WATERPOWER
HYDRO BASICS

JULY 15-16, 2024

COLORADO CONVENTION CENTER
DENVER, COLORADO

CO-LOCATED WITH

HYDROVISION INTERNATIONAL

Electrical Basics

- ❑ Properties of Electricity
- ❑ Ohms Law
- ❑ AC/DC Current
- ❑ The Power Triangle

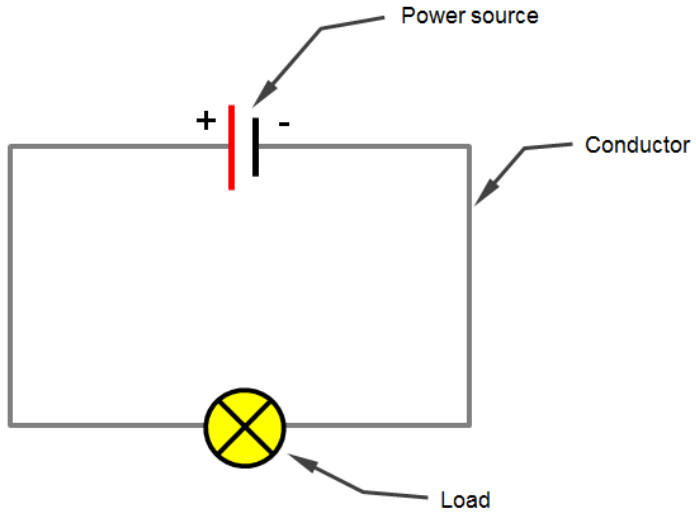
Overview: Power Generation Electrical Assets

- The Switchyard & Take-off Structures
- Switchgear & Transformers
- Generator & Excitation
- Protective Devices
- DC Systems
- Instrumentation & Control

Electricity is the flow of electrons through conductors within an electrical circuit.

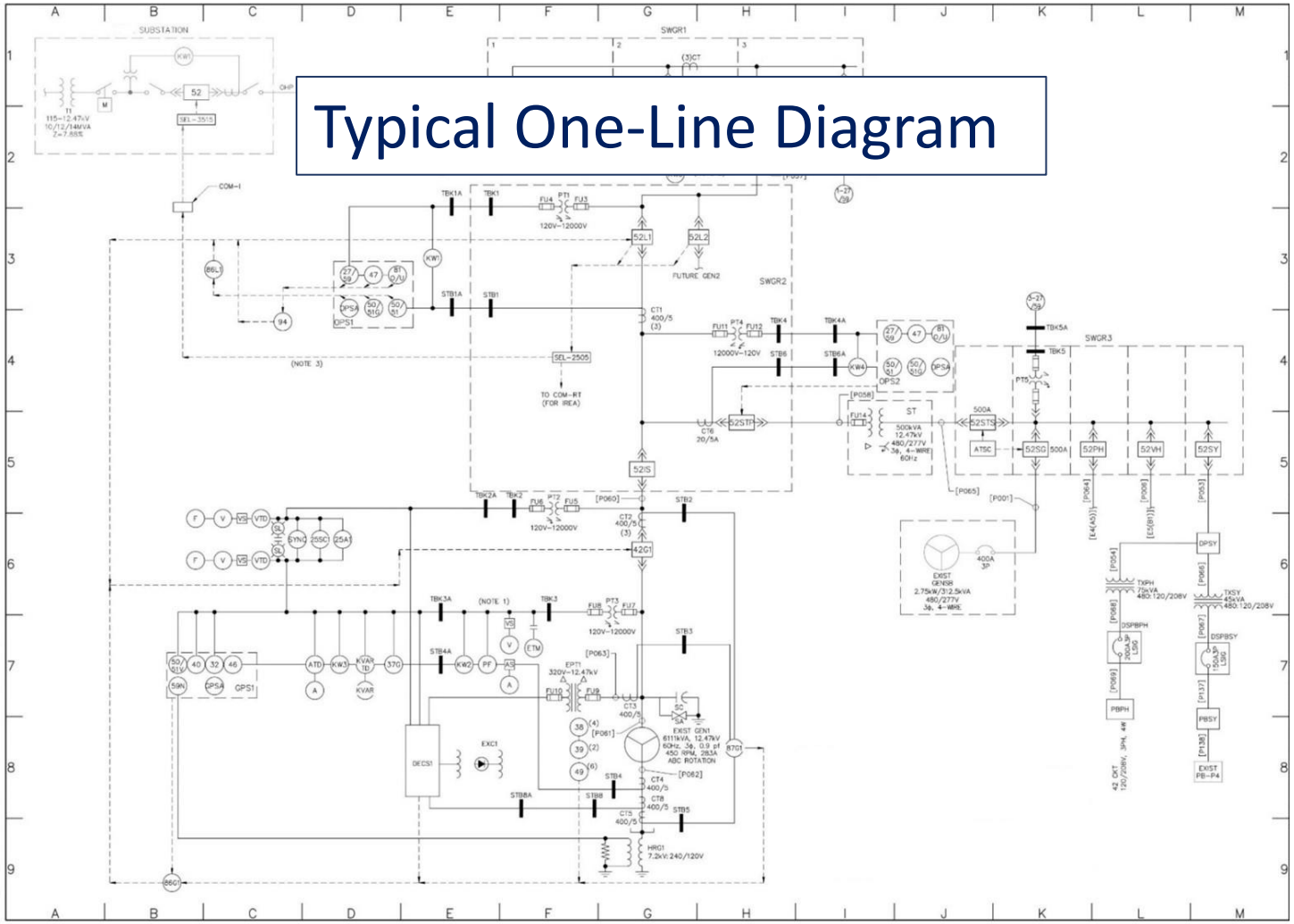
Electrical circuit in hydropower include.

- Generator
- Protective Devices
- Conductors
- Transformers
- Switchgear



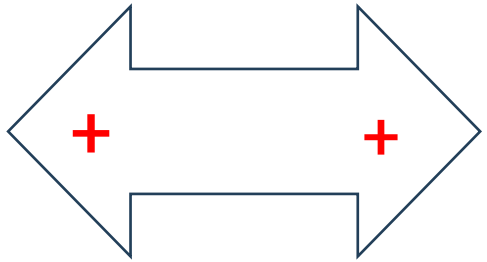
Electricity must have a complete path for electrons to flow from the source to the load.

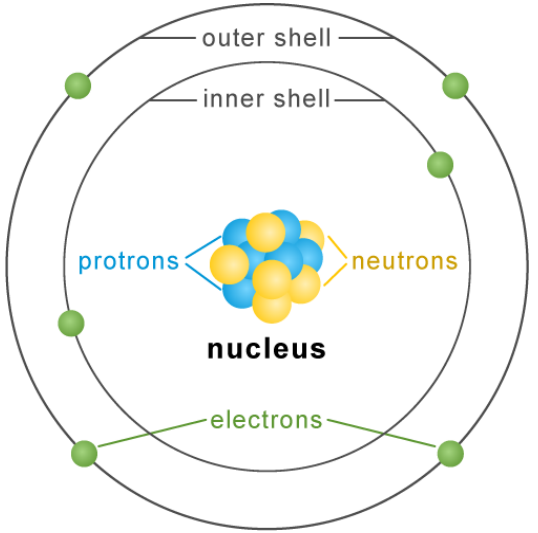
What does an electrical circuit look like on paper?



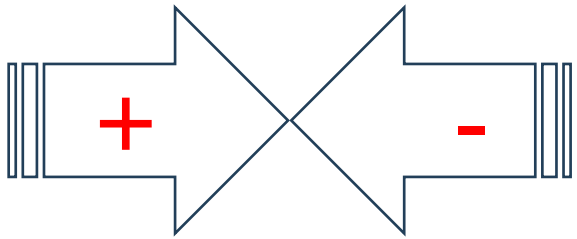
The Atom

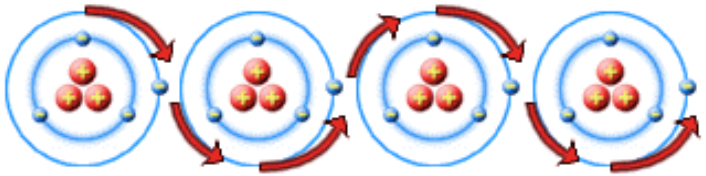
- Protons (+) & Neutrons are contained in the nucleus.
- Electrons (-) are moving in valence shells.
- Like charges repel



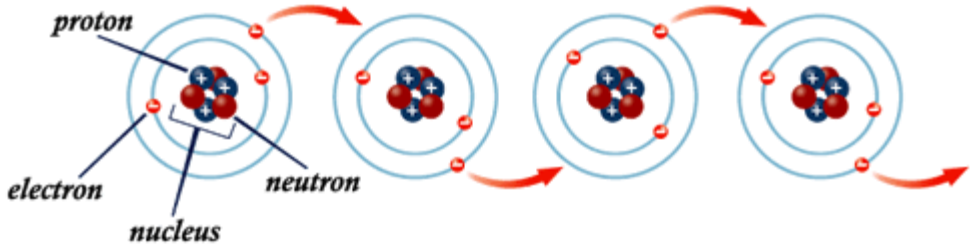


- Opposite charges attract.





- Some electrons are held loosely in the outer shell.
- This makes it easier for electrons to move from 1 atom to another.
- That movement of electrons is the foundation of how electricity starts.



Properties of Electricity

I

Current

- Symbol: *(I)*
- Measured in *amperes or amps.*
- Current is the *flow* of electrons between 2 points through a conductor within an electrical circuit.

V

Voltage

- Symbol: *(E or V)*
- Measured in *volts.*
- Voltage is the amount of charge or "*pressure*" in a conductor. Electromotive Force (EMF)

Resistance

R

- Symbol: *(R)*
- Measured in *ohms.*
- Resistance (DC) or Impedance (AC) is the opposition to *current flow.*

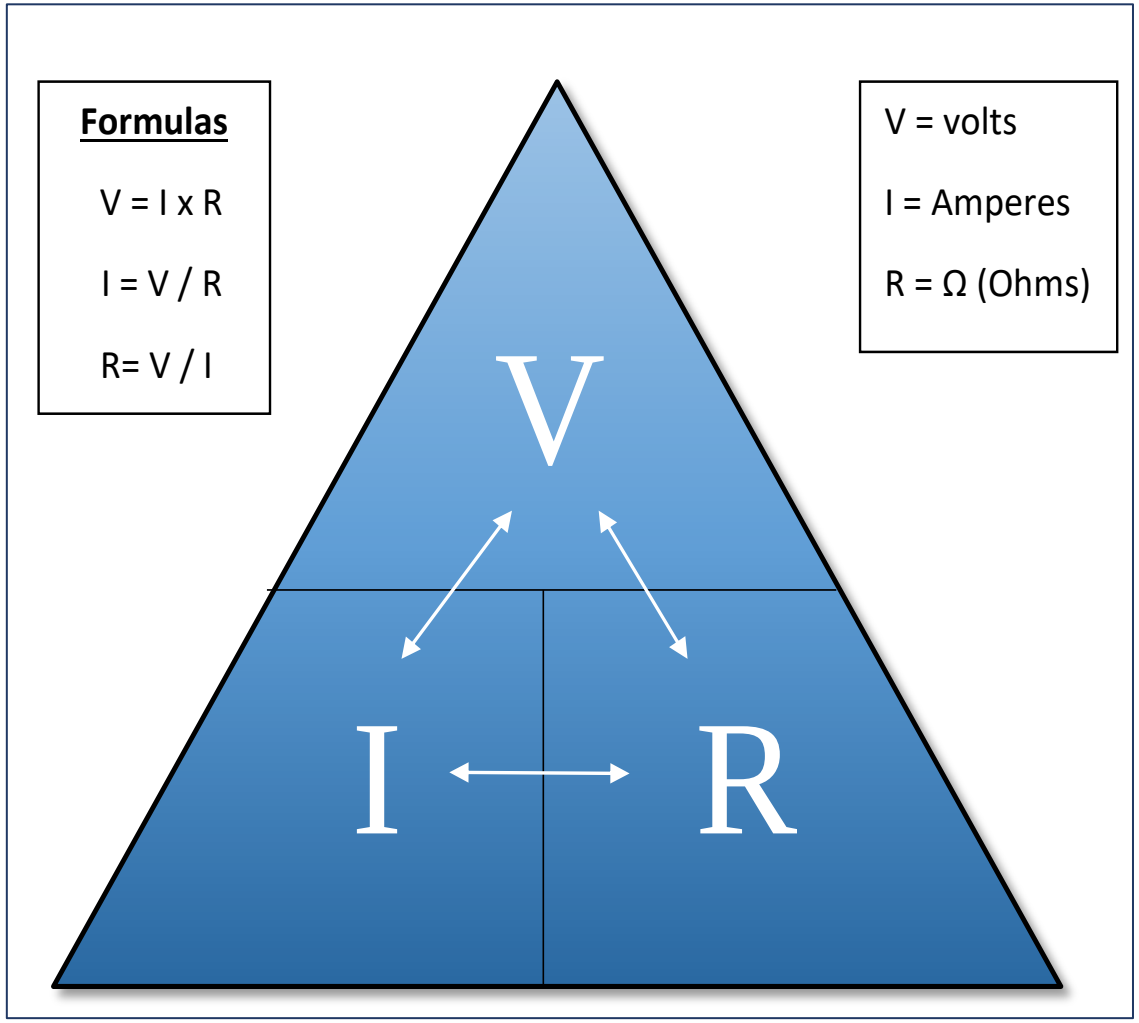
Power

P

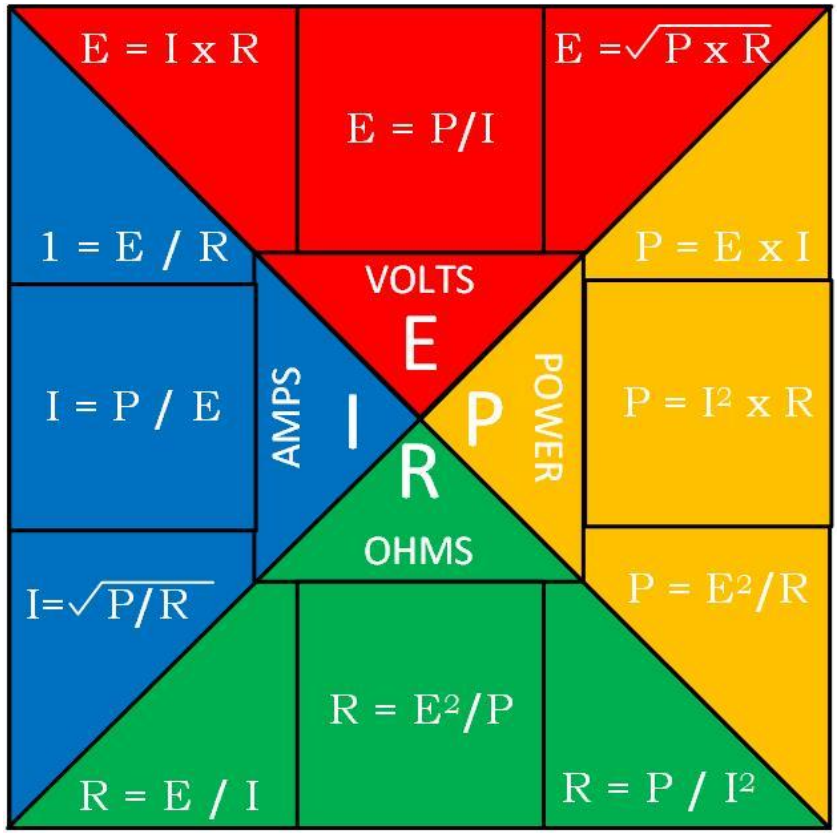
- Symbol: *(P)*
- Measured in *watts [instantaneously or a given point in time]*
- Measured in *watt-hours* or *kilowatt-hours [overtime] as Energy*

Ohm's Law Triangle

There is a Relationship between Volts, Amps & Resistance.

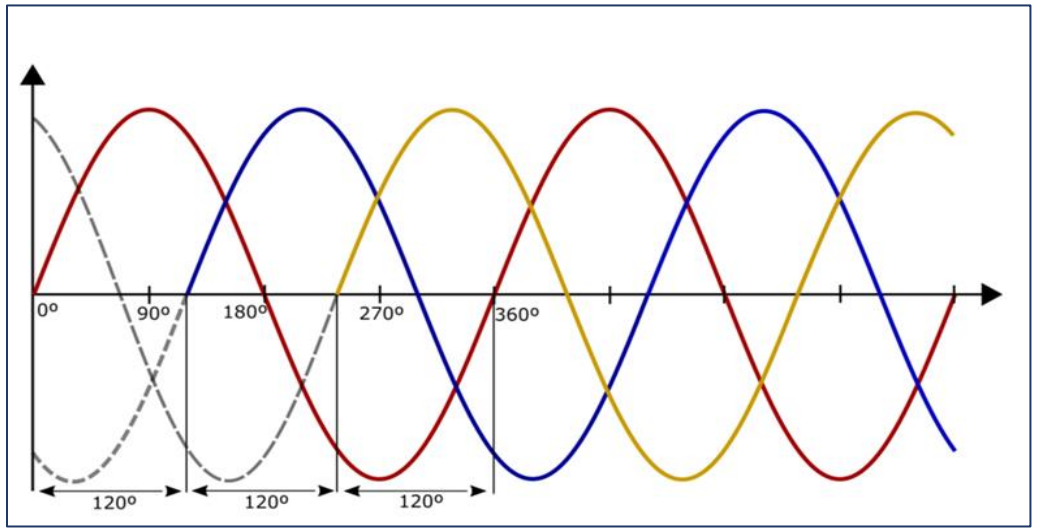


One step further by adding in Power to see the formulas to calculate known values



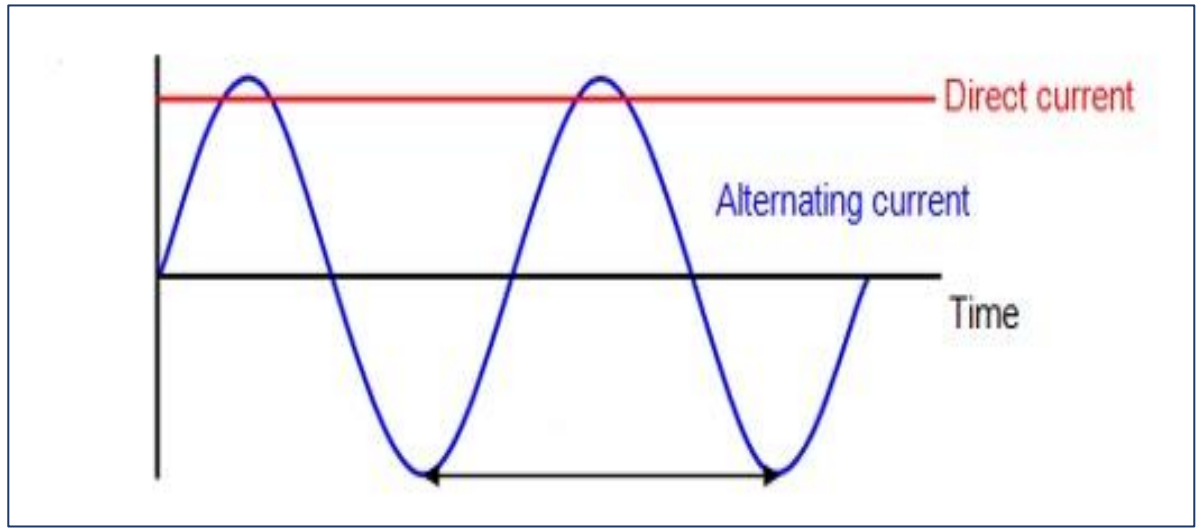
Types of Electrical Current

Source → Load



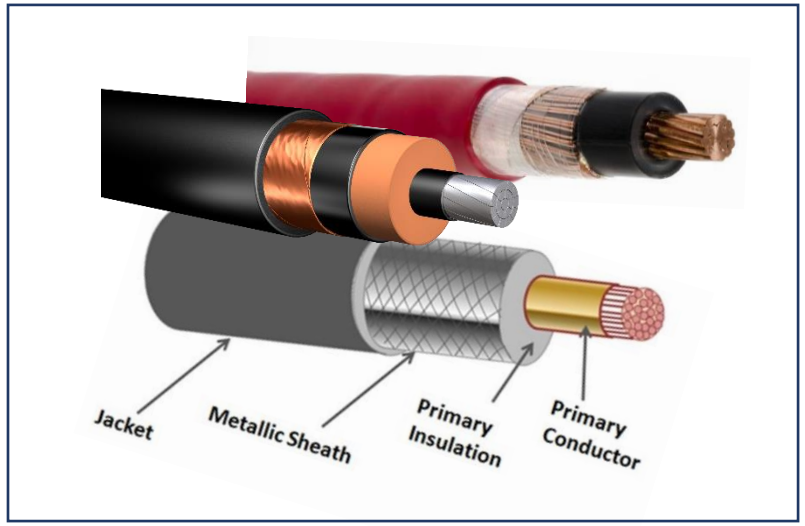
Alternating Current [AC]

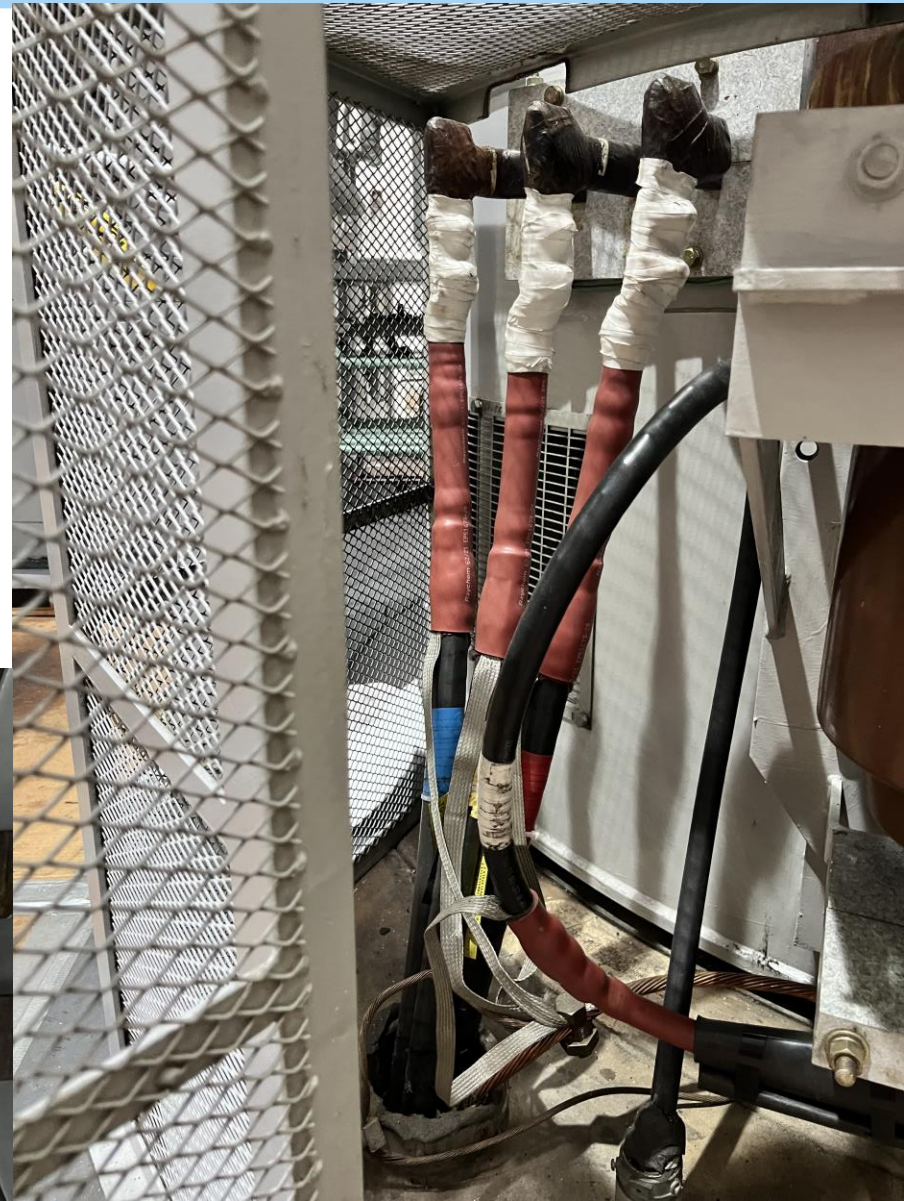
Source → Load



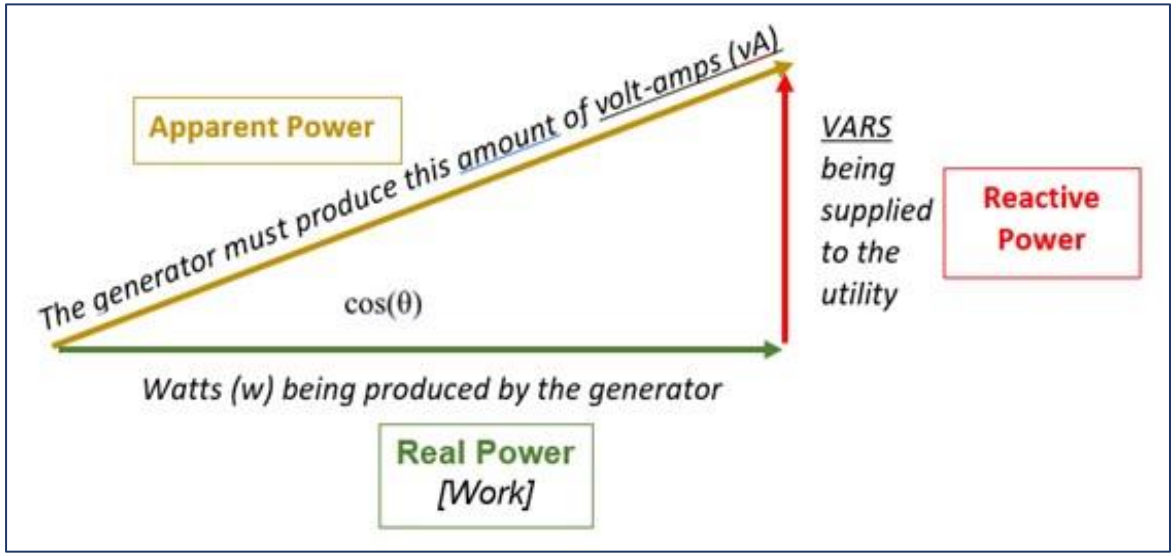
Direct Current [DC]

Conductors


Jacket
Metallic Sheath
Primary Insulation
Primary Conductor



The Power Triangle



Power in an AC circuit.

Relationship are interrelated quantities between *Active Power*, *Reactive Power* & *Apparent Power*.

❑ Real Power

- Measured in watts.
- Known as true or active power, this is the ***in-phase*** power that performs work.

❑ Reactive Power

- Measured in volt-amps reactive, this is the ***out-of-phase*** power, does not perform work.
- Makes it more difficult for real power to do it job.
- Occurs when current wave form is out of phase with the voltage wave form.
- Necessary for Inductive & Capacitive Loads

Apparent Power

- Total power delivered to an AC circuit.

Power Factor

- PF = watts / Volt-Amperes
- The ratio of real power to apparent power,
- This is an instantaneous measurement of how effective your plant is producing real power.

Power Factor Explained through the Beer Analogy

The Glass = Apparent Power

Volt-Amps - [vA]

The Foam = Reactive Power

Volt-amps reactive [vars]

Wattless power - Doesn't performs work

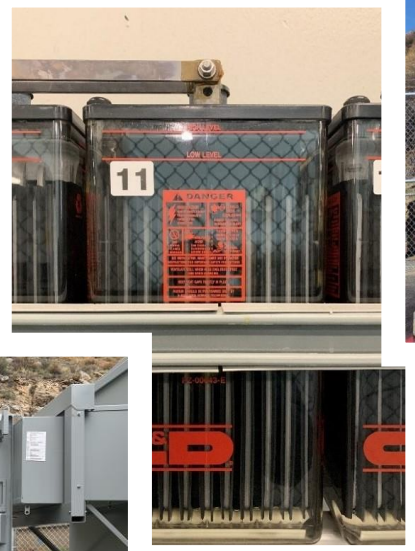
The Beer = Real Power

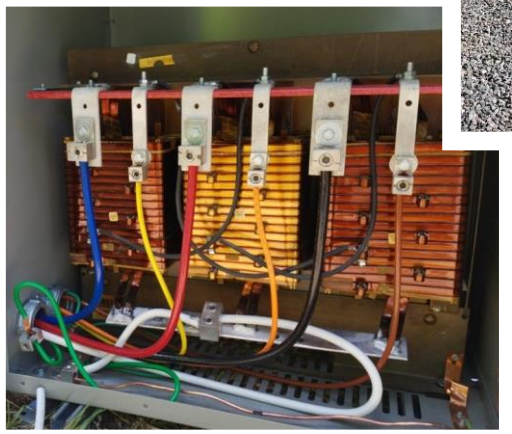
Watts - [w]

The value add, this is where the work happens

The less foam, the better the power factor. No foam equals power factor of 1.0

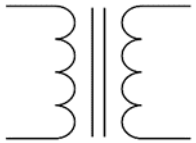
Hydropower Generation Assets



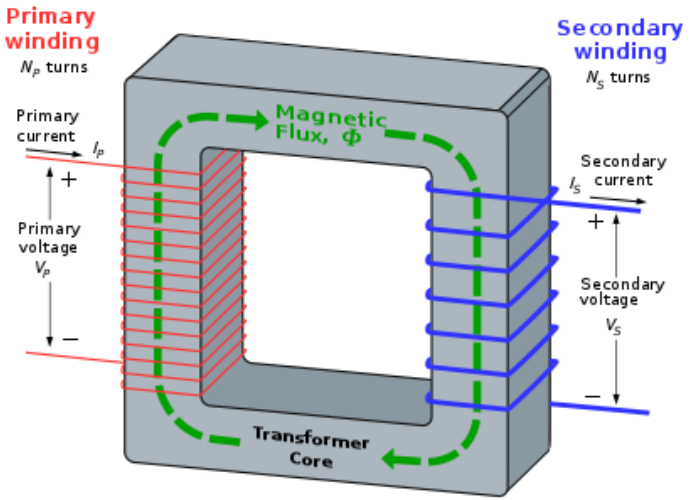


The Switchyard *[SWYD]* & Take off Structures

Transformers



XFMR



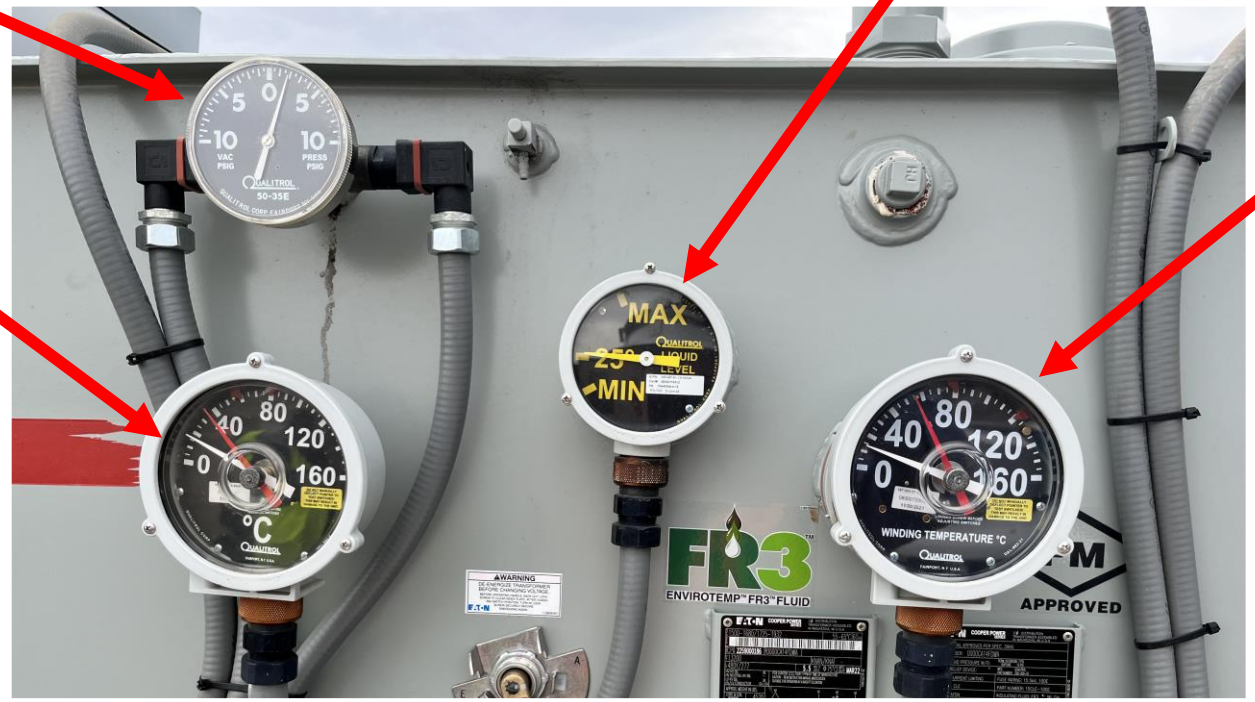
Pressure range

[optimal 0 - +4 psig]

Liquid Level

Liquid Temperature

- *White arm = current temp*
- *Red arm = last highest temp*



Winding Temperature

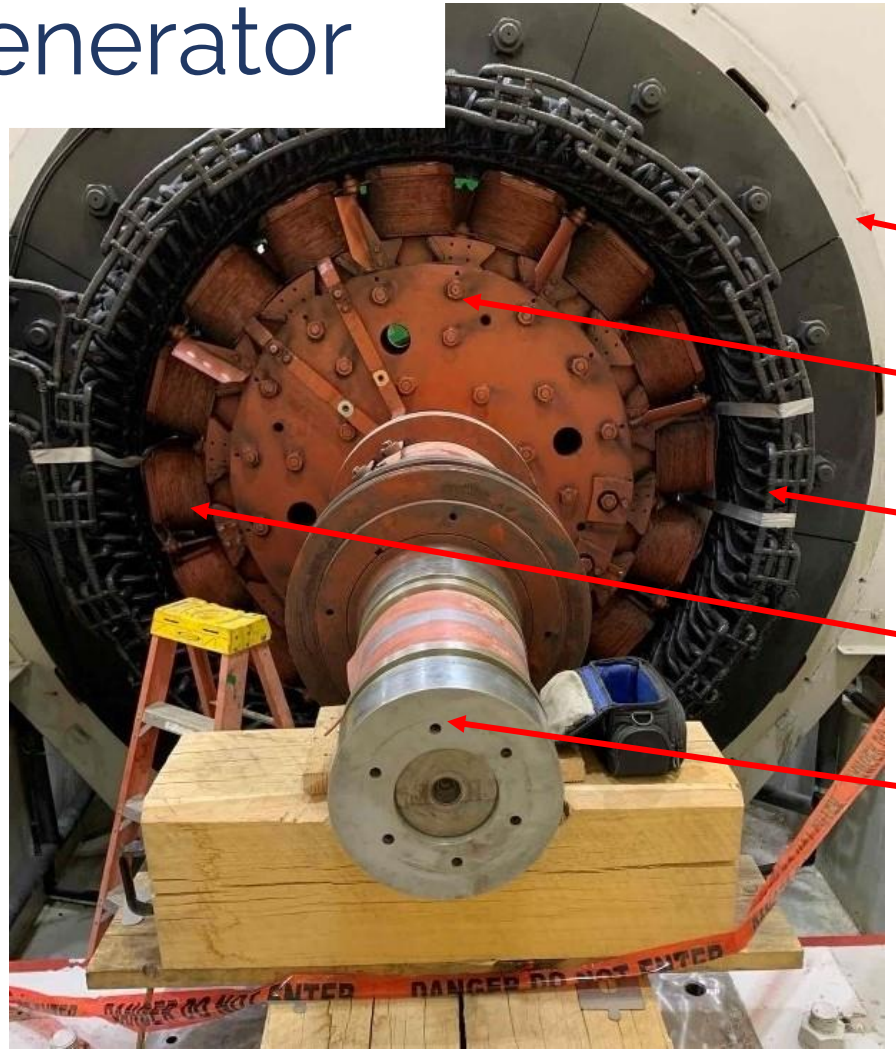
- *White arm = current temp*
- *Red arm = last highest temp*

- ❑ Stepping voltage up/down results in **ENERGY LOSS** in the form of **HEAT.**
- ❑ Cooling helps to mitigate the damaging effects of heat.
- ❑ Operators can sometimes monitor these changes using external mounted gauges.

Switchgear

- ✓ ANSI and IEEE standards define voltage classifications as follows:
- ✓ Switchgear is classified by the maximum voltage it can service.
- ✓ For example, 15 kV switchgear (maximum voltage rating) is commonly applied at various actual voltages including: 12.47 kV, 13.2 kV, 13.8 kV and 14.4 kV.
    - **Low voltage**: up to 600V
    - **Medium voltage:** between 600V and 69 kV
    - **High voltage**: between 69 kV and 230 kV
    - **Extra-high voltage** and ultra-high voltage classes

The Generator



- Generator Housing
- Rotor
- Stator
- Poles
- Shaft

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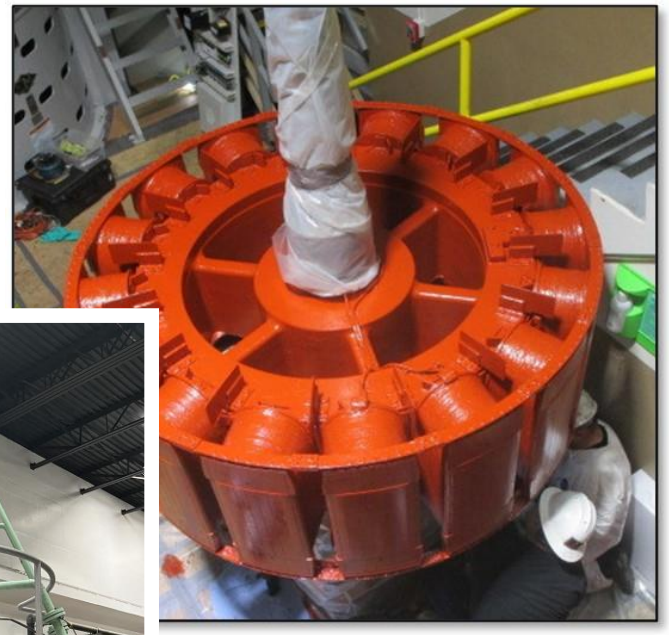


Excitation System

- Continuous DC current to the rotor windings.
- Responsible for maintaining constant terminal voltage in synchronous generators.
- AVR - Means of control

- Without excitation current, the generator operates without field current, therefore voltage is not induced in the stator windings.

Digital Governor

- Main controller of the prime mover – Turbine.
- Start, maintains and adjusts a unit's speed.
- Adjusts a unit's output when operators or other supervisory control commands are requested.
- Performs normal shutdown operations.
- Responds to emergency shut down during abnormal conditions like overspeed.

DC Systems

Backup DC power to critical equipment

- Bypass valves
- Lube Oil Systems
- Fire & Life Safety Systems
- PLCs

Instrumentation & Controls

- Integrated system of assets working together
- Monitors for safe system operations
- Controls system functionality
- I&C systems transmit data that informs
  - ✓ Automated system adjustments or notifications
  - ✓ Operator driven decision making
- Has the ability to react in real time to changes throughout the system

Protective & Isolation Devises

- Relays
- Circuit Breakers
- Fuses
- Disconnect switch
- Reclosure switch

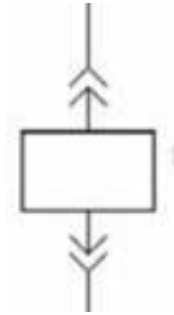
Protective Relays

Categories of Relays

- **Protection**
- **Monitoring**
- **Programing**
- **Regulating**
- **Auxiliary**

BE1-11g Generator Protection System

Circuit Breakers



Draw out breakers

- Provides a point of isolation.
- Designed to open during an electrical fault from ***overcurrent***.
- Interrupts ***current flow.***
- All different types and sizes.
- Unlike fuses, circuit breakers are designed for repeated operations

IEEE Device Codes

Standards in place across the electrical industry

Found on drawings like one-lines

Commonly used Protective Devises in Hydropower

- 42G Main Generator Breaker Control
- 52T Utility Feed Transformer, Breaker Control
- 52L Main Line Breaker Control
- 52STP Station Transformer Primary
- 52STS Station Transformer Secondary
- 86T Main Power Transformer
- 86G – Generator Lockout

Additional Resources

1. Handbook of Large Generators, Operations & Maintenance, 2021, IEEE Press, Bomben, Mottershead, Kerszenbaum, Klempner.

2. Department of Energy_Fundamentals Handbook, Electrical Science, Volume 1 thru 4.

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