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Basic Electricity

TESCO's Meter School

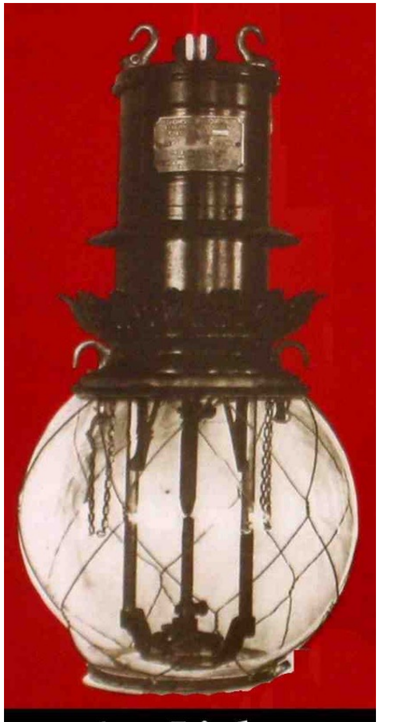
Date

Time

Presented by

A Little History

- **1800** Volta
  - First electric battery
- **1802**
  - Electric Arc Lamp invented
- **1830-31** Faraday and Henry
  - Changing magnetic field can induce an electric current. Build first very crude electric motors in lab.
- **1832** Pixii
  - First crude generation of an AC current.
- **1856** Siemens
  - First really practical electric motor
- **1860s** Varley, Siemens and Wheatstone
  - Each develop electric dynamos (DC Generators).


Arc Light

Electricity Starts to Take Off

- **1870s**
  - First electric railroad and street lights in Berlin (DC).
- **1879** Edison
  - Incandescent light bulb
- **1880**
  - First electric elevator (DC).
- **1885-88** Thomson, Ferraris, Tesla
  - Each develop AC electric induction motors.
  - Tesla is granted a US patent for induction motor in 1888.
- **1890** Dolivo-Dobrovolsky
  - First three phase generator, motor and transformer

AC vs DC

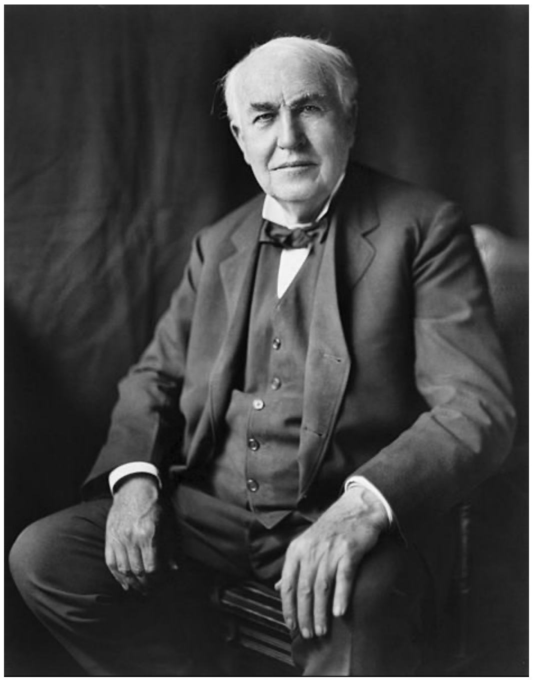
- **Direct Current (DC)** – an electric current that flows in one direction.(IEEE100)

- **Alternating Current (AC)** – an electric current that reverses direction at regularly recurring intervals of time. (IEEE100)

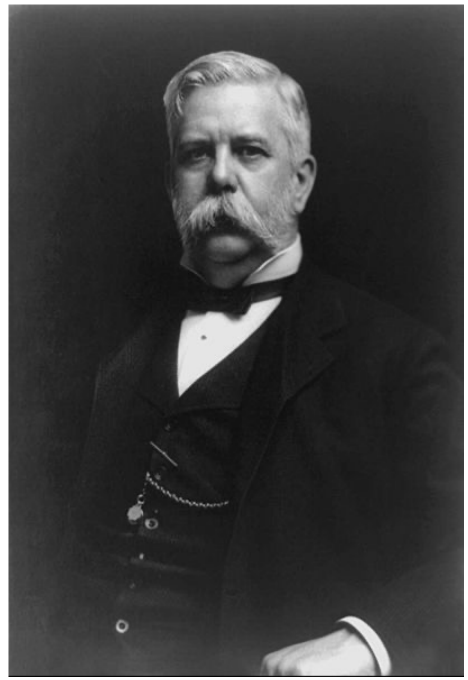
AC vs DC

- Edison and Westinghouse
  - Edison favored DC power distribution, Westinghouse championed AC distribution.
  - The first US commercial electric systems were Edison's DC systems.
- First AC system was in 1893 in Redlands, CA. Developed by Almirian Decker it used 10,000 volt, three phase primary distribution.
- Siemens, Gauland and Steinmetz were other pioneers.

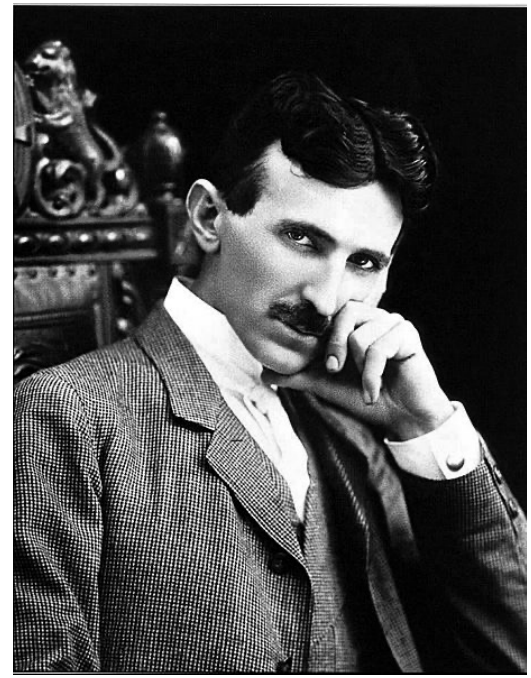
WAR OF THE CURRENTS



Thomas Edison



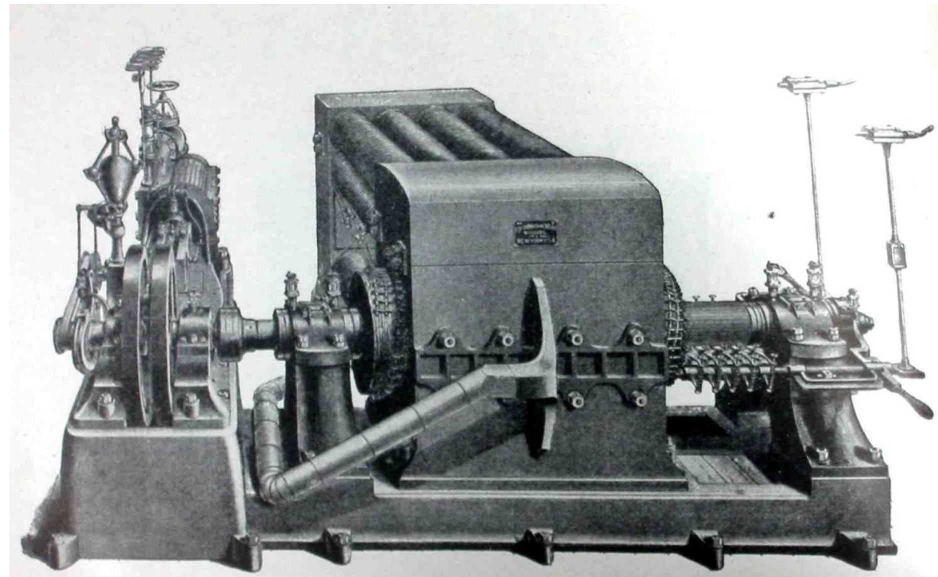
George Westinghouse



Nikola Tesla

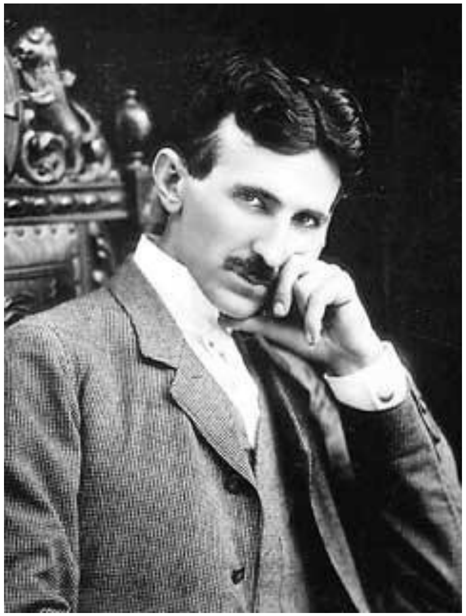
THE PROBLEM WITH DIRECT CURRENT

- High losses required generators to be near the loads – maximum of one mile without huge conductors
- Difficult to change voltages for transmission with DC


Jumbo Number 9—the Dynamo Which Supplied the First Current to the Public

Edison's Jumbo Number 9
at Pearl Street in New York City

1888: A Young Serb Named Никола Тесла (Nicola Tesla) Meets George Westinghouse



Nicola Tesla, "The Wizard of The West"

1893: World's Fair Chicago lighted by Westinghouse / Tesla

1882: Induction Motor

1888: Westinghouse, American entrepreneur and engineer meets Tesla

1893: Westinghouse Awarded the Contract for Powerhouse at Niagara Falls

Edward Dean Adams power station at Niagara, with ten 5,000-horsepower Tesla/Westinghouse AC generators — the culmination of Tesla's dream. **(Courtesy Smithsonian Institution)**

AC Theory - History

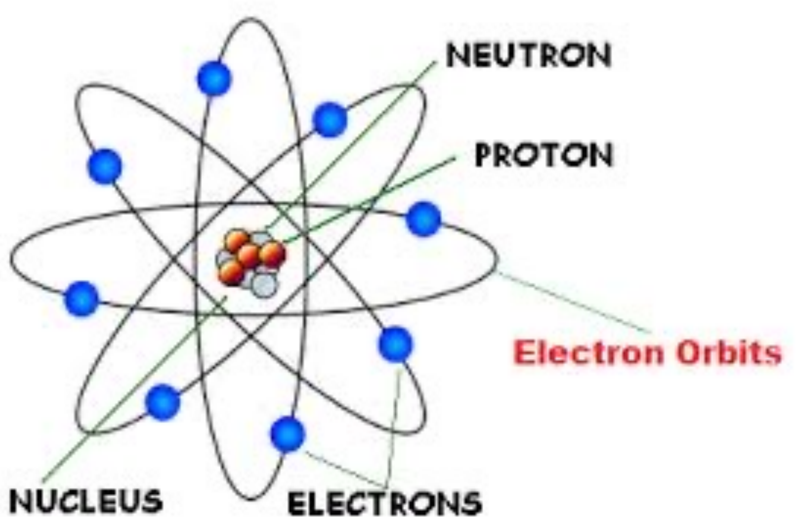
- By 1900 AC power systems had won the battle for power distribution.
  - Transformers allowed more efficient distribution of power over large areas.
  - AC motors were cheaper and easier to build.
  - AC electric generators were easier to build.

AC CIRCUITS

- An AC circuit has three general characteristics
  - Voltage
  - Frequency
  - Phase
- In the US, the household value is 120 Volts with other common voltages being 208, 240, 277 and 480 Volts. The frequency is 60 Hertz (cycles per second).

Some Background

- **The Atom**
  - All matter is made up of atoms.
  - Atoms are composed of three particles
    - Protons – with a positive charge
    - Electrons – with a negative charge
    - Neutrons – with no charge

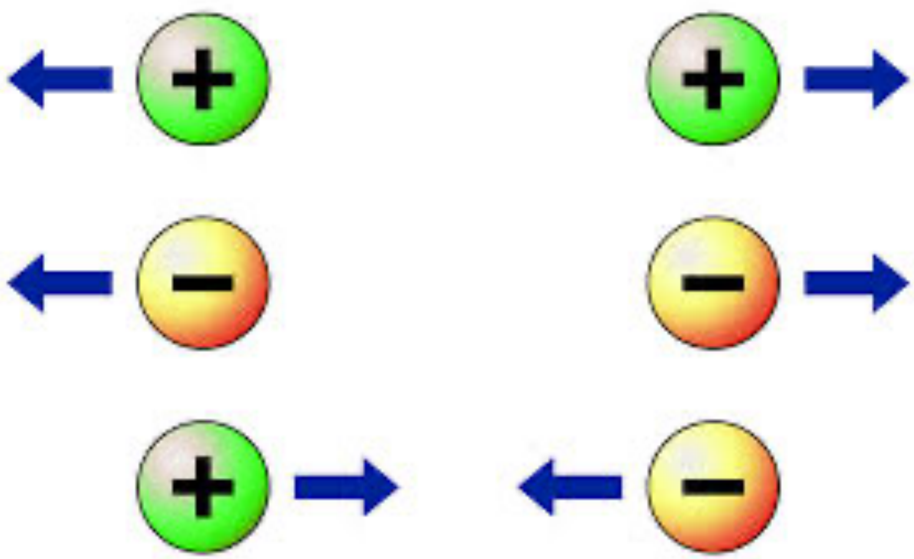


Each atom has the same number of protons and electrons. That number is called the atomic number of the atom and determines the element.

For example: If the atomic number is 8 as shown in the figure to the left the element is Oxygen (O).

Some Background

- **Charge**
  - Opposite charges attract each other.
  - That is what holds the electrons of an atom to the protons of the nucleus.
  - Like charges repel each other.

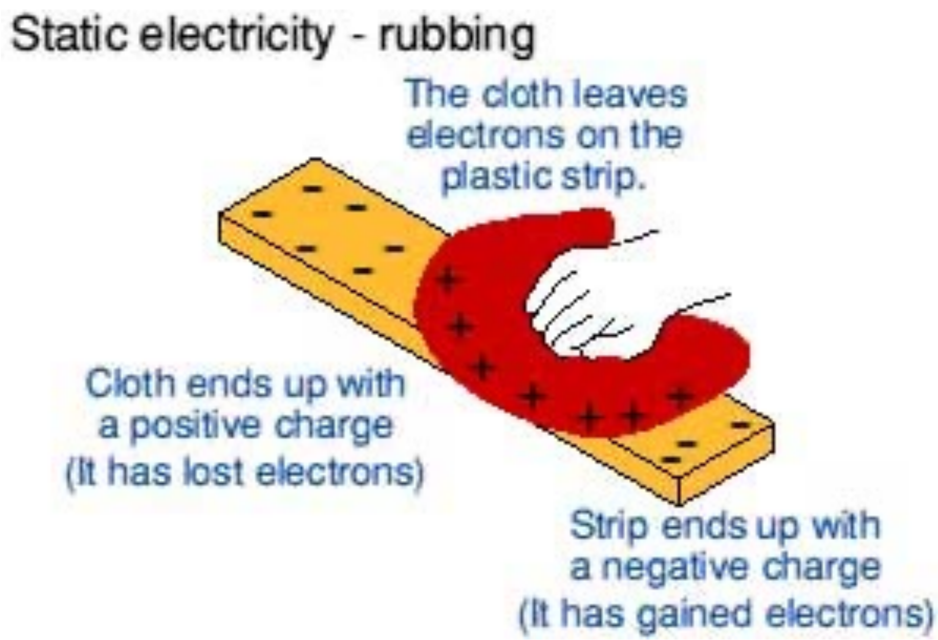


Man "Discovers" Electricity

- **Static Electricity**
  - Awareness of a "strange force" goes back to the beginning of recorded history. Early man realized that rubbing a piece of amber with an animal skin imparted some mystical property to the amber.
    - It would attract hair and small bits of debris.
    - We get the same effect when we rub a balloon on a fur or cloth

MAN "DISCOVERS" ELECTRICITY

- **Static Electricity**
  - What is this strange force? "Static" electricity.
    - Rubbing the cloth across an insulator causes electrons to move from one object to the other. This leaves one object with more electrons than it should have and the other with less. The cloth has less so it becomes positively charged.

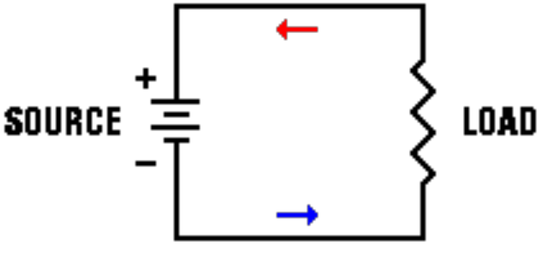


“DYNAMIC” ELECTRICITY

- **Current – Electrons flowing from one place to another**
  - If one object has a negative charge and another has a positive charge Electrons will flow from the negative to the positive if they are connected

PRACTICAL ELECTRICITY

- **Direct Current – DC**
  - In our “zap” electrons briefly travelled from the negative object to the positive object.
    - Until the excess electrons ran out the current flowed.
    - Once they ran out the current stopped.
  - A battery is a device that continuously supplies electrons through a chemical reaction.
    - Hook the positive side of a battery through a load to the negative side and electrons will flow.
    - This is a current (a flow of electrons)
    - Since it goes in only one direction it is called **DIRECT CURRENT**



PRACTICAL ELECTRICITY

- **Direct Current – DC**
  - Sources of direct current include
    - Batteries – electrons are supplied by a chemical reaction
    - Thermocouples – electrons are supplied by heat
    - Photovoltaic cells – electrons are supplied by light
    - Electronic Power Supplies – Generally transform AC electricity to DC electricity because electronic devices run off of DC electricity
  - There always has to be some form of energy to produce the electrons for the current
  - Modern electronic devices all run off of DC electricity

DC Electricity

- **Basic Concepts**
  - Current – The flow of electrons
    - The general convention is that a POSITIVE current is a current that flows from the positive terminal of the source to the negative terminal of the source
    - Why – Electrons actually flow the other direction?
      - Scientists made up the conventions long before they discovered electrons, they got it backwards and we still use the convention today.
  - Voltage – A measure of the potential difference between two points
    - Voltage is to current, as the pressure in a pipe is to the water
    - The higher the voltage (potential difference), the easier it is for current to flow
  - Impedance – Something which resists the flow of current.
    - Resistor – The most common and simplest impedance
    - Capacitor – An impedance which stores the electrons as they try to flow through
      - Energy is stored in an electric field
    - Inductor – An impedance which resists the change in current flowing through the device
      - Energy is stored in a magnetic field

Basic Electrical Units

- Charge – Coulombs
  - “Q” – 1 coulomb = 6.2415 x10^{18} electron charges
- Current – Amperes
  - “I or A” – 1 ampere = 1 coulomb per second of charge flow
- Voltage – Volt
  - “V or E” – The potential difference required to do 1 joule of work
- Impedance – Resistance - Ohm
  - “R” – Resistance
  - Ohm’s Law - $V = IR$
  - One volt applied across one ohm results in 1 ampere of current.

Basic Electrical Units

- Impedance – Capacitance - Farad
  - "C" – Capacitance
- Impedance – Inductance - Henry
  - "L" – Inductance
- Power – Watt
  - A **rate** of energy consumption. A measure of work performed.
  - For DC electricity = product of voltage and current
- Energy – For Electricity – Watt-Hours (DC ONLY – AC IS MORE COMPLICATED)
  - The energy when one ampere flows with a potential of one volt for one hour

Ohms Law

Voltage = Current times Resistance

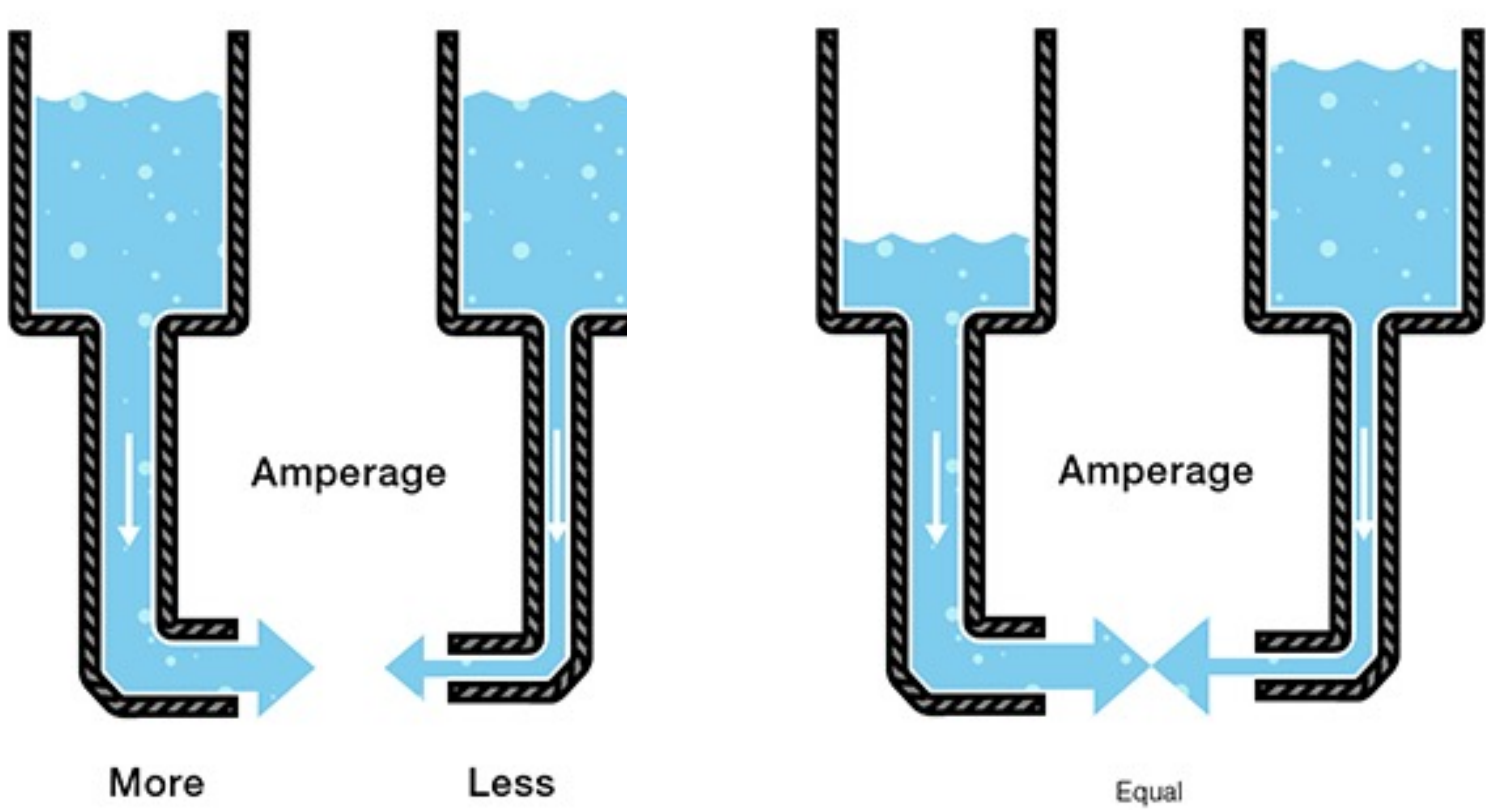
$V = I \times R$

THE MOST USEFUL AND THE MOST FUNDAMENTAL OF THE ELECTRICAL LAWS

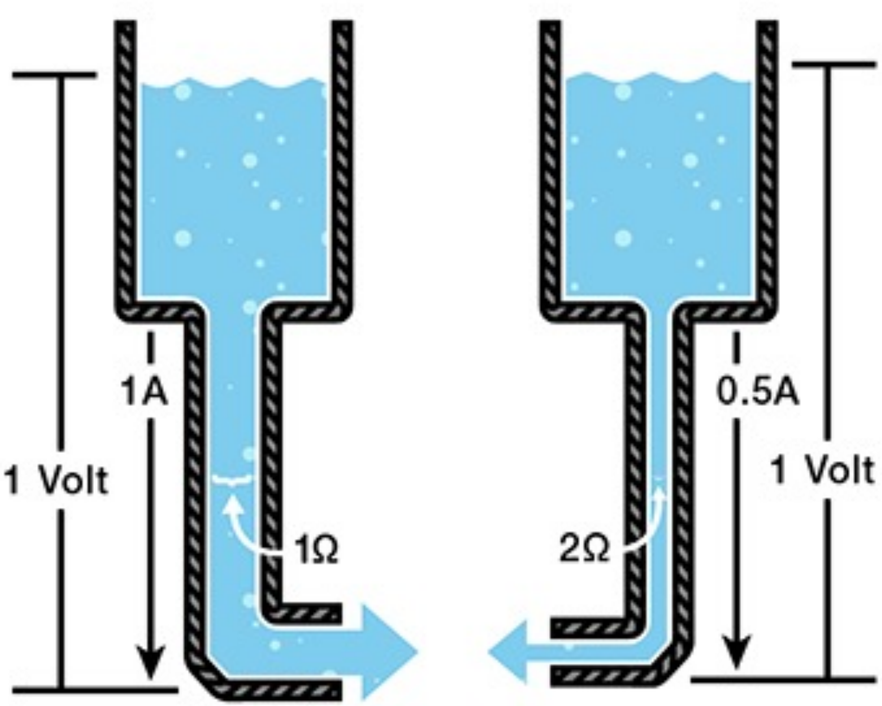
Comparing Electricity to Water flowing from a hose

- Voltage is the equivalent of the pressure in the hose
- Current is water flowing through a hose (coulombs/sec vs gal/sec). The water in a system is the "charge" (coulombs)
- Impedance(Resistance) is the size of the hose. The nozzle would provide a change in resistance.
- Power is how fast water flows from a pipe (gallons per minute vs kilowatts). Power is a rate of energy consumption

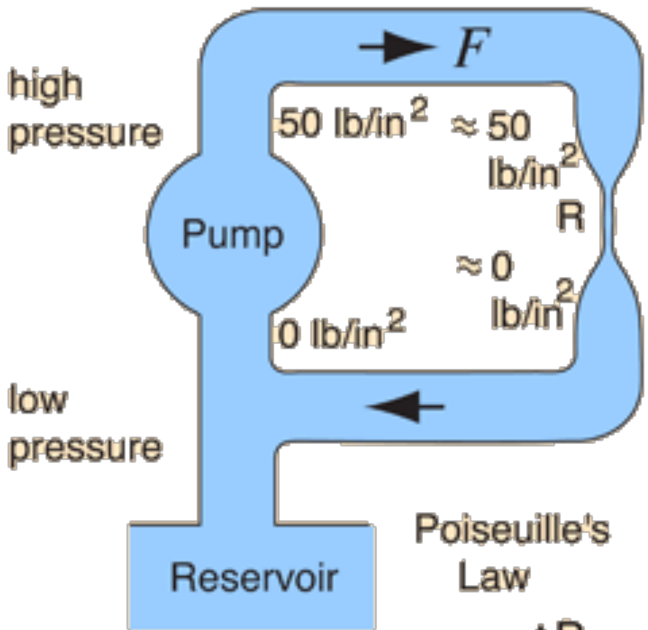
Basic Concepts: Electricity and Water



Basic Concepts: Electricity and Water

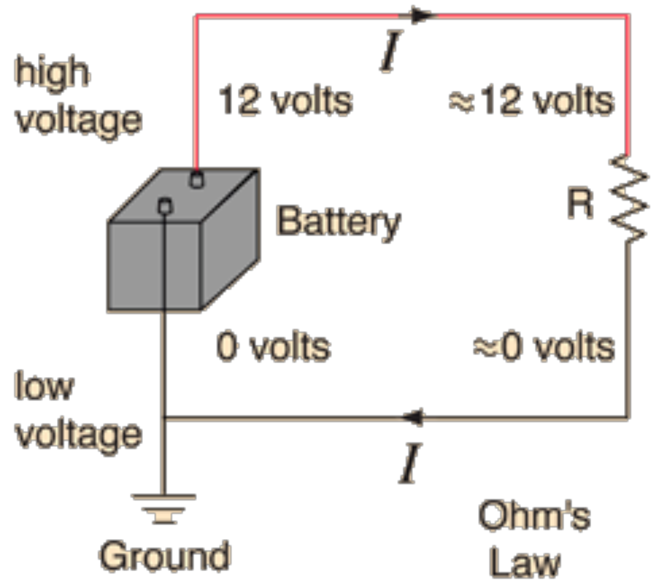


Practical Electricity



$$F = \frac{\Delta P}{R}$$

charge flowrate = current = $\frac{\text{coulombs}}{\text{second}}$ = amperes



$$I = \frac{\Delta V}{R}$$

BASIC ELECTRICAL LAWS

- Ohms Law Examples
  - If V = 20 volts and I = 5 amperes what is the resistance?

    R = V / I = 20 / 5 = 4 ohms
  - If R = 20 ohms and V = 120 volts what is the current?

    I = V / R = 120 / 20 = 6 amps
  - If I = 10 amperes and R = 24 ohms what is the voltage?

    V = I x R = 10 x 24 = 240 volts

  - Problem: If V = 240 volts and R = 6 ohms what is the current?

    I = V / R = 240 / 6 = 40 amps

BASIC ELECTRICAL LAWS

Power is Voltage x Current

- Power = Voltage x Current = V x I = I^2R = V^2/R

Voltage (volts):	Current (amps):	Resist.(ohms):	Power:
$V=I \times R$	$I = V/R$	$R = E/I$	$P=V \times I$
$V=P/I$	$I = P/V$	$R = P/I^2$	$P=I^2 \times R$
$V=\sqrt{(P \times R)}$	$I = \sqrt{(P/R)}$	$R = V^2/P$	$P= V^2/R$

BASIC ELECTRICAL LAWS

- Power = Voltage x Current = V x I = I^2R = $V^{2/}R$
  - If V = 20 volts and I = 8 amperes what is the power?

    P = V x I = 20 x 8 = 160 watts
  - If R = 5 ohms and V = 120 volts what is the power?

    P = $V^{2/}$R = 120 x 120 / 5 = 2880 watts
  - If I = 10 amperes and R = 20 ohms what is the power?

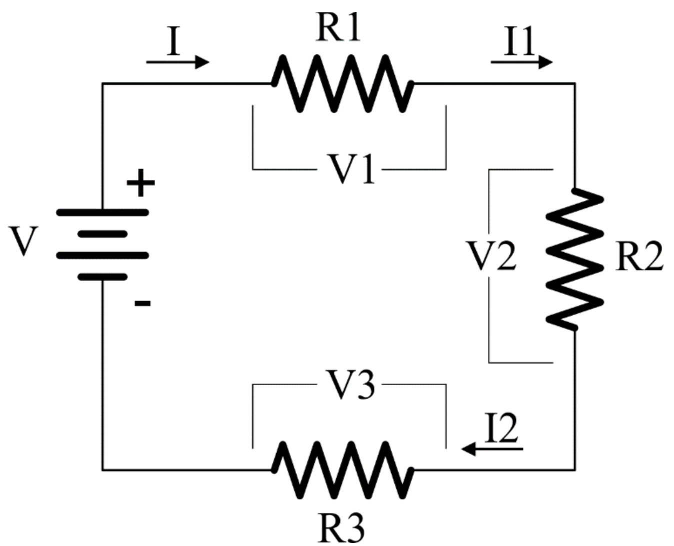
    P = I^2R = 10 x 10 x 20 = 2000 watts

1 kilowatt (kW) = 1,000 watts

1 megawatt (MW) = 1,000,000 watts

BASIC ELECTRICAL LAWS

- Kirchoff's Voltage Law (KVL)
- The sum of the voltages around a circuit loop is zero.



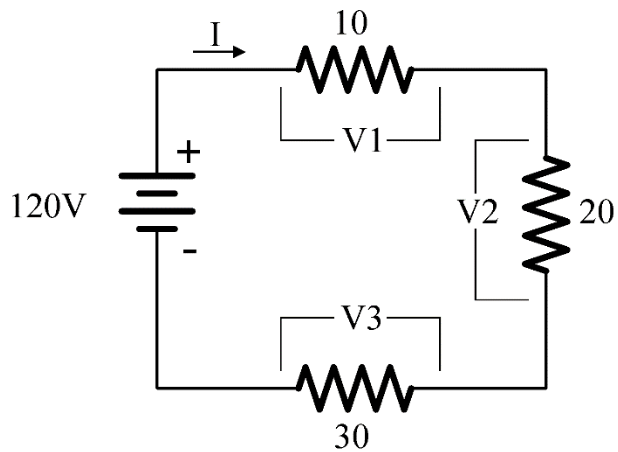
Resistors in series add

V = V1 + V2 + V3 = I * (R1 + R2 + R3) = I1 * R1 + I2 * R2 + I3 * R3

I = I1 = I2 = I3

Basic Electrical Laws

- Kirchoff's Voltage Law (KVL) – PROBLEM #1



What is the current in the circuit?

What are V1, V2, V3?

I = V / R = V / (R1 + R2 + R3) = 120/(10+20+30) = 2 amperes

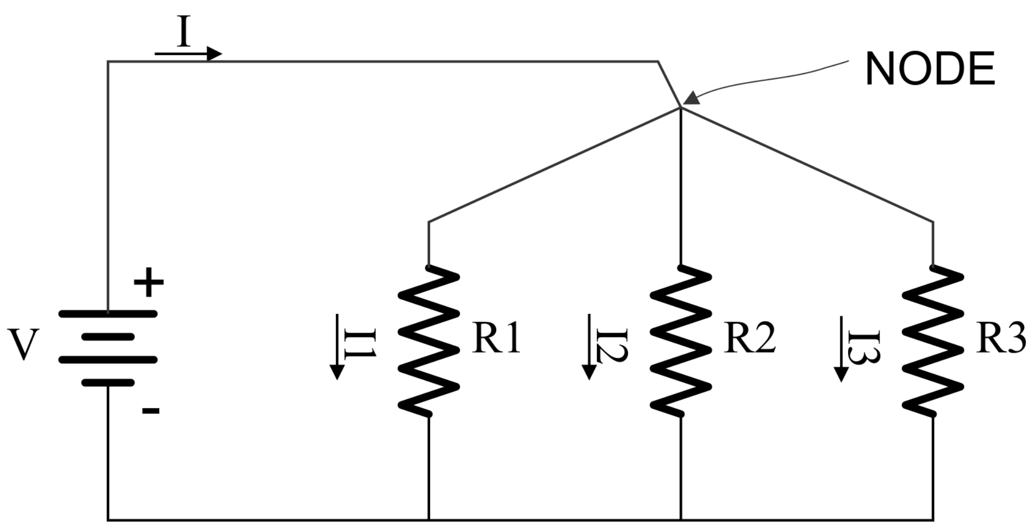
V1 = I*R1 = 2 *10 = 20 volts

V2 = I*R2 = 2 *20 = 40 volts

V3 = I*R3 = 2 *30 = 60 volts

BASIC ELECTRICAL LAWS

- Kirchoff's Current Law (KCL)
- The sum of the currents at a node in a circuit is zero.



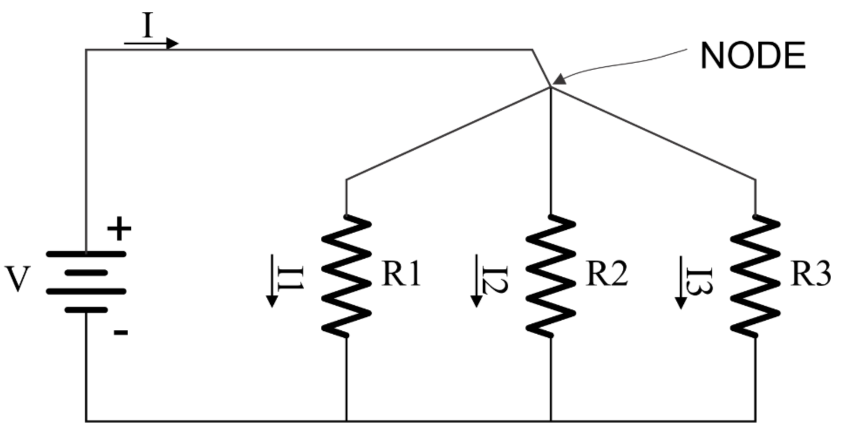
I = I1 + I2 + I3

- If Loads are placed in parallel they sum up.
- So does power

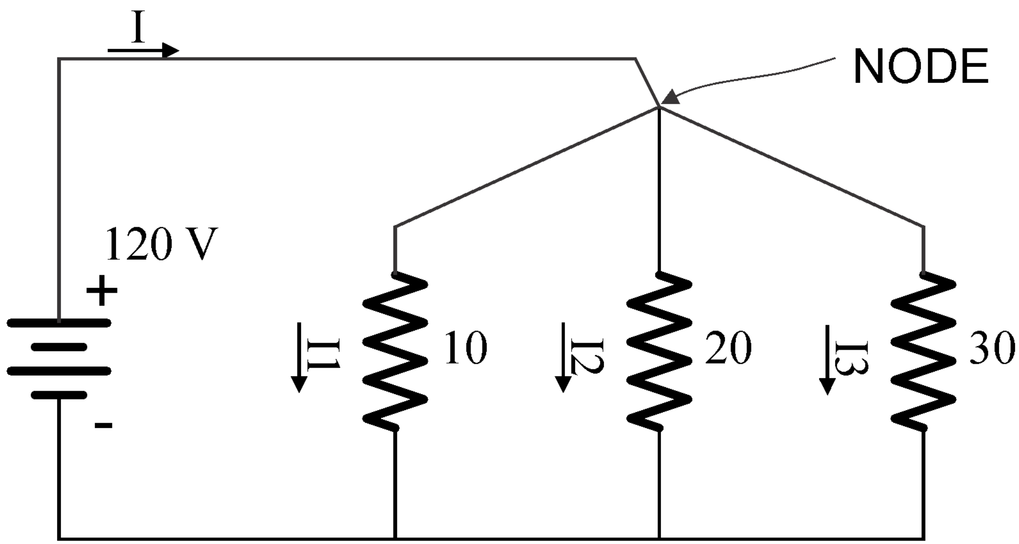
P = V x I = V x I1 + V x I2 + V x I3

BASIC ELECTRICAL LAWS

- Resistors in Parallel
- I = I1 + I2 + I3
- $\frac{V}{R} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$
- $\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$
- $R = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$



Basic Electrical Laws



Compute

I1, I2, I3

I

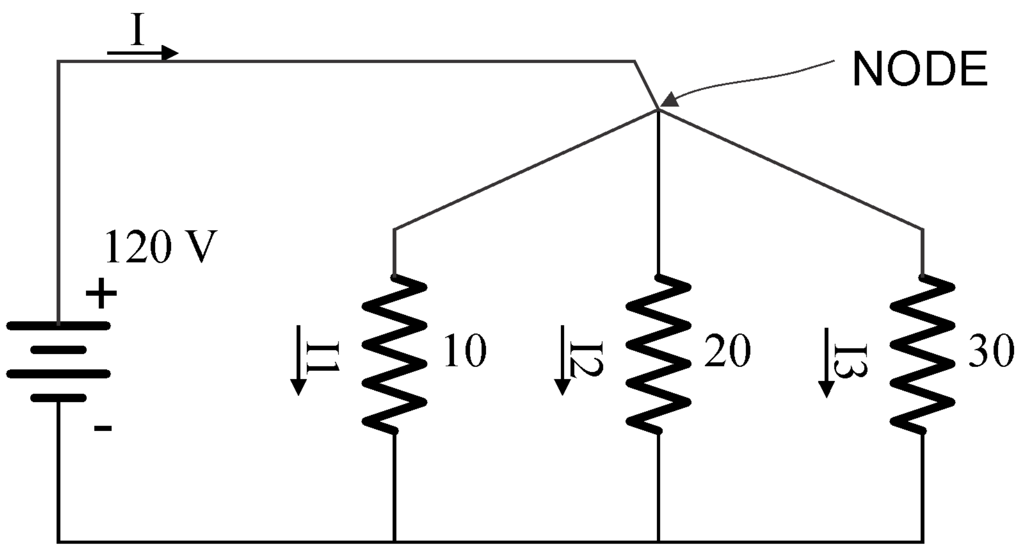
R (parallel resistance of R1, R2, R3)

I1 = 120/10 = 12A, I2=120/20=6A, I3=120/30= 4A

I = 12 + 6 + 4 =22A

R = V/I = 120 / 22 = 5.4545 ohms

BASIC ELECTRICAL LAWS



Compute

I1, I2, I3

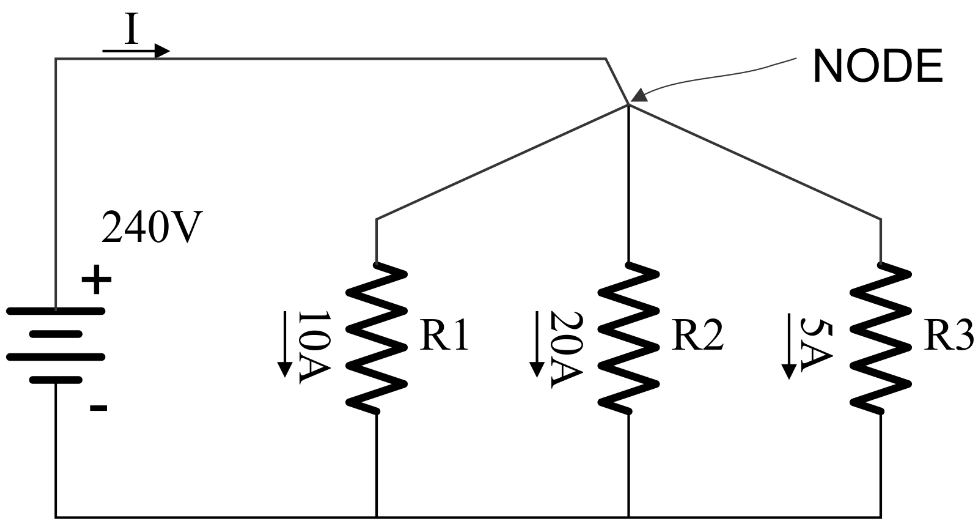
I

R (parallel resistance of R1, R2, R3)

R = V/I = 120 / 22 = 5.4545 ohms

- $R = \frac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}}$

Basic Electrical Laws



Compute

R1, R2, R3

I

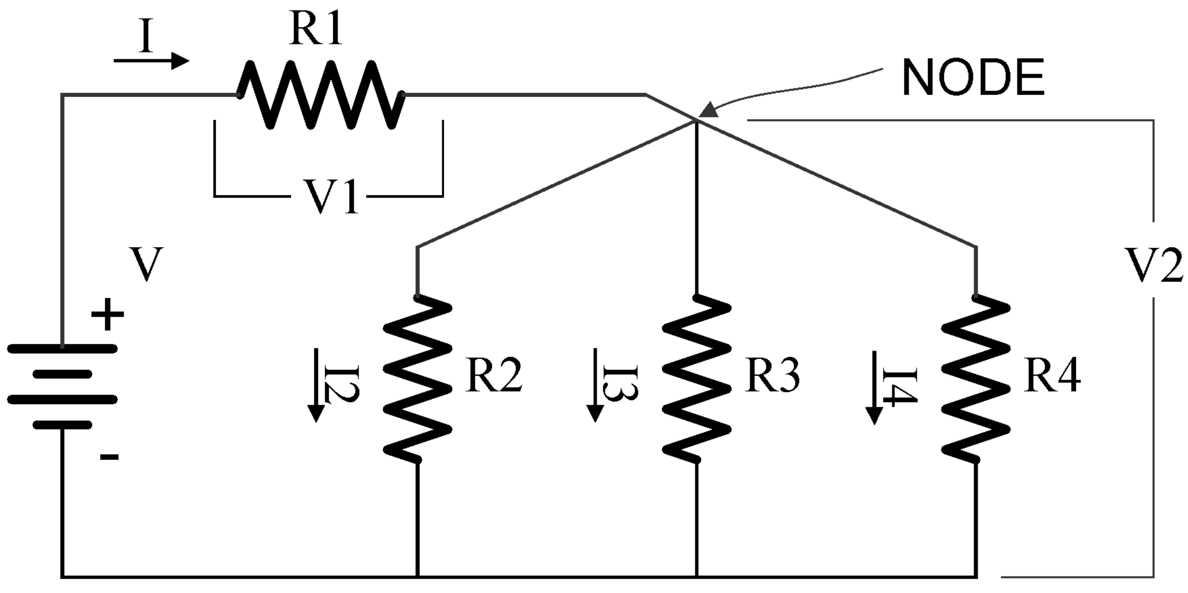
R (parallel resistance of R1, R2, R3)

I = 10 + 20 + 5 =35A

R = V/I = 240 / 35 = 6.857 ohms

BASIC ELECTRICAL LAWS

- More complex circuits

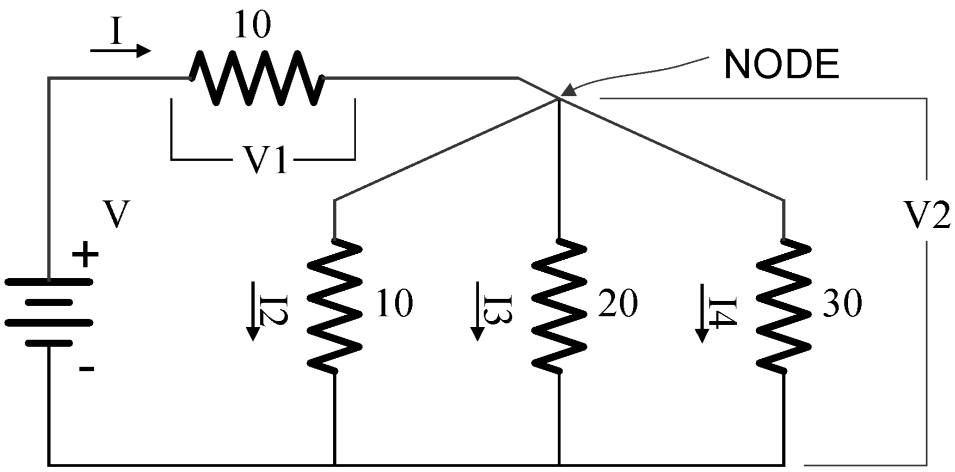


I = I1 + I2 + I3

$$R = R1 + \frac{1}{\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}}$$

BASIC ELECTRICAL LAWS

- More complex circuits

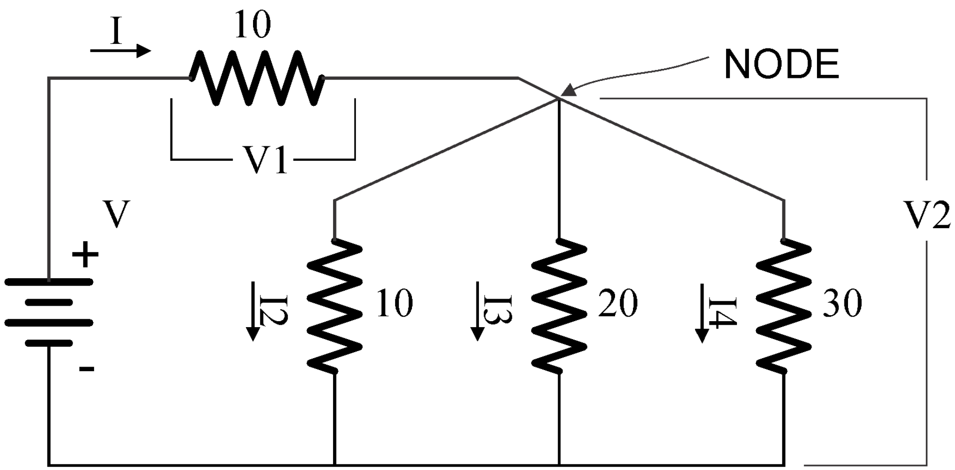


$$R = R1 + \frac{1}{\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}}$$

$$R = 10 + \frac{1}{\frac{1}{10}+\frac{1}{20}+\frac{1}{30}} = 10 + 5.4545 =$$

Basic Electrical Laws

- More complex circuits

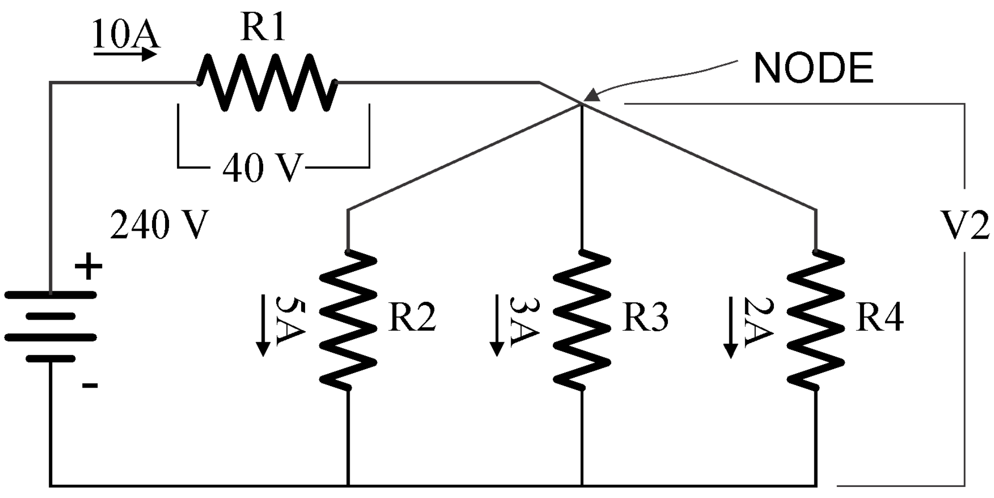


$$R = R1 + \frac{1}{\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}}$$

$$R = 10 + \frac{1}{\frac{1}{10}+\frac{1}{20}+\frac{1}{30}} = 10 + 5.4545 = 15.4545$$

Basic Electrical Laws

- More complex circuits



<u>Compute</u>

V2

R1, R2, R3, R4

Total Power

V2 = 240 – 40 = 200 volts

R1 = 40/10 = 4, R2 = 200/5 = 40,

R3 = 200/3 = 66.667, R4 = 200/2 = 100

Basic AC Theory
Power – The Simple View

E = Voltage (rms)

I = Current (rms)

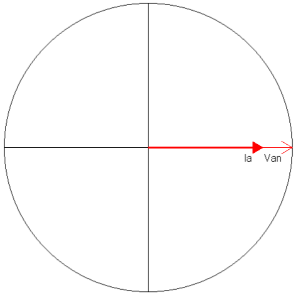
PF = Power Factor

Power = Watts = E x I x PF

Power is sometimes referred to as Demand

Sinusoidal Waveforms Only

NO Harmonics



For a 120 Volt service drawing 13 Amps at Unity (1.0) PF, how much power is being drawn?

Power = 120 x 13 x 1.0 = 1560 Watts

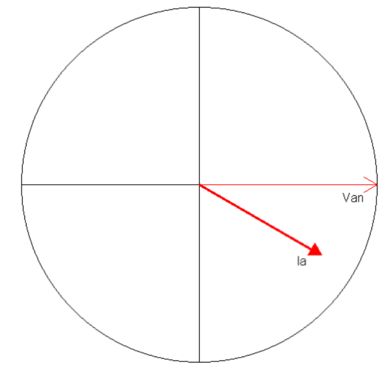
Basic Meter Math
Power – The Simple View

For a 120 Volt service drawing

13 Amps at 0.866 PF,

how much power is being drawn?

Power = 120 x 13 x 0.866 = 1351 Watts

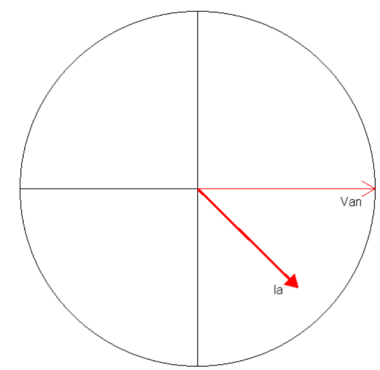


For a 480 Volt service drawing

156 Amps at 0.712 PF,

how much power is being drawn?

Power = 480 x 156 x 0.712 = 53,315 Watts



Basic AC Theory
Power – The Simple View

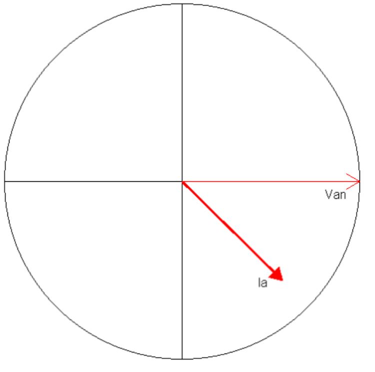
In the previous example we had:

Power = 480 x 156 x 0.712 = 53,315 Watts

Normally we don't talk about Watts, we speak in Kilowatts

1000 Watts = 1 Kilowatt = 1 kW

Watts / 1000 = Kilowatts



For a 480 Volt service drawing

156 Amps at Unity (0.712) PF,

how many Kilowatts are being drawn?

Power = 480 x 156 x 0.712 / 1000 = 53.315 kW

Basic AC Theory
Energy – What We Sell

If power is how fast water flows from a pipe,

then energy is how much water we have in a bucket

after the water has been flowing for a specified time.

Energy = Power x Time

1 kW for 1 Hour = 1 Kilowatt-Hour = 1 kWh

Energy (Wh) = E x I x PF x T

where T = time in hours

Energy (kW) = (E x I x PF / 1000) x T

Basic Meter Math
Energy – What We Sell

For a 120 Volt service drawing 45 Amps at a Power Factor of 0.9 for 1 day,

how much Energy (kWh) has been used?

Energy = (120 x 45 x 0.9 / 1000) x 24 = 116.64 kWh

For a 240 Volt service drawing 60 Amps at a Power Factor of 1.0 for 5.5 hours,

how much Energy (kWh) has been used?

Energy = (240 x 60 x 1.0 / 1000) x 5.5 = 79.2 kWh

Basic Meter Math
Energy – What We Sell

For a 120 Volt service drawing 20 Amps at a Power Factor of 0.8 from 8:00AM to 6:00PM,

and 1 Amp at PF=1.0 from 6:00PM to 8:00AM

how much Energy (kWh) has been used?

8:00AM to 6:00PM = 10 hours

6:00PM to 8:00AM = 14 hours

Energy = (120 x 20 x 0.8 / 1000) x 10 = 19.2 kWh

Energy = (120 x 1 x 1 / 1000) x 14 = 1.68 kWh

Energy = 19.2 kWh + 1.68 kWh = 20.88 kWh

BASIC AC THEORY
WHAT IS VA?

Power was measured in Watts. Power does useful work. The power that does useful work is referred to as

"Active Power."

VA is measured in Volt-Amperes. It is the capacity required to deliver the Power. It is also referred to as the "Apparent Power."

Power Factor = Active Power / Apparent Power

VA = E x I

PF = W/VA

Basic Meter Math
Power – VA

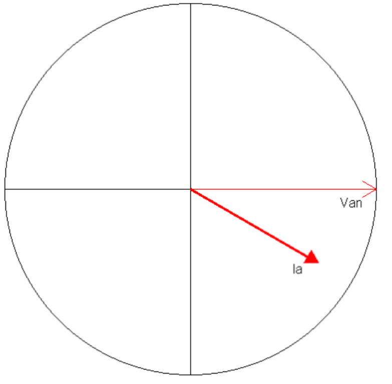
For a 120 Volt service drawing 13 Amps at 0.866 PF

How much power is being drawn?

Power = 120 x 13 x 0.866 = 1351 Watts

How many VA are being drawn?

VA = 120 x 13 = 1560 Volt-Amperes



BASIC METER MATH
POWER – VA

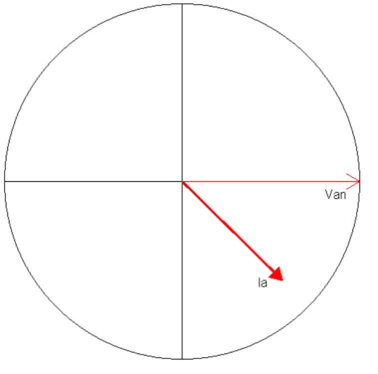
For a 480 Volt service drawing 156 Amps at 0.712 PF

How much power is being drawn?

Power = 480 x 156 x 0.712 = 53,315 Watts

How many VA are being drawn?

VA = 480 x 156 = 74,880 Volt-Amperes



BASIC METER MATH
POWER – VA

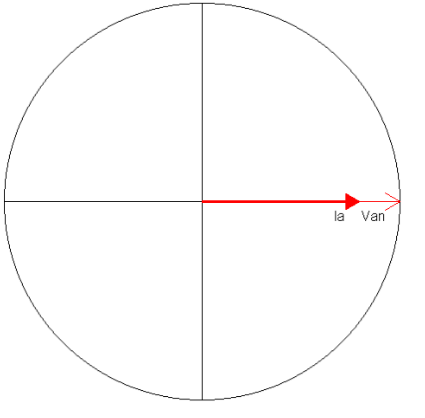
For a 120 Volt service drawing 60 Amps at 1.00 PF

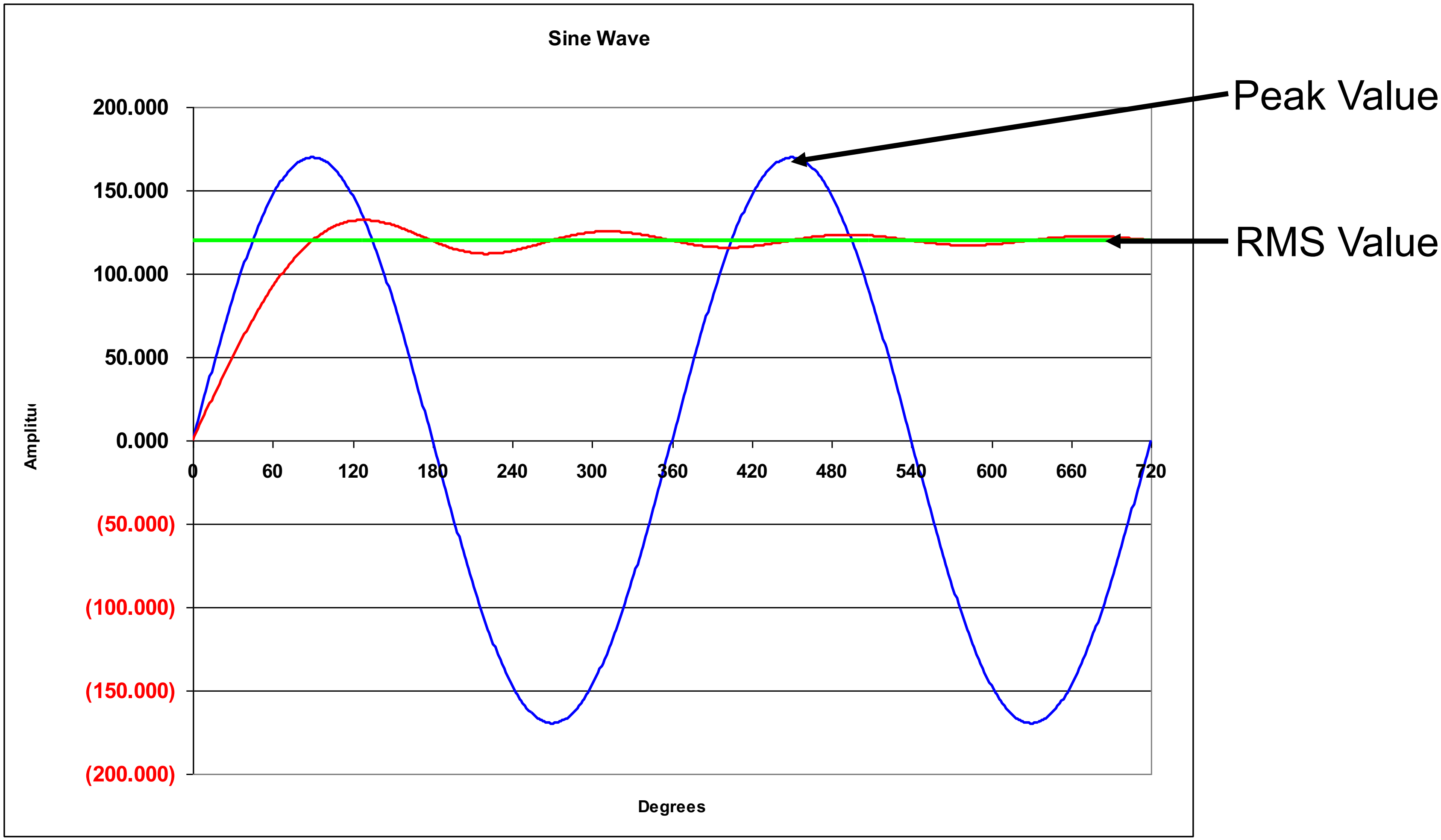
How much power is being drawn?

Power = 120 x 60 x 1.00 = 7,200 Watts

How many VA are being drawn?

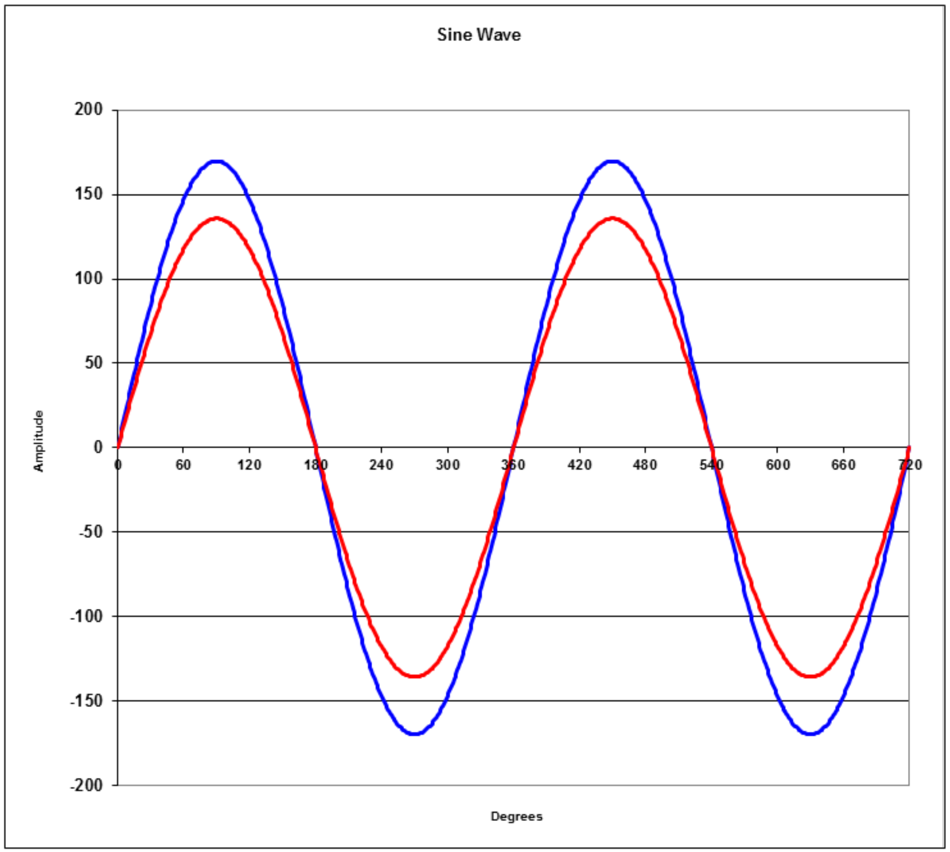
VA = 120 x 60 = 7,200 Volt Amperes

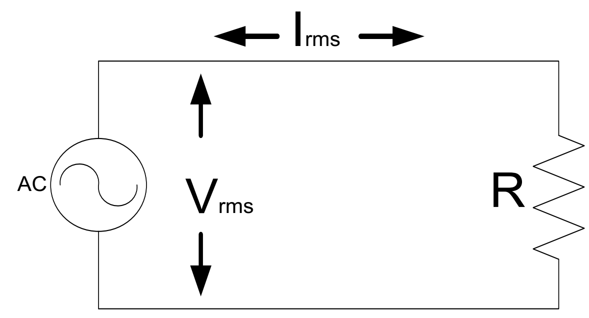


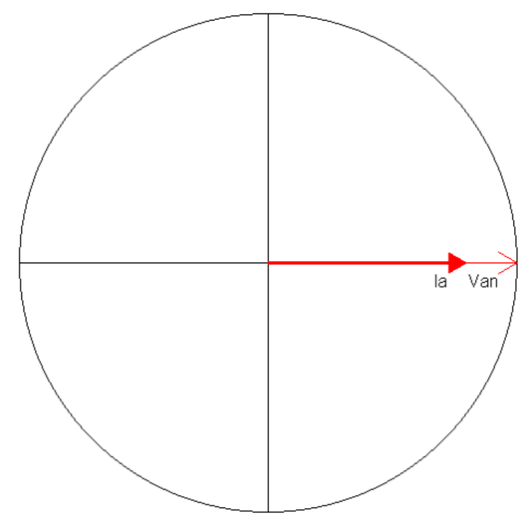


Sine Wave
200.000
150.000
100.000
50.000
0.000
(50.000)
(100.000)
(150.000)
(200.000)
Amplitu
0
60
120
180
240
300
360
420
480
540
600
660
720
Degrees
Peak Value
RMS Value

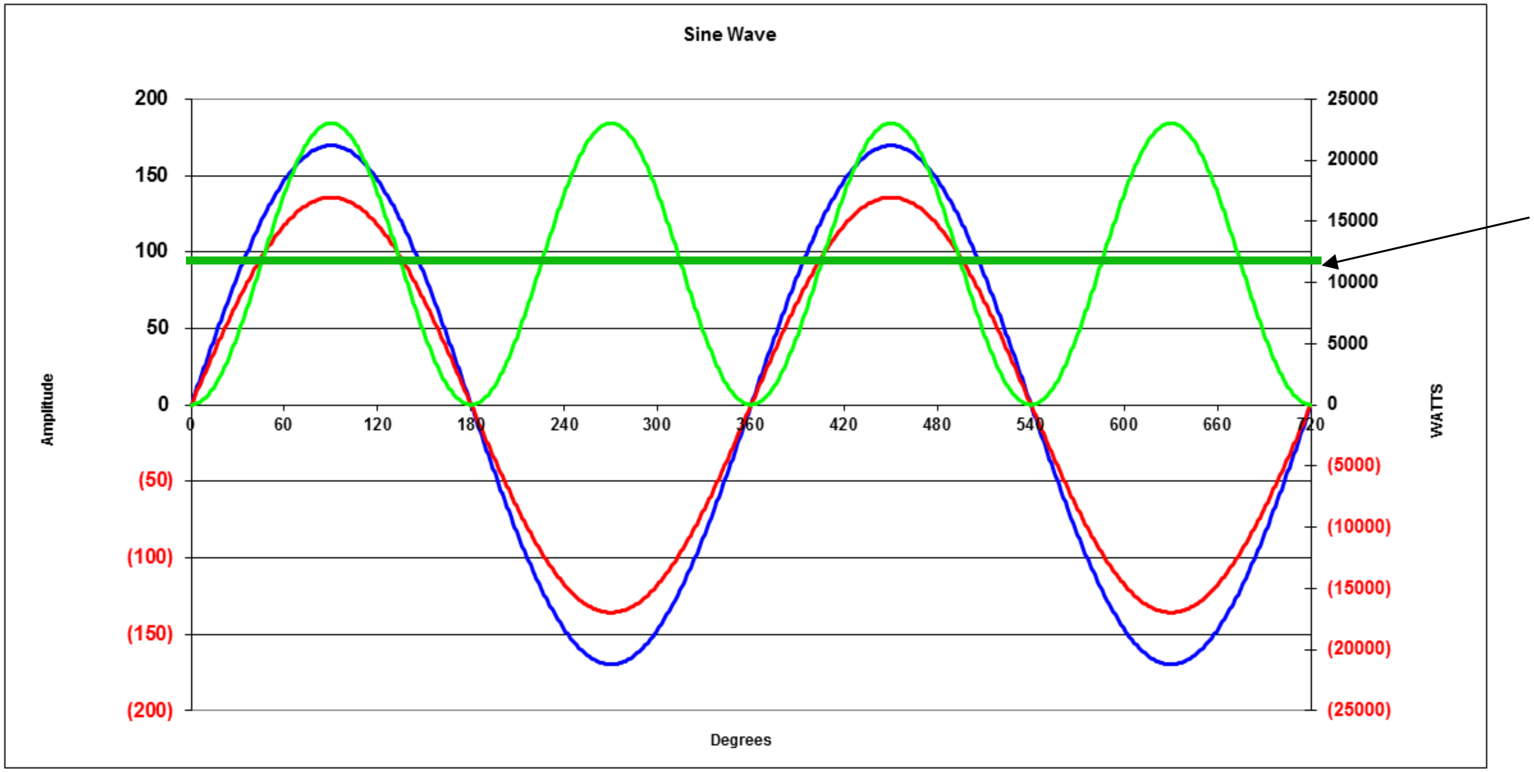
Basic AC Theory
Power Factor = 1.0







Basic AC Theory
Instantaneous Power



$$V = 120\sqrt{2}Sin(2\pi ft)$$

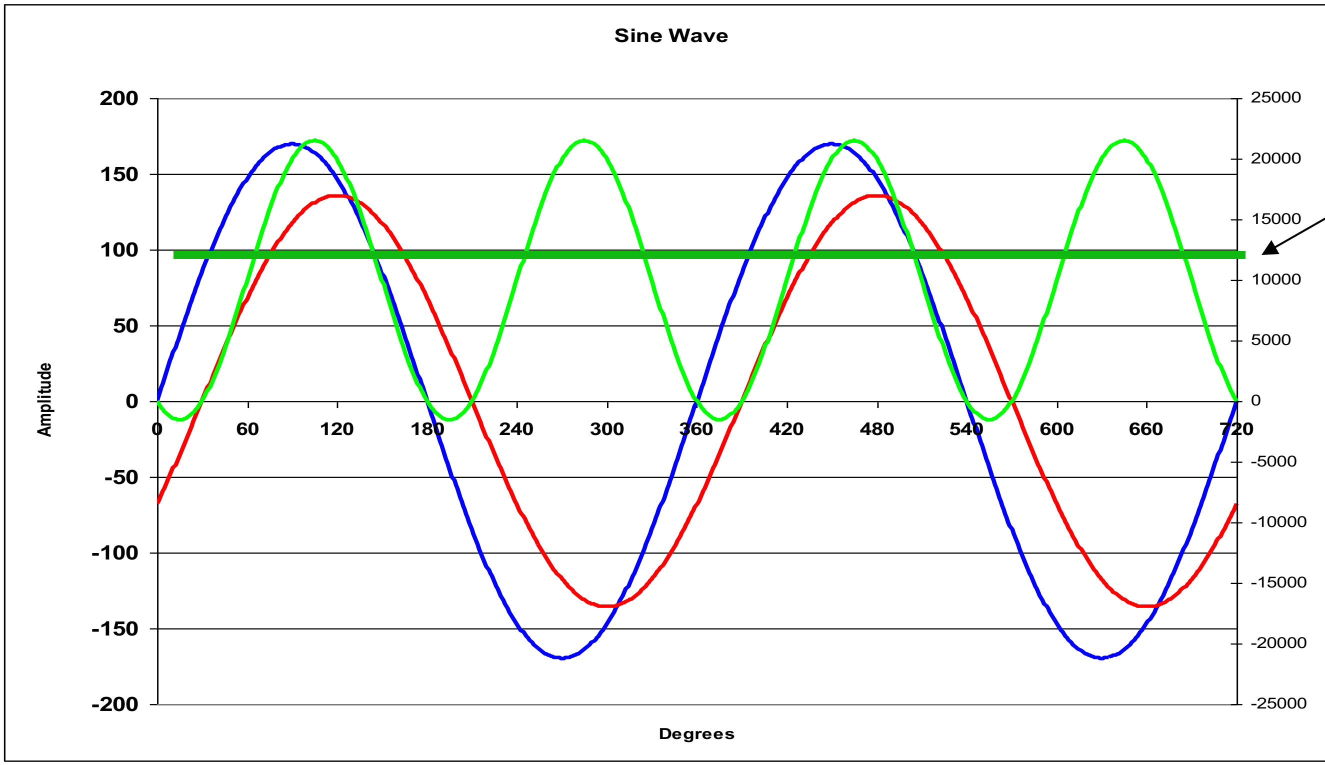
$$I = 96\sqrt{2}Sin(2\pi ft)$$

$$P = 120 \bullet 96 \bullet Cos(0)$$

P = 11520 Watts

Power is a "rate of flow" like water running through a pipe.

Basic AC Theory
Instantaneous Power



Average Power

$V = 120\sqrt{2}Sin(2\pi ft)$

$I = 96\sqrt{2}Sin(2\pi ft - 30)$

$P = 120 \bullet 96 \bullet Cos(30)$

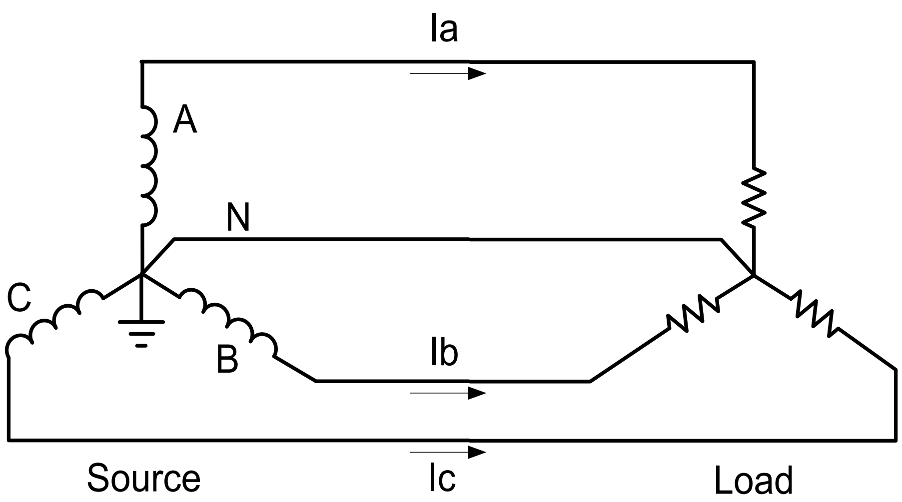
P = 9,976 Watts

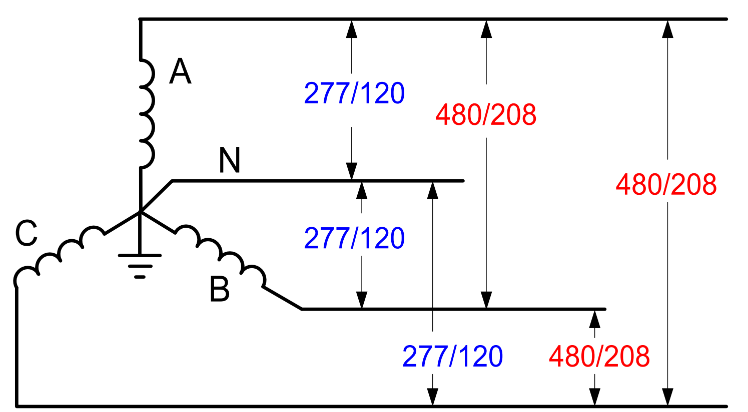
PF=0.866

Basic Meter Math
What about polyphase systems?

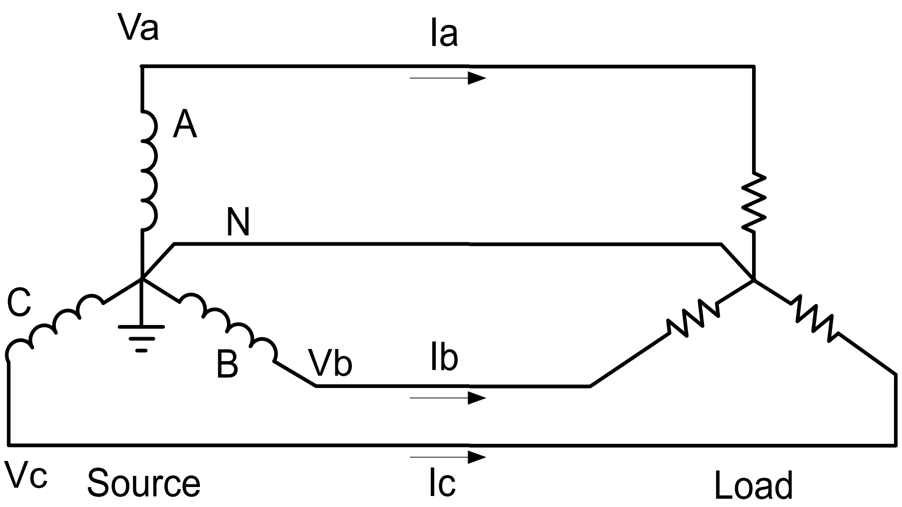
Calculating power in a polyphase system is actually simple but sometimes we make it complex.

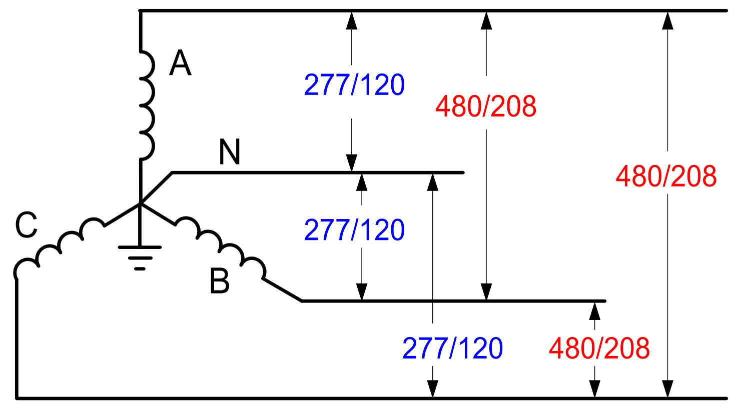
3 Phase, 4-Wire "Y" Service





Basic Meter Math
3 Phase, 4-Wire "Y" Service





The total power is equal to the sum of the power in each phase.

$$P_{total} = E_a \times I_a \times Cos(\theta_a) + E_b \times I_b \times Cos(\theta_b) + E_c \times I_c \times Cos(\theta_c)$$

In a balanced system where $V_a = V_b = V_c$ and $I_a = I_b = I_c$ and $\theta_a = \theta_a = \theta_a$

$$P_{total} = 3 \times E_a \times I_a \times Cos(\theta_a)$$

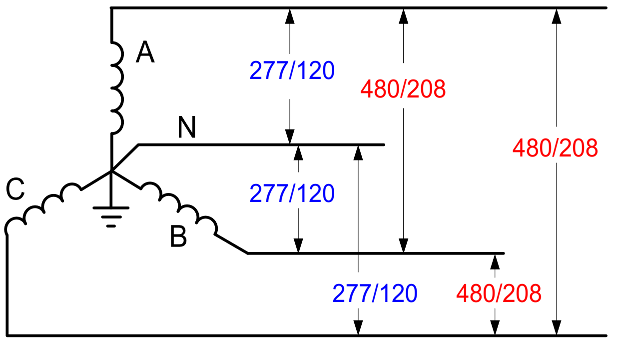
Basic Meter Math
3 Phase, 4-Wire "Y" Service

For a balanced system

$E = 277\ V$

$I = 20\ A$

$PF = 1.00$



In a balanced system where $V_a = V_b = V_c$ and $I_a = I_b = I_c$ and $\theta_a = \theta_a = \theta_a$

$$P_{total} = 3 \times E_a \times I_a \times \mathrm{Cos}(\theta a) = 3 \times Ea \times Ia \times PF$$

$$P_{total} = 3 \times 277 \times 20 \times 1.0$$

$$P_{total} = 3 \times 277 \times 20 \times 1.0 = 16{,}620\ W$$

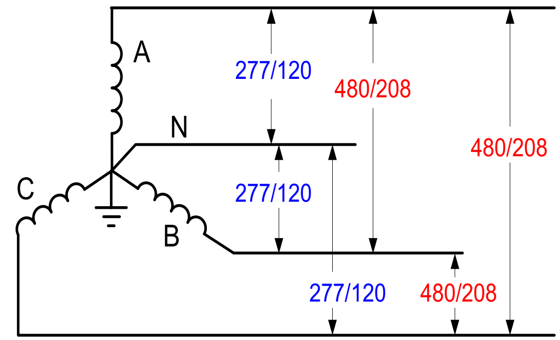
Basic Meter Math
3 Phase, 4-Wire "Y" Service

For a unbalanced system

$E_a = 284$ V, $E_b = 274$ V, $E_c = 276$ V

$I_a = 20$ A, $I_b = 32$ A, $I_c = 30$ A

$PF_a = 0.900$, $PF_b = 0.784$, $PF_c = 0.866$



The total power is equal to the sum of the power in each phase.

$$P_{total} = P_a + P_b + P_c$$

$$P_{total} = E_a \times I_a \times \mathrm{Cos}(\theta_a) + E_b \times I_b \times \mathrm{Cos}(\theta_b) + E_c \times I_c \times \mathrm{Cos}(\theta_c)$$

$P_a = 284 \times 20 \times .900 = 5{,}112$

$P_b = 274 \times 32 \times .784 = 6{,}874$

$P_c = 276 \times 30 \times .866 = 7{,}170$

$$P_{total} = 5{,}112 + 6{,}874 + 7{,}170 = 19{,}156$$

BASIC AC THEORY
WHAT IS VA?

If we were trying to decide how big the transformers in the last example need to be, we would need to calculate the kVA of the loads rather than the kW.

REMEMBER

VA is measured in Volt-Amperes. It is the capacity required to deliver the Power. It is also referred to as the "Apparent Power".

VA = E x I

PF = W/VA

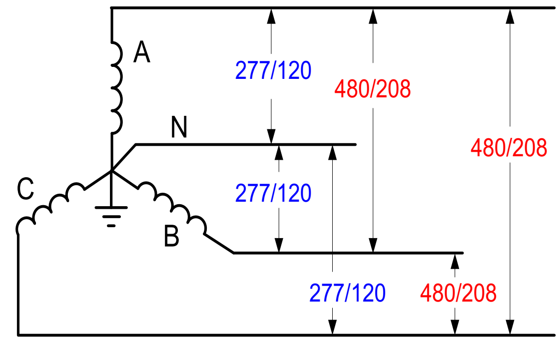
Basic Meter Math
3 Phase, 4-Wire "Y" Service

What is the VA for each phase?

$E_a = 284$ V, $E_b = 274$ V, $E_c = 276$ V

$I_a = 20$ A, $I_b = 32$ A, $I_c = 30$ A

$PF_a = 0.900$, $PF_b = 0.784$, $PF_c = 0.866$



The total power is equal to the sum of the power in each phase.

$$VA_{total} = VA_a + VA_b + VA_c$$

$$VA_{total} = E_a \times I_a + E_b \times I_b + E_c \times I_c$$

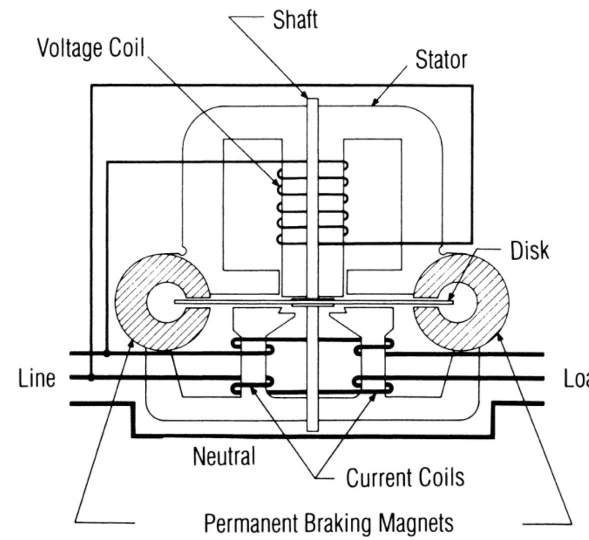
$P_a = 284 \times 20 = 5{,}680$ $P_b = 274 \times 32 = 8{,}768$ $P_c = 276 \times 30 = 8{,}280$

$$P_{total} = 5{,}680 + 8{,}768 + 8{,}280 = 25{,}328$$

Would you use 5kVA, 7.5kVA, 10kVA, 25kVA or 40kVA transformers?

Induction Meters

- Using concepts put forth by Tesla and Ferraris, several inventors created early induction watthour meters
- Two coils and a conducting (usually aluminum) disk. A braking magnet.
- Magnetic field from the first coil generates *eddy currents* in the disk
- Magnetic field from the second coil interacts with the eddy currents to cause motion
- Disk would accelerate without bound except for eddy currents caused by motion through fixed magnetic field which slows the disk
- The end result is that each revolution of the disk measures a constant amount of energy



BASIC ENERGY FORMULA

- The essential specification of a watthour meter's measurement is given by the value
  Kh [Watthours per disk revolution]

$$E\left[\textbf{Watthours}\right] = K_h\left[\frac{\textbf{watthours}}{\textbf{disk revolution}}\right] * n\left[\textbf{disk revolutions}\right]$$

- The watthour meter formula is as follows:

1893: BLONDEL'S THEOREM

- The theory of polyphase watthour metering was first set forth on a scientific basis in 1893 by Andre E. Blondel, engineer and mathematician. His theorem applies to the measurement of real power in a polyphase system of any number of wires. The theorem is as follows:

  - If energy is supplied to any system of conductors through N wires, the total power in the system is given by the algebraic sum of the readings of N wattmeters, so arranged that each of the N wires contains one current coil, the corresponding voltage coil being connected between that wire and some common point. If this common point is on one of the N wires, the measurement may be made by the use of N-1 wattmeters.

Questions and Discussion

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