UESTC3005 - POWER ENGINEERING

#01 – INTRODUCTION

Semester 1 – 2021/2022

University of Glasgow

电子科技大学

University of Electronic Science and Technology of China

Outline

- Introduction to Course
  - Course Aim
  - Course Content
  - Readings and Others
  - Delivery and Assessment
- Introduction to Electrical Power System
  - The War of Currents
  - Prevailing AC Power Systems
  - Edison’s Revenge

Course Lecturer:

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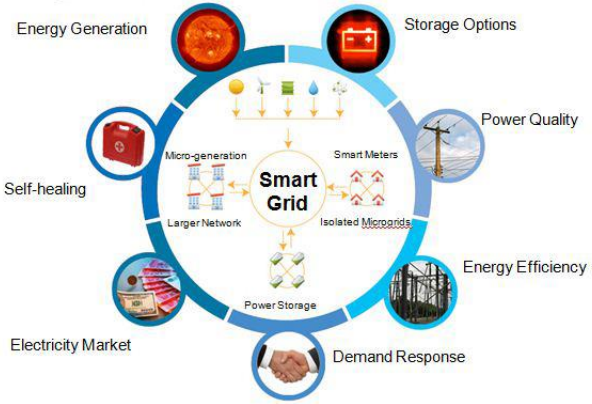
Over the last few years, Electrical Power Engineering has seen a significant resilience, primarily through the increase in the development of renewable energy technologies. As a result there has been a significant increase in employment opportunities for graduates with the necessary skills/education

Course Aim

The Power Engineering course aims to enable E&EE students to ***analyse and design fundamental electrical power systems****, such as* ***power measurement, power efficiency, voltage/current calculation, ……***



ELECTRICAL POWER SYSTEMS (EPS)

POWER Engineering

Electrical Generation (AC) → **Transmission (AC)** → **Distributions & Loads (AC)**

Step-Up Transformers

Step-Down Transformers

66kV

138kV+

415V/240V (in UK)

Synchronous Generators

Wire/Cable Lines

Induction Motor

Induction Generators

- Coal Powered (2400MW)
- Nuclear (1200MW)
- Hydro-electric (400MW)
- Wind (2MW)

Rotating Machinery

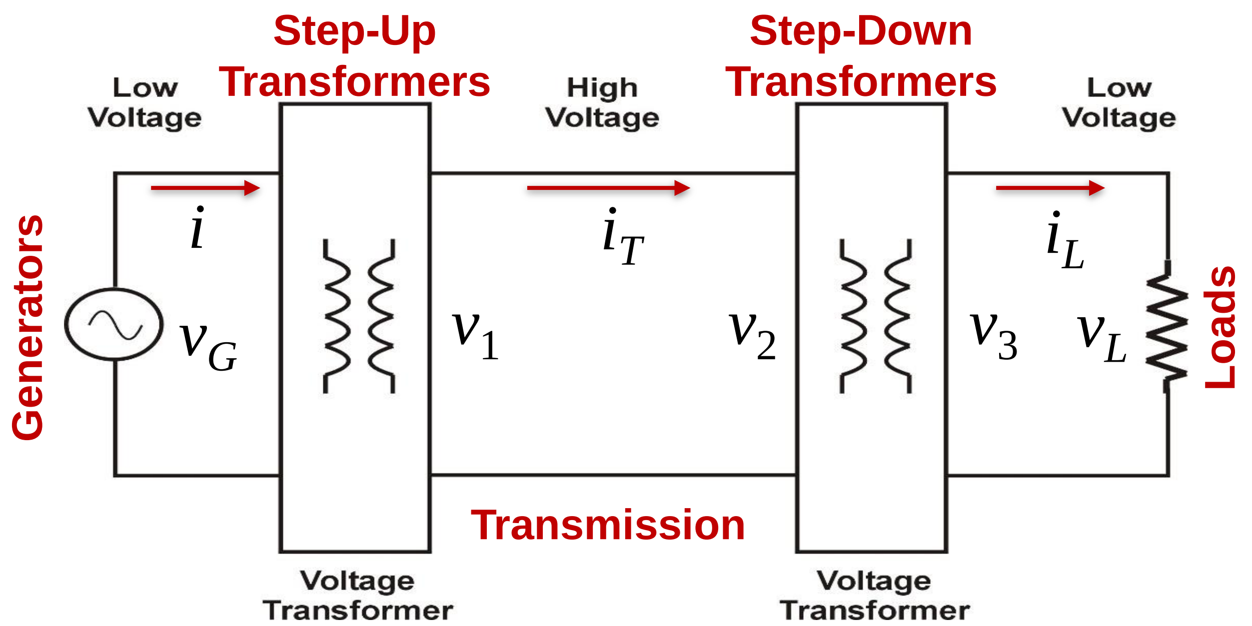
Heating

Lighting

………….

Electrical Power System Analysis

POWER Engineering



Equivalent Circuit of EPS - An AC Sinusoidal Circuit

Methodology

1 → 2 → 3

Device Modelling

equivalent RCL circuits of generators, motor, transformers…

Circuit Topology

1 or 3-phase circuits
Δ, Y, 3-phase 3-wire, 3 phase 4-wire, …

Circuit Analysis

power measurement
power efficiency
voltage/current calculation

LECTURE TOPICS

Part	#	Topic
1st Part	1	**Introduction:** DC v AC Systems Fundamentals of AC systems
1st Part	2	**Single & Three Phase Systems:** R,L & C Loads · Phasor Diagrams · Power Triangle · Balanced/Unbalanced 3 Phase Loads · Power Measurement
2nd Part	3	**Transformers:** Magnetics · Ideal/Real Transformer · Equivalent Circuit · No Load & Short Circuit Tests · Three Phase Transformers
3rd Part	4	**3 Phase Induction Motors:** Construction · Theory of Operation · Equivalent Circuit · No Load & Locked Rotor Tests · Variable Speed Operation
4th Part	5	**3 Phase Synchronous Generators:** Construction · Theory of Operation · Equivalent Circuit · Modes of Operation · Safe Operating Area
4th Part	6	**Exam Preparation**

Laboratory Sessions

Power Engineering Lab:
Research Building 330A

1st Session

1 & 3 Phase Power Systems

- Voltage, Current and Power Factor measurements
- Real, Apparent and Reactive power measurements
- 3 phase power systems: Delta and Wye connected loads

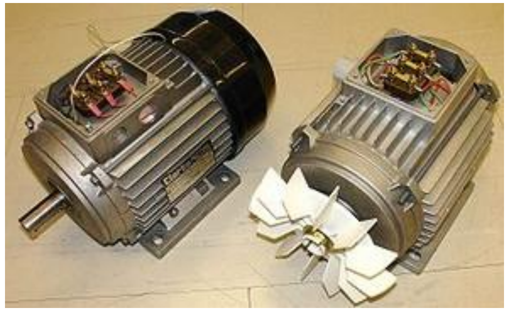
2nd Session

Transformers

- No load and Short circuit tests to determine equivalent circuit parameters
- Voltage Regulation from no load to full load
- Efficiency measurements

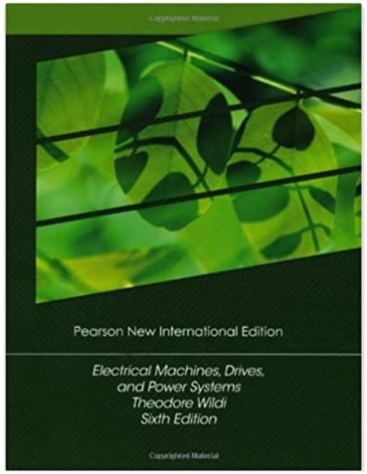
3rd Session

3 Phase Induction Motor



- No load and locked rotor tests to determine equivalent circuit parameters
- Torque v Speed, and efficiency measurements
- Comparison with simulation results

RECOMMENDED READING

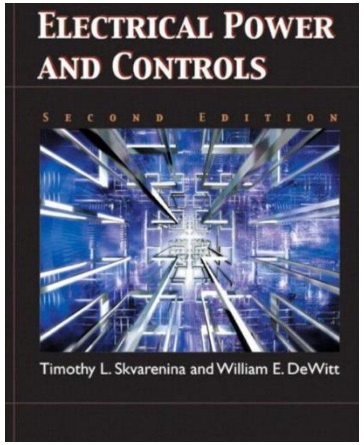


Electrical Machines, Drives & Power Systems

Theodore Wildi

Pearson Publishing (Sixth Version)

ISBN 13-978-1292024585



Electrical Power and Control

Timothy Skvarenina, William DeWitt

Pearson Publishing

ISBN 0-13-113045-5

Course Delivery

- 12 Weeks' Lectures
  - 1 lecture session (1.5 hours each) per week
- 3 Weeks' Laboratories
  - 6 lab sessions (1.5 hours each) per week

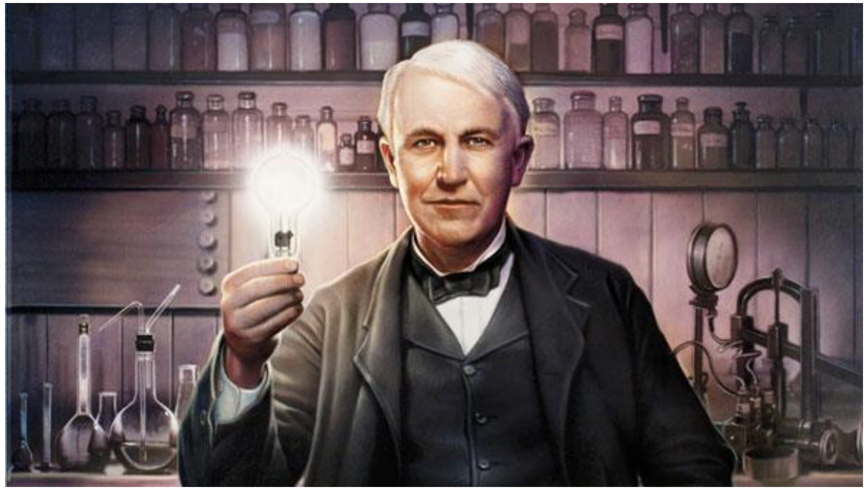
Course Assessment

- 75%: Final Exam (2 hours)
- 15%: 3 Laboratories
- 10%: Assignment

Your Route to getting a Credit for this course

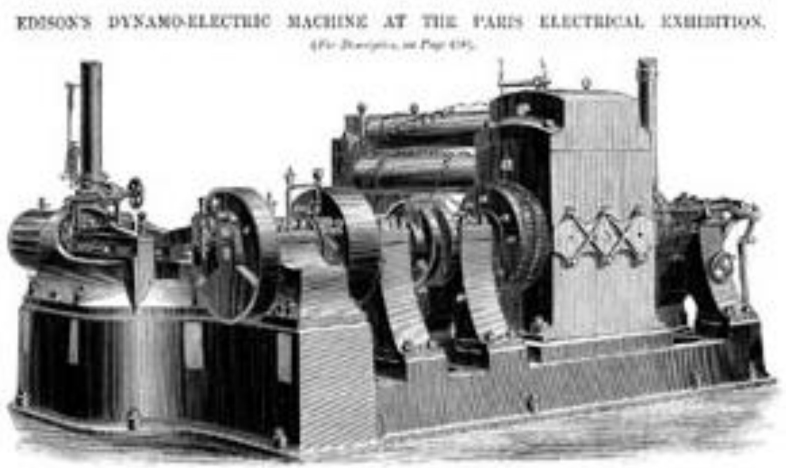
- You MUST attend at least 50% of the lectures/tutorials
- You MUST attend all 3 laboratory sessions and submit your individual laboratory report by the specified date
- You must gain a sufficiently high grade in the Final exam



Thomas Edison was the father of many landmark inventions, including the phonograph, the modern **light bulb**, the electrical grid, and motion pictures……

A Direct Current (DC) Power System



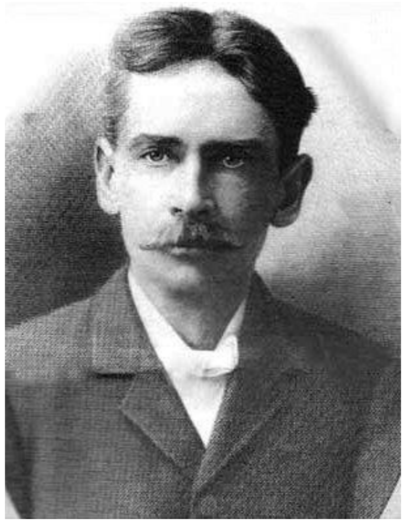
- **Since 1882, Edison had installed DC electrical generator stations (driven by Steam Turbines) in New York and London - initially to power electric Edison's lighting bulbs.**
- **By 1887, 121 "Edison" DC power stations across America were supplying power for lighting, heating and DC electric motors.**
- **Business was booming, until…….**

DC power generator: **110V, maximum transmission distance from generator to the load is about 1 mile.**

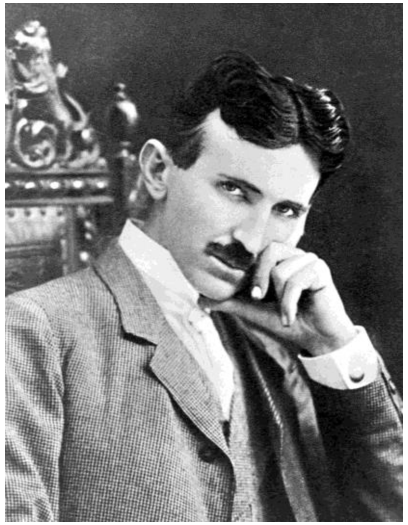
Step up/down (multiple) DC voltage: **N/A**

Westinghouse enters the AC business in 1880s

George Westinghouse Jr.



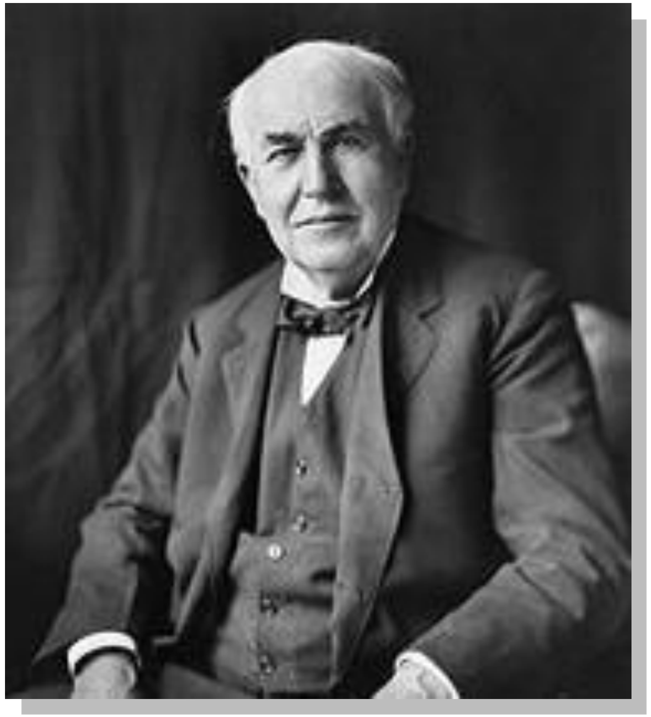
William Stanley



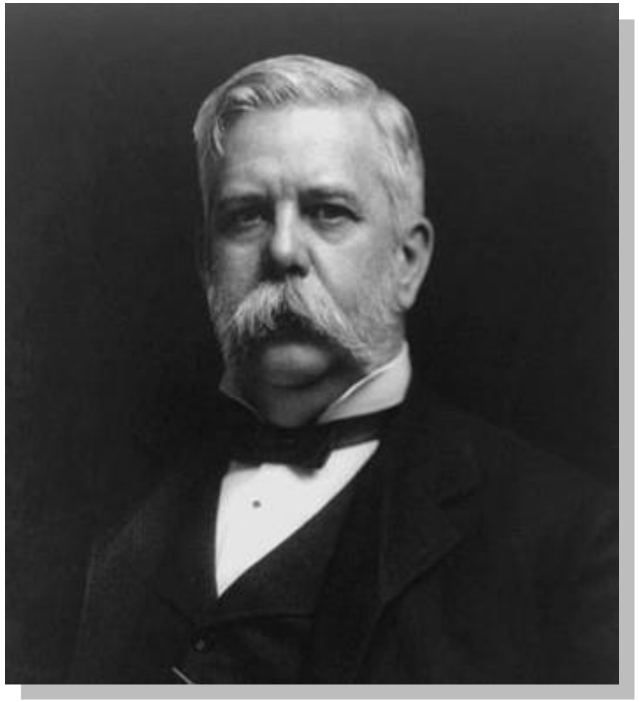
Nikola Tesla

- **From the early 1880s George Westinghouse** put all his resources into the development of **alternating current (AC)** system
- **Westinghouse** backed **William Stanley** to develop the **first practical AC transformer** and build **the first AC systems**.
- **By the end of 1887 Westinghouse** had **68 AC power stations** to **Edison's 121 DC**-based stations.
- **In July 1888 Westinghouse** paid **Nikola Tesla** a substantial amount to license 's US patents for a **poly-phase AC induction generator/motor**.

The War of the Currents

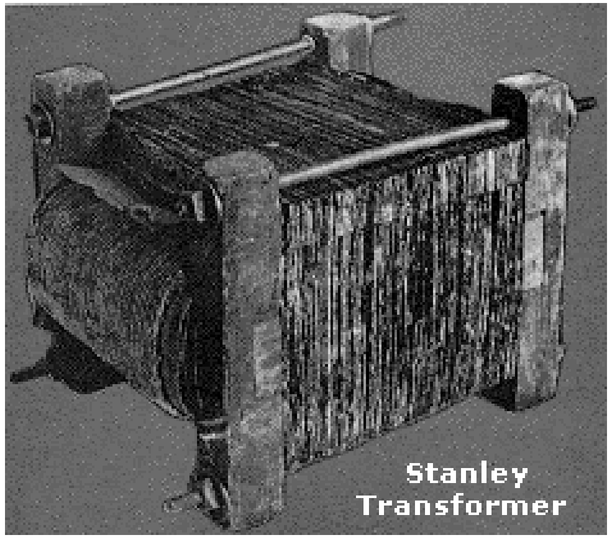


Thomas Edison

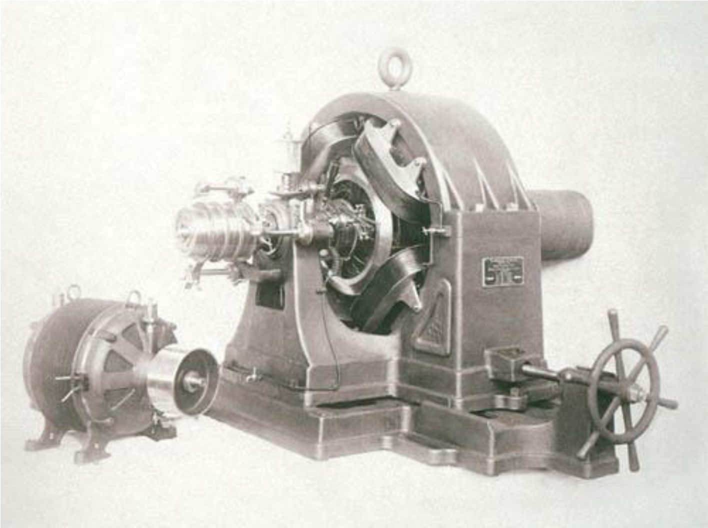


George Westinghouse

KEYS TO AC'S COMPELLING SUCCESS



Stanly Transformer

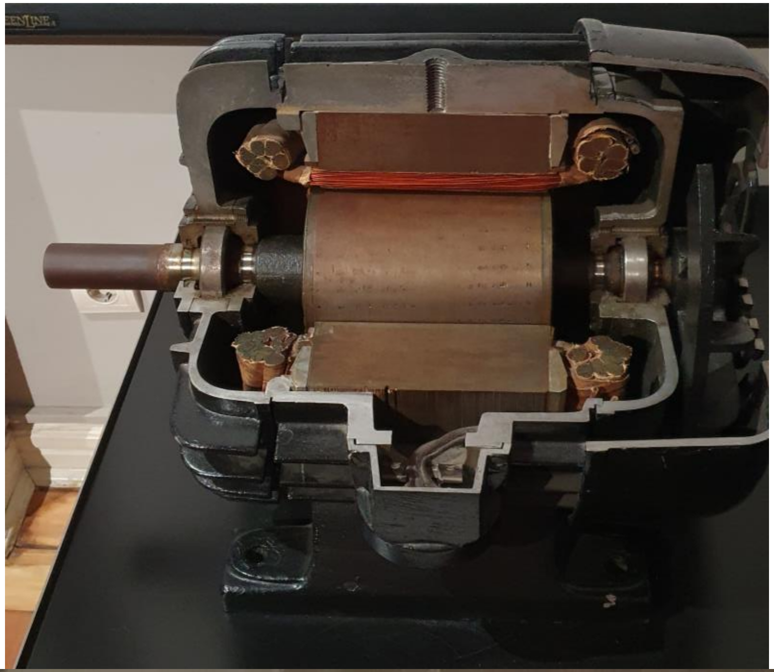


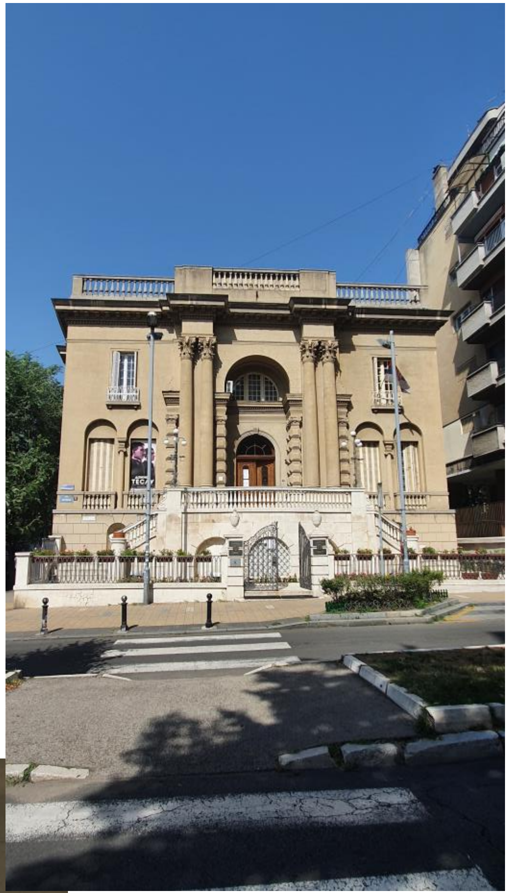
Tesla Poly-phase AC motor

AC systems of the day – *more powerful, efficient, flexible*

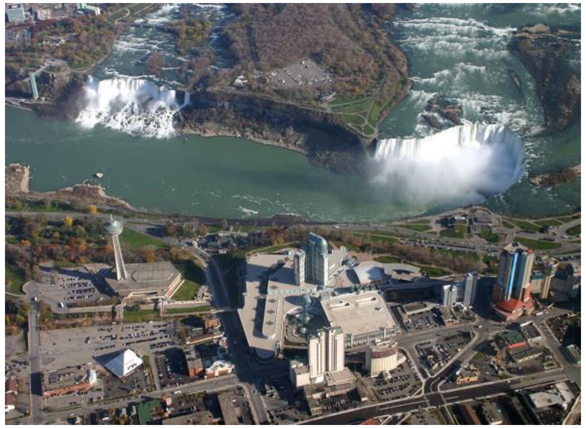
- **AC transformer**: static, low cost, reliable and easy for use AC voltage step up/down, enabling long distance transmission and distributions
- **Poly-phase AC induction motor**: higher power rating, cheaper to construct, more robust and required less maintenance than DC motors,,

Nicola Tesla’s Museum in Belgrade, Serbia

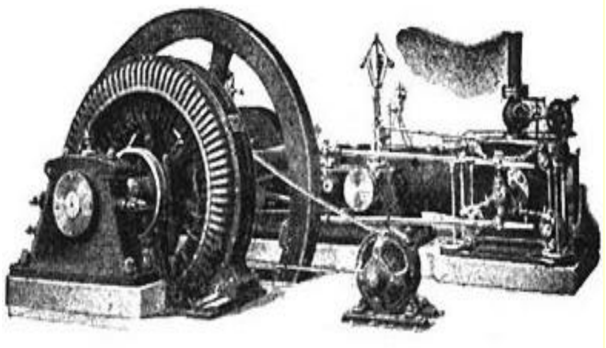




KEY EVENTS OF AC POWER



Niagara Falls



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

- **In 1893**, **Westinghouse** won the bid to light **World's Columbian Exposition in Chicago** with **AC** System. It demonstrated the safety, reliability, and efficiency of a fully integrated **AC** system.
- **In 1895**, **Westinghouse** got the contract for building a two-phase **AC** generating system, **the Adams Power Plant, at Niagara Falls,** while a contract to build the three-phase **AC** distribution system the project needed was awarded to **General Electric**.
- **In 1908 Edison** said to **George Stanley**, son of AC transformer inventor **William Stanley, Jr.** "Tell your father I was wrong"

A SIGNIFICANT EXAMPLE OF DC VS AC

This example has historical significance, in the **1880's** the **Niagara Falls Power Company** offered a prize of **$100,000** to anyone who could develop **an economic method of transmitting electricity long distance.**

Niagara Falls

32km's

Transmission Lines

Buffalo, NY State

Hydro Electricity Generation Plant

Loads: lighting, heating, electric motors

Power System Specifications:

1) The Hydroelectric generator plant outputs 4MW
2) The power loss in the transmission lines should be limited to 5% of the generated power over the distance of 32km
3) User load voltage = 110V (rms)

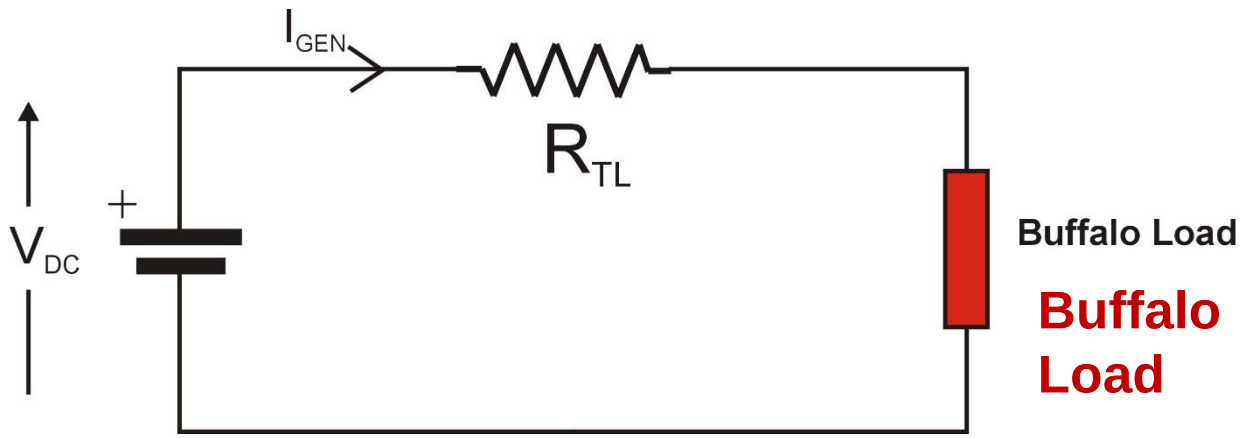
DC System Solution

V_{GEN} = 110V

P_{GEN} = 4MW

Hydro Generator

Transmission Line (TL)



Buffalo Load

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

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

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

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

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

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

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

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

$$P_{TL} = 200kW$$

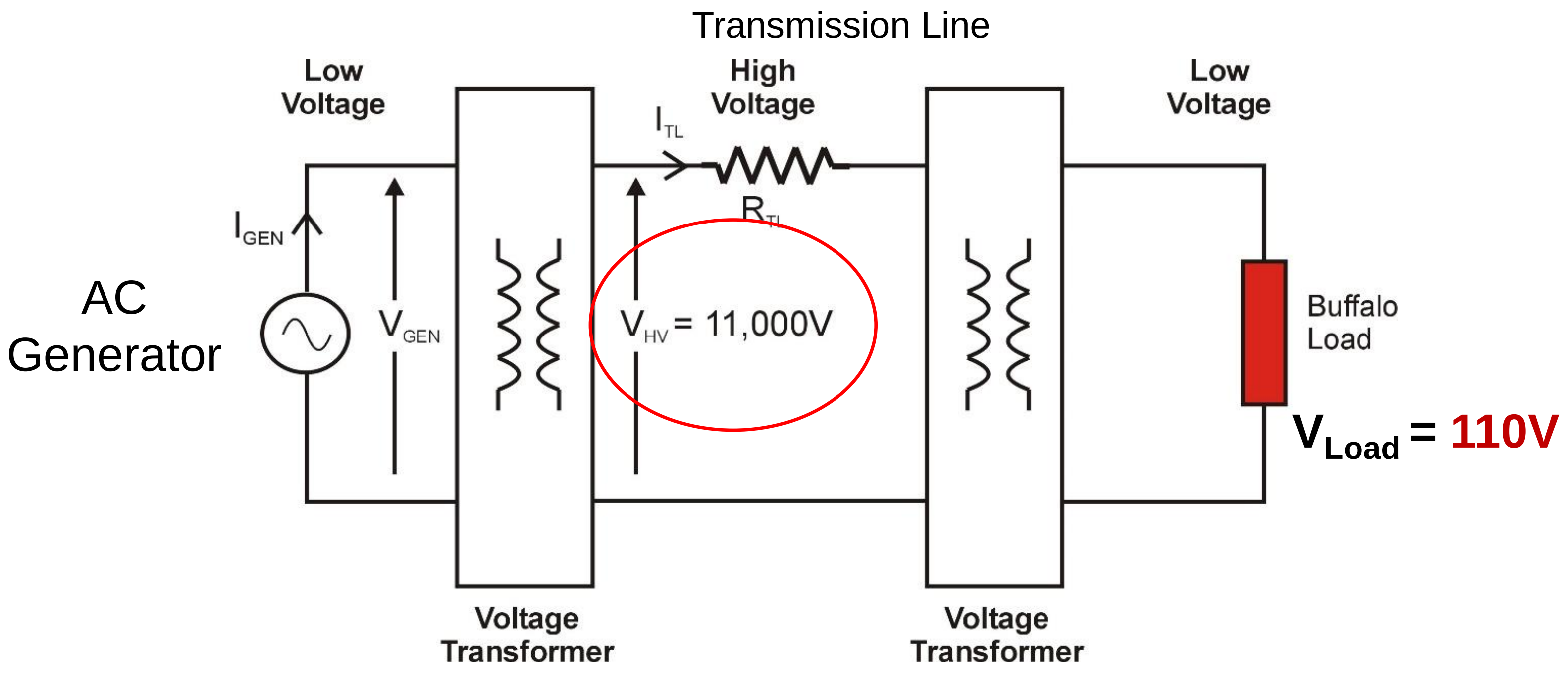
$$P_{TL} = I_{GEN}{}^{2}.R_{TL}$$

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

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

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

AC System Solution



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

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

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

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

$$I_{TL} = 363A$$

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

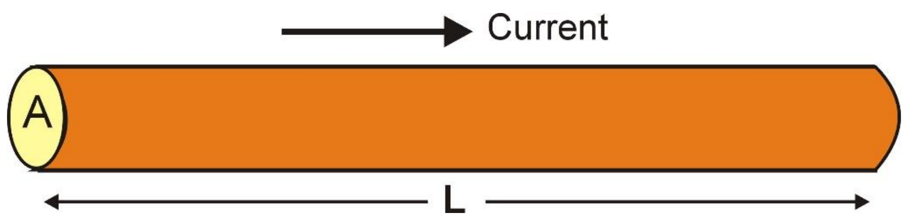
$$R_{TL} = \frac{P_{TL}}{I_{TL}^2}$$

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

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

Note: the assumption is that the transformers Are simply 100% efficient!

WIRE RESISTANCE AND WIRE DIMENSIONS



Length = L (m)

Cross Sectional Area = A (m^2)

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

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

Cross Sectional Area of DC & AC Transmission Lines:

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

Note: Resistivity for Copper = 1.68e-8Ωm

Wire Dimensions

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:

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

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

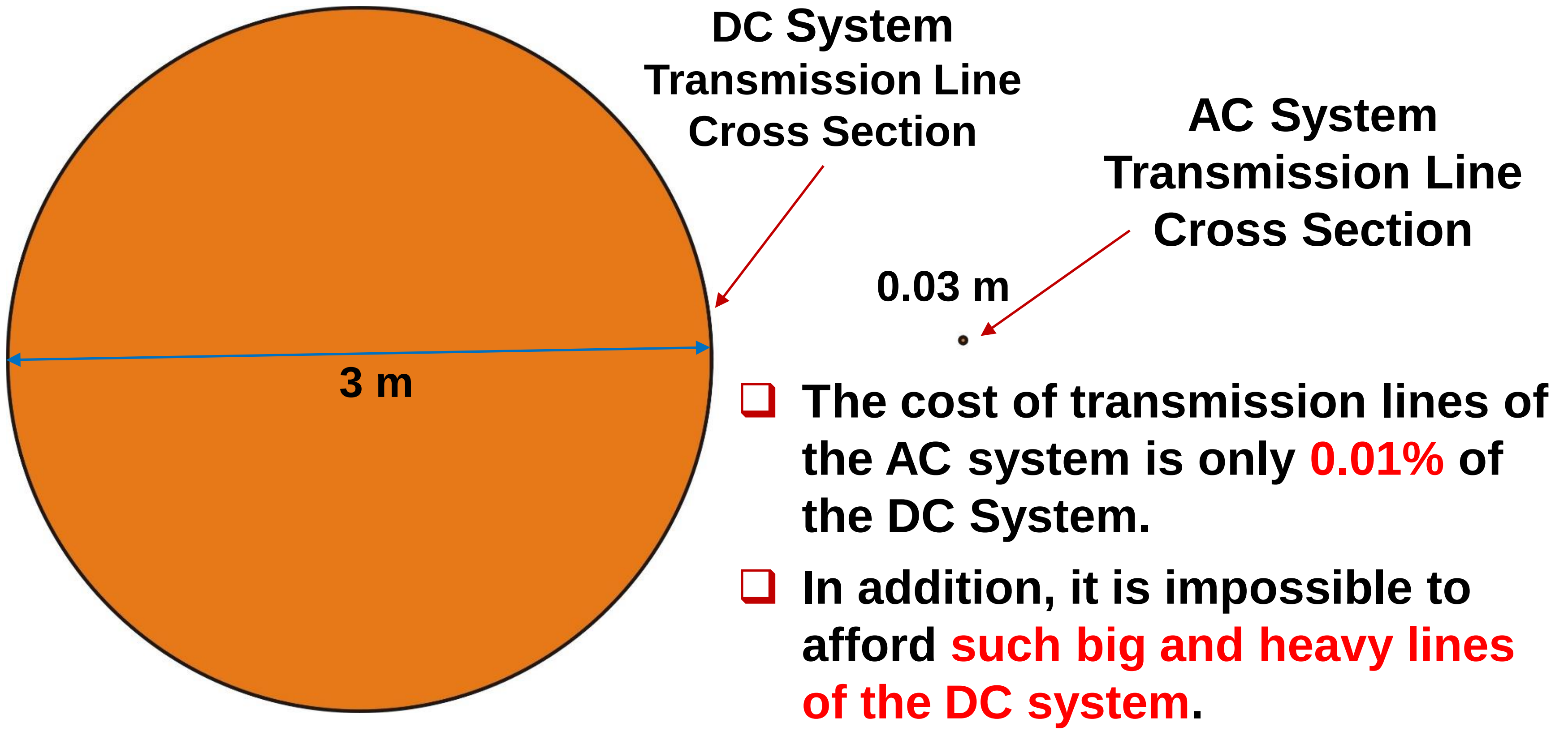
Diameter^2 = $\frac{4 \text{ x Area}}{\pi}$

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

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

$$Diameter = 0.03m$$

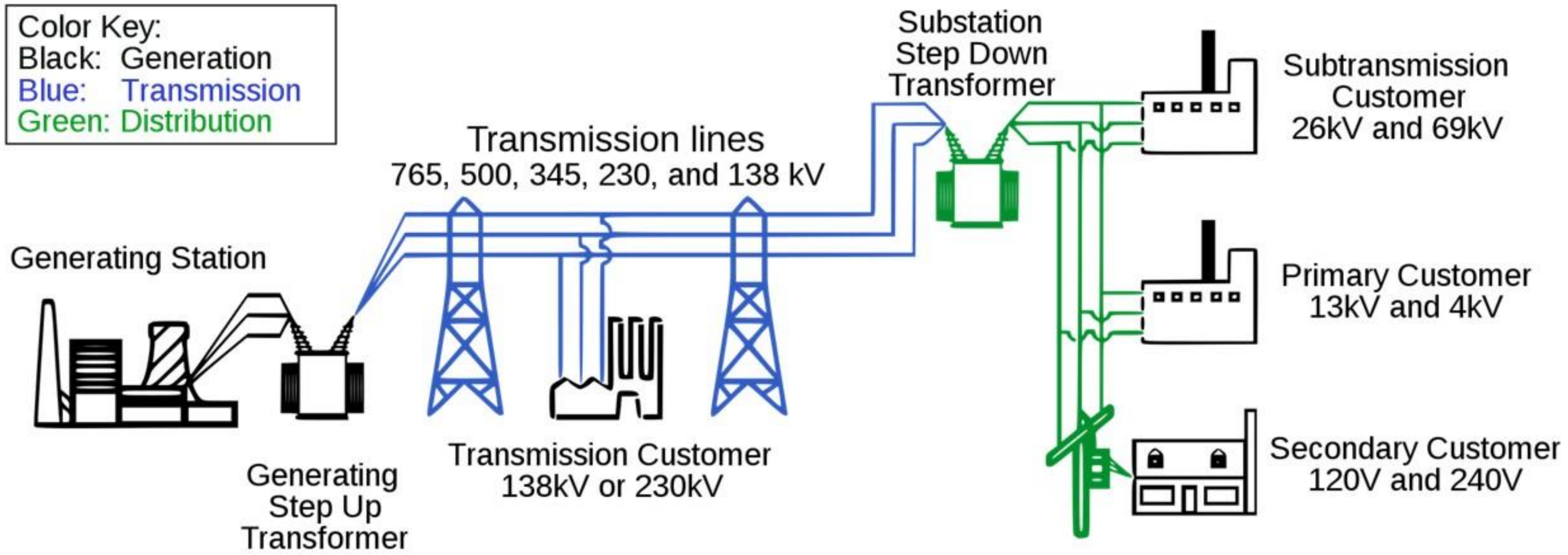
Wire Dimensions



- The cost of transmission lines of the AC system is only **0.01%** of the DC System.
- In addition, it is impossible to afford **such big and heavy lines of the DC system**.

At midnight November 16, 1896, The first one thousand horsepower of electricity surging to Buffalo over a long distance via a fully integrated AC system by Westinghouse and General Electric.

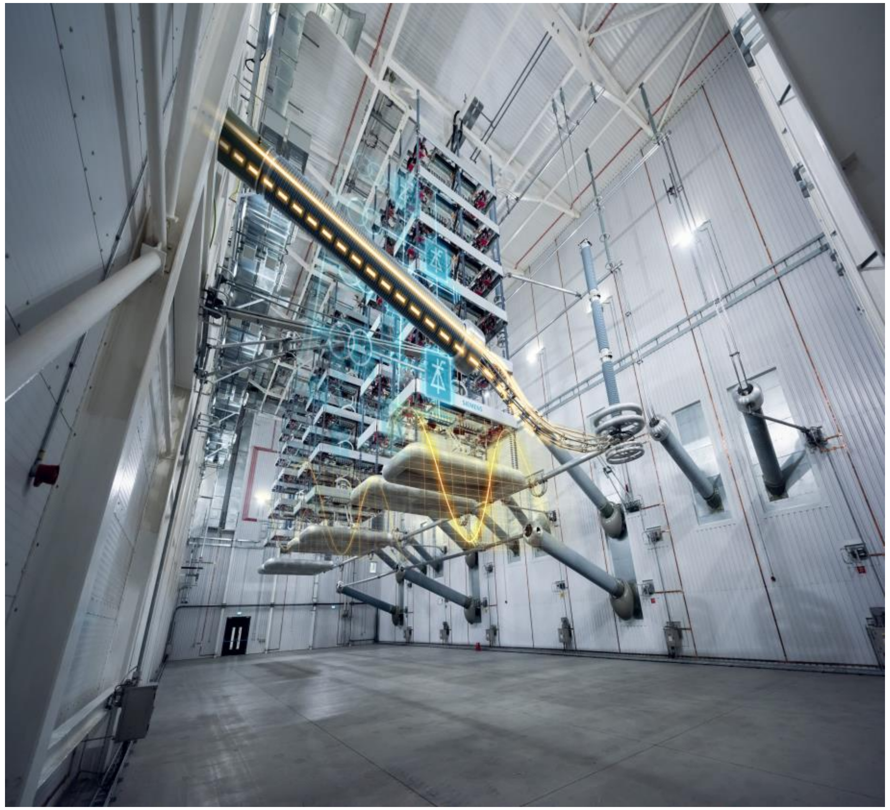
From early 1900's all the industrial nations adopted AC Generation/Transmission Systems

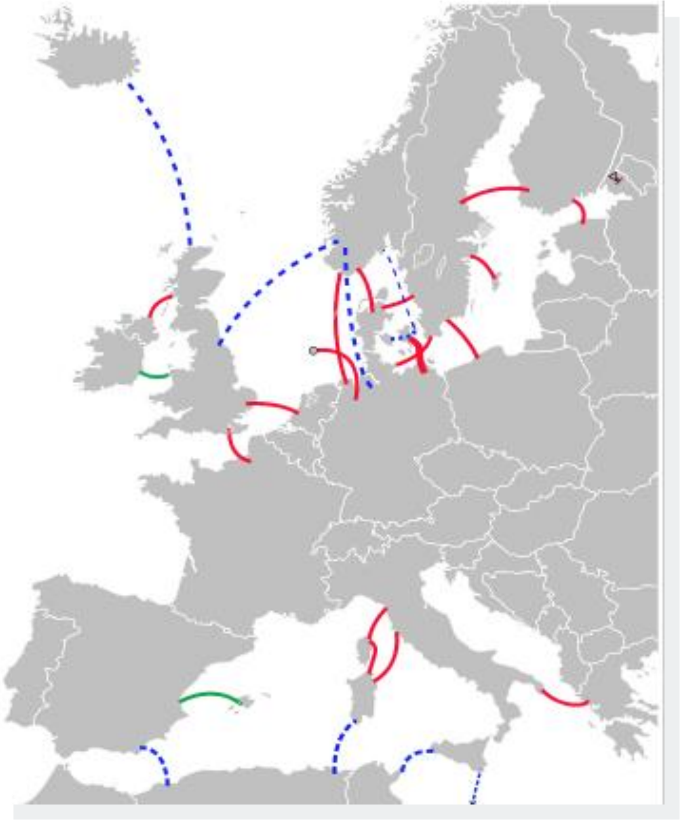


A Modern AC Electrical Power Generation/Transmission/Distribution System

Edison's 'revenge'

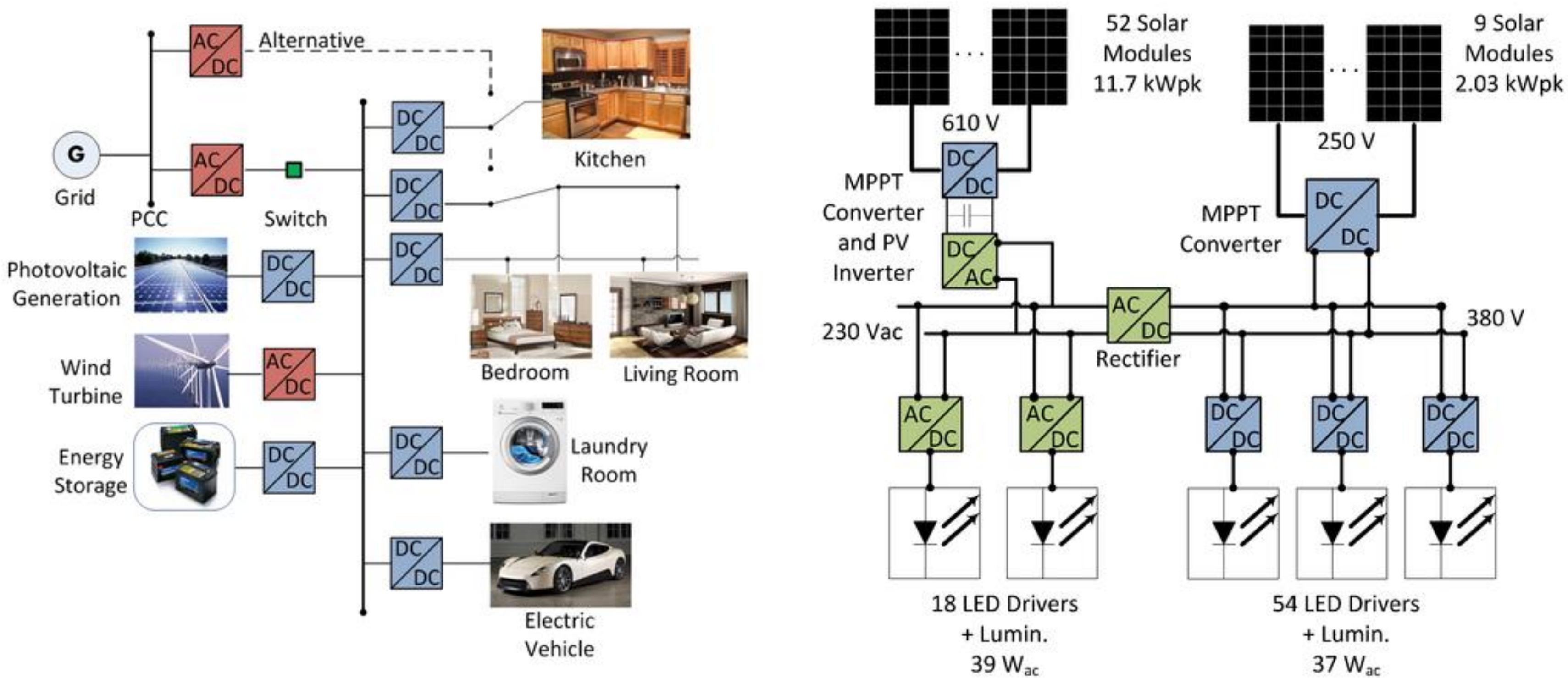
High Voltage Direct Current (HVDC) systems have been possible since the 1950's due to Power Electronic Converters. For a number of reasons these systems are now the system of choice for subsea interconnections, and very long distance overland transmission.





Edison's 'revenge'

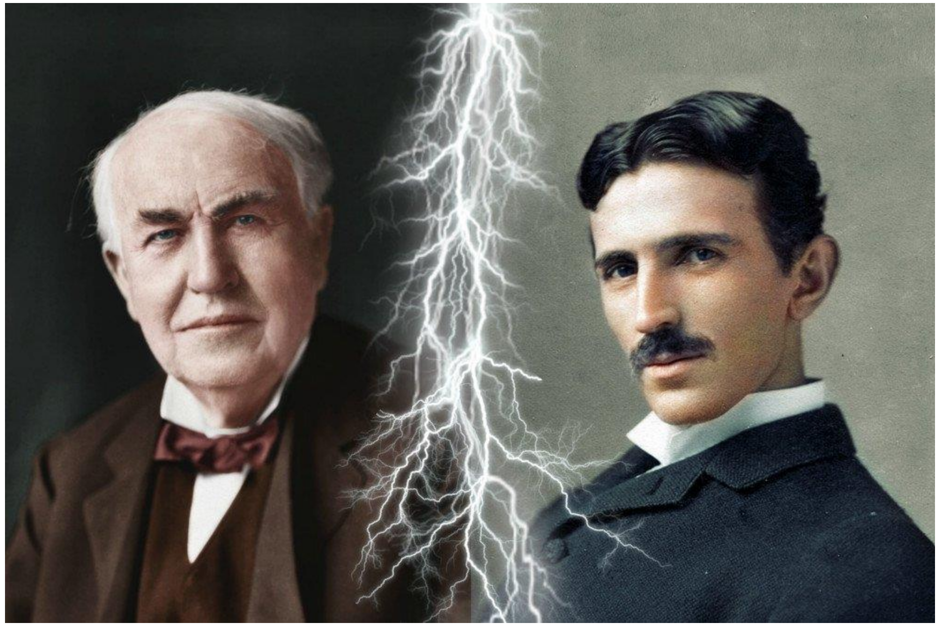
DC bus distribution systems become more and more attractive (efficient, easy control…) than AC bus Distribution Systems due to Power Electronic Converters.



(a) (b)

The War of Currents never ends.

Thomas Edison and **Nikola Tesla** shaped the history of Electrical Power System.

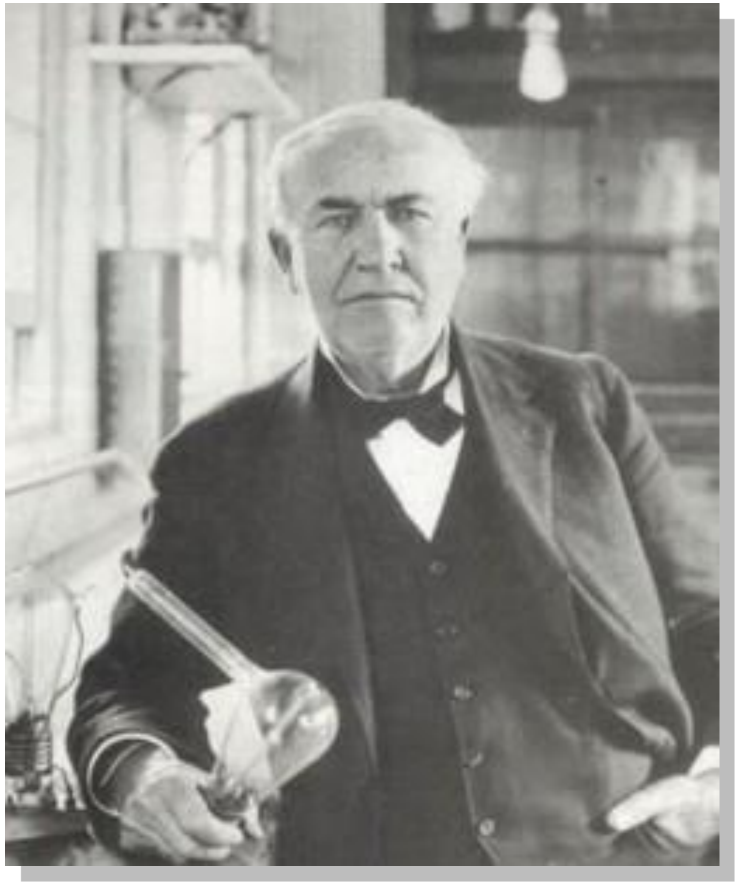


For the full story, read https://en.wikipedia.org/wiki/War_of_the_currents

For the 2017 film, see The Current War.

Edison Quote of the Day

" I have never failed, I've just found 10,000 ways that don't work"



POWER Engineering

#01 Introduction to Course and Electrical Power System