

Transmission 101: Technical Aspects

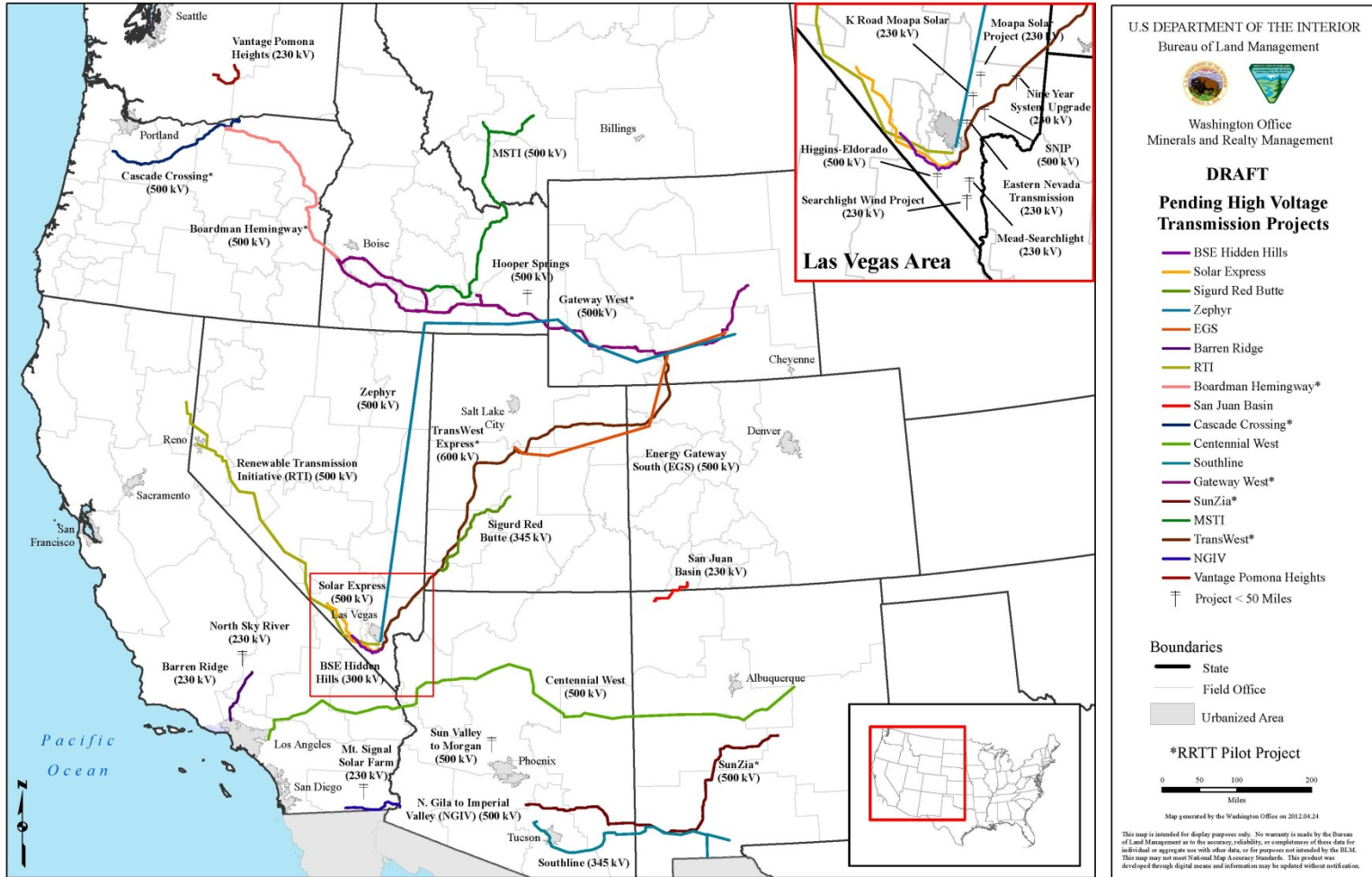


*BLM Transmission Training
Webinar Series*

Webinar 6

July 25, 2013

MAP Pending High Voltage Lines





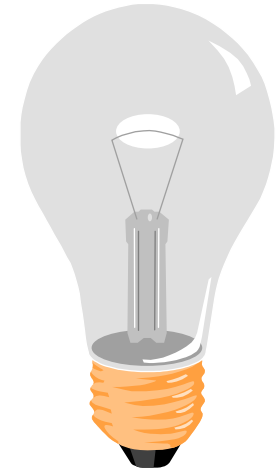
TRANSMISSION FUNDAMENTALS

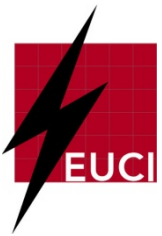




AGENDA

- **Electricity Basics**
- **Types of transmission**
- **Characteristics of transmission**
- **Functions of transmission lines**
- **Role of transmission in the interconnected environment**
- **What determines power flow?**
 - **Example of Line Flows**
- **Loop flows**
- **Power system protection**
- **NERC compliance**
- **Questions**





DEFINITION OF ELECTRICITY... then and now

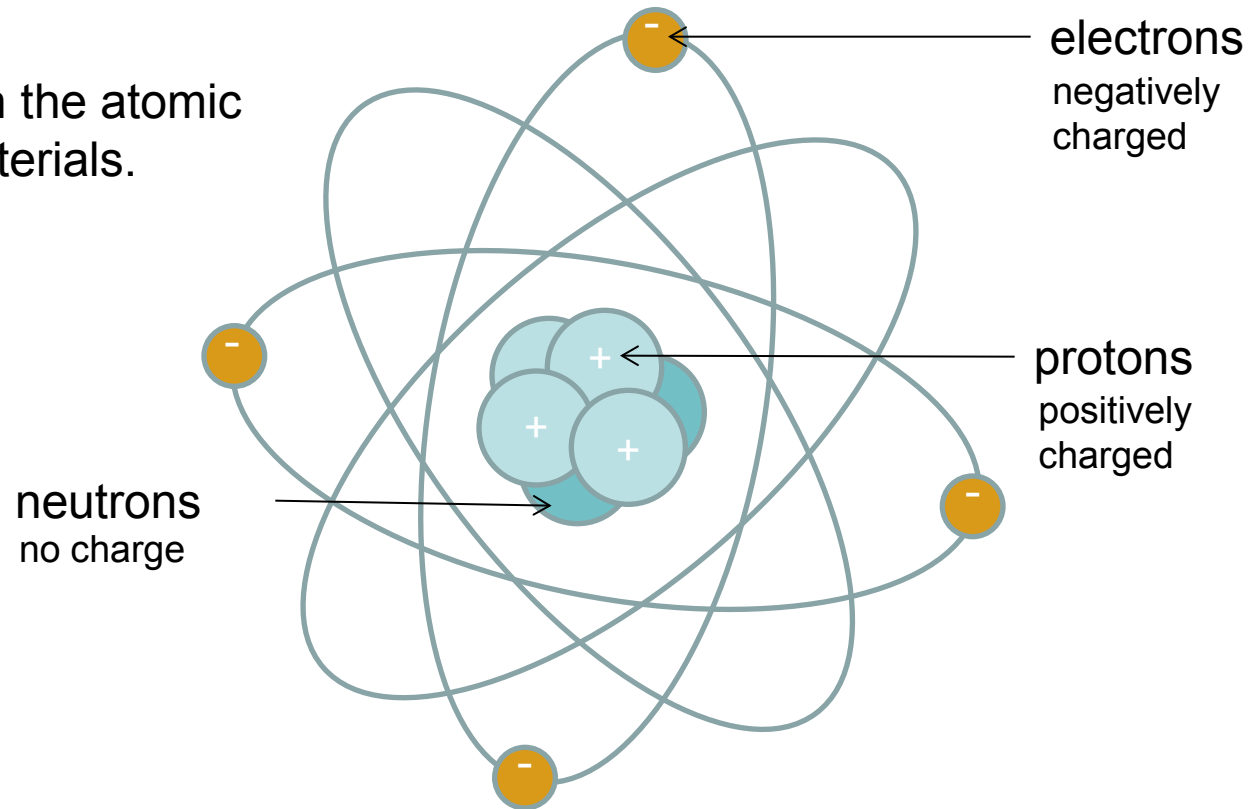
- *ELECTRICITY, n. The power that causes all natural phenomena not known to be caused by something else. Ambrose Bierce The Devil's Dictionary, 1881–1906*
- *ELECTRICITY, n. A form of energy generated by friction, induction, or chemical change , and having magnetic and radiant effects - Webster's Dictionary....now*



Electricity Basics

How does electricity work?

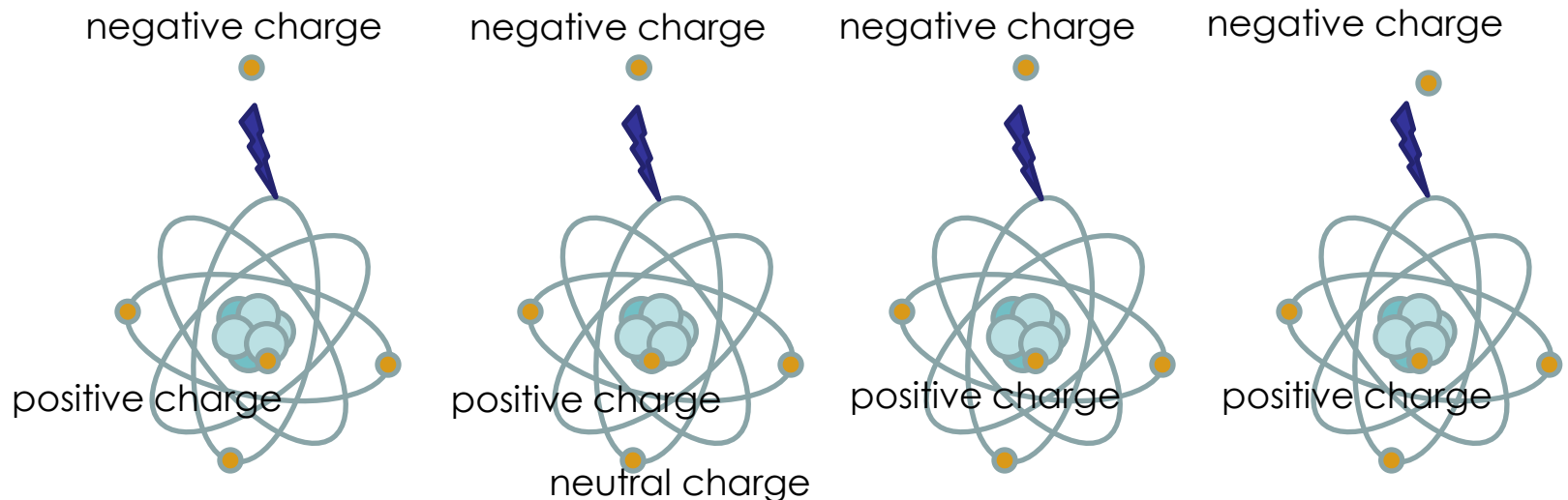
Electricity exists in the atomic structure of all materials.





Electricity Basics (Cont'd)

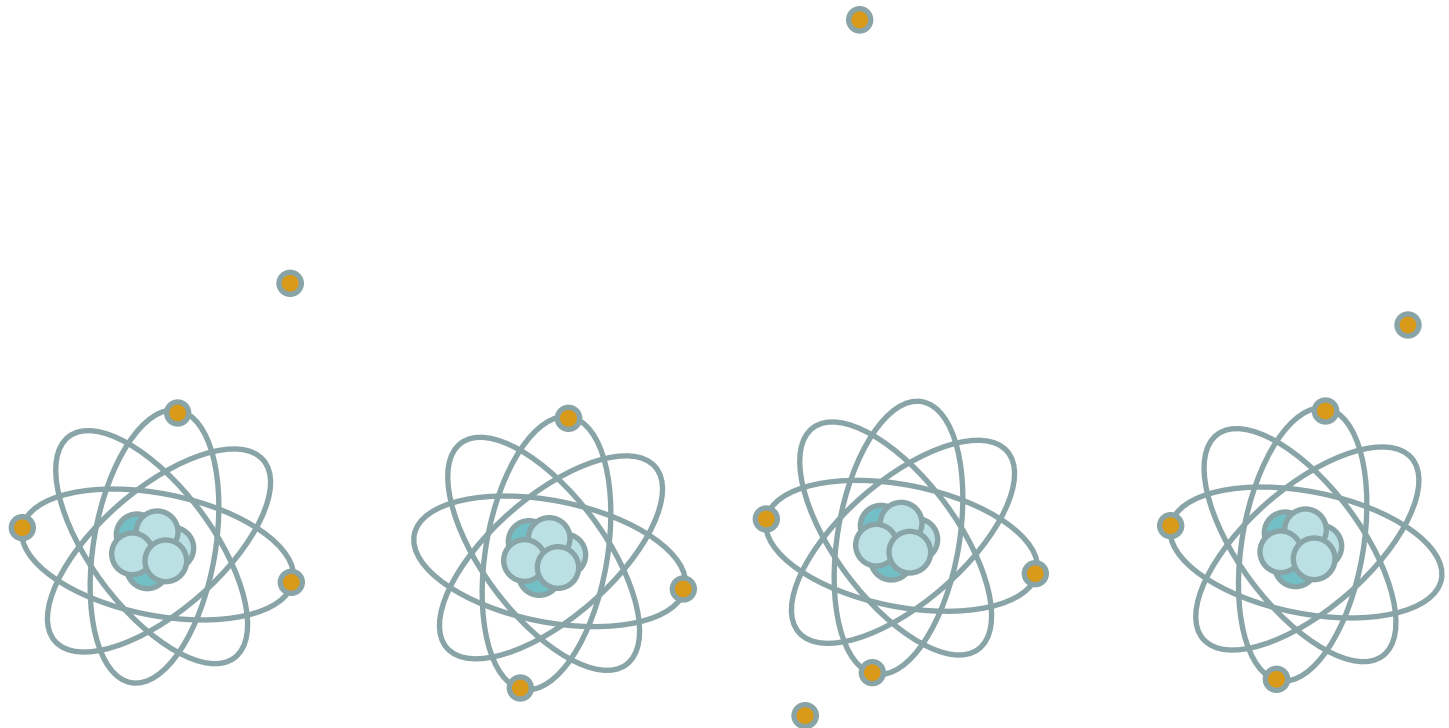
- However, energy (like a magnetic force) can pull electrons from their atoms.
- If the number of electrons equals the number of protons in an atom, the atom is not charged.
- The negatively charged electrons are attracted to the positively charged atoms.
- This attraction, or electrical potential difference, is called **VOLTAGE**.





Electricity Basics (Cont'd)

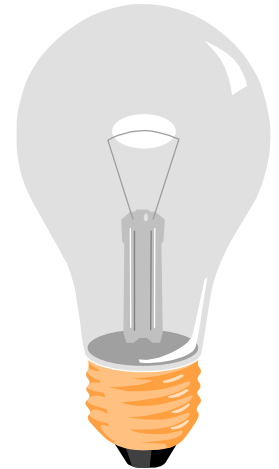
In a circuit, voltage causes the electrons to move in an electric current.





TECHNICAL ASPECTS OF ELECTRIC TRANSMISSION

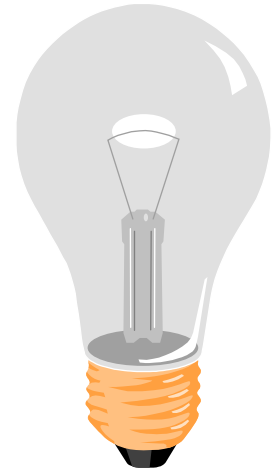
- **Types**
- **Characteristics**
- **Functions**
- **Role of transmission in the interconnected environment**
- **What determines power flow?**
- **Loop flows**
- **Impact of inadequate transmission**
- **Power system protection**





TERMS & DEFINITIONS

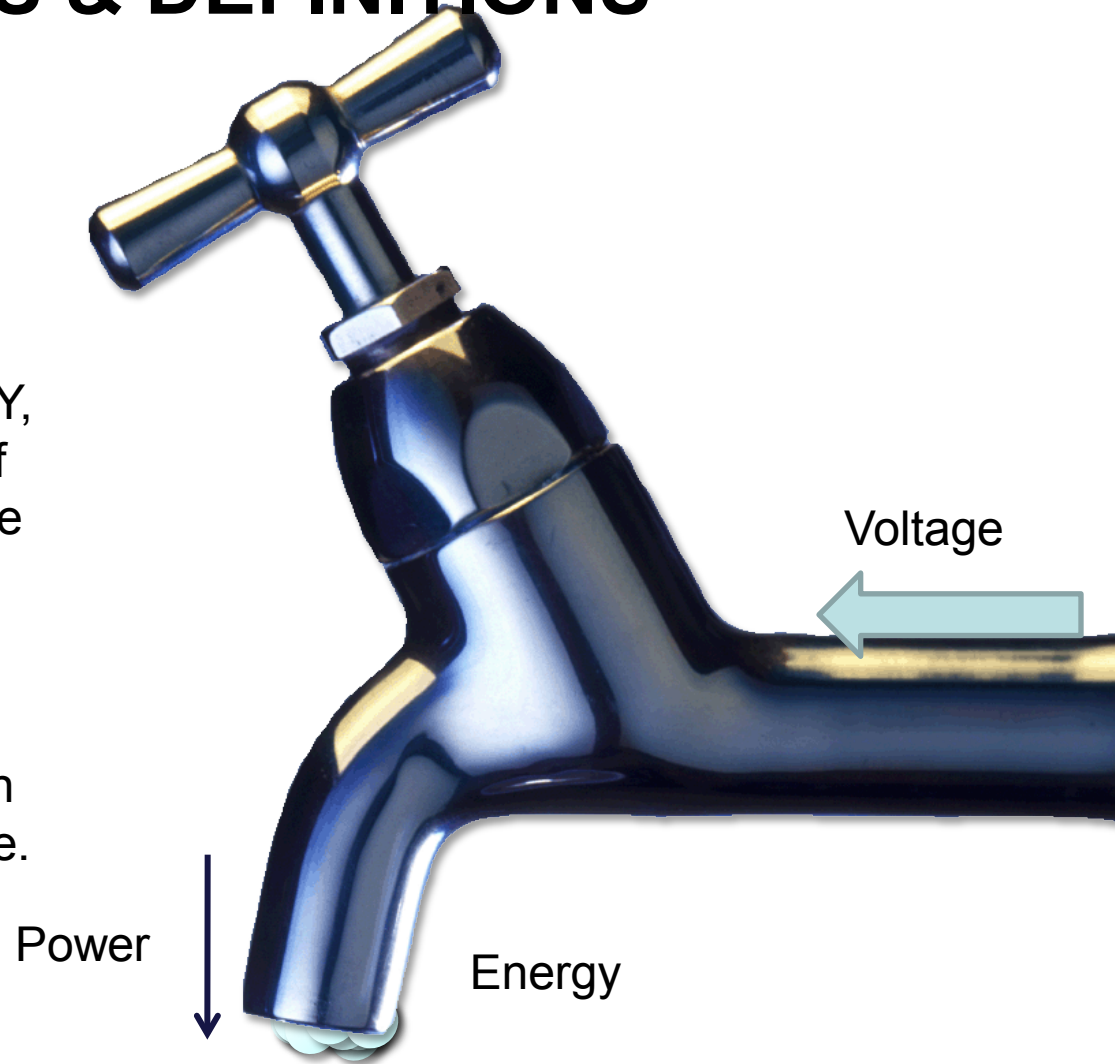
- **Voltage (volts)**
 - **Analogy - water pressure**
- **Current (amperes)**
 - **Analogy - water flow in a pipeline**
- **Power (watts)**
- **Energy (watt-hours)**
- **Frequency (hertz)**
- **Resistance/ Impedance (ohms)**





TERMS & DEFINITIONS

- Voltage is the driving force behind an electrical current, like water pressure in a plumbing system.
- If the water is ENERGY, the rate and amount of water coming out of the faucet is POWER.
- If you increase the voltage, more current (water) passes through the pipe at a faster rate.





TERMS & DEFINITIONS



- POWER is the rate at which ENERGY is generated or consumed.
- **watts** = the *rate* energy is generated/consumed
= *volts (pressure) x amperes (volume)*
- **watt hours** = the *change* of power per hour
= *watts x hours*

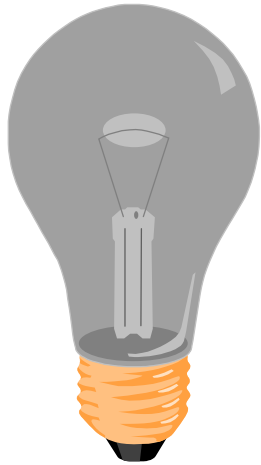


TERMS & DEFINITIONS

Open - Contingency

Open Circuit

Out of Service



Closed

“Hot”

Energized

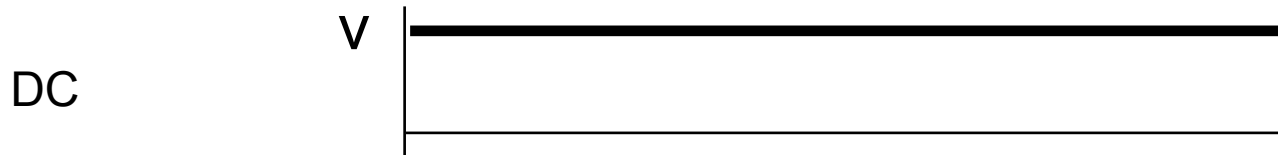
In-Service





DIRECT CURRENT VERSUS ALTERNATING CURRENT

- http://en.wikipedia.org/wiki/War_of_Currents
- DC – constant direct current, does not vary with time
 - Battery (flashlight: 3 volts, automobiles: 12 volts)
 - High voltage DC (HVDC): 600,000 volts

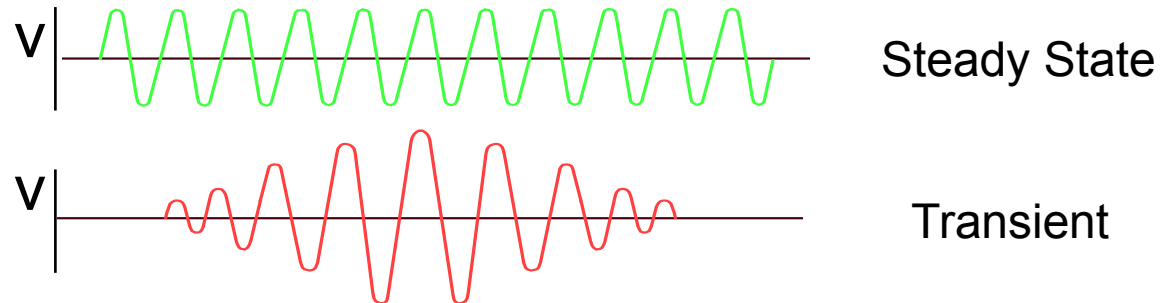




DC versus AC

AC - alternating current, varies with time
Utility systems (household: 120/240 volts,
transmission lines: up to 765,000 volts)

AC



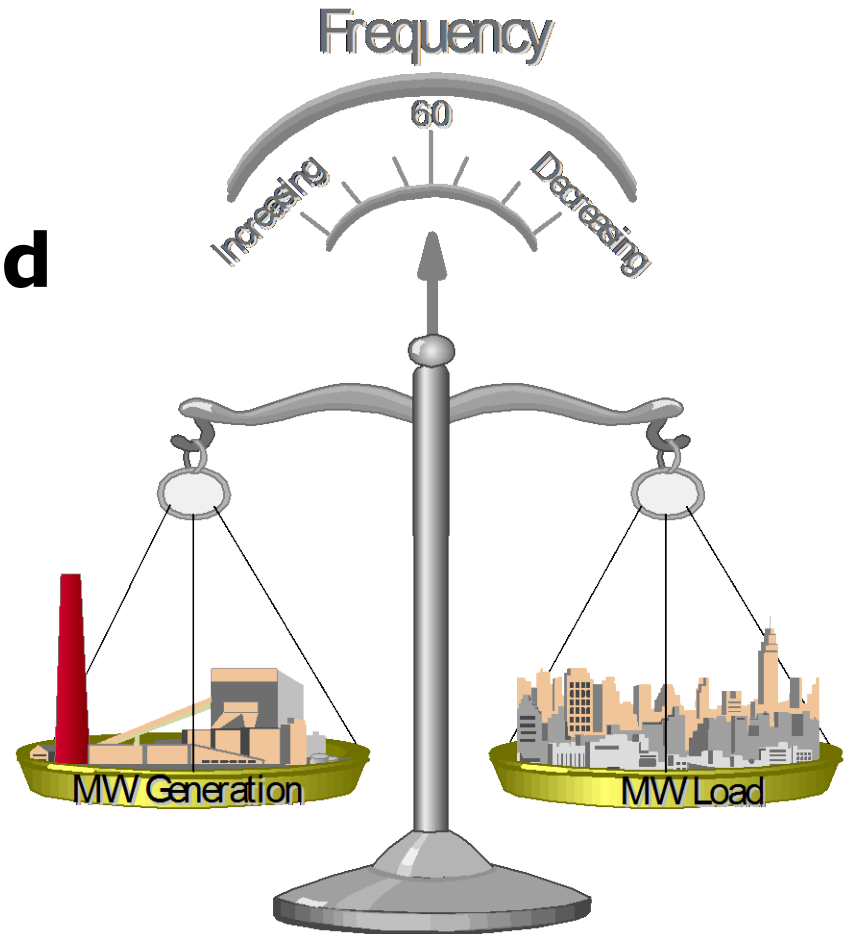


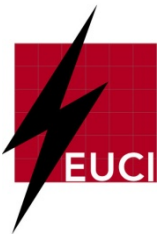
UNIQUENESS OF ELECTRICITY (AC)

- **Cannot be stored!**

Must be produced and delivered in exact quantity demanded

Has qualities of voltage and frequency



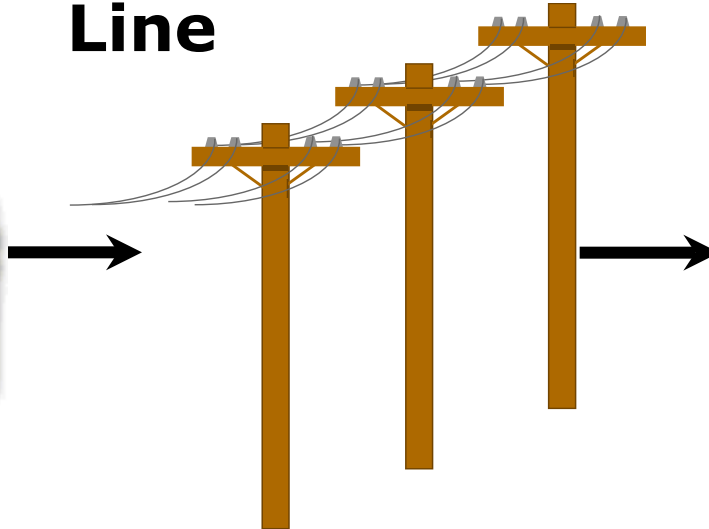


ELECTRICITY WORKS BY...

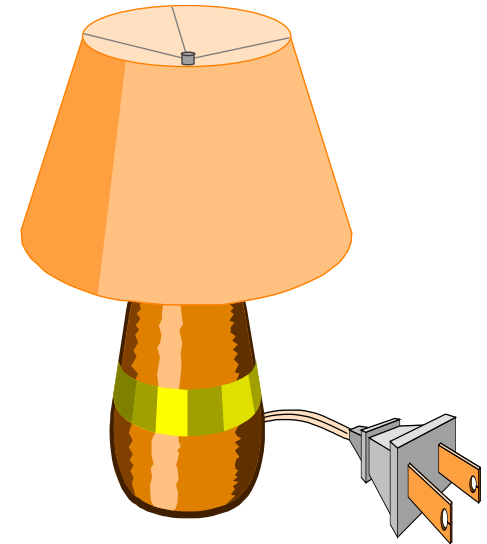
Generator



**Transmission
Line**



Load



... Moving electrons!!

... Strictly laws of physics!!

... No corporate/state boundaries!!



WIRES (CONDUCTORS) & RESISTANCE

- **Conductors**
 - Copper
 - Aluminum
 - Steel
 - Other Metals
 - Wood
 - Water
 - Human Body
 - Super Conductors
- **Resistance**
 - Very Low
 - Very Low
 - Low
 - Varies
 - High
 - Varies
 - Medium/ Varies
 - Extremely low



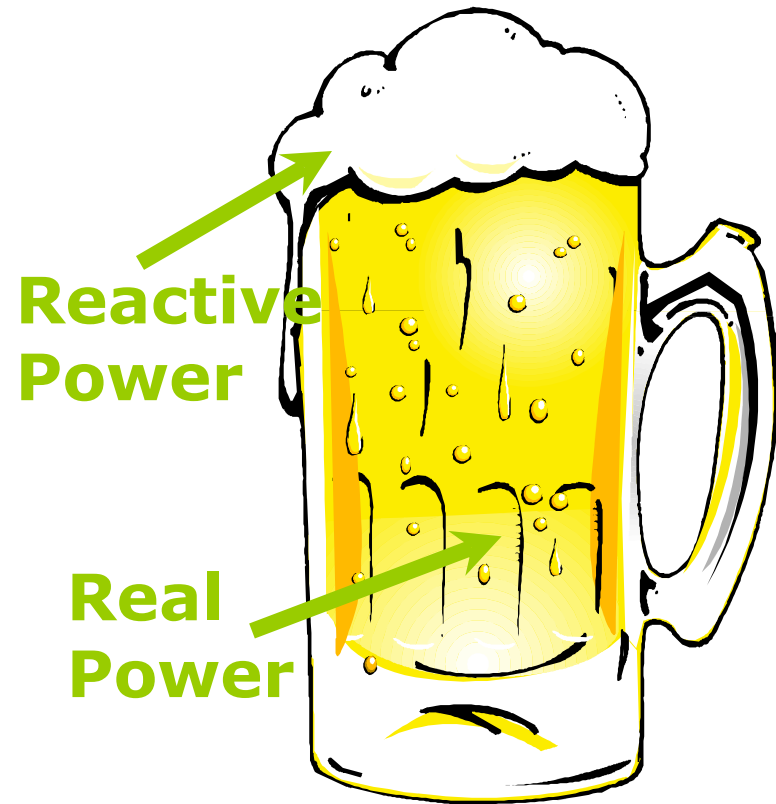
AC TERMS & DEFINITIONS

- **Single Phase - one energized wire**
- **Three Phase - three energized wires**
- **Volts, Amps, etc. apply as with DC**
- **Hertz - frequency of variations in cycles per second, e.g. 60 hertz or 60 Hz**
- **Power (real power) in KW or MW**
- ***Reactive Power (VArS) in KVArS or MVArS***



WHAT ARE VARs ANYWAY?

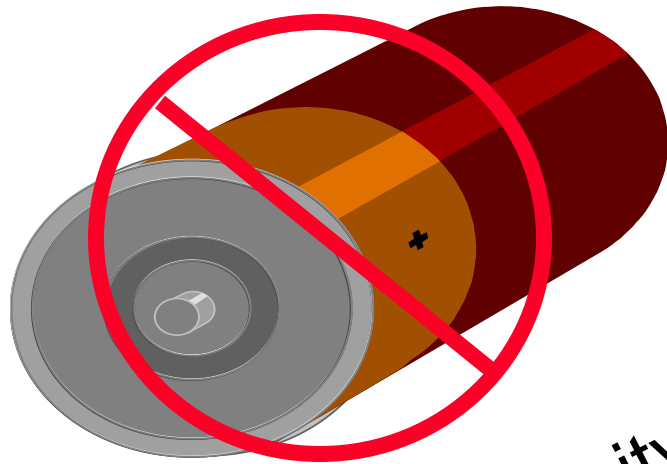
- This mug of beer is made up of beer & foam
- Electric Power is made up of Real Power (beer) and Reactive Power (foam)



Just as the mug must hold the beer and the foam, so must the wire and transformers carry the total power (kVA)

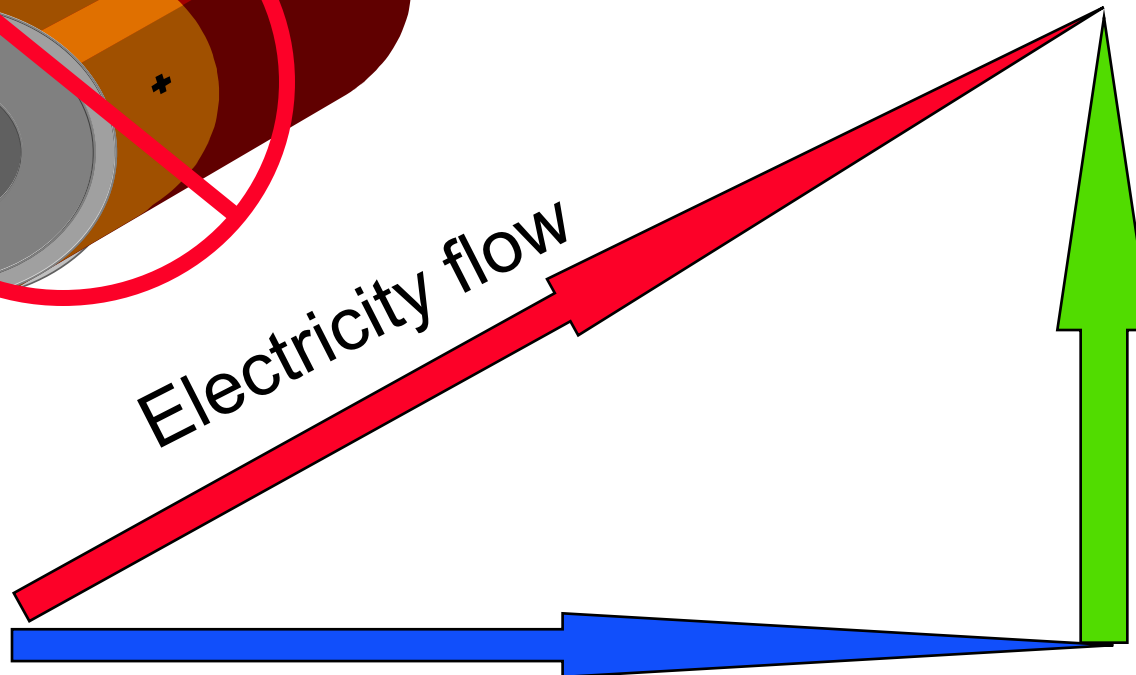


WHAT'S A VAR ANYWAY?



Doesn't apply to DC

AC



Electricity flow

Reactive
Power
VARs

Real power (work done)

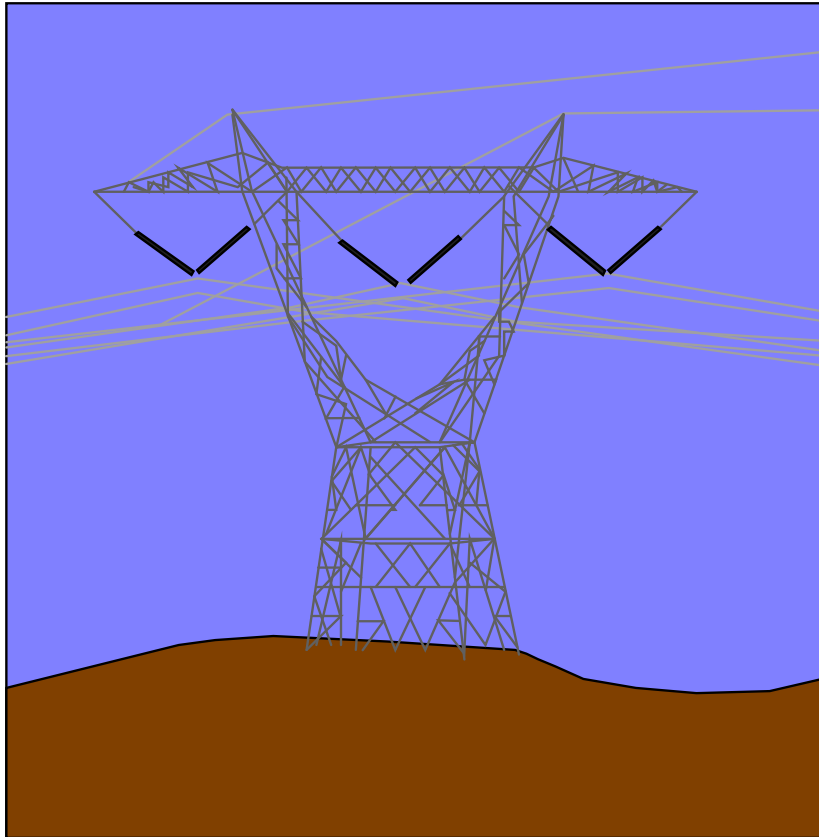


Resistance and Reactance

- Resistance - Ohm's Law says current flows across the path of least resistance
 - Real Power Losses are due to Resistance
- Reactance - System Characteristics that raise or lower voltage: capacitors/reactors



WHAT IS A TRANSMISSION LINE ?



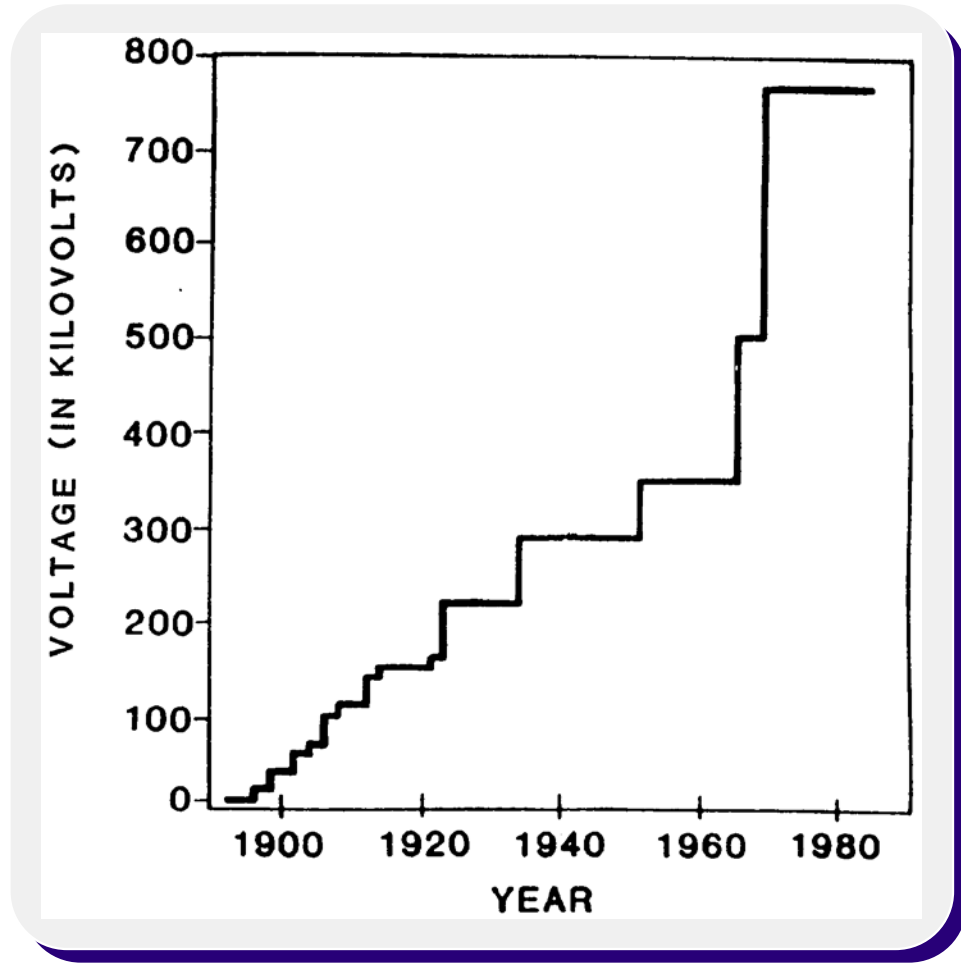
- A power line that delivers electricity at a high voltage level
 - Overhead
 - Underground (Cable)
- Usually higher voltage lines used in utility systems



AC TRANSMISSION VOLTAGES IN THE U.S.

- 765 kV (+)
- 500 kV
- 345 kV* (+)
- 230 kV*
- 161 kV*
- 138 kV* (+)
- 115 kV*
- 69 kV*
- 34 kV*

* Underground cables also





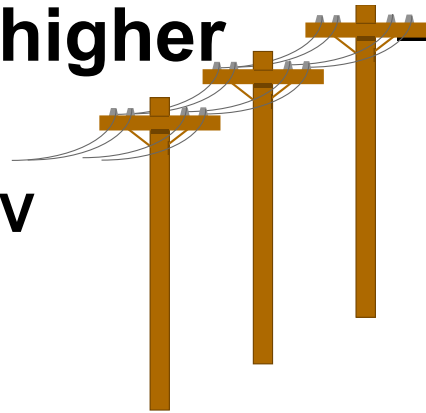
TRANSMISSION vs. DISTRIBUTION

- **Transmission**

- “Parallel” circuits
- Network connected
- Typically higher voltages
 - 34 to 765kV

- **Distribution**

- “Series (radial) and parallel” circuits
- Typically lower voltages
 - 6 – 34 kV
- FERC “7 factor test”



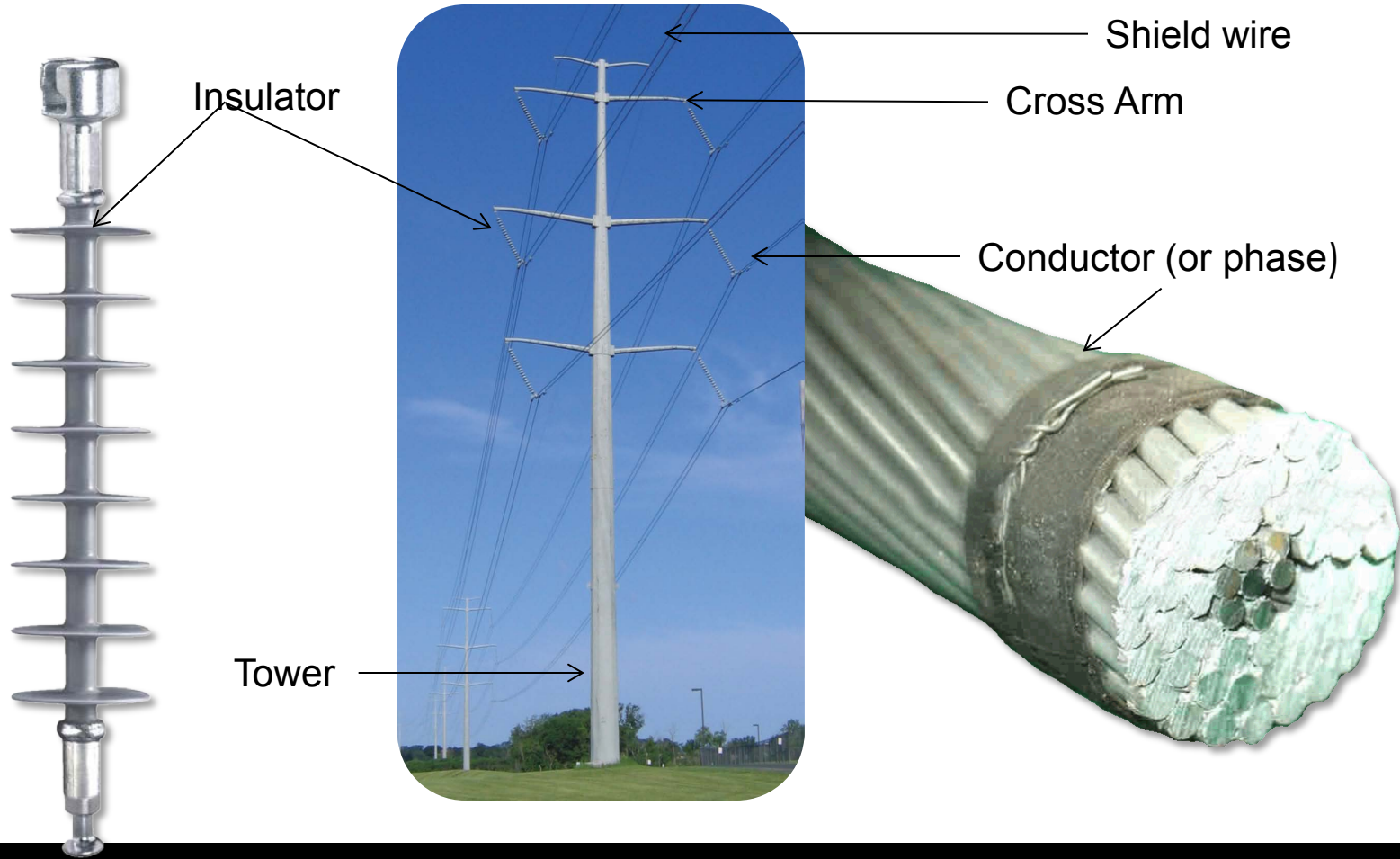


TRANSMISSION SYSTEM COMPONENTS

- **Transmission lines**
- **Underground cables**
- **Substation**
 - **Transformers**
 - **To step-up or step-down voltages**
 - **Circuit breakers and switches**
 - **To connect and disconnect**
 - **Protection equipment**
 - **Metering equipment**

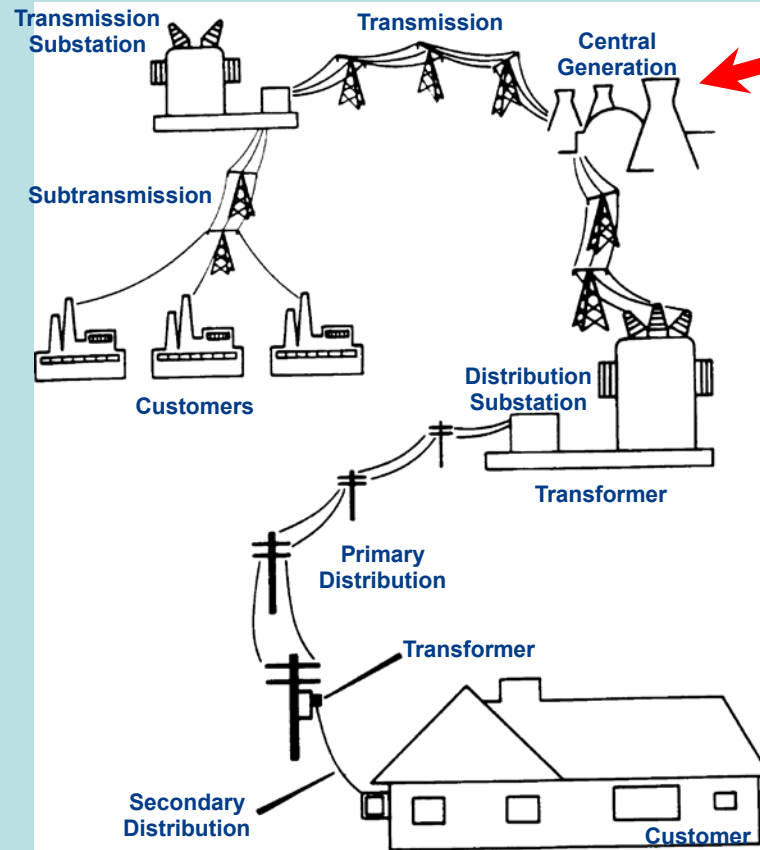


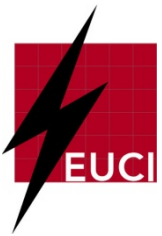
TRANSMISSION TOWER COMPONENTS



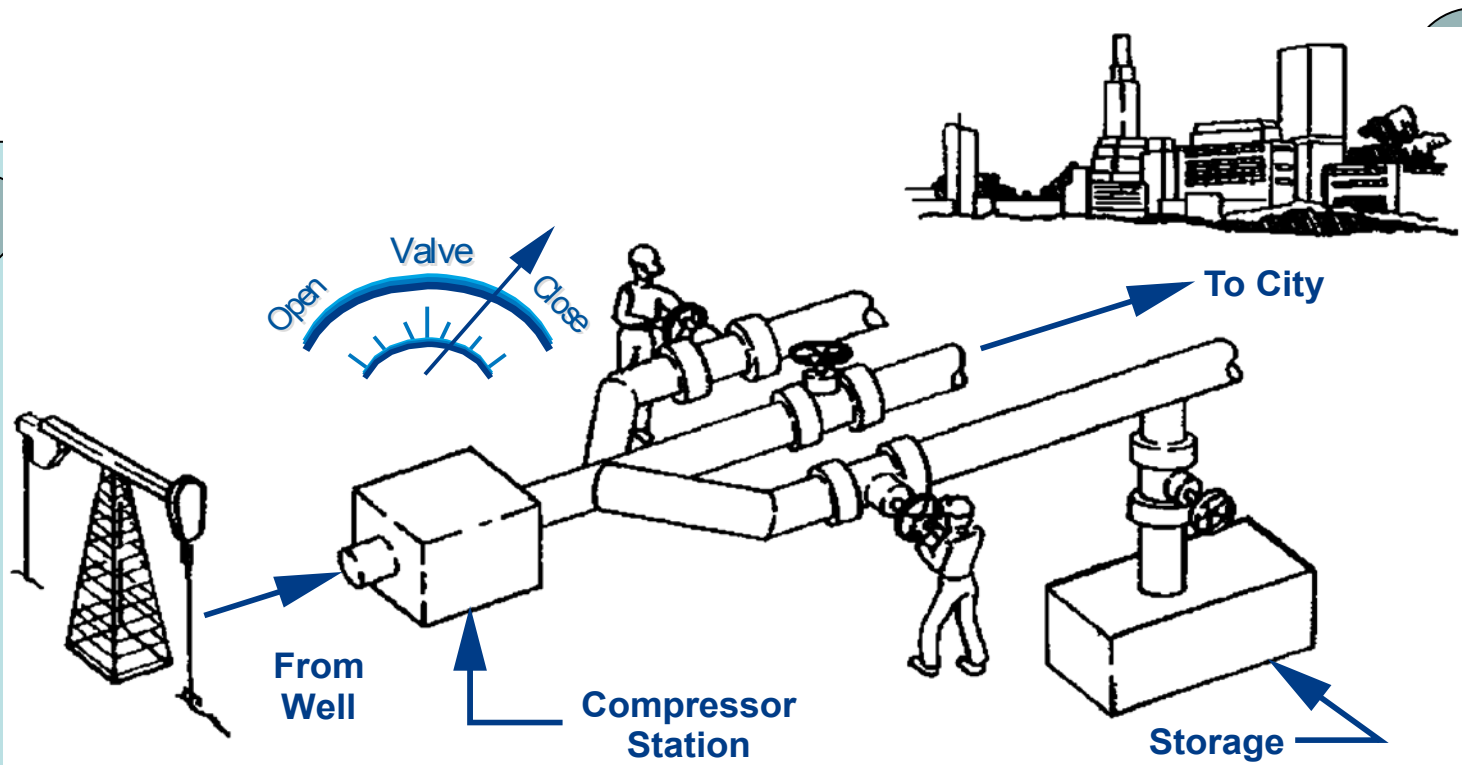


TRANSMISSION SYSTEM



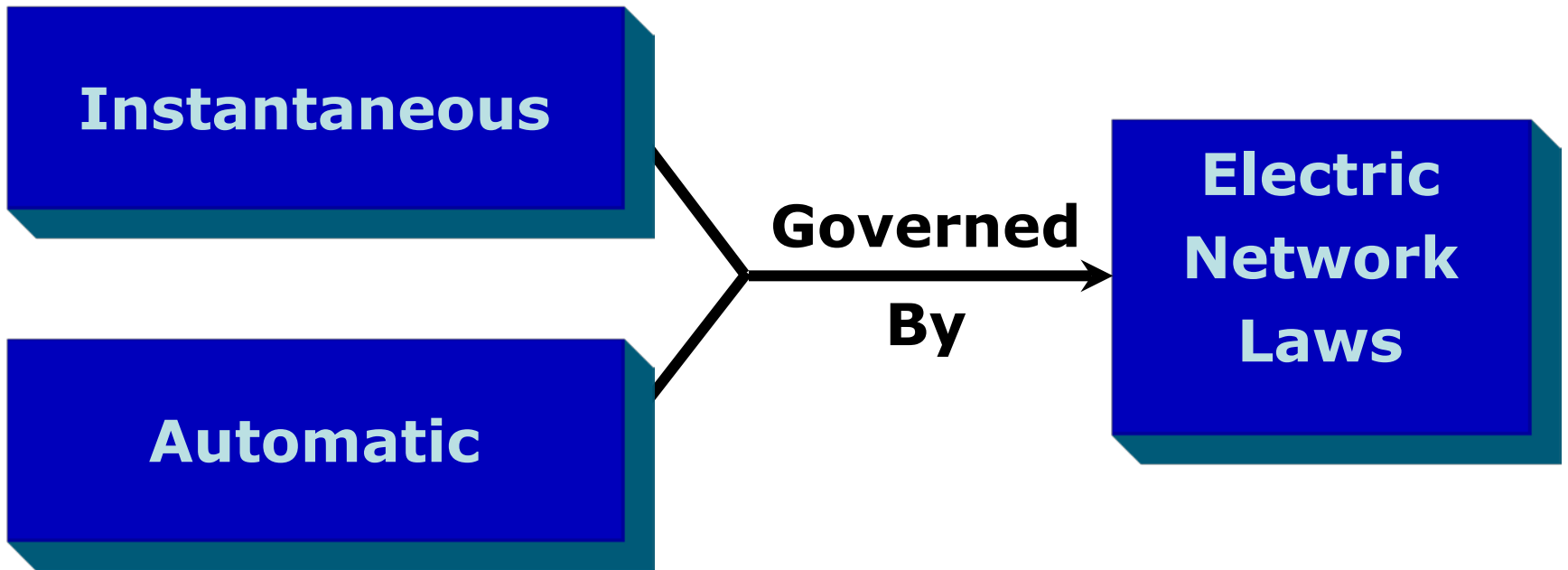


NATURAL GAS SYSTEM





OPERATION OF ELECTRIC TRANSMISSION SYSTEMS





FUNCTIONS OF TRANSMISSION SYSTEMS

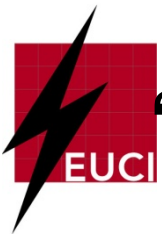
- **Delivery of electricity**
- **Integrating medium**
 - **Generators to load centers**
 - **Distribution systems**
- **Interconnection with other utilities**
- **Support voltages**
- **Reliability maintained through multiple paths**



SYSTEM LIMITS vs. ELEMENT RATINGS AND CONSTRAINTS

Network capability is not the sum of the element ratings!!!

- **Network Limitations (Constraints):**
 - Facility loading
 - Transfer capability
 - Voltage limits and voltage stability
 - Generator stability: transient/steady state
 - Inadequate capacity
 - Facility outages



“WHERE HAS ALL THE POWER GONE?”

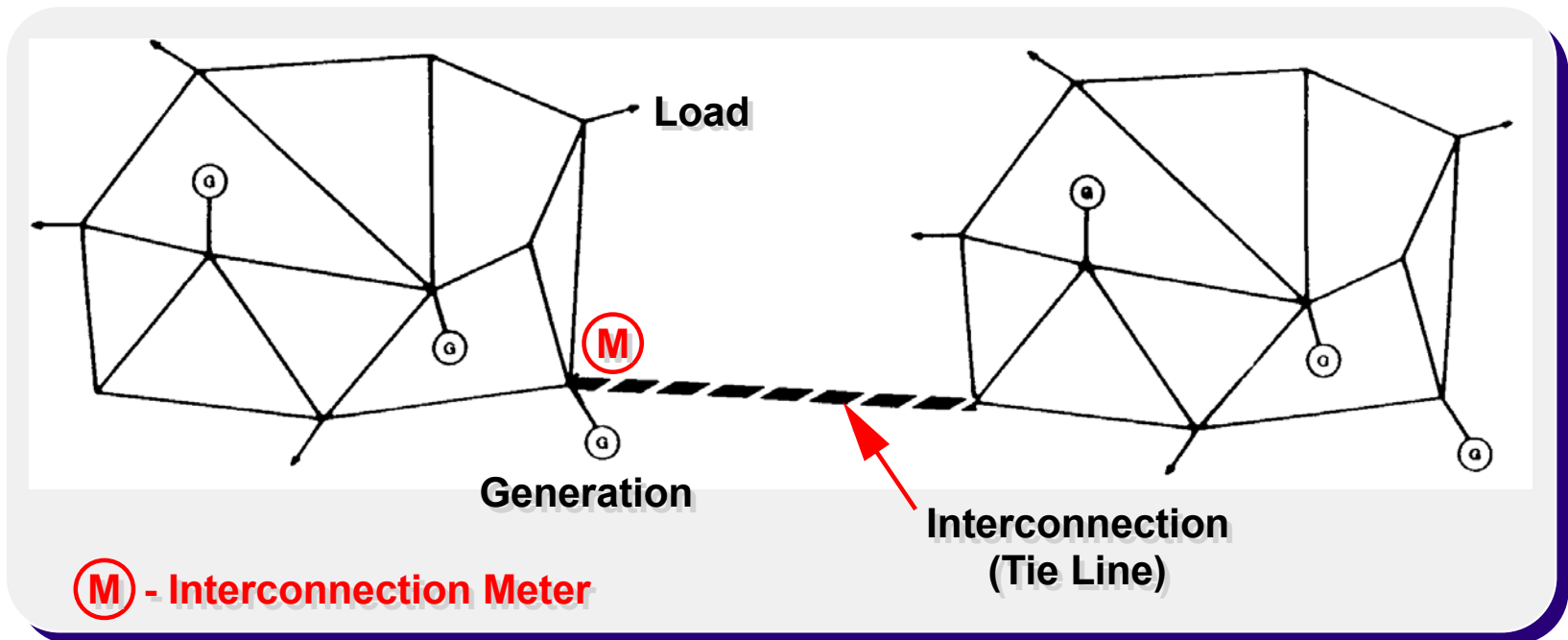
- **Customer Demand**
 - Load varies instantly
 - Load takes a daily and yearly shape
- **Losses in the system – transmission, distribution and load**
- **“Customer” takes on several meanings in today’s industry structure - retail, wholesale, aggregator, marketer, ...**
- **Obligation to serve ?**



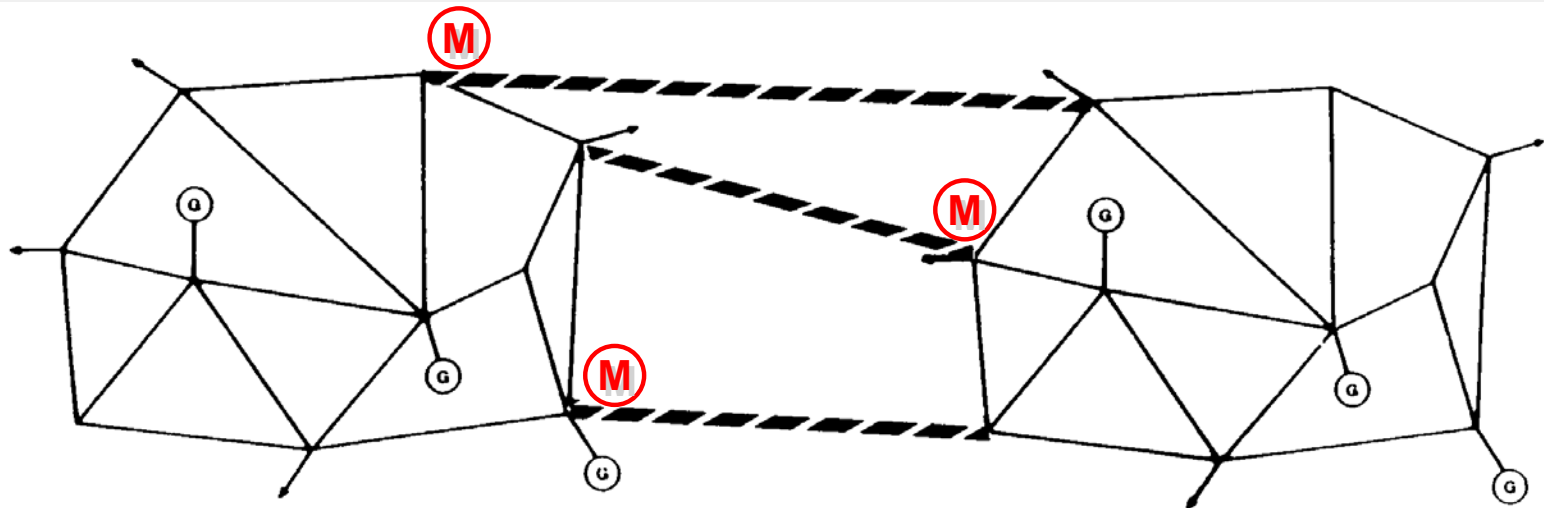
TWO SYSTEMS - ONE INTERCONNECTION

↓ Control Area 1

↓ Control Area 2



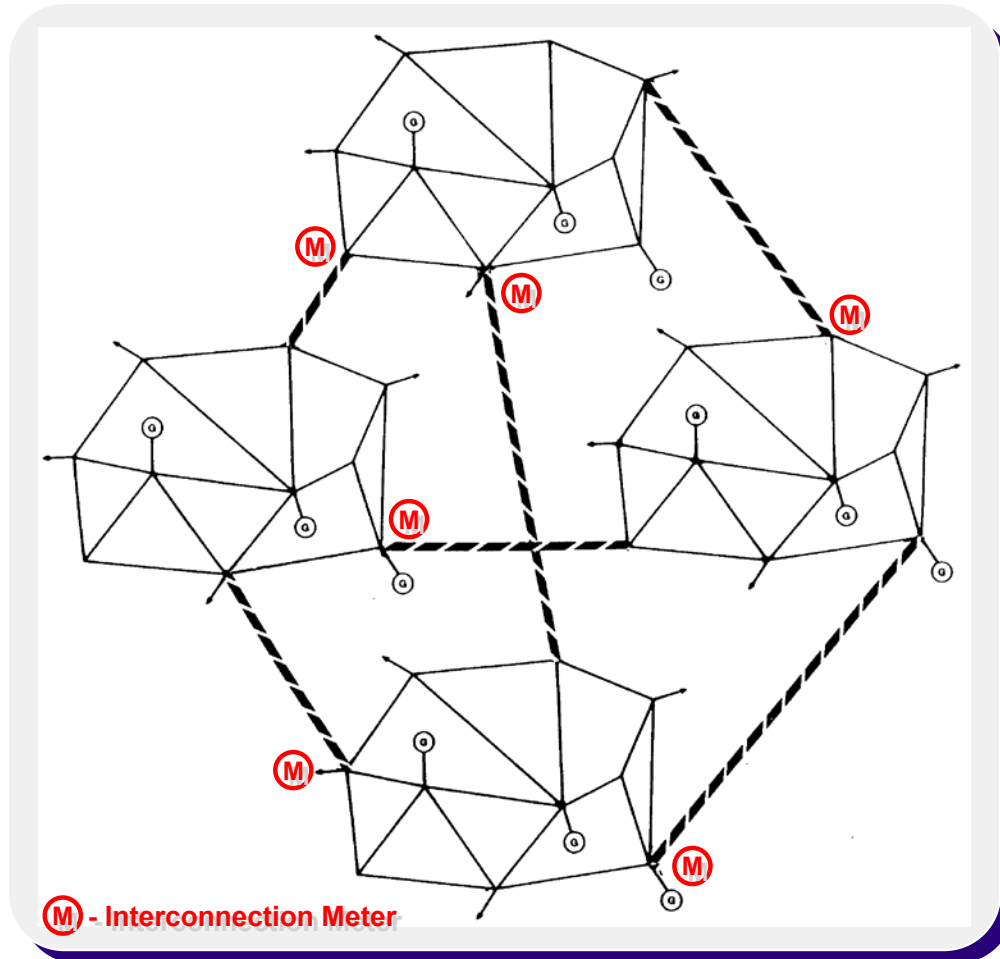
TWO SYSTEMS - MULTIPLE INTERCONNECTIONS



(M) - Interconnection Meters

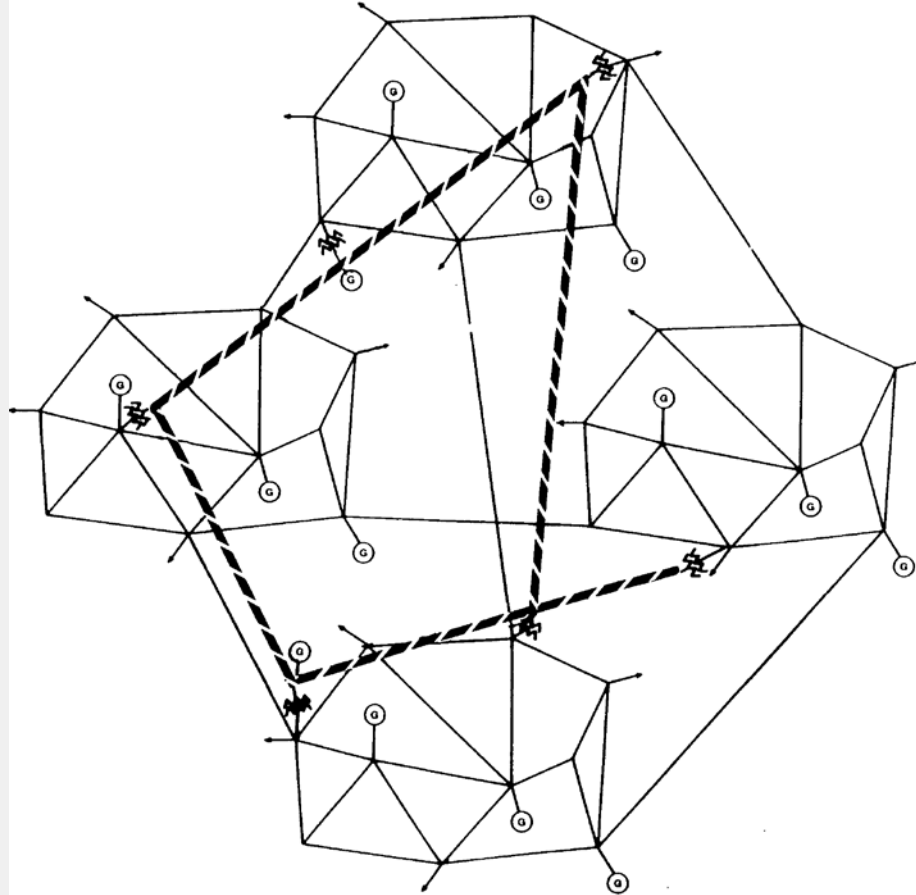


MULTIPLE SYSTEMS - MULTIPLE INTERCONNECTIONS



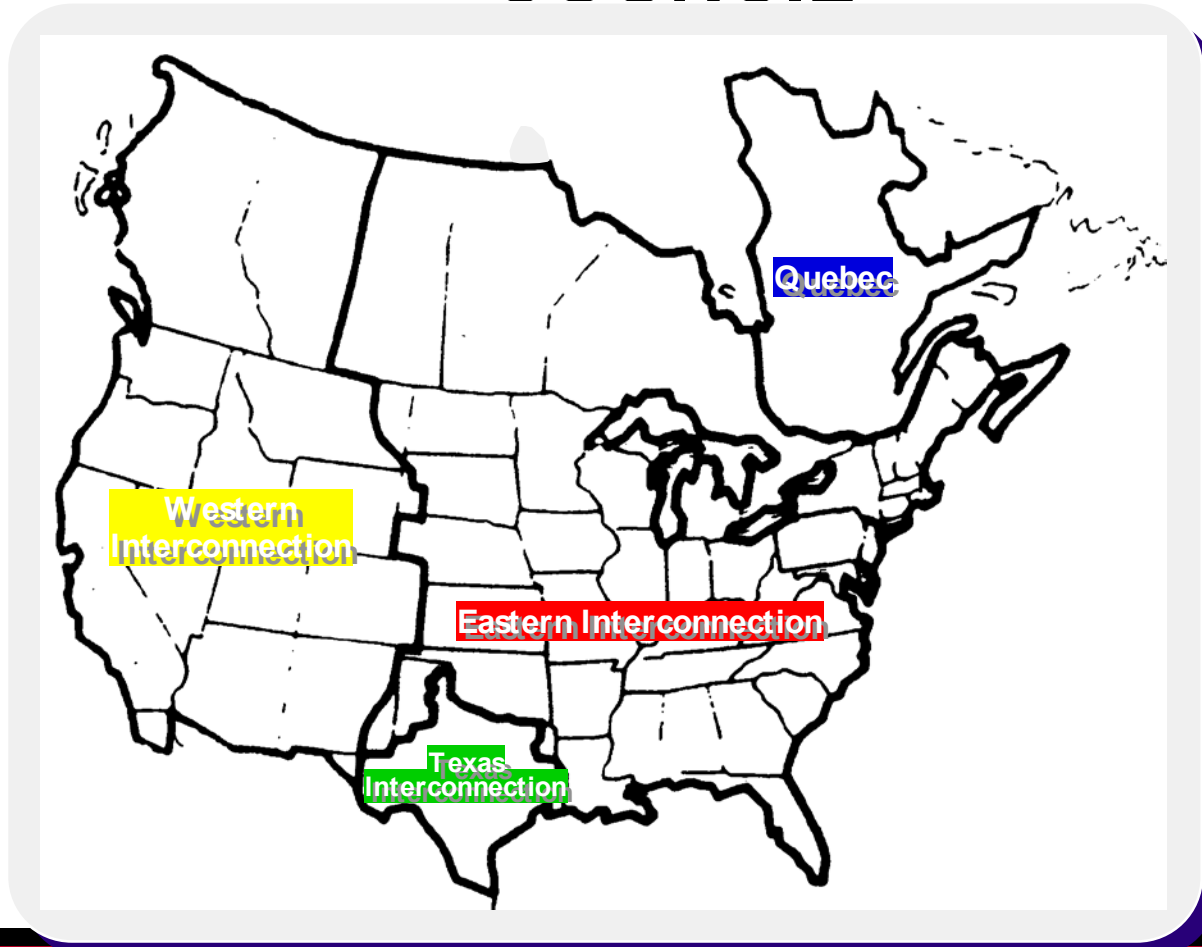


MULTIPLE SYSTEMS - MULTIPLE INTERCONNECTIONS - MULTIPLE VOLTAGE LEVELS





INTERCONNECTIONS of the NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL





WESTERN INTERCONNECTION





TRANSMISSION INTERCONNECTIONS

- **Benefits:**
 - **Lower generation reserve requirements**
 - **Fewer transmission facilities**
 - **Power sales and purchases for economic and emergency reasons**



TRANSMISSION INTERCONNECTIONS

- **Disadvantages:**
 - **Interconnected systems are impacted by each other's planning and operating practices**
 - **Potential for widespread uncontrolled cascading outages if not well-coordinated**
 - **Blackouts**
 - **Loop flows**
 - **Current follows the least resistance path**
 - **No corporate/state boundaries observed**

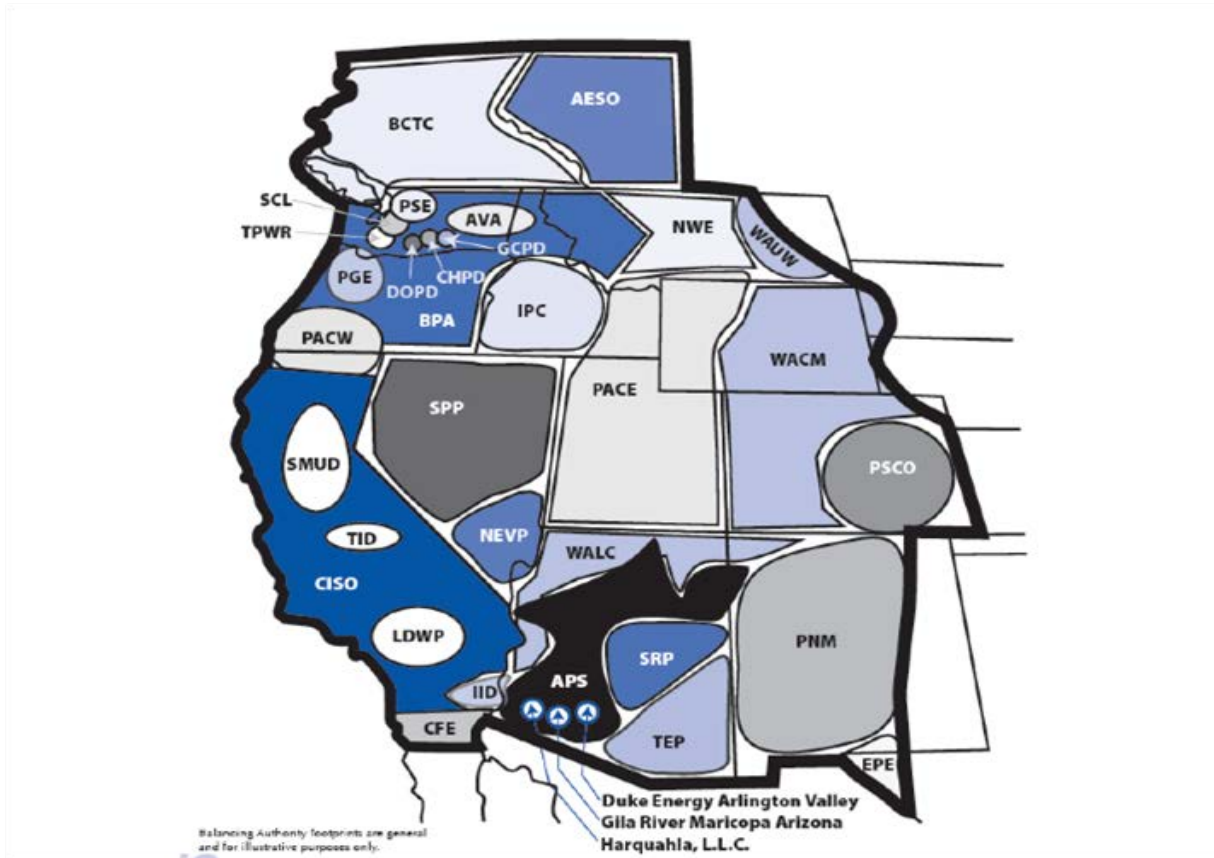


WHAT DETERMINES POWER FLOW?

- **Network structure**
- **Electrical characteristics of each line**
- **Distribution of generation resources and load centers**
- **Operation of generation resources**



WECC Balancing Areas





Reliability -- What it Means

- ❑ Definition
 - Adequacy and Security
- ❑ Network design effects on reliability
 - Planning and operations
- ❑ The role of balancing authorities
- ❑ Path definition, constraints, and flowgates
- ❑ Causes and impacts of an outage





RELIABILITY OF ELECTRICAL SERVICE

RELIABILITY n.s. The NERC Definition of Reliability is composed of two terms:

Adequacy: The ability of the system to meet the instantaneous peak demand under a variety of conditions. The adequacy of the system is planned and managed in real time.

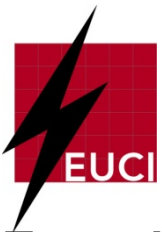
Security: The ability of the system to withstand the sudden loss of any one element or generating unit and be able to correct to a new operating point. The security of the system is managed in real time utilizing pre-approved planning and operating guides.



ADEQUACY OF SERVICE



- **Adequacy of Supply:** The measure of available generation in an area that can be reliably delivered across the grid. Both Gen and Trans availability are important.
- Demand is measured at meters all over the system. Defines Borders.
- Generation is scheduled to meet hourly demand in Balancing Area (BA).
- Balancing Area controlled at local level. High speed communications.
- Generator Dispatch accomplished by market or utility choice.



Security of Transmission Grid

- **Transmission Grid Security is monitored in Real-Time.**
 - **Safety Margin is Paramount. Path Rating Maintained?**
- **Transmission Outages are Frequent. Too Fast for Manual Fix.**
- **Consequences of System Disturbances Must be Managed.**
 - **Re-Adjust within 30 minutes to Safe Operating Point**
- **Power System Operations Happens in a Control Room.**
 - **Manned 24-7**
- **Operational Visibility. Extent of Control. Coordination of BA's.**
- **During Emergency, Market Rules Suspended. Support Mandatory**
- **Arrange for Generation Dispatch to Assist. Be Sure to Get Paid!**

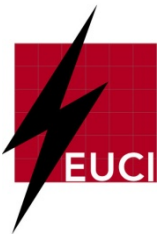




Security of Transmission Grid



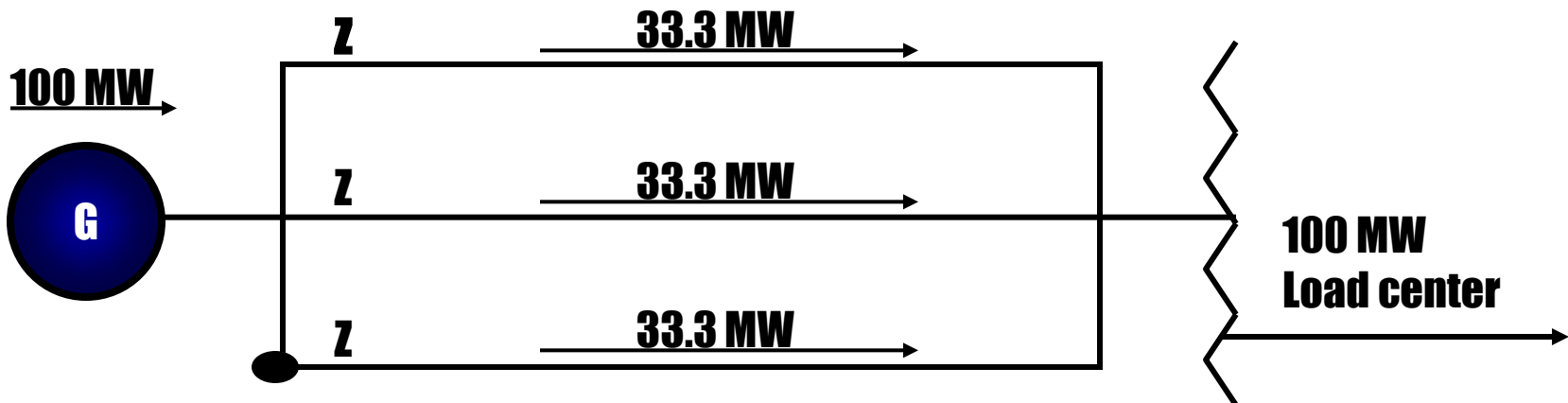
- **Transmission Outages are Hard to Predict**
 - **Declared Emergency??**
 - **Snow, Hurricane, Tornado, Flood**
 - **Most Frequent Cause ??????**
- **Consequences of System Disturbances Managed.**
 - **Re-Adjust to new Safe Operating Conditions**
 - **Lights May Still Be Out in Some Areas**
- **Operational Visibility During Emergency**
 - **Must Be Maintained At All Times**
 - **NERC Standards and Certification**
 - **Communication Protocol**



CONNECTING GENERATION TO LOADS

Example A

Three transmission lines having equal impedances
(z)

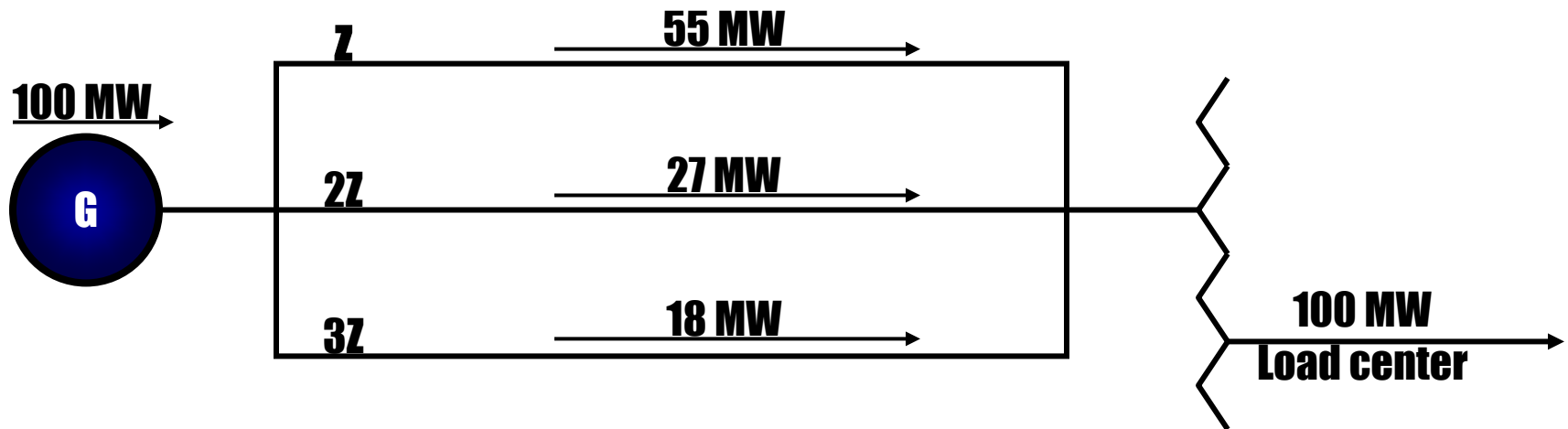




CONNECTING GENERATION TO LOAD CENTERS

Example B

Three transmission lines having unequal impedances (z), ($2z$) and ($3z$)

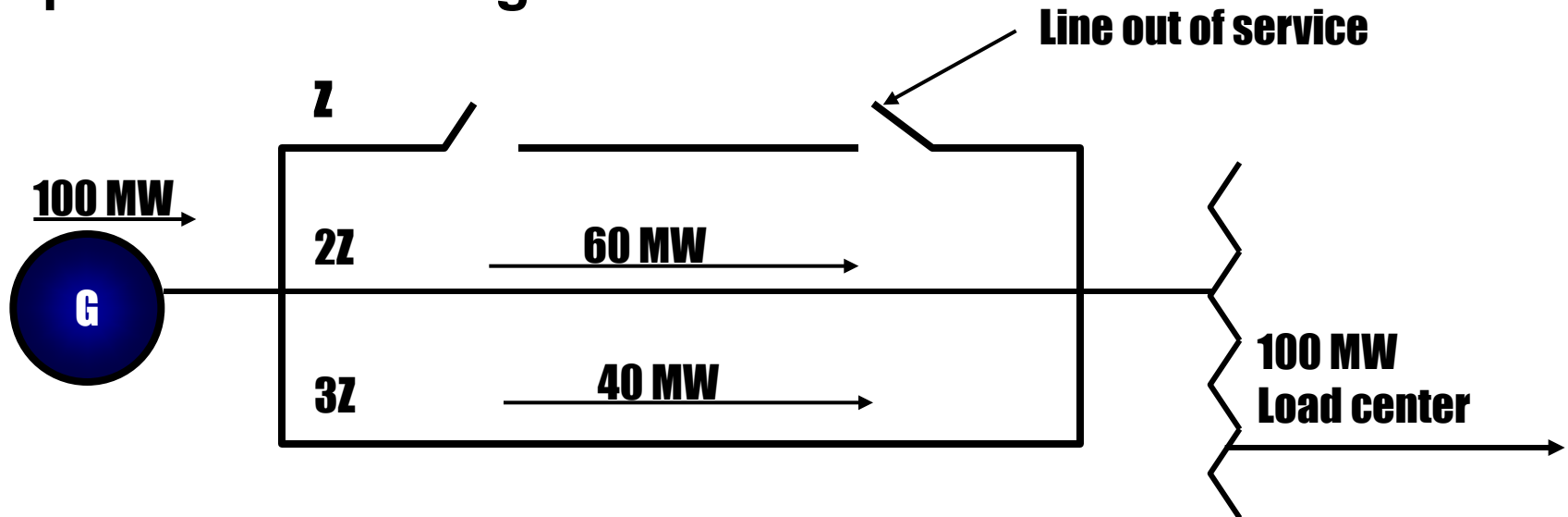




CONNECTING GENERATION TO LOAD CENTERS

Example C

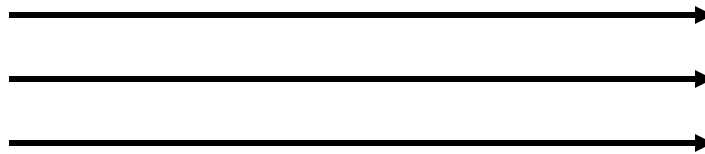
Impact of line outages



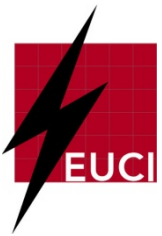


RELIABILITY REQUIRES ADEQUATE TRANSMISSION SYSTEM MARGINS

**Insufficient
transmission**



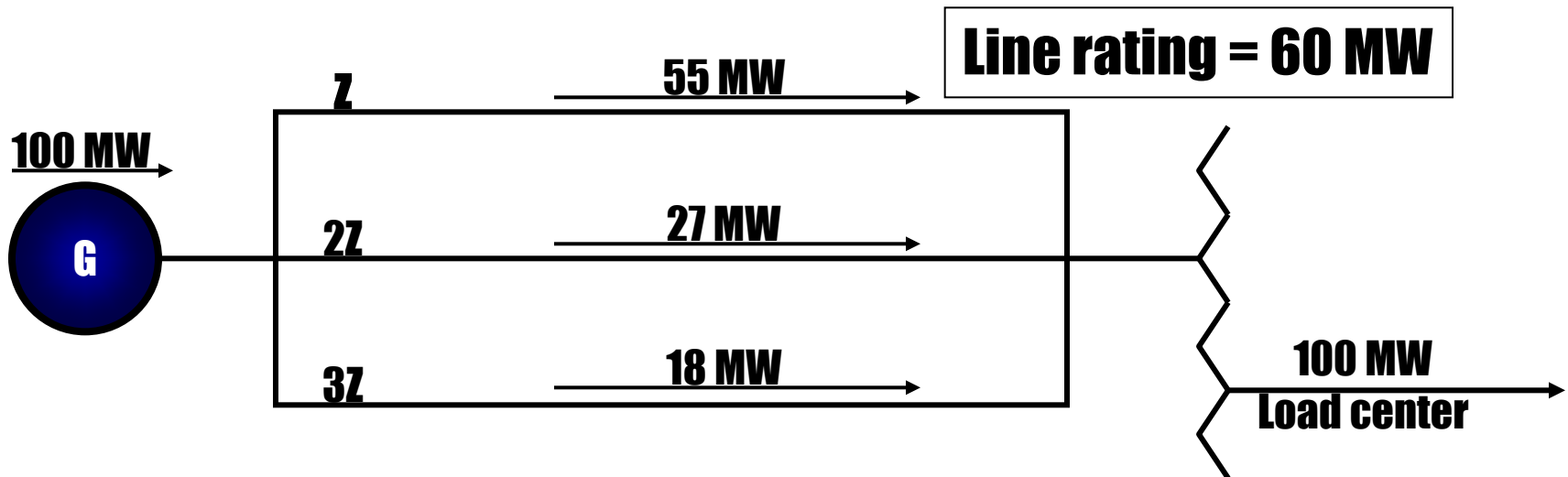
**Widespread
power
interruptions**



IMPACTS OF INADEQUATE MARGINS

Example A

Three transmission lines having unequal impedances z , $2z$ and $3z$; adequate margin

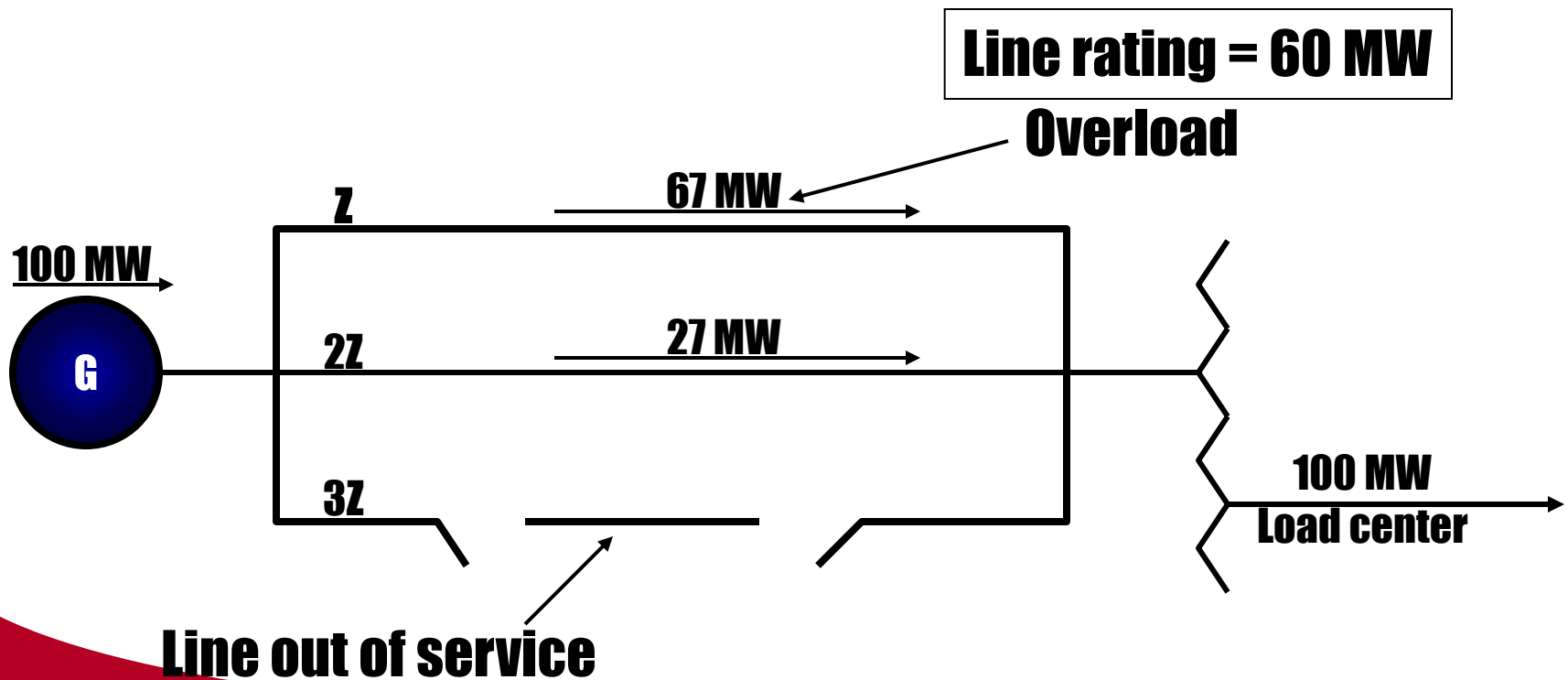




IMPACTS OF INADEQUATE MARGINS

Example B

Impact of having inadequate transmission margin





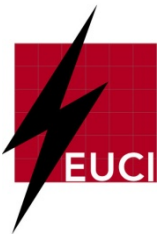
WECC PATH RATING PROCESS

- **WECC Defined System Interfaces – Path**
- **Path Rating Process is rigorous analysis**
- **Paths may have Seasonal Ratings**
 - **Temperature Dependent**
 - **Generation Dependent**
- **New Trans Affects Existing Path Ratings**
- **Path Ratings are Critical to Market Success**



TRANSMISSION SYSTEM PROTECTION

- **Why Power System protection?**
 - **To cause prompt removal from service any element that suffers short circuit/abnormal operation in order to:**
 - **Maintain safety,**
 - **Prevent damage to the equipment,**
 - **Maintain reliable operation of the rest of the system.**

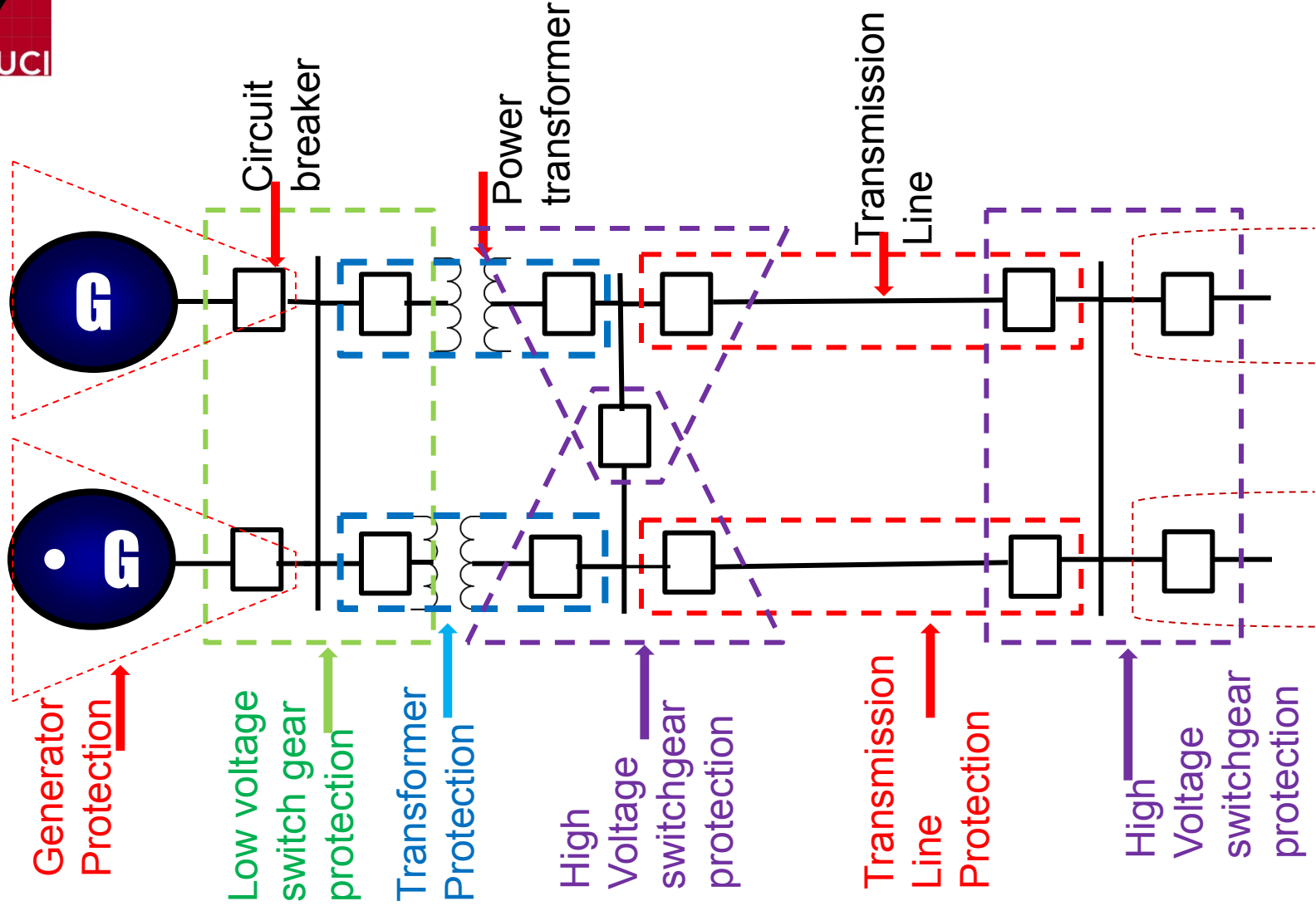


TRANSMISSION SYSTEM PROTECTION

- **Protective Relaying Equipment**
 - **Circuit Breakers**
 - **Protective relays**
 - **Current and potential transformers**
 - **Control circuitry, DC power, and ancillary equipment**
- **Protective relays**
 - **Electromechanical**
 - **Electronic**
 - **Digital**
- **Generally, faults are cleared in 5 milli seconds**
- **Primary and back-up protection**



POWER SYSTEM PROTECTION



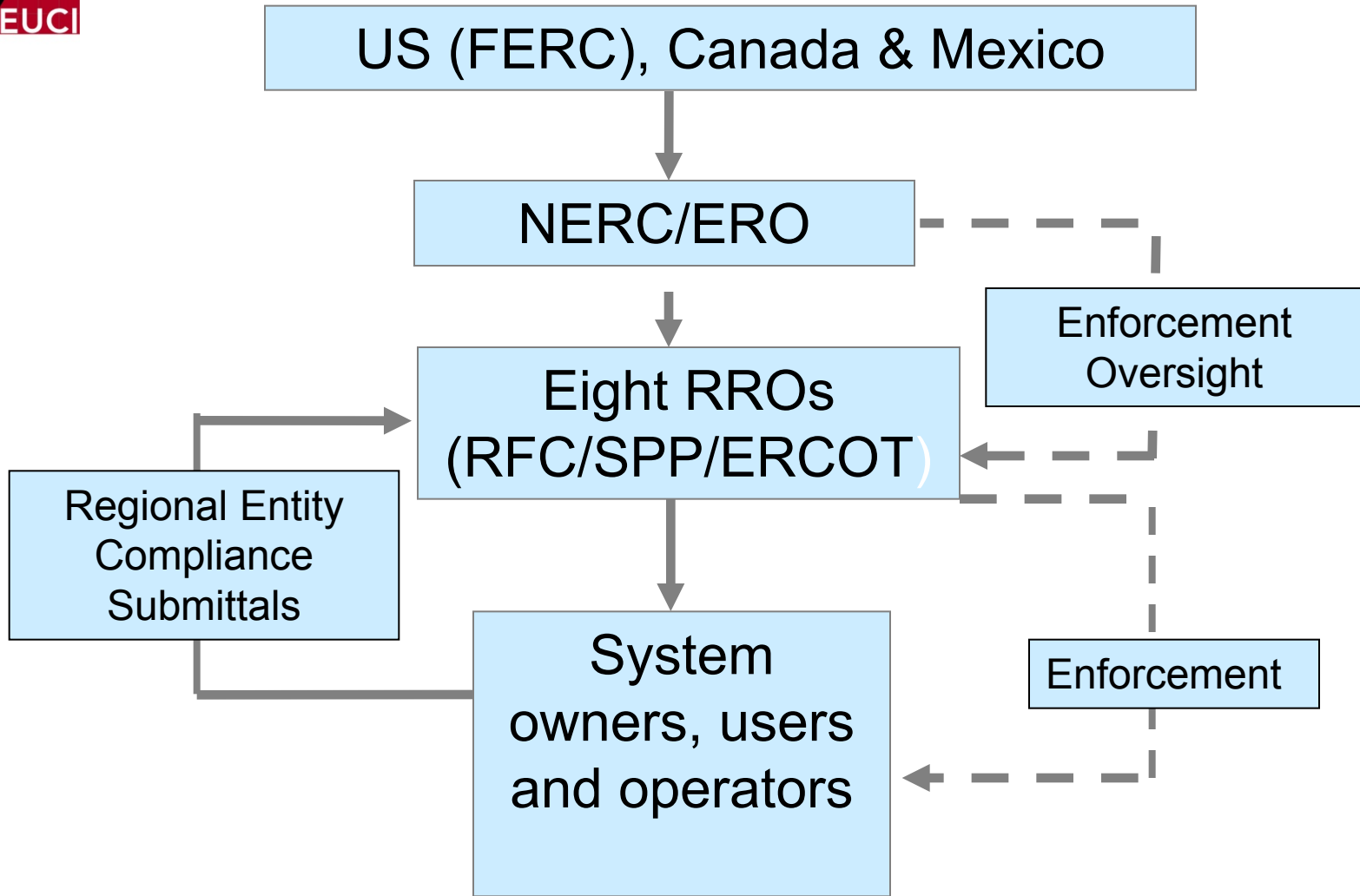


NERC RELIABILITY STANDARDS A COMPLIANCE PLAN

- FERC approved NERC as an ERO, per EPCA 2005
- Voluntary to mandatory reliability compliance era
- To start with, over 100 standards and over 1000 requirements to be complied with



NERC Compliance Process Overview





Risks: Penalties and Sanctions

Violation Risk Factor	Violator Size & Time Horizon Limits	Violation Severity Level			
		Lower	Moderate	High	Severe
Lower	Base Penalty	\$1,000	\$3,000	\$6,000	\$10,000
	Lower Upper	\$1,000 \$2,000	\$1,000 \$6,000	\$1,500 \$12,000	\$2,000 \$20,000
Medium	Base Penalty	\$5,000	\$15,000	\$25,000	\$40,000
	Lower Upper	\$2,000 \$10,000	\$3,000 \$30,000	\$5,000 \$50,000	\$8,000 \$80,000
High	Base Penalty	\$35,000	\$50,000	\$70,000	\$100,000
	Lower Upper	\$7,000 \$70,000	\$10,000 \$100,000	\$14,000 \$140,000	\$20,000 \$200,000

Lower – Usually Administrative Violations

Medium – Potential to Effect the BES (Bulk Electric System)

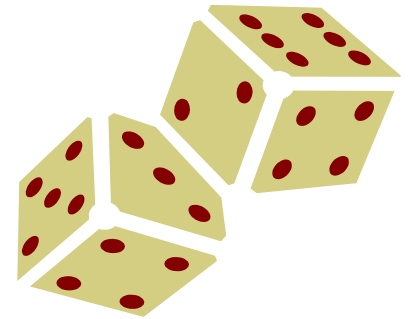
High – Potential for Instability, Separation or Cascading





Risks: Penalties and Sanctions (Cont'd)

- FERC statutory limit: \$1,000,000 per violation per day
- Non-financial sanctions allowed
- Penalty funds apply to marginal cost of enforcement, reconciled in budget
- Other qualitative factors for consideration:
 - Repeat infractions
 - Prior warnings
 - Deliberate violations
 - Self-reporting and self-correction
 - Quality of entity's compliance program



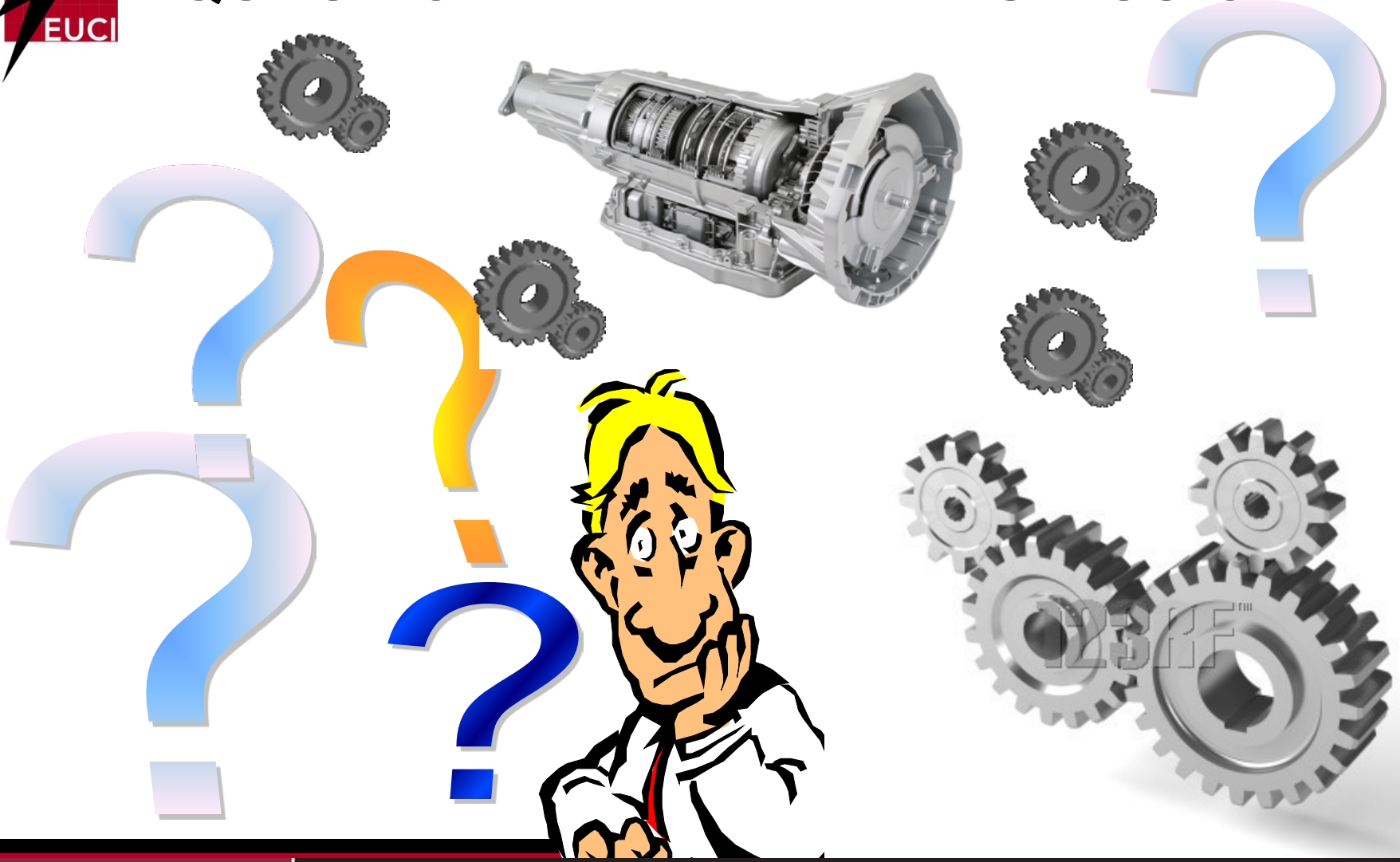


NERC COMPLIANCE

- The NERC process is continually evolving
- NERC compliance is here for the long term
- Need to be proactive participant in this regulatory process – *“Culture of Compliance”*
- Access NERC at: <http://www.nerc.com>



QUESTIONS ABOUT TRANSMISSION?



Kim Berns, Division Chief
Division of Lands, Realty & Cadastral Survey
BLM – Washington Office
kmberns@blm.gov
202-912-7350

Lucas Lucero, Rights-of-Way Branch Chief
BLM - Washington Office
llucero@blm.gov
202-912-7342