POWER ENGINEERING

#02 – DC & AC ELECTRICAL POWER

2018

University of Glasgow

AC/DC

Which is better for Electrical Power System ?

The Year is 1886

20 years since the end of the American Civil War

10 Year since Custer's defeat at the Battle of The Little Bighorn

America is now going to experience another "War"

"THE WAR OF THE CURRENTS"

THE WAR OF THE CURRENTS

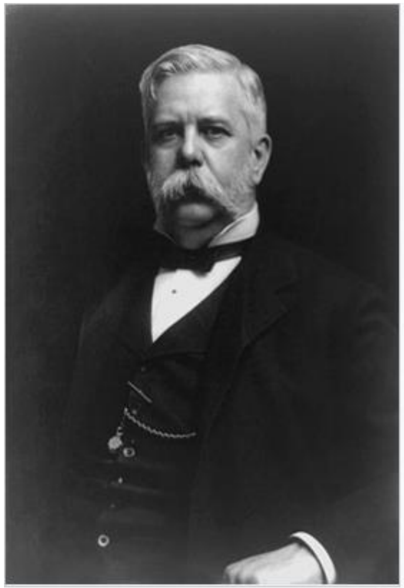
American inventor and businessman Thomas Edison established the first investor-owned electric utility in 1882, basing its infrastructure on DC power.

Thomas Edison

Electricity

DC systems VS AC systems

DC:Direct current
AC: Alterating current



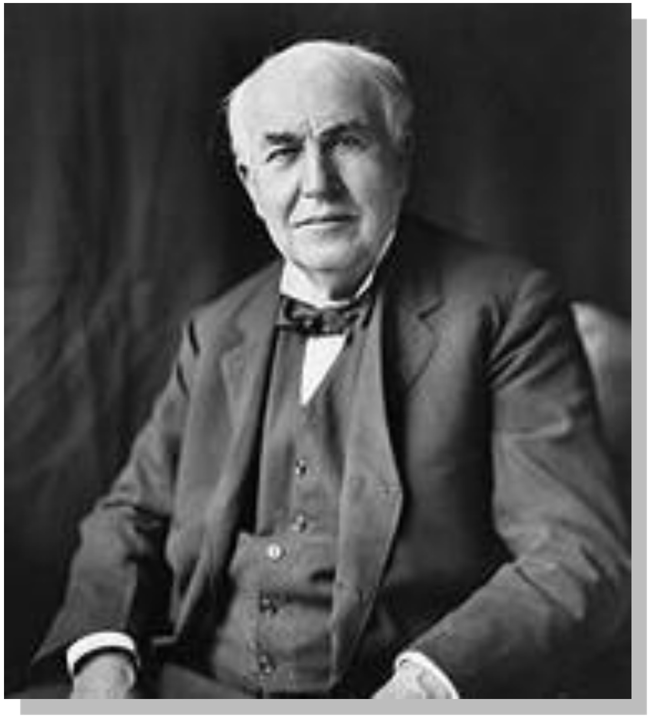
American entrepreneur and engineer George Westinghouse introduced a rival AC-based power distribution network in 1886.

George Westinghouse

- **Now Many applications require DC current for proper operation, e.g. computers, phones …**
- **Now HVDC is the most economic way to transmit electricity over long distance (> 1000km) without instability issues…**

- **Why AC systems are compelling since 1890s ?**

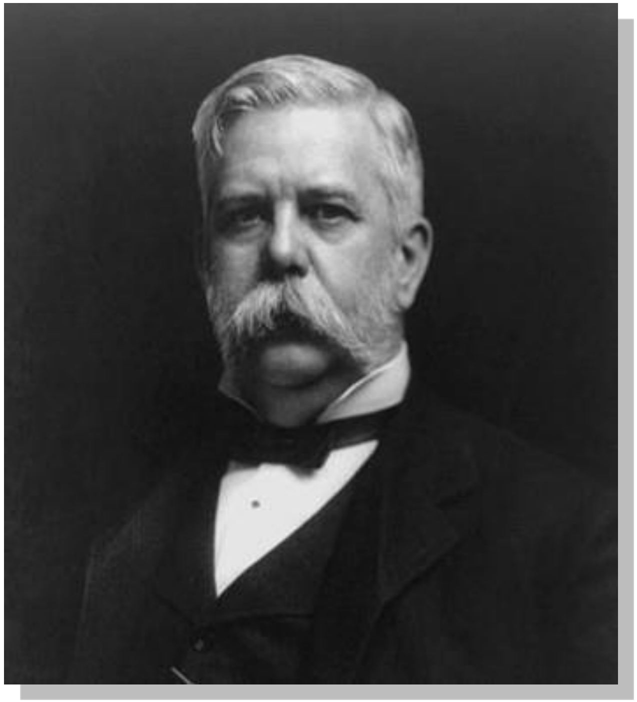
“The War of the Currents”



Thomas Edison

DC

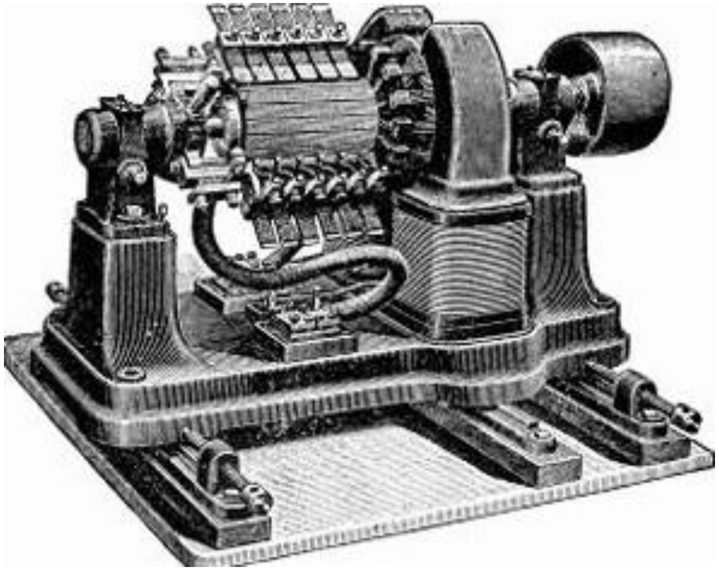
V



George Westinghouse
+ Nikola Tesla

AC

Early DC Power Sources:

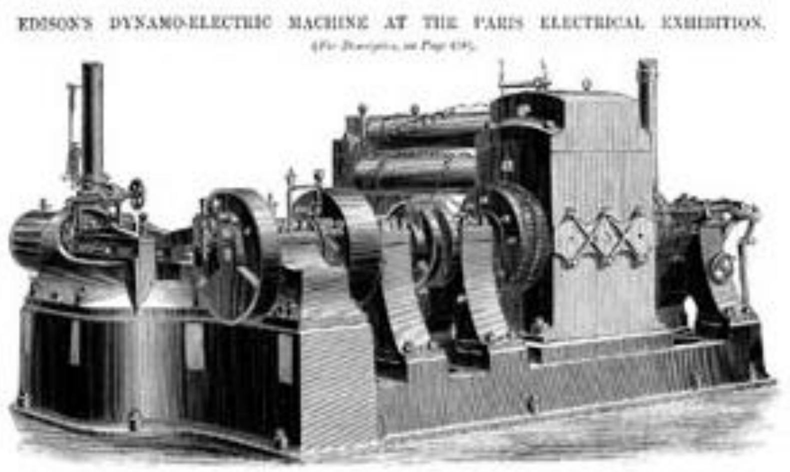


Early DC 'Dynamo' typically
Belt driven by a Steam Engine

Specification (@1400rpm):
Vout = 7V DC
Iout = 310A
Pout = 2170W

Early DC Battery (50V+)

A DC System

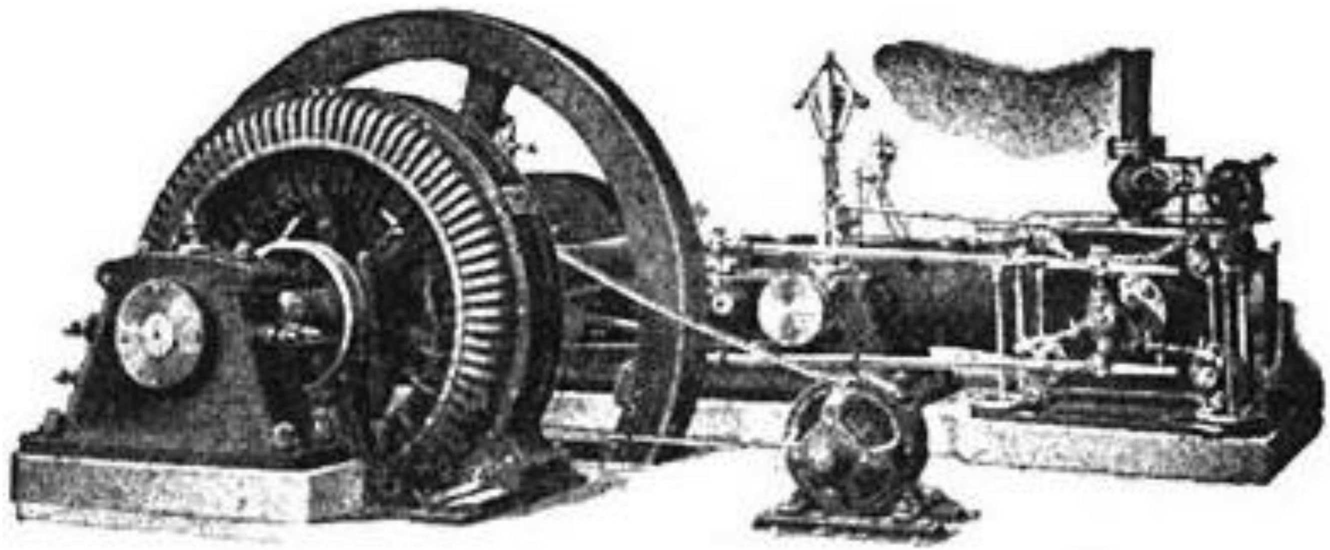


Output voltage of DC generator is 110V, and maximum transmission distance is about 1 mile. How to step up/down DC voltage ???

Since 1882 Edison had installed DC electrical generator stations[*1] (driven by Steam Turbines) in New York and London - initially to provide power for electric lighting (another of Edison's inventions!). Business expanded rapidly and by 1887 there were 121 "Edison" power stations across America supplying power for lighting, heating and DC electric motors. Business was booming and the future was looking very bright (pardon the pun!) , until…….

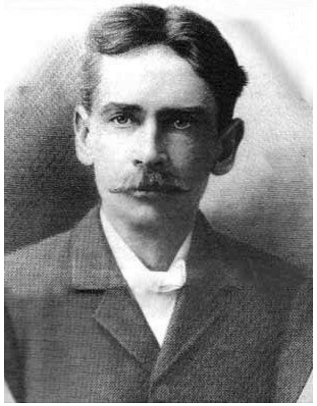
[*1] note: the generator stations were typically only 1-2km away from the load centres

Early AC Power Sources:

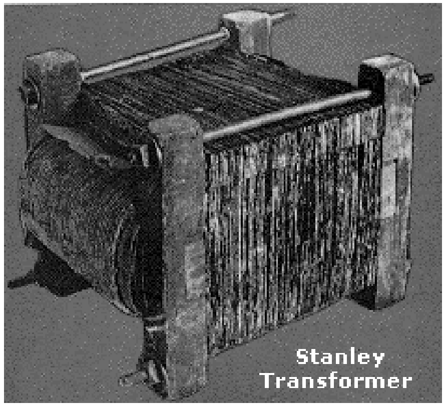


An early (1900's) Steam driven AC Alternator (75kW)

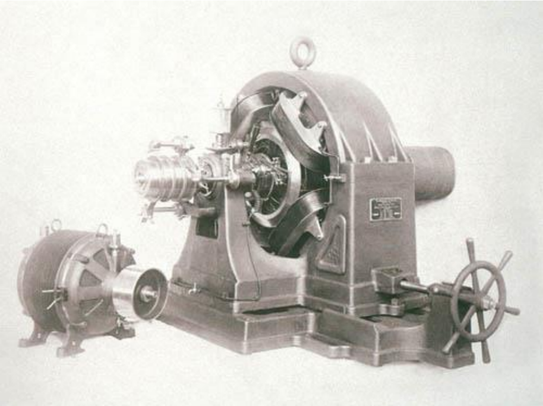
KEYS TO AC SYSTEMS' SUCCESS



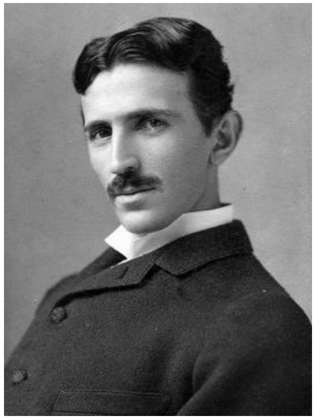
William Stanley, Jr.



Stanly Transformer



Tesla Poly-phase AC motor



Nikola Tesla

AC systems

Low cost, reliable and easy-for use AC voltage level conversion (step up/down)

More reliable, cheaper, smaller and higher power rating, higher speed than DC motor

Transformer – AC voltage level *power converter*, "the lethal weapon" with poly-phase AC motor determine the success of AC systems – *high power, efficient and flexible* .

An AC System

Niagara Falls

Hydro Electricity Generation Plant

32km's

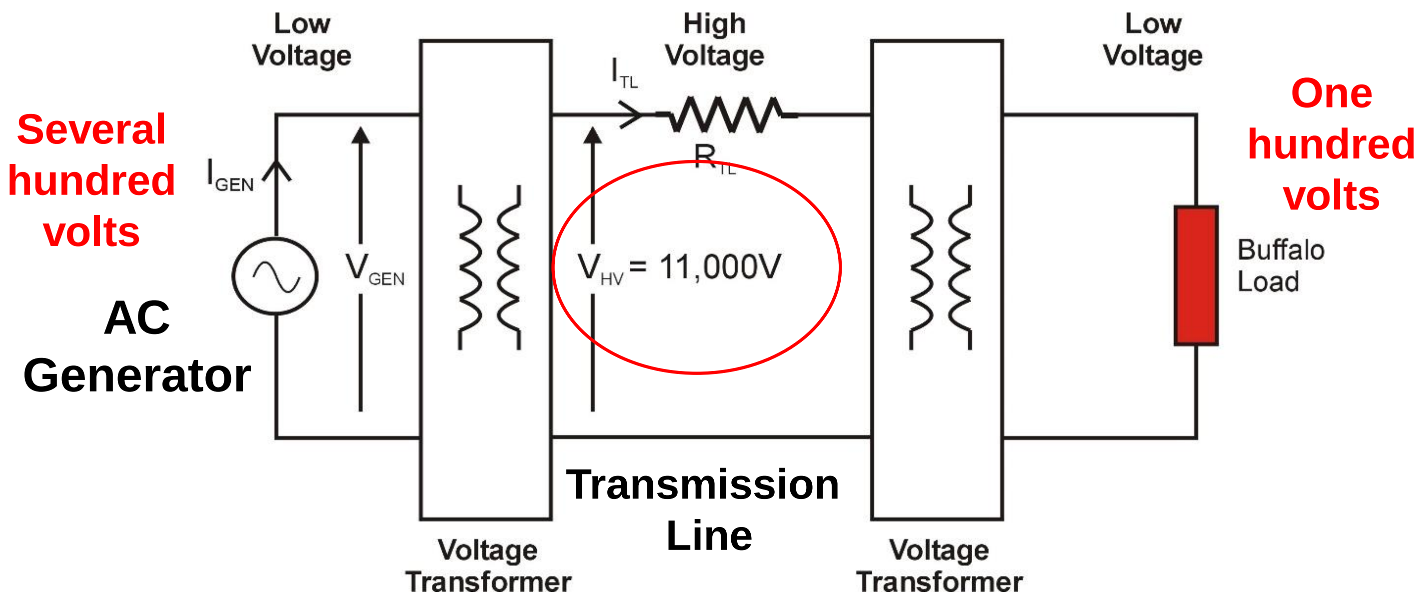
Transmission Line

Buffalo, NY State

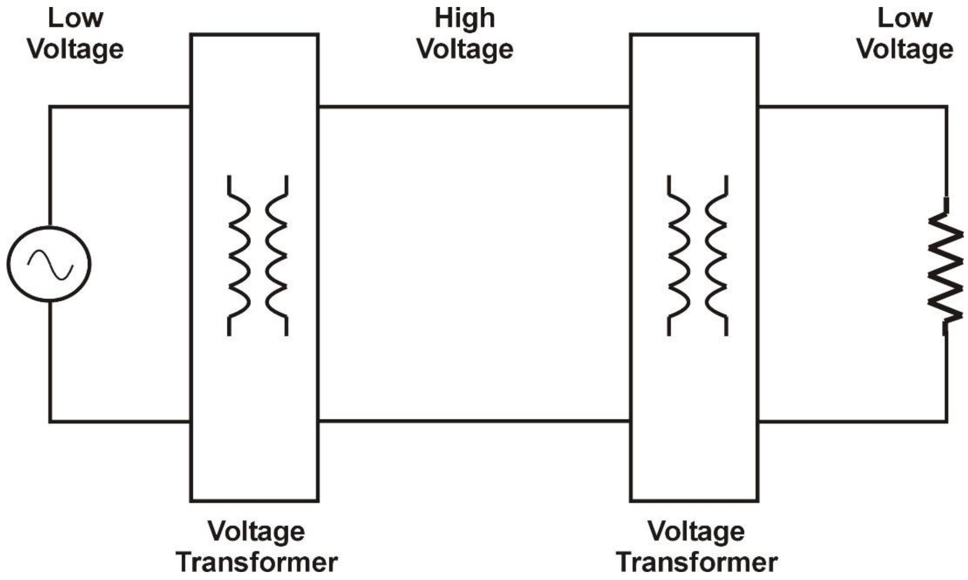
Loads: lighting, heating, electric motors

This example ha
1880's the Niaga
a prize of $100,0
an economic me
long distance.

At midnight November 16, 1896, The first one thousand horsepower of electricity surging to Buffalo over a long distance.



AC System's 'secret weapon': *The Transformer*



The electrical transformer, invented and developed in the early 1800's, allows AC voltage magnitudes to be changed relatively easily and cheaply (it does not require any moving parts)

So does this ability to change AC voltage levels give an AC power system any advantage over its DC counterpart??

BLACK CAT, WHITE CAT, WHOEVER CATCH MICE IS A GOOD CAT.
CHINESE WAY, WESTERN WAY, WHATEVER WORKS THE BEST IS A GOOD WAY.

Specification:

1] The Hydroelectric generator plant outputs 4MW

2] The power loss in the transmission lines should be limited to 5% of the generated power

Some Useful Equations:

Voltage (V) = Current (A) x Resistance (Ω)

Power (W) = Voltage (V) x Current (A)

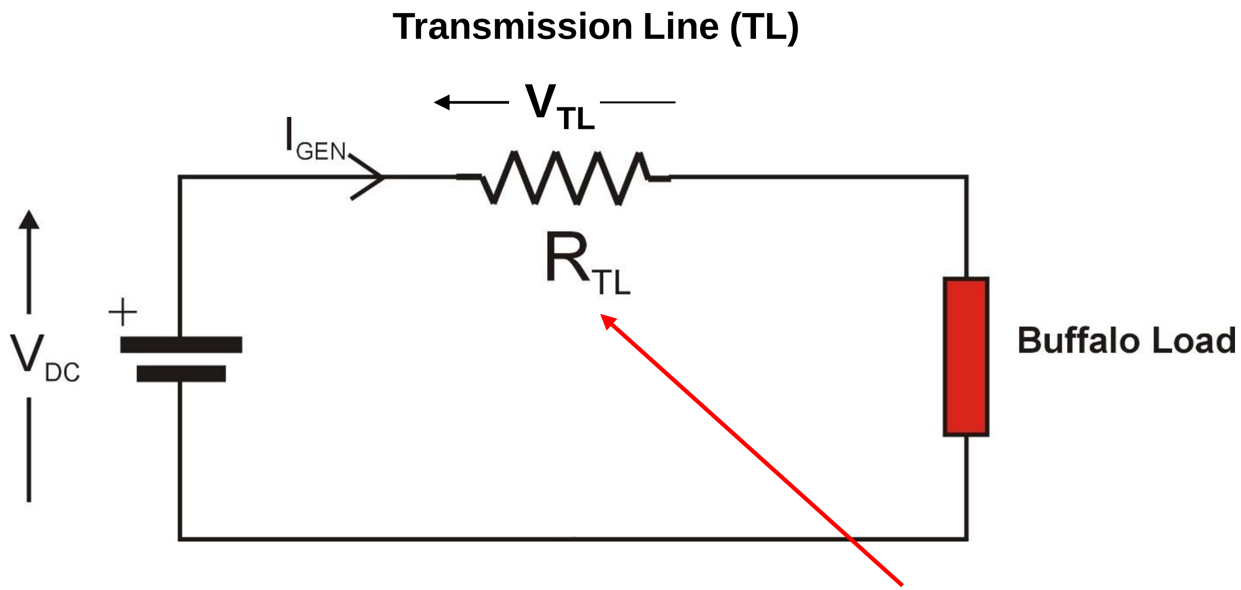
Note: all power's are average powers and all voltages and currents are rms values – we will talk more about average and rms!

DC System Solution:

$V_{GEN} = 110V$

$P_{GEN} = 4MW$

Generator



Generator Power Output

$$P_{GEN} = V_{GEN}.I_{GEN}$$

Transmission Line Power Loss

$$P_{TL} = V_{TL}.I_{GEN}$$

$$V_{TL} = I_{GEN}.R_{TL}$$

$$P_{TL} = I_{GEN}.I_{GEN}.R_{TL}$$

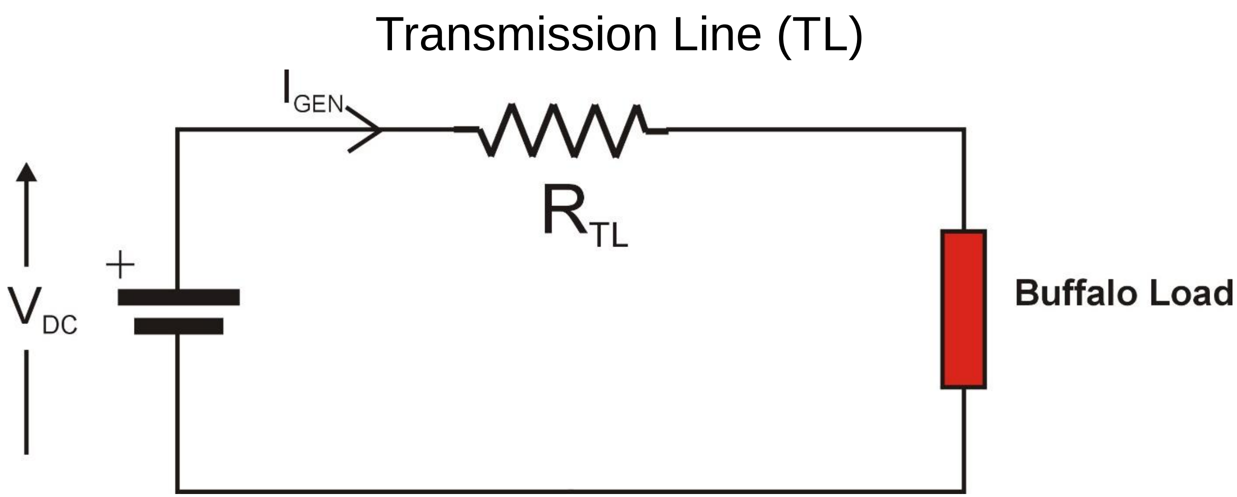
$$P_{TL} = I_{GEN}{}^{2}.R_{TL}$$

DC System Solution:

$V_{GEN} = 110V$

$P_{GEN} = 4MW$

Generator



Calculate I_{GEN} ⟶ **Calculate Power loss in TL** ⟶ **Calculate TL Resistance**

$$P_{GEN} = V_{GEN}.I_{GEN}$$

$$I_{GEN} = \frac{P_{GEN}}{V_{GEN}}$$

$$I_{GEN} = \frac{4,000,000}{110}$$

$$I_{GEN} = 36,363A$$

$$P_{TL} = P_{Total}.\frac{5}{100}$$

$$P_{TL} = 4e^{6} \times 0.05$$

$$P_{TL} = 200,000W$$

$$P_{TL} = 200kW$$

$$P_{TL} = I_{GEN}{}^{2}.R_{TL}$$

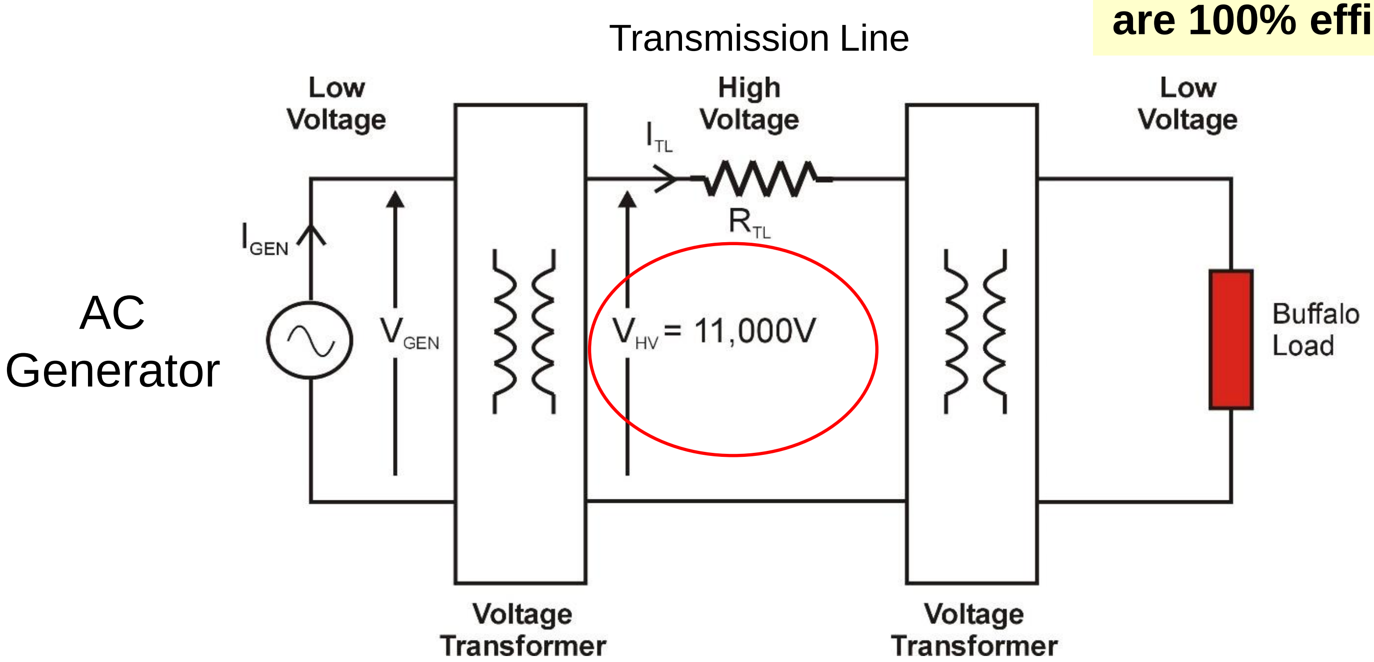
$$R_{TL} = \frac{P_{TL}}{I_{GEN}{}^{2}}$$

$$R_{TL} = \frac{200,000}{36363^{2}}$$

$$R_{TL} = 151e^{-6}\Omega$$

AC System Solution:

Note the assumption is that the transformers are 100% efficient!



Calculate I_{TL} → **Calculate TL Resistance**

$$P_{GEN} = V_{GEN}.I_{GEN} = V_{HV}.I_{TL}$$

$$I_{TL} = \frac{P_{GEN}}{V_{HV}}$$

$$I_{TL} = \frac{4,000,000}{11,000}$$

$$I_{TL} = 363A$$

$$P_{TL} = I_{TL}^2.R_{TL}$$

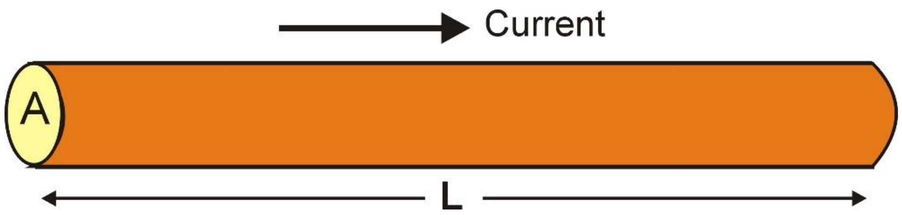
$$R_{TL} = \frac{P_{TL}}{I_{TL}^2}$$

$$R_{TL} = \frac{200,000}{363^2}$$

$$R_{TL} = 1.51\Omega$$

We now need to look at how the resistance of a wire is determined by its dimensions

Resistance of a Copper Conductor:



Length = L (m)

Cross Sectional Area = A (m^2)

$$\boxed{R = \frac{\rho l}{A}}$$

$$\text{Resistance } (\Omega) = \frac{\text{Resistivity } (\Omega\text{m}) \times \text{Length (m)}}{\text{Cross Sectional Area } (\text{m}^2)}$$

We can now calculate the required Cross Sectional Area of the DC & AC Transmission Lines:

$$\text{Cross Sectional Area } (\text{m}^2) = \frac{\text{Resistivity } (\Omega\text{m}) \times \text{Length (m)}}{\text{Resistance } (\Omega)}$$

Resistivity for Copper = 1.68e-8Ωm

DC System

Calculation of Transmission line Cross-Sectional Area/diameter:

$$A_{DC} = \frac{1.68e-8x32,000x2}{151e-6}$$

$$A_{DC} = 7.12m^2$$

$$Diameter^2 = \frac{4 \text{ x Area}}{\pi}$$

$$Diameter^2 = \frac{4x7.12}{\pi}$$

$$Diameter^2 = 9.07$$

$$Diameter = 3m$$

AC System

Calculation of Transmission line Cross-Sectional Area/diameter:

$$A_{DC} = \frac{1.68e-8x32,000x2}{1.51}$$

$$A_{DC} = 712e-6m^2$$

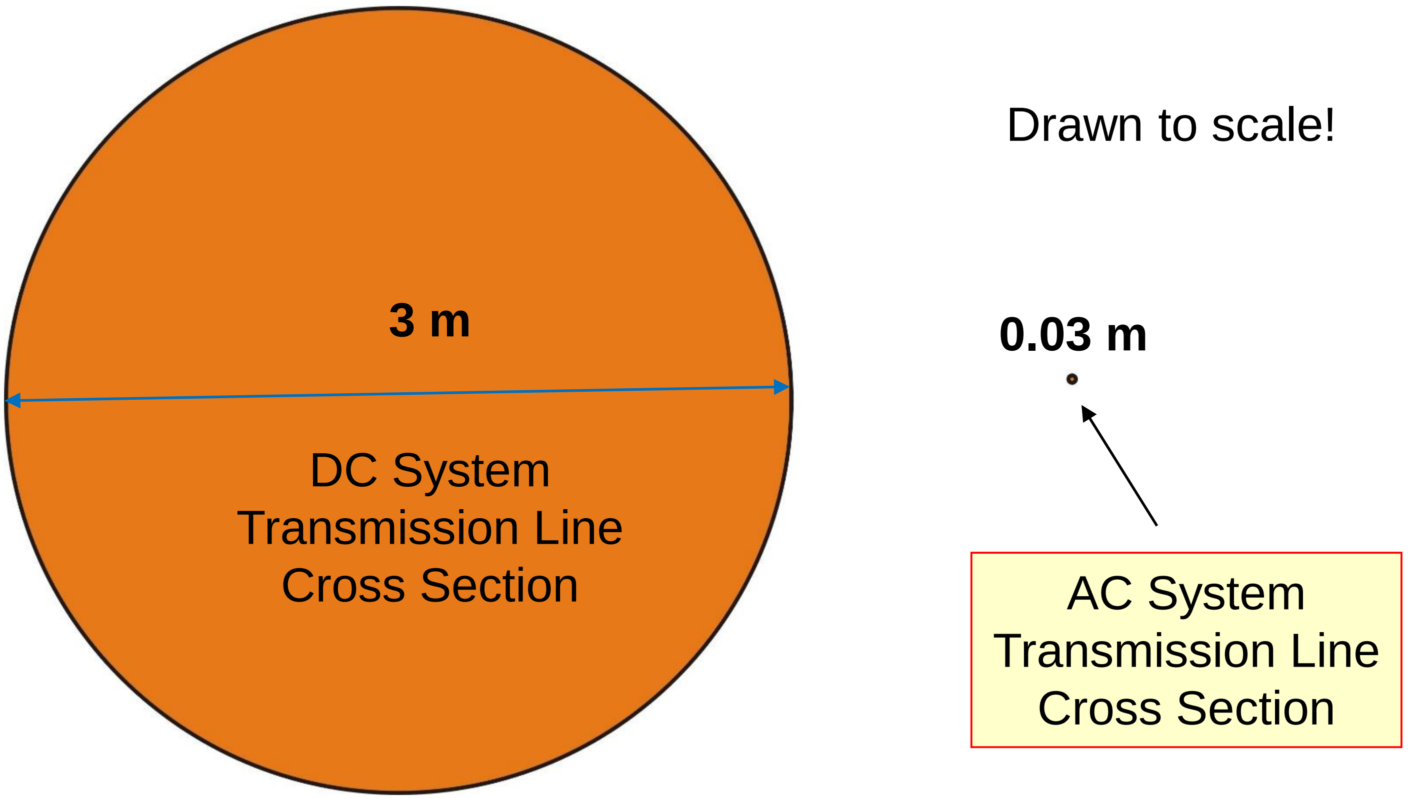
$$Diameter^2 = \frac{4 \text{ x Area}}{\pi}$$

$$Diameter^2 = \frac{4x712e-6}{\pi}$$

$$Diameter^2 = 907e-6$$

$$Diameter = 0.03m$$

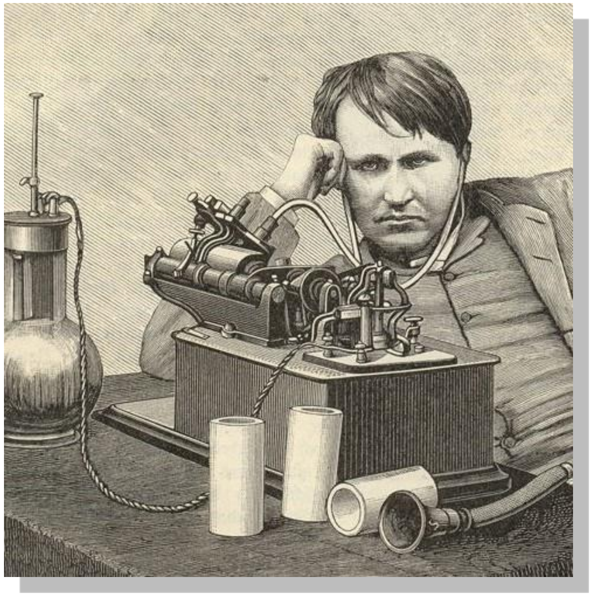
Results:



If the cost of the transmission line was proportional to the weight of copper then the AC System would cost 0.01% of the DC System – Which system do you think was adopted??

Additional Benefits of an AC System:

- **AC Generators were cheaper to construct and required less maintenance than their DC counterpart**
- **The Induction Motor was more robust and required less maintenance than the DC motors of the day – the Induction Motor required an AC power supply**



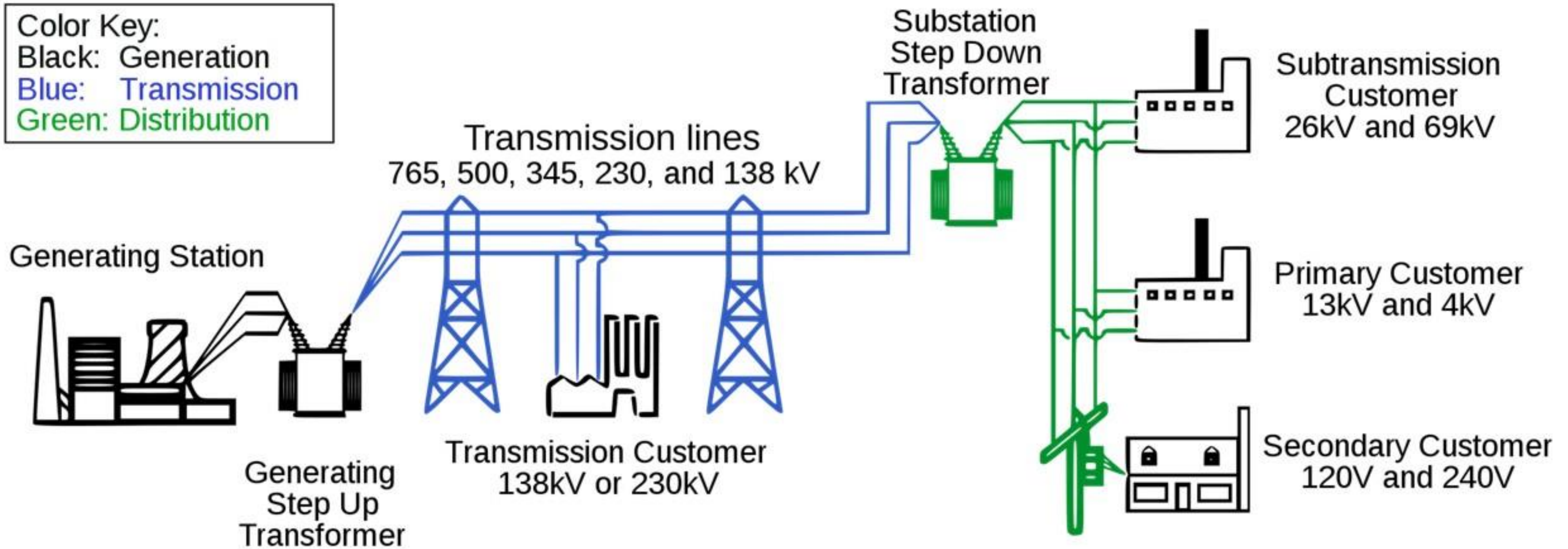
Thomas Edison

Despite all this Edison did not give up and waged a bitter PR "war" with Westinghouse over the next 10 years.

As part of his PR campaign Edison developed an AC powered Electric Chair and publicly electrocuted[*1] a range of animals (including an elephant!) in an attempt to persuade the public that AC was more dangerous than DC.

[*1] he even tried to coin the phrase "being Westinghoused"

He failed, **and from early 1900's all the industrial nations adopted AC Generation/Transmission Systems:**

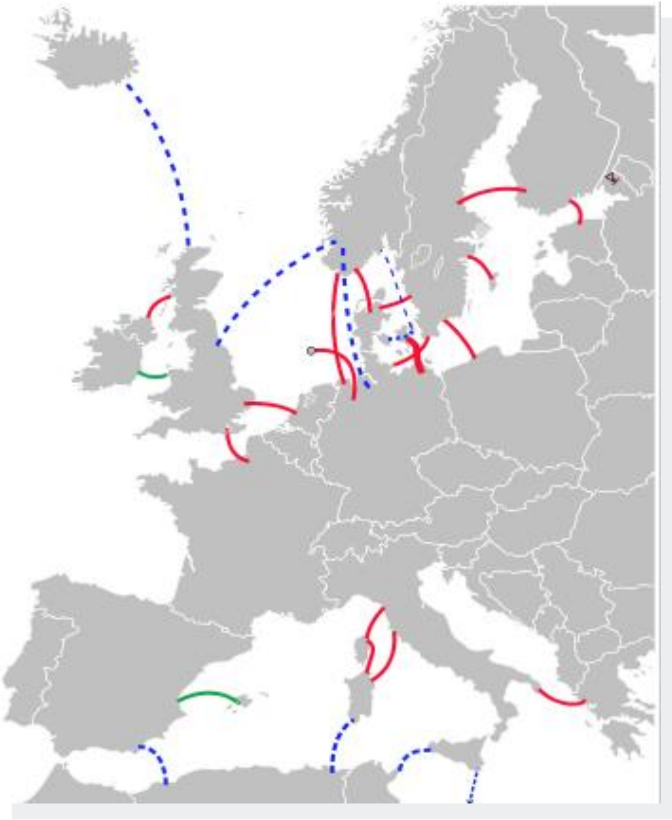


A Modern AC Power Generation/Transmission/Distribution System

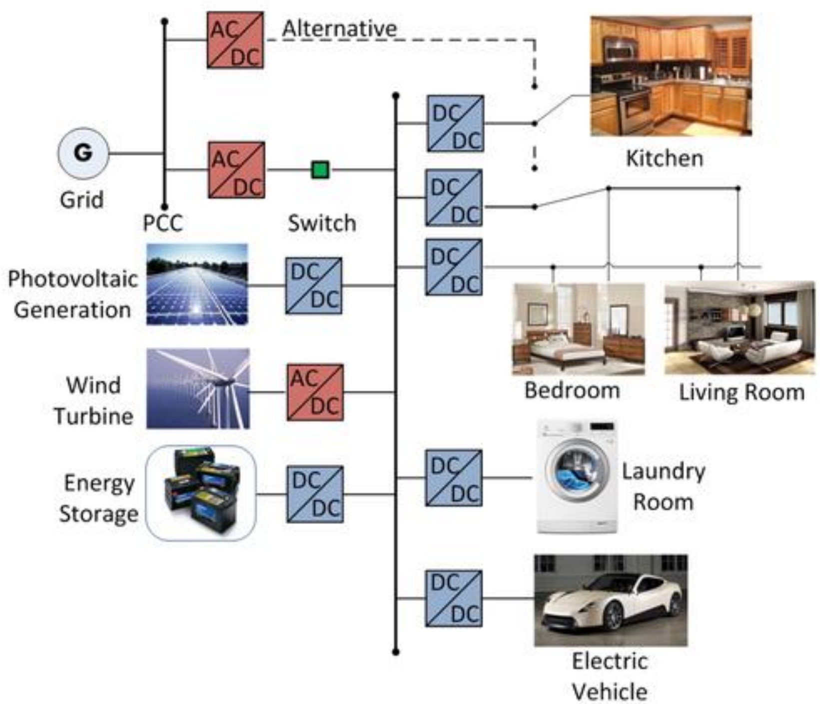
LiTTLE BOX CHALLENGE

Google | IEEE

Edison's 'revenge': **High Voltage Direct Current (HVDC) systems have been possible since the 1950's due to Power Electronic Converters. For a number of reasons these systems are now the system of choice for subsea interconnections, and very long distance overland transmission.**



Edison's 'revenge': **DC bus distribution systems become more and more attractive (efficient, easy control…) than AC bus Distribution Systems due to Power Electronic Converters.**



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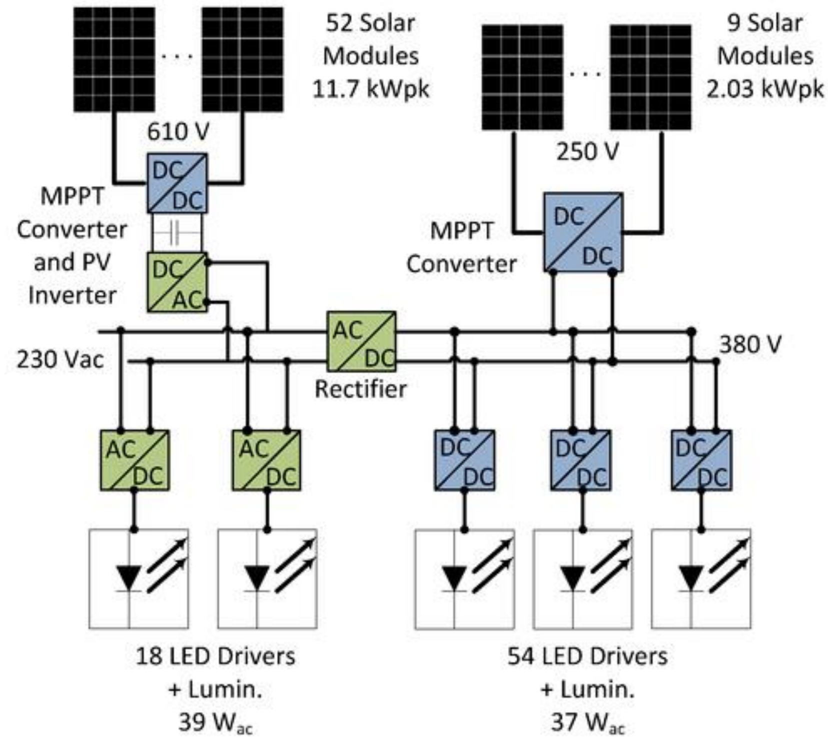

(b)