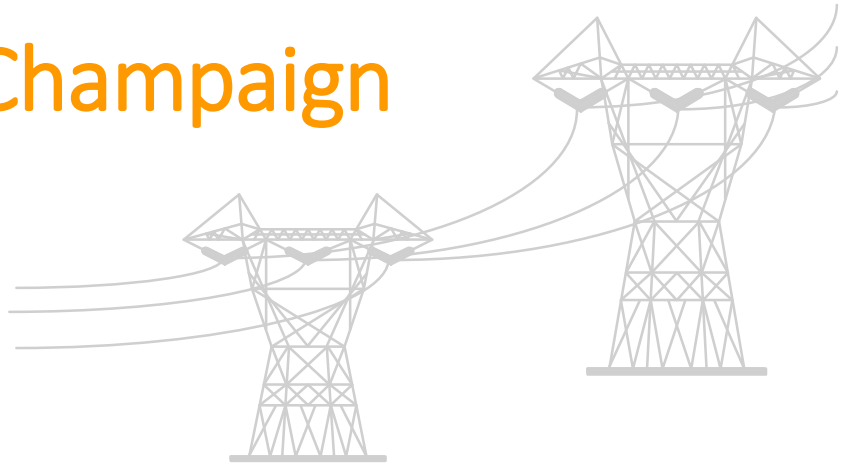
CREDC Electricity Primer

(also called “Big Wire Basics”)

Pete Sauer

University of Illinois at Urbana-Champaign



September 9, 2016

All-hands meeting – onboarding 2016

CREDC

CYBER RESILIENT ENERGY DELIVERY CONSORTIUM

ASU
Arizona State University

Dartmouth

Washington State University

Rutgers University

Oregon State University OSU

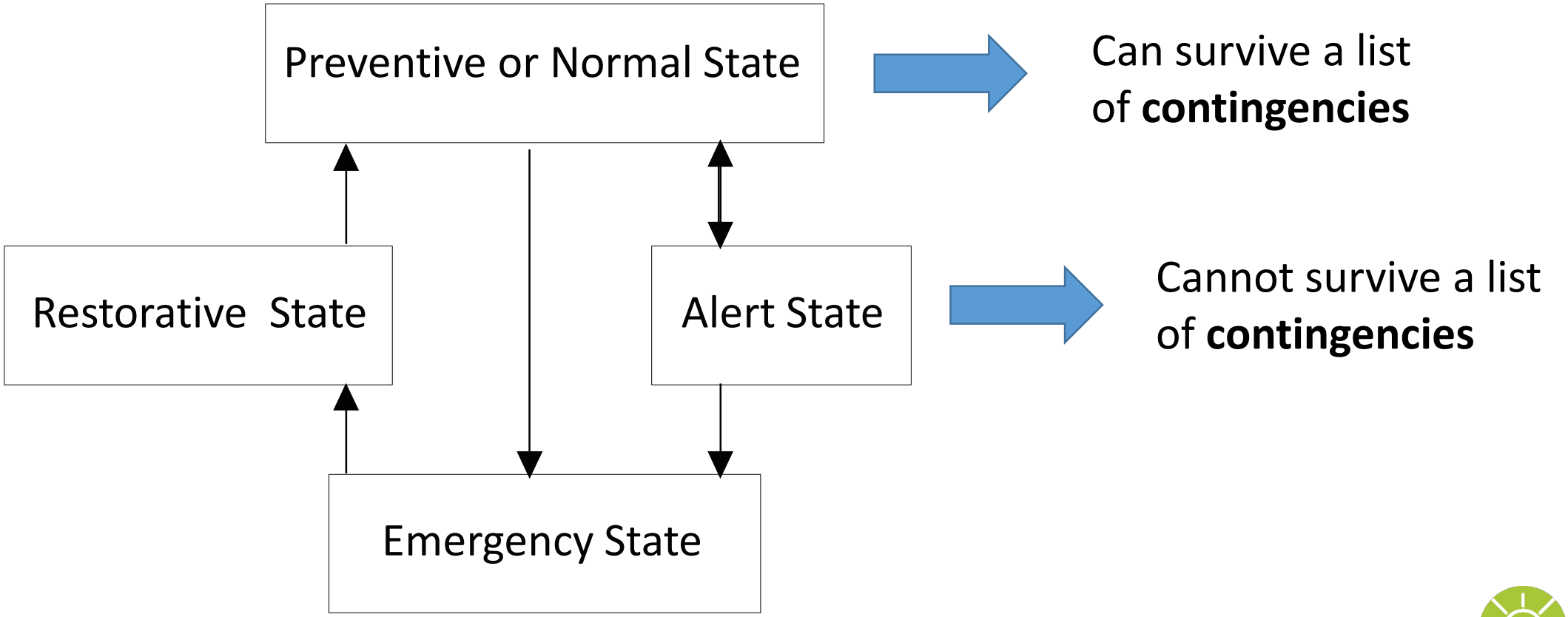
University of Houston

Tennessee State University

Pacific Northwest National Laboratory

Argonne National Laboratory

Traditional Power System Operating States



CREDC

Contingencies

Disturbances that might happen on a power system:

Loss of a line. Transformer, generating station, major load

Causes of contingencies

Storms (knock down lines)

Tree growth (touch bare wires)

Breakdown with age (insulation fails)

Squirrels and snakes (touch things)

Poor or careless maintenance (mistakes)

Sabotage (disgruntled employees or terrorists)

Other contingencies (cascading outages)

Hackers (cyber attacks)

What does it mean to survive a contingency?

- **Thermal:** all power flows are within acceptable range (rated)
- **Voltage:** all points are within acceptable range (rated plus or minus 5%)
- **Stability:** all generators remain in synchronism (at 60 HZ speed)

There are mathematical models and equations (metrics) for all of these.

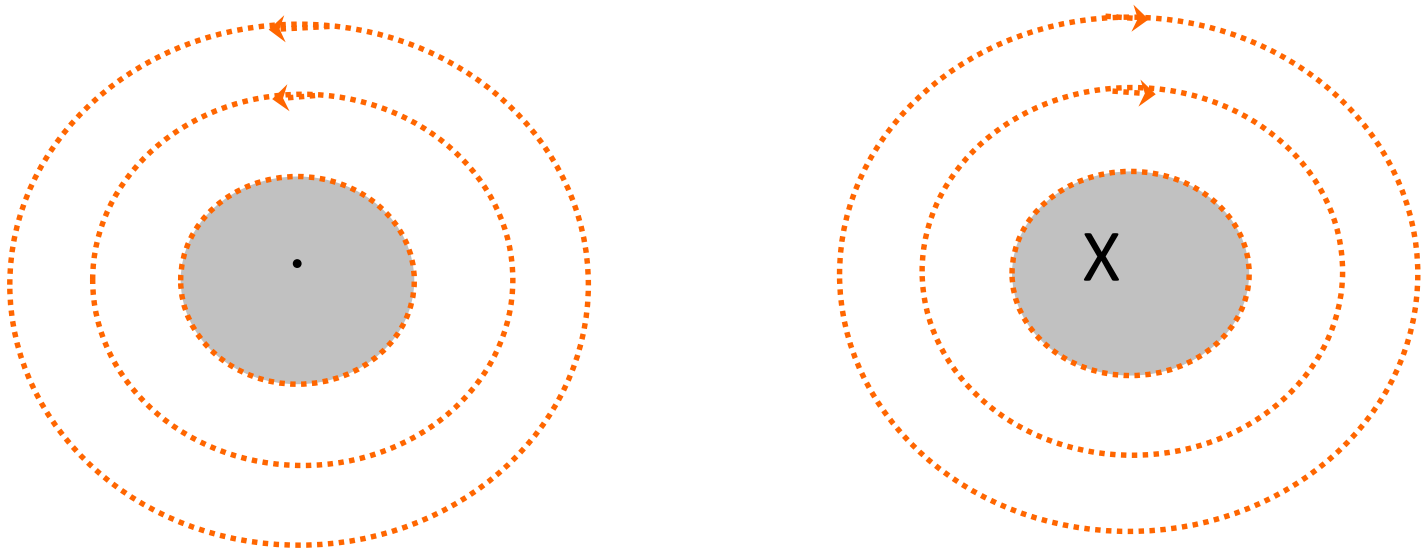
Voltage

- Voltage is the separation of charge (Insulators and air keep charges separated)
- Electric fields "due to voltage"

- In our houses the voltage is 120 or 240 Volts – **(OH – insulated, UG – insulated)**
- In our cities, the voltage is 12,000 Volts (12KV) – **(OH – bare, UG – insulated)**
- In the cornfields, the voltage is 345,000 Volts (345 KV) – **(OH – bare, UG – insulated)**

Current

- Current is the movement of charge



- In our houses, current flows in the wires when something is turned on
- Magnetic fields "due to current"

How are voltage and current related?

- Voltage is created by a “source” - perhaps a battery or a generator.
- Current flows when a “load is switched across a voltage source”
- The amount of current depends on the “Resistance” of the load.

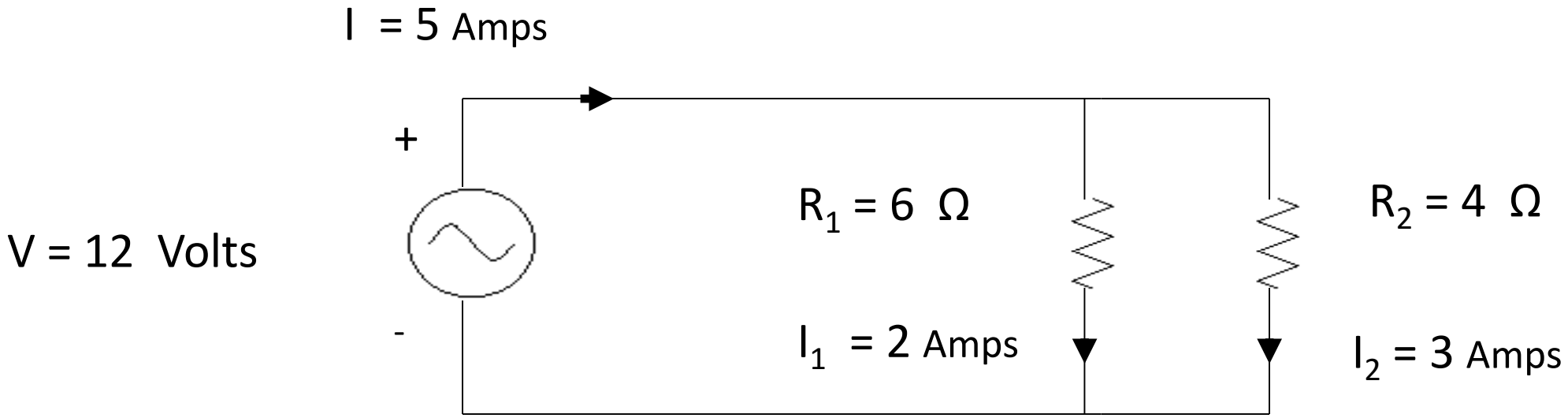
Fundamental Laws

- Kirchhoff’s voltage law: The sum of voltage around a closed path =0.
- Kirchhoff’s current law: The sum of currents into a point =0.
- Ohm’s law: The ratio of voltage divided by current is the “resistance” of the load.

Example of Ohm's law

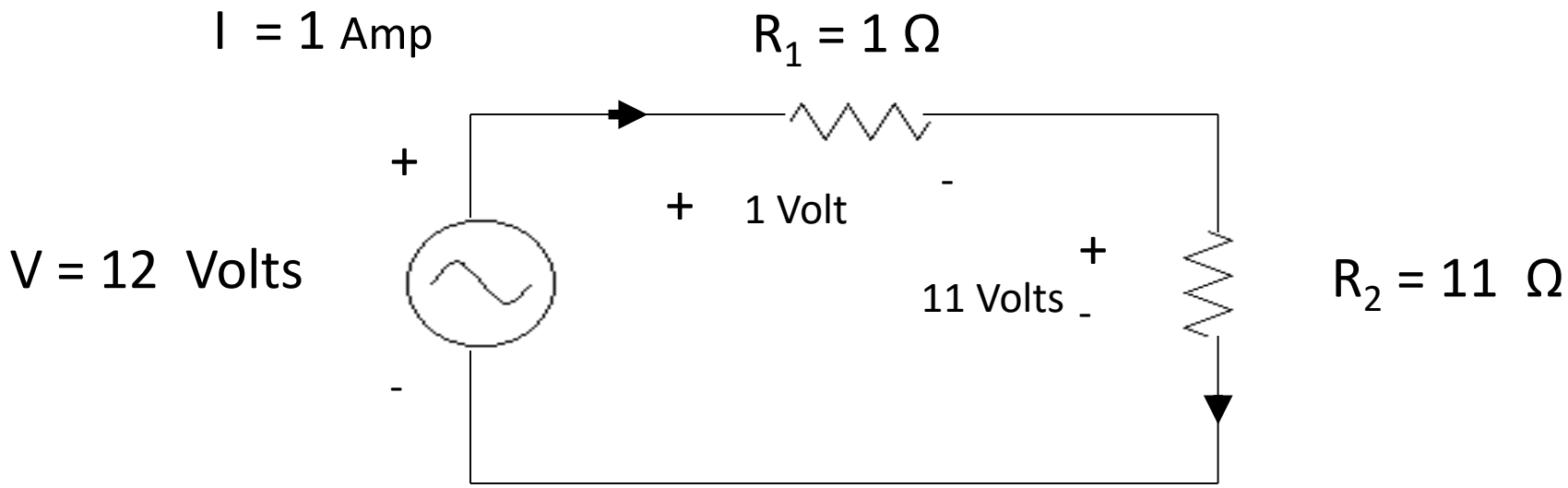
- **V = I R**
- **or**
- **I = V/R = 12 Volts/6 Ohms = 2 Amps**

Parallel connection



This "circuit" satisfies Ohm's law and Kirchhoff's laws. These laws determine how current flows in the lines and how the voltage is distributed to the loads (note: in this case there is only one voltage).

Series connection



This "circuit" satisfies Ohm's law and Kirchhoff's laws. These laws determine how current flows in the lines and how the voltage is distributed to the loads (note: in this case there is only one current).

Types of Electricity

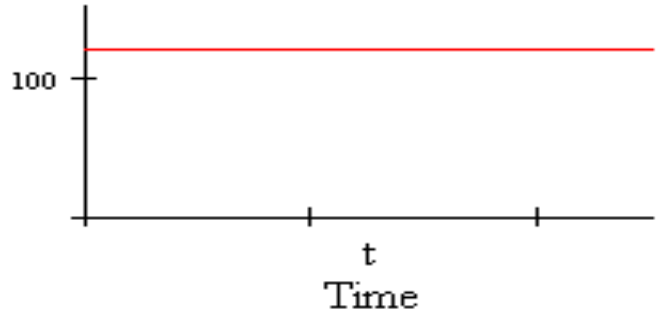
DC

- Batteries
- Fuel cells
- Electronic converters

Average = 120 Volts

Peak = 120 Volts

RMS = 120 Volts



DC Voltage

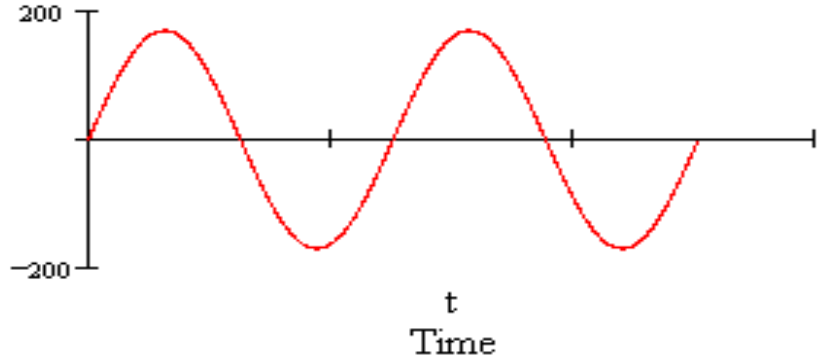
AC

- Rotating machines
- Electronic converters
- 60 Hertz in the US

Average = 0 Volts

Peak = 170 Volts

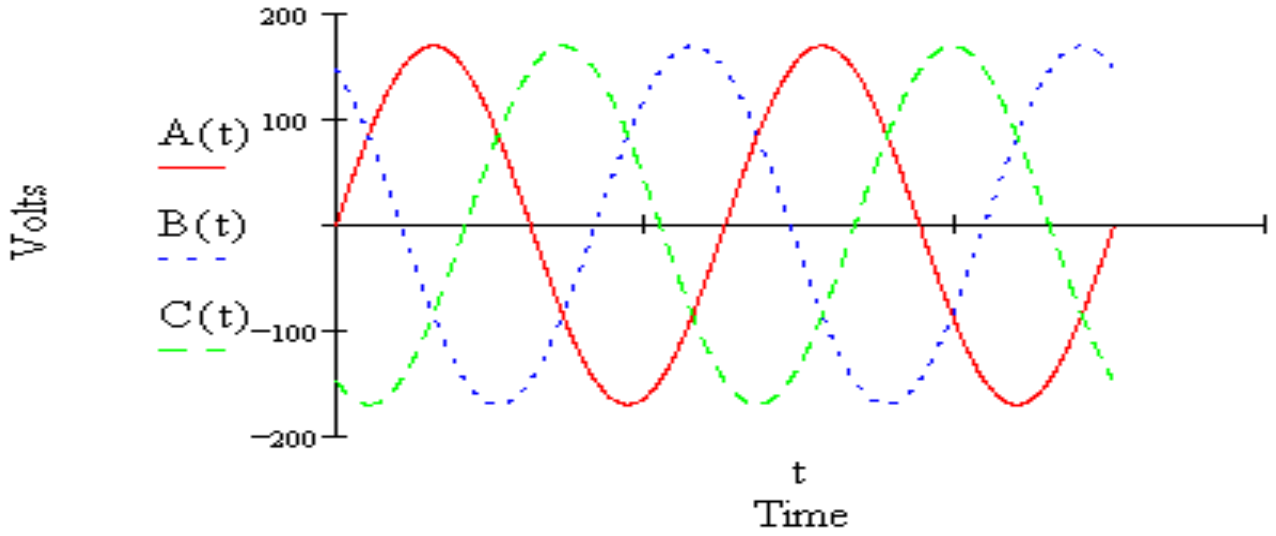
RMS = 120 Volts



AC Voltage

3-Phase AC

Bulk power generation/transmission and commercial use



3 Phase Power

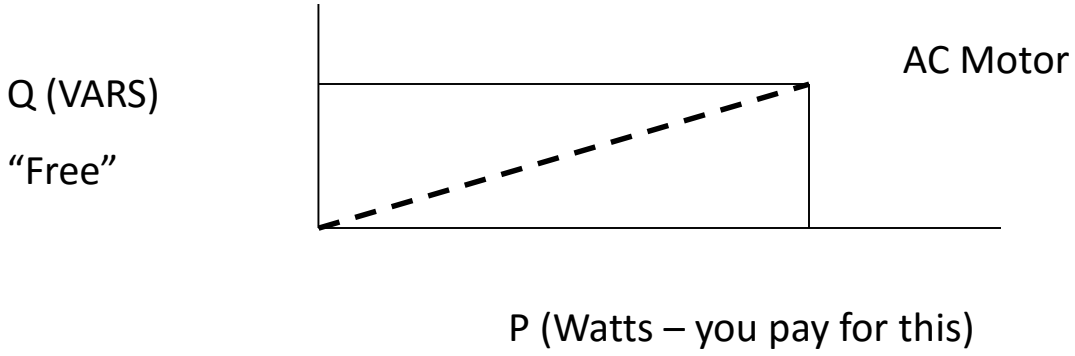
Power and Energy

- Power = work done / time
- Power = the rate at which energy is used
- Lifting a 100 pound mass 6 feet in 2 sec takes a power of 300 foot-pounds/sec

This is about 400 Joules/sec
This is the same as 400 Watts
This is the same as 0.4 KW
This is about 0.5 HP (1 HP = 746 W)
Typical energy cost is $0.10 per KWH

Reactive power

Some loads consume two types of power



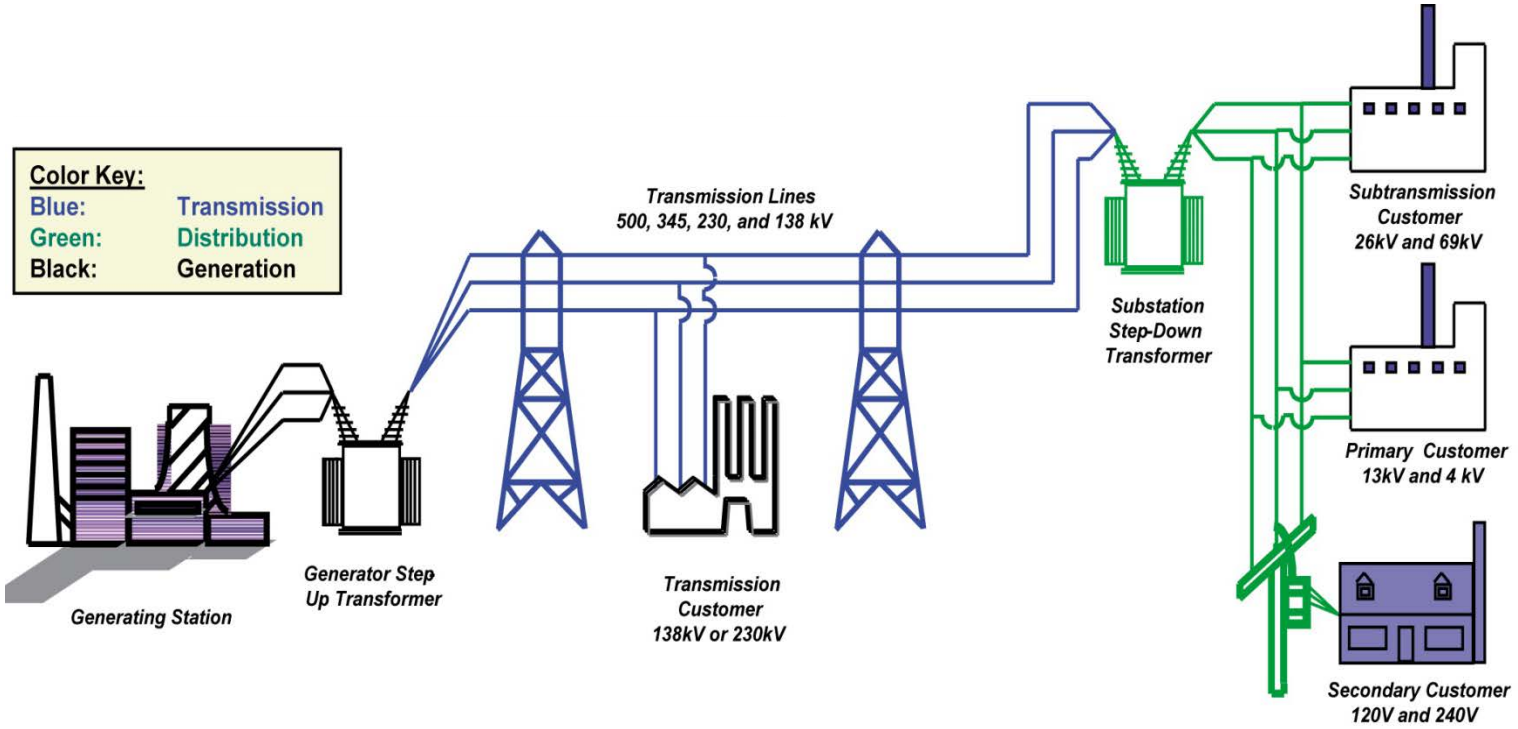
Basic Power System Components

Fuel, Furnace and boiler, Turbine and governor, Generator and exciter

Step-up transformer

Transmission lines

Step-down transformer



Distribution line (medium voltage), Transformer (step-down)

Loads – motors, lights etc. (low voltage)

Who’s in charge?

Federal Energy Regulatory Commission (FERC)

North American Electric Reliability Corporation (NERC)

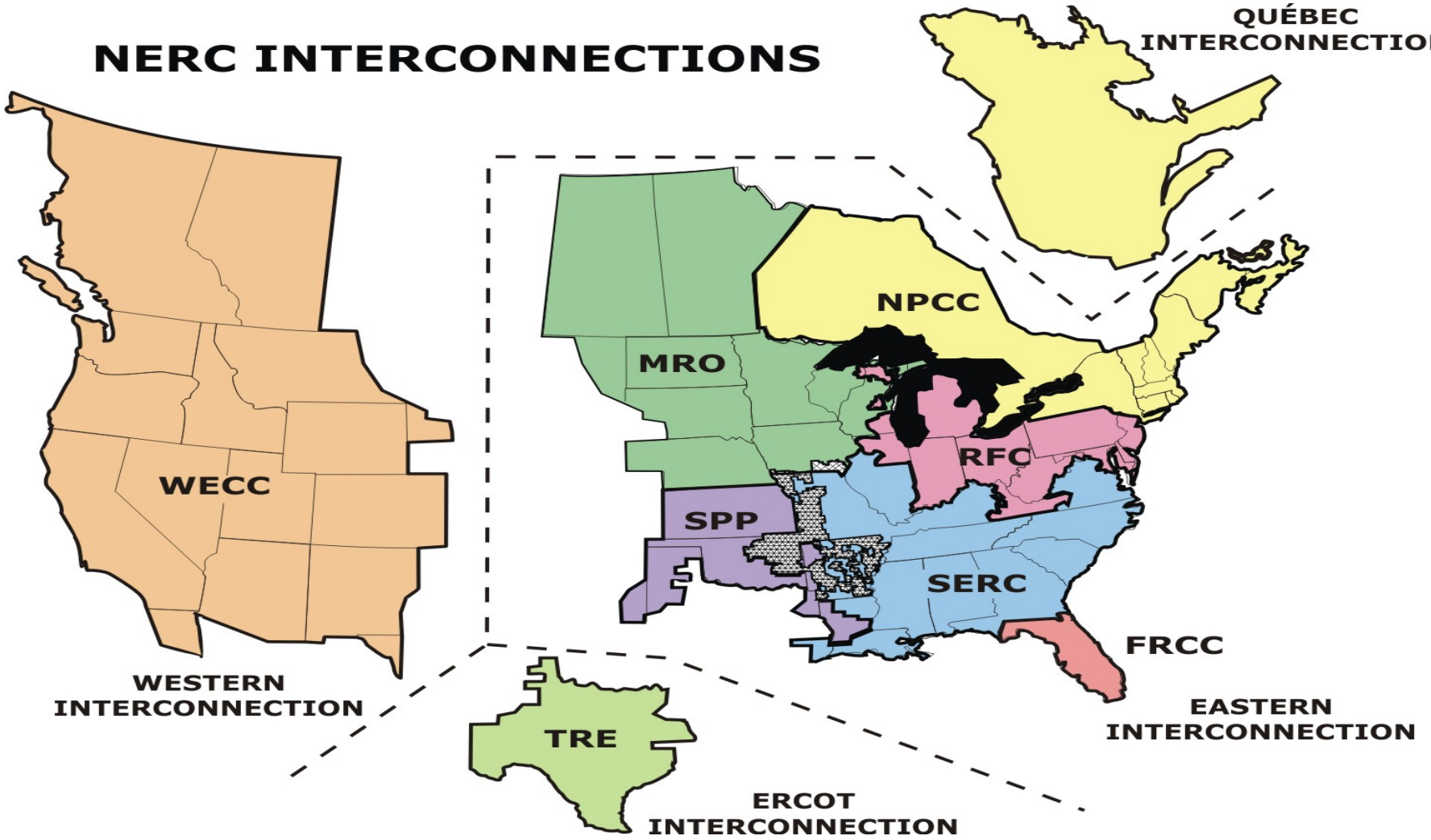
State legislatures

State commerce commissions

ISOs and RTOs

Control Area Operators (Balancing Authority Operators)

North American Electric Reliability Corp.



Created June 1, 1968 after 1965 NYC blackout

Started in Princeton, NJ - now located in Atlanta, GA

Control centers

Energy Management System (EMS) software

- Supervisory Control and Data Acquisition (SCADA)
- State Estimation, Power Flow
- Contingency Analysis
- Automatic Generation Control
- Economic Dispatch, Optimal Power Flow, Unit Commitment
- Data Analytics
- PMU applications
- Monitoring and alarms

Protection systems

What happens when a short circuit (fault) occurs?

i.e. suppose your kid sticks a two-pronged fork in the outlet of your house!

The fault must be detected quickly

The fault must be removed (cleared) quickly (even though the fork is still in the outlet)

Fuses

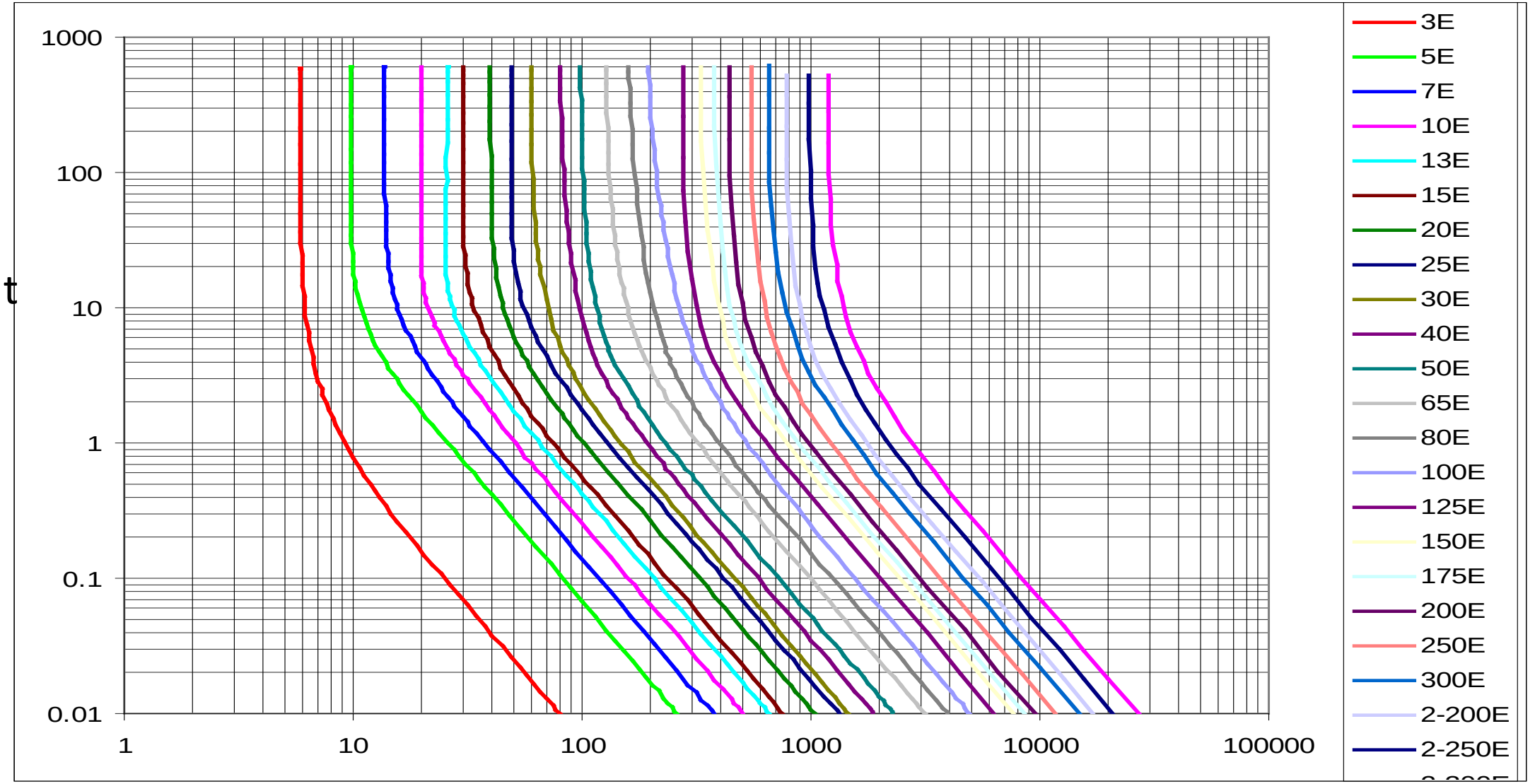
Fuses are local devices (they act on what they feel at that point)

Detection and clearing are combined – the fuse element melts – opening the line and thereby “clearing” the fault.

Fuses have two duty ratings – the “normal” current (i.e. 20 Amps) and the maximum fault current capability (i.e. 10,000 Amps)

Fuses have time-current characteristics

Min melt Time



Current

Courtesy S&C Electric

Relays and circuit breakers

Relays are local devices (they act on what they feel at that point).

The relay is a device that detects the presence of something – say high current.

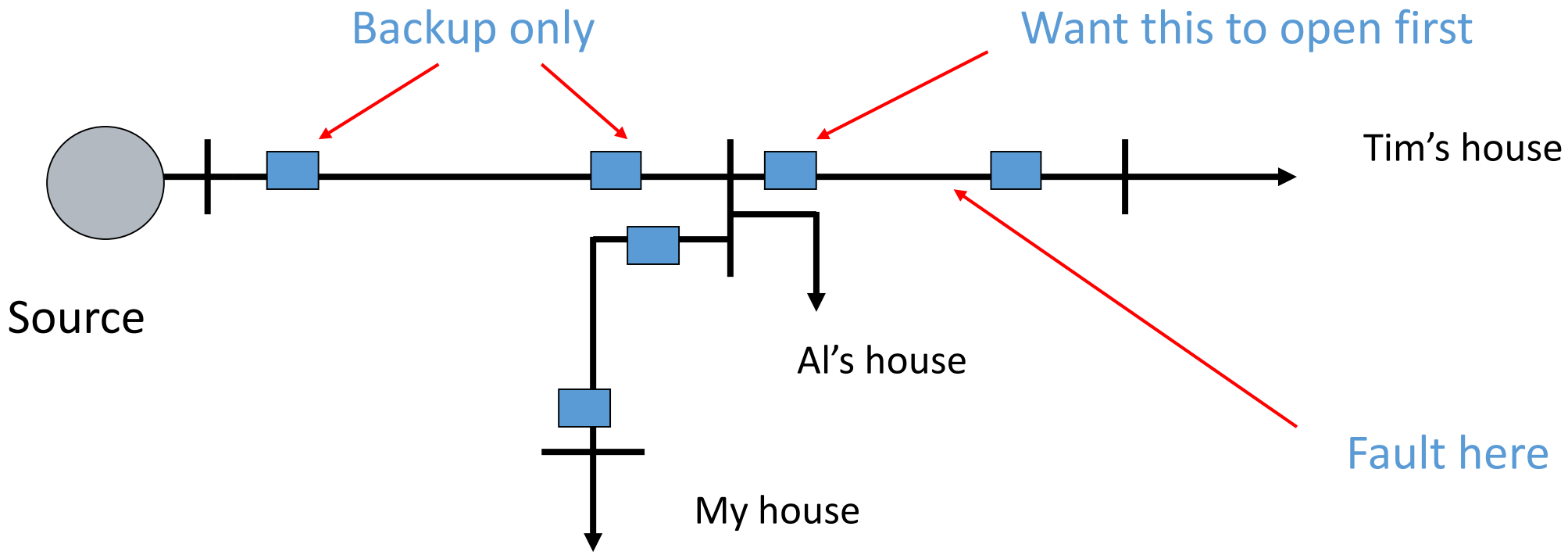
The relay sends a signal to one or more circuit breakers to open.

Circuit breakers actually provide the “clearing” by opening the circuit.

Relays and circuit breakers have time-current characteristics.

Coordination

The right fuses and or relays/circuit breakers need to operate at the right place and right time.



Time evolution of substation devices and tools

1900 — 1950 — 2000

Electromechanical
(Screwdrivers)

Solid state
(Solder guns)

Digital
(Laptops)