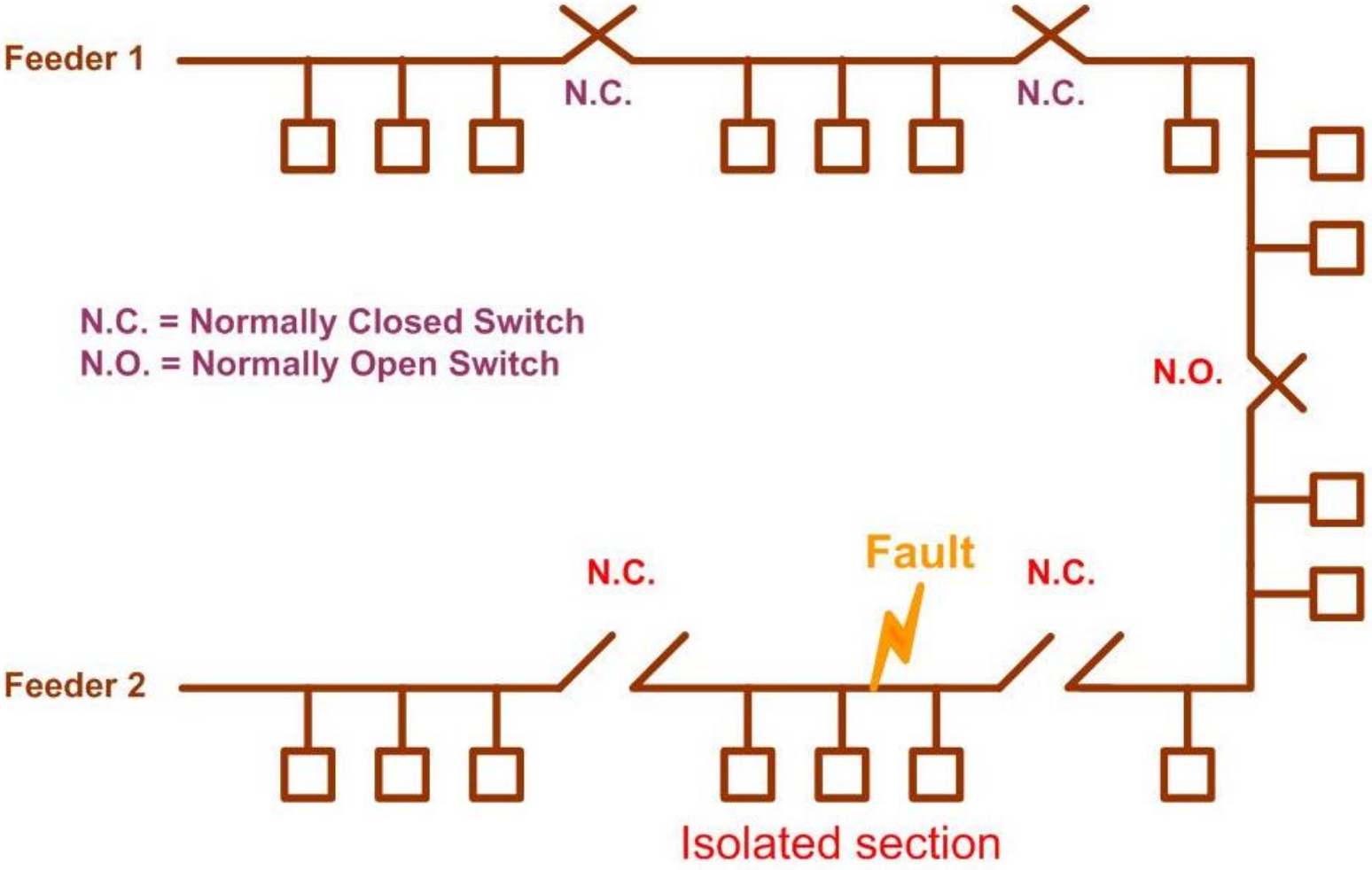
Loop System


Primary Feeders
1
2
Each load can be served from either feeder
Normally Open (N.O.) Switch

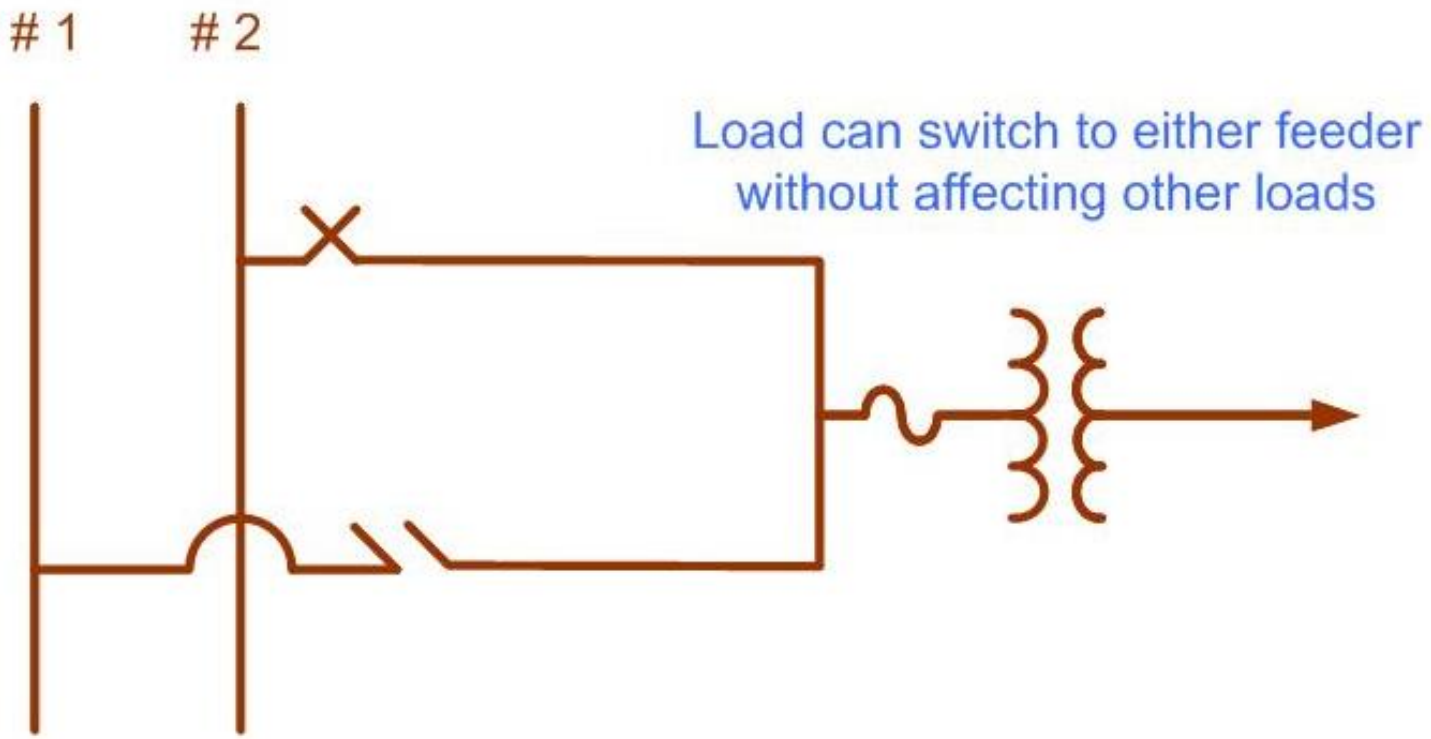
Sectionalizing a Loop System: Before

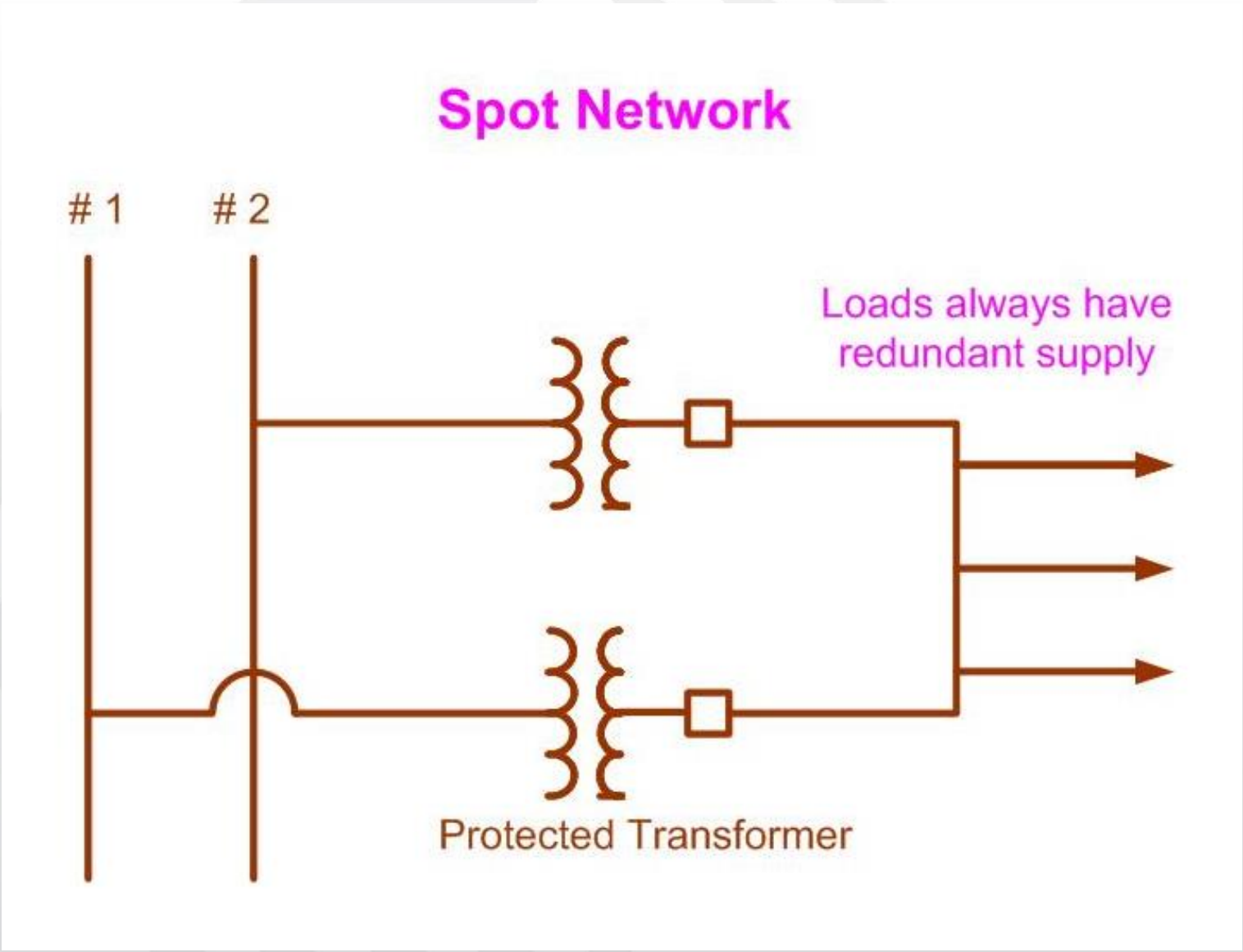


Sectionalizing a Loop System: After



Primary Selective System

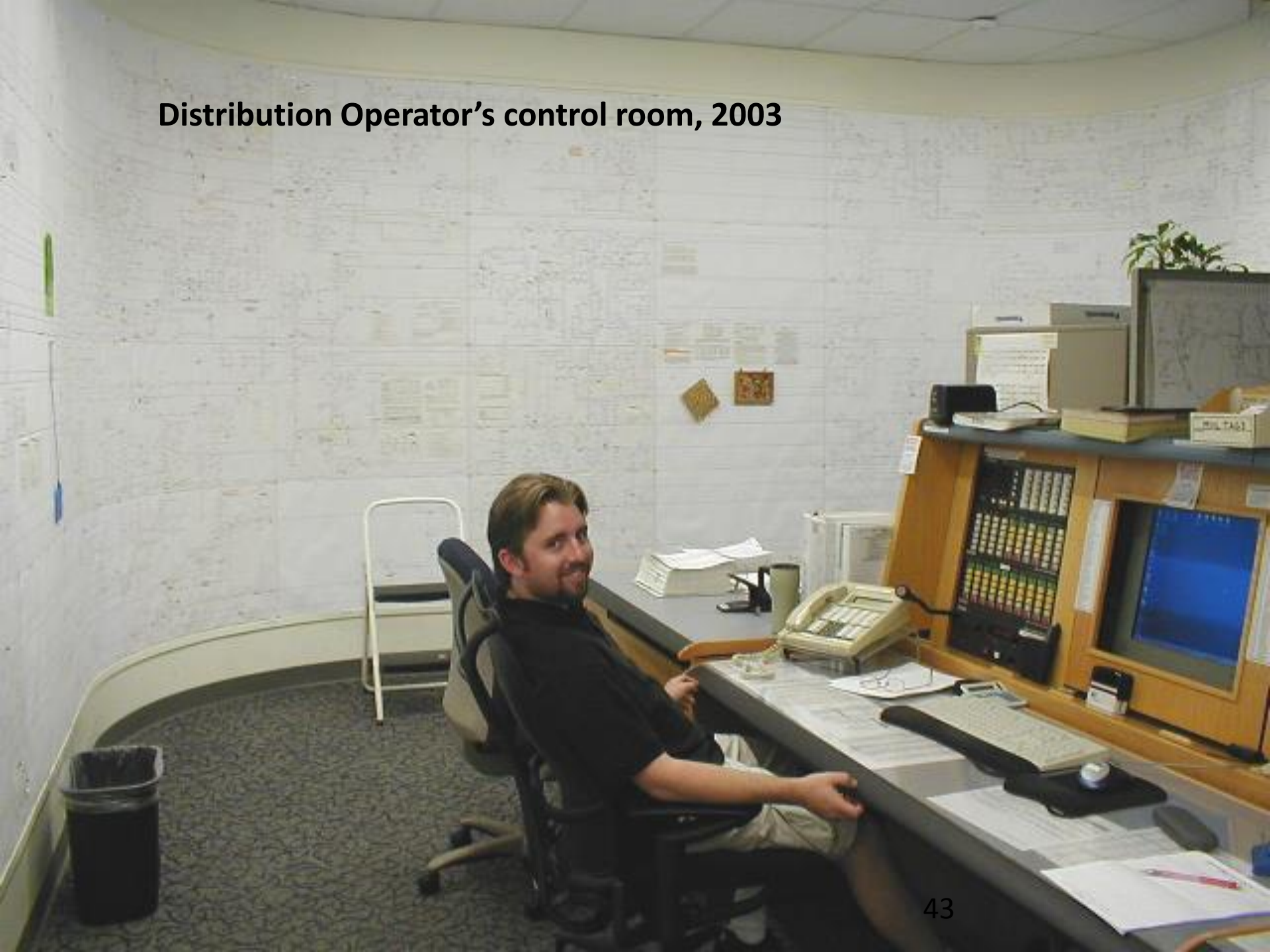


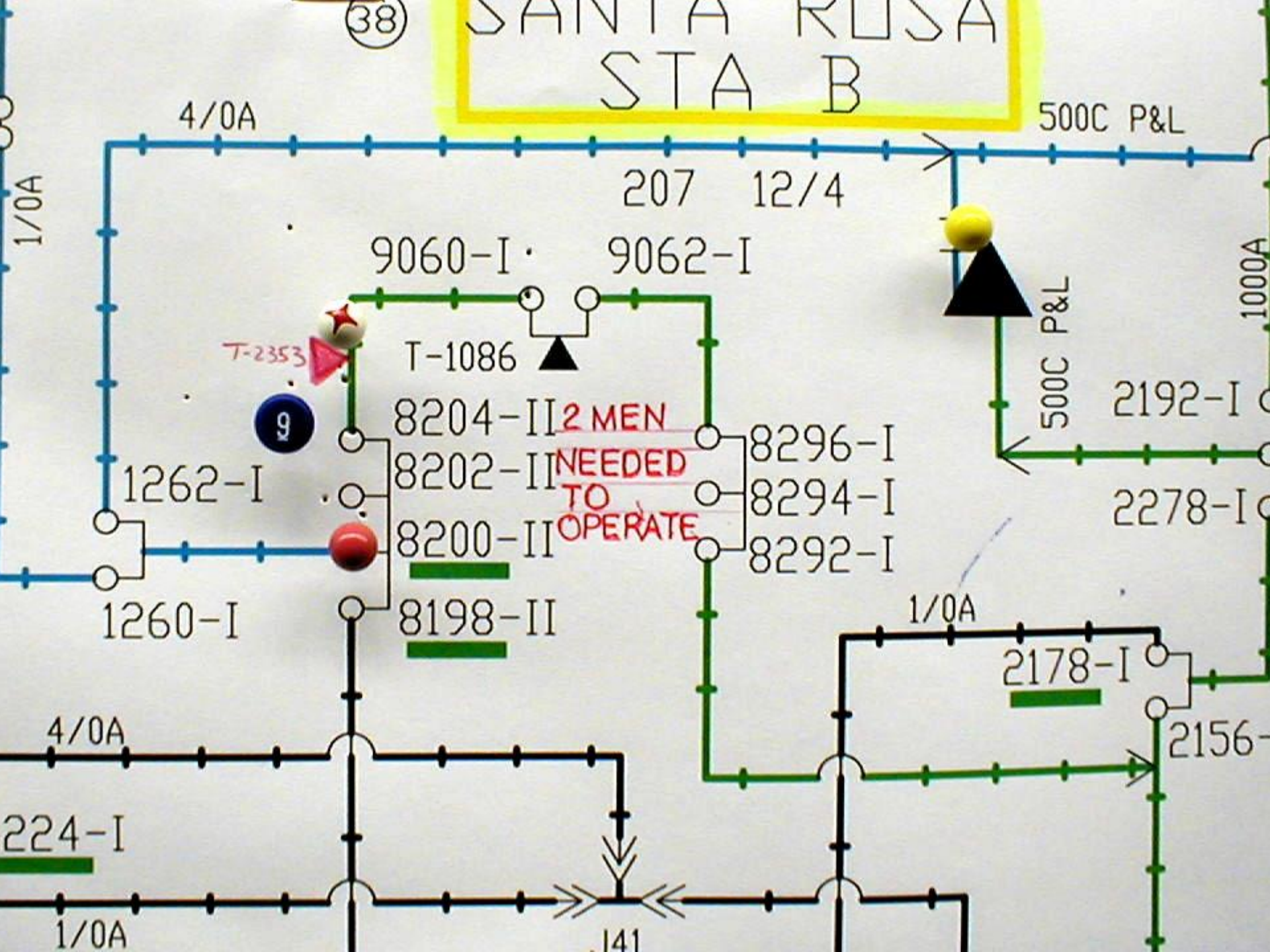


Spot networks are much more expensive and used only in high-stakes settings such as downtown business districts of big cities

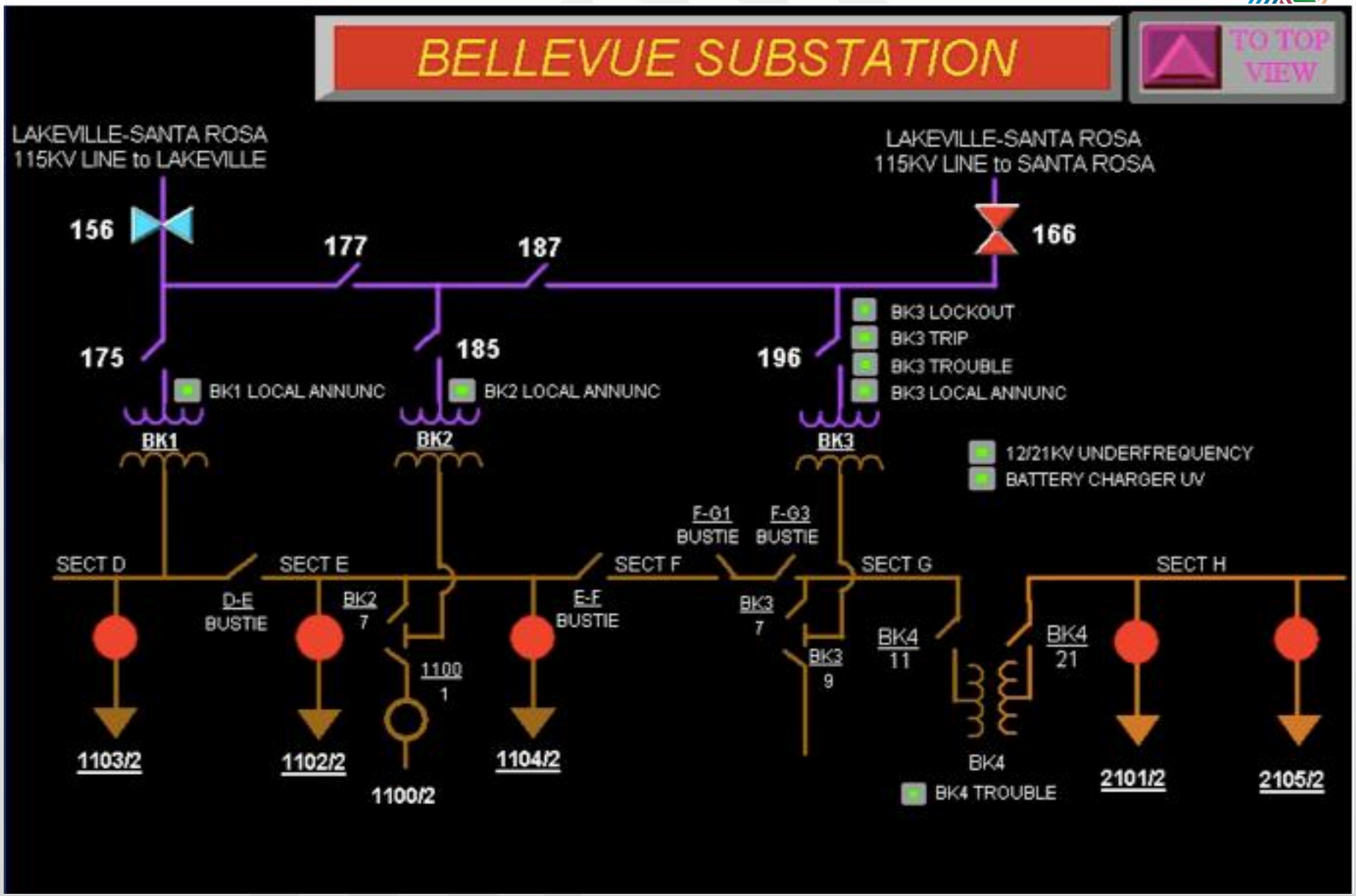
Present State of Utilities

- Distribution Ops and Planning


Distribution Operator’s control room, 2003


38
SANTA ROSA
STA B
4/0A
500C P&L
207
12/4
1/0A
9060-I
9062-I
1000A
T-2353
T-1086
500C P&L
9
8204-II
2 MEN
NEEDED
TO
OPERATE
8296-I
2192-I
1262-I
8202-II
8294-I
2278-I
8200-II
8292-I
1260-I
8198-II
1/0A
2178-I
4/0A
2156-
224-I
1/0A
141

newer DO control room at SDG&E


BELLEVUE SUBSTATION
TO TOP VIEW
LAKEVILLE-SANTA ROSA 115KV LINE to LAKEVILLE
LAKEVILLE-SANTA ROSA 115KV LINE to SANTA ROSA
156
166
177
187
175
185
196
BK1 LOCAL ANNUNC
BK2 LOCAL ANNUNC
BK3 LOCKOUT
BK3 TRIP
BK3 TROUBLE
BK3 LOCAL ANNUNC
12/21KV UNDERFREQUENCY
BATTERY CHARGER UV
BK1
BK2
BK3
F-G1 BUSTIE
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SECT H
D-E BUSTIE
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BK2 7
1100 1
BK3 7
BK3 9
BK4 11
BK4 21
BK4
BK4 TROUBLE
1103/2
1102/2
1100/2
1104/2
2101/2
2105/2

Existing & Emerging Technologies

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