Electrical energy distribution from power station to home

Part 1: Transmission

Bibliography

- B.M. Weedy, B.J. Cory, Electric Power Systems (4th Edition)
- Behic R. Gungor, Power Systems
  - St George's: 621.3191

Electrical power systems

- **GENERATION**
  - **producing electricity from various sources, e.g. coal, oil, nuclear, gas and wind to produce electricity from power stations.**

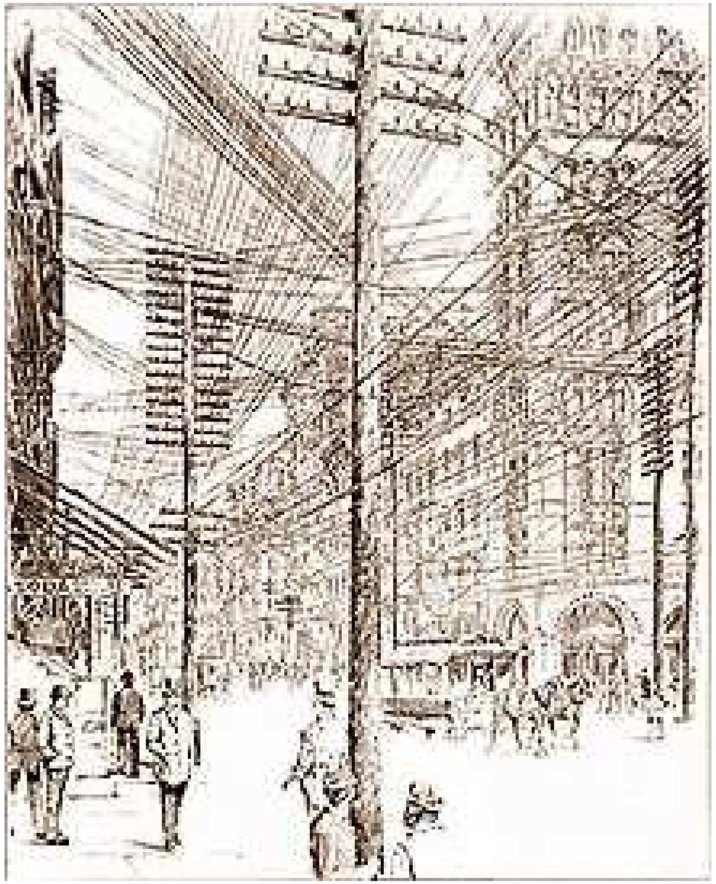
- **TRANSMISSION**
  - **The process of carrying electricity at high voltages from power stations either by overhead or underground cables.**

- **DISTRIBUTION**
    - **The process of delivering electricity from the high voltage transmission systems to the low voltage regional distribution system, by using the local wires, transformers and substations, to customers.**

- **SUPPLY**
    - **The process of buying electricity in bulk and selling it on to customers. Therefore supply is the retail activity in which businesses compete for customers**

First central generating station

- 1882 Edison created the first central generating station
  - 400 x 83W lamps = 33kW
- Specialised loads
  - Typically motors
  - Whose motor?
    - Voltage? 100 -120V
    - AC or DC
      - Frequency? 25Hz -133Hz

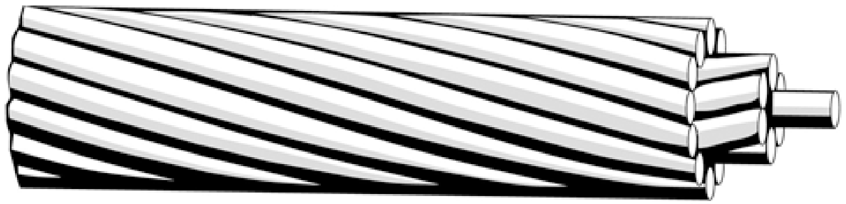


Voltage and health

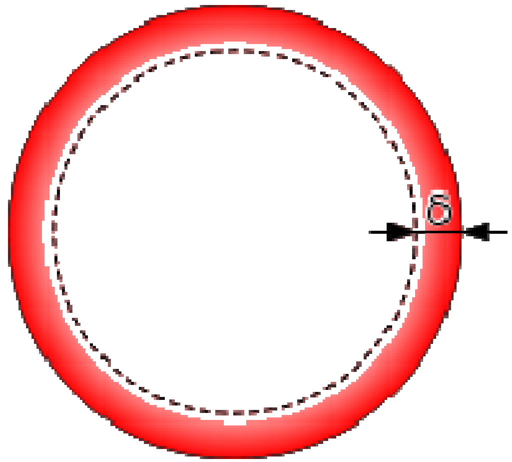
- "It's volts that jolts, but mills that kills"
  - V = IR
  - Resistance of a human 300 – 100,000 Ω
- Voltage demand vs. Health
  - "A human being can survive 100V"
    - The "Let go" threshold: sustained muscular contraction (10mA)
    - Primarily "Skin" conduction / dielectric
  - AC vs DC
    - Fibrilation:
      - AC = 60mA
      - DC = 300 - 500mA
    - High voltage: Burns: heating resistance
      - AC: short out skin: lower resistance
      - DC: higher resistance

Wires: voltages and frequencies

- Aluminium conductor steel reinforced (ACSR)
  - 59% conductivity of Cu
  - 0.47 – 0.017Ω/km



- Wires: the skin effect
  - AC has a high relative resistance
    - conduction is limited to the outer skin of the cable
  - δ depends on:
    - AC frequency...(and)
    - Electro-magnetic properties of the conductor...
    - ...creating eddy currents in the core...
    - ...in response to the varying magnetic field
  - The *lower* frequency the better
  - Generation efficiency: The *higher* frequency the better



Power loss in transmission

- $P = 400 \times 83 = 33kW = VI$
- $I = P / V = 33kW / 100 = 330A$
- $R = 0.05\ \Omega/km$

Energy lost in transmission?

- $P = I^2R$
- At 100Vdc
  - $(330)^2 \times 0.05 \approx 5.1$ kW/km
- At 240Vdc
  - $(137.5)^2 \times 0.05 \approx 0.88$ kW/km
- At 1kVdc
  - $(33)^2 \times 0.47 \times 0.5 \approx 0.051$kW/km

AC vs DC

War of Currents (1886 – 1891)

- Transmission loss
  - Higher voltage → lower currents → less loss
- The transformer (AC): Westinghouse/Telsa's camp
  - 1831 Induction: Michael Faraday and Joseph Henry
  - 1836 induction Coil: Nicholas Callan
  - 1876 "transformer" Pavel Yablochkov
  - 1883 open core transformer Lucien Gaulard and John Dixon Gibbs
  - 1884 closed core transformer Károly Zipernowsky, Ottó Bláthy and Miksa Déri
  - 1886 E transformer William Stanley
- DC "transformer": Edison's camp
  - Rotary converter or Motor-generator set
  - 1902 Mercury Arc Valve Peter Cooper Hewitt
  - 1950 Thyristor William Shockley (proposed), Gordon Hall (1956 Bell Labs)

- AC cons
  - 1882: No motor
- AC pros
  - 1883: Induction motor invented
  - 1883: Cheaper to generate
  - 1883: Cheaper to transmit
- DC cons
  - Inefficient to transmit
- DC pro
  - 1882: Motors and lighting available and well established

Transformers

Step-up Transformers at generator plant: 15-25kV up to 275 or 400kV

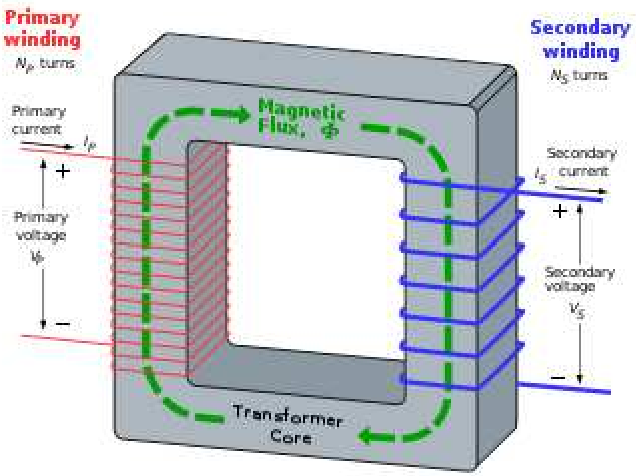
Step-down transformers at each step in the transmission/distribution chain

e.g. 275:132 kV

132:11kV

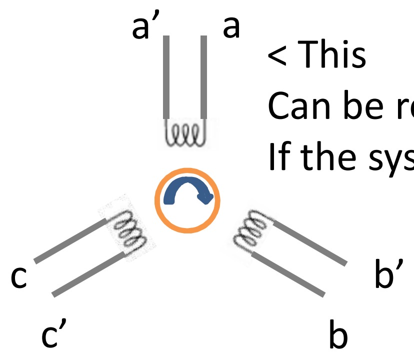
11kV:400V

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}.$$

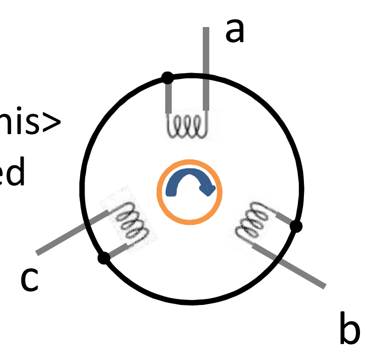


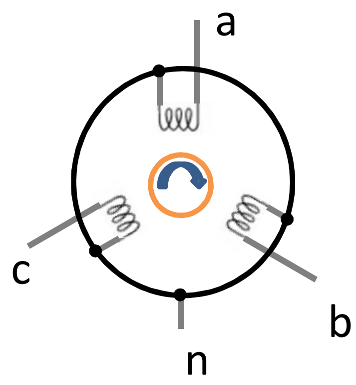
3 phase AC

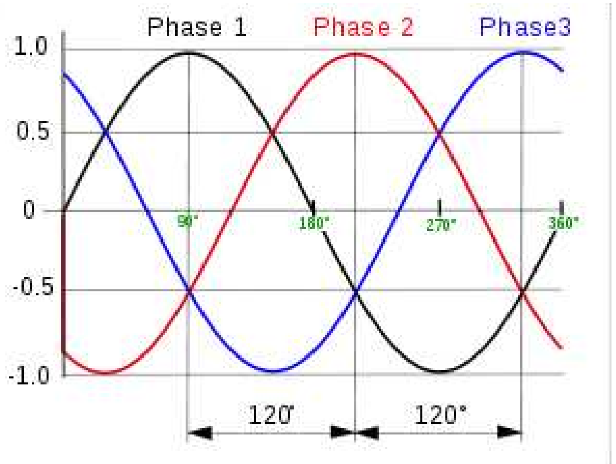
- Why 3 phase?
  - Generator design
  - Fewer wires (balanced)
  - Rotating magnetic field: Electric motor
- Unbalanced 3 phase
  - Neutral wire

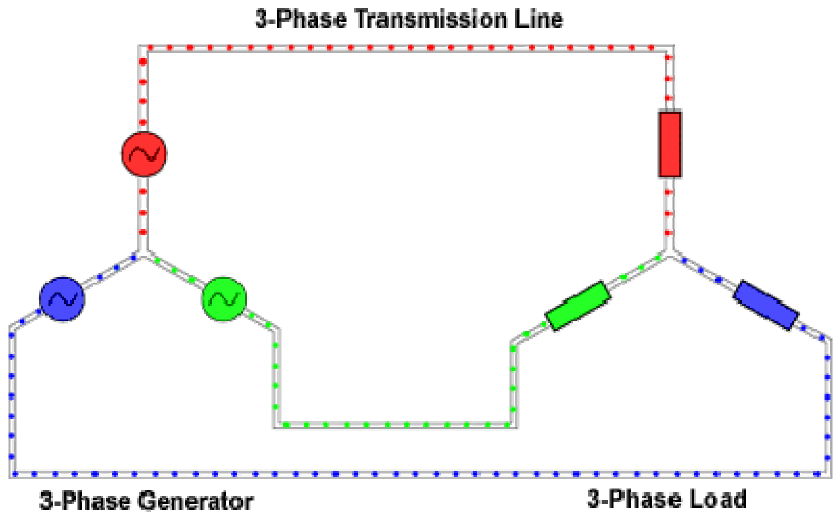


< This
Can be replaced with this>
If the system is balanced



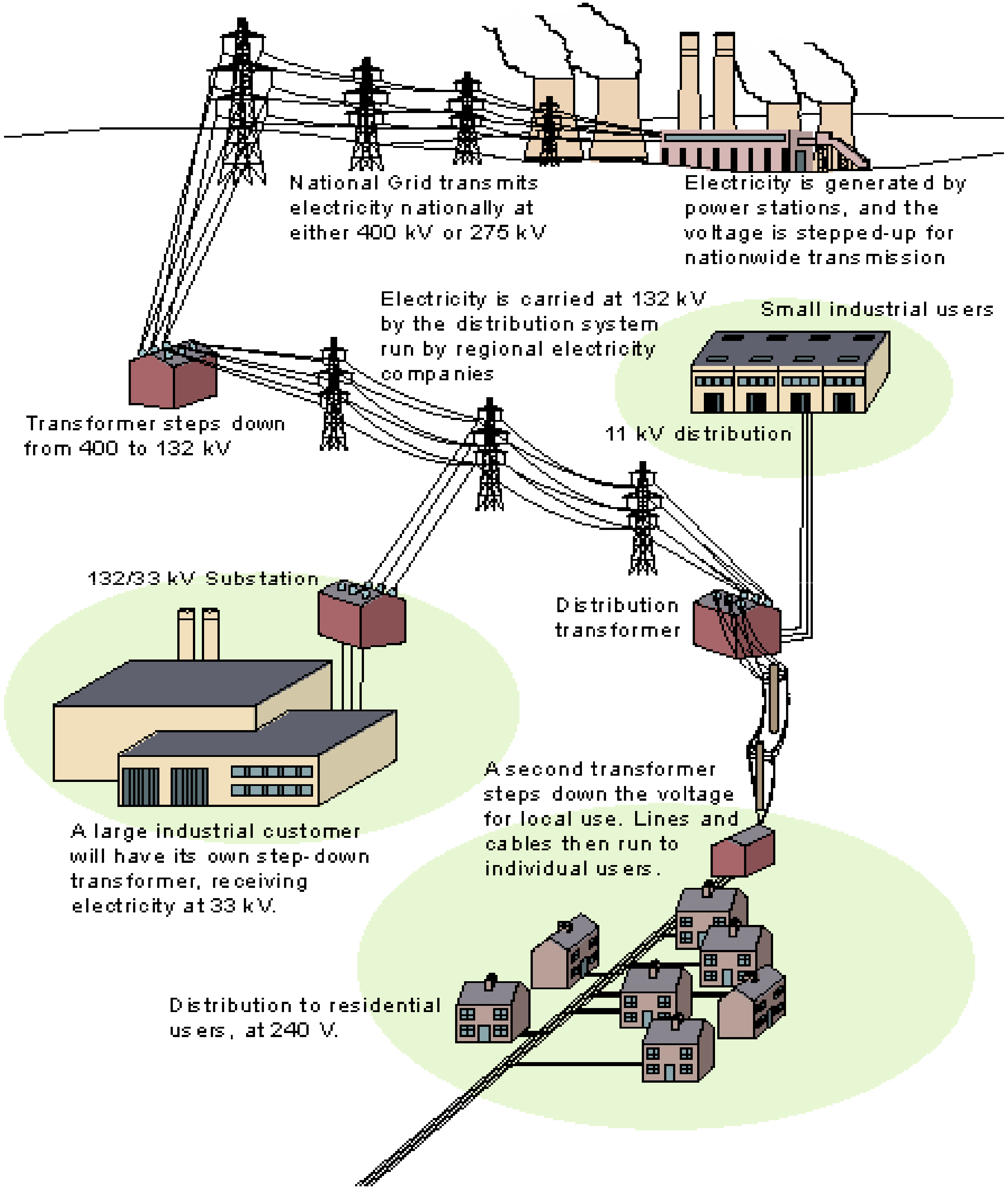






HVDC

- There is a limit to the AC transmission distance
- Reasons for HVDC:
  - Interconnect 2 systems for stability: UK-France
  - Interconnect 2 systems of different frequency: Japan
  - More economic than HVAC over long distance
- Converters are expensive!
  - Rectifier: AC to DC converter
  - Inverter: DC to AC converter
  - 30-100km run to offset conversion equipment cost.


National Grid transmits electricity nationally at either 400 kV or 275 kV
Electricity is generated by power stations, and the voltage is stepped-up for nationwide transmission
Electricity is carried at 132 kV by the distribution system run by regional electricity companies
Small industrial users
Transformer steps down from 400 to 132 kV
11 kV distribution
132/33 kV Substation
Distribution transformer
A large industrial customer will have its own step-down transformer, receiving electricity at 33 kV.
A second transformer steps down the voltage for local use. Lines and cables then run to individual users.
Distribution to residential users, at 240 V.

<u>Transmission Voltages in UK</u>

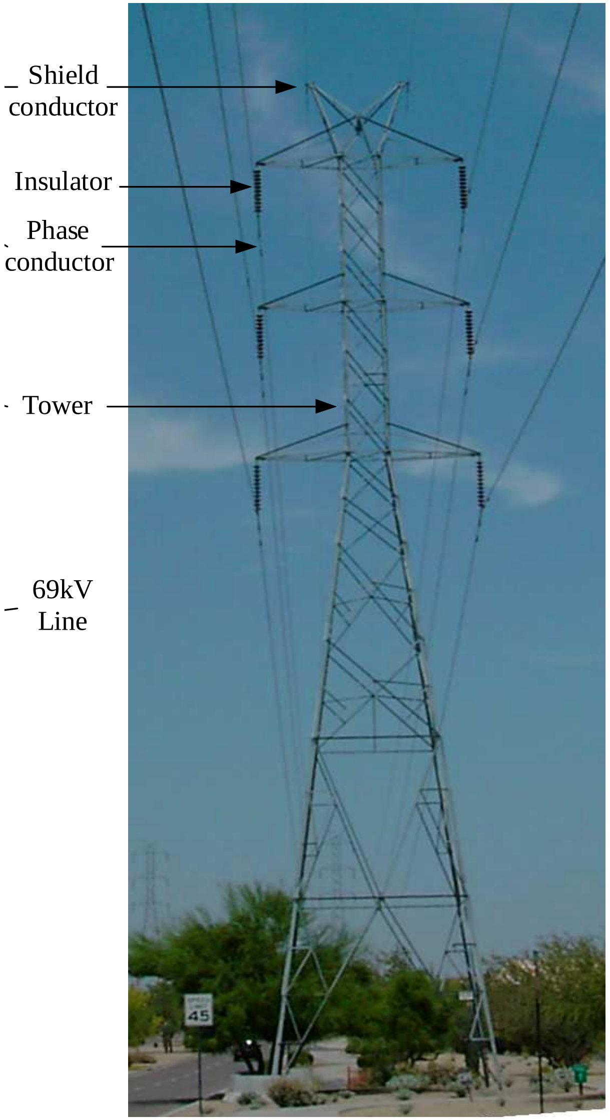
400kV

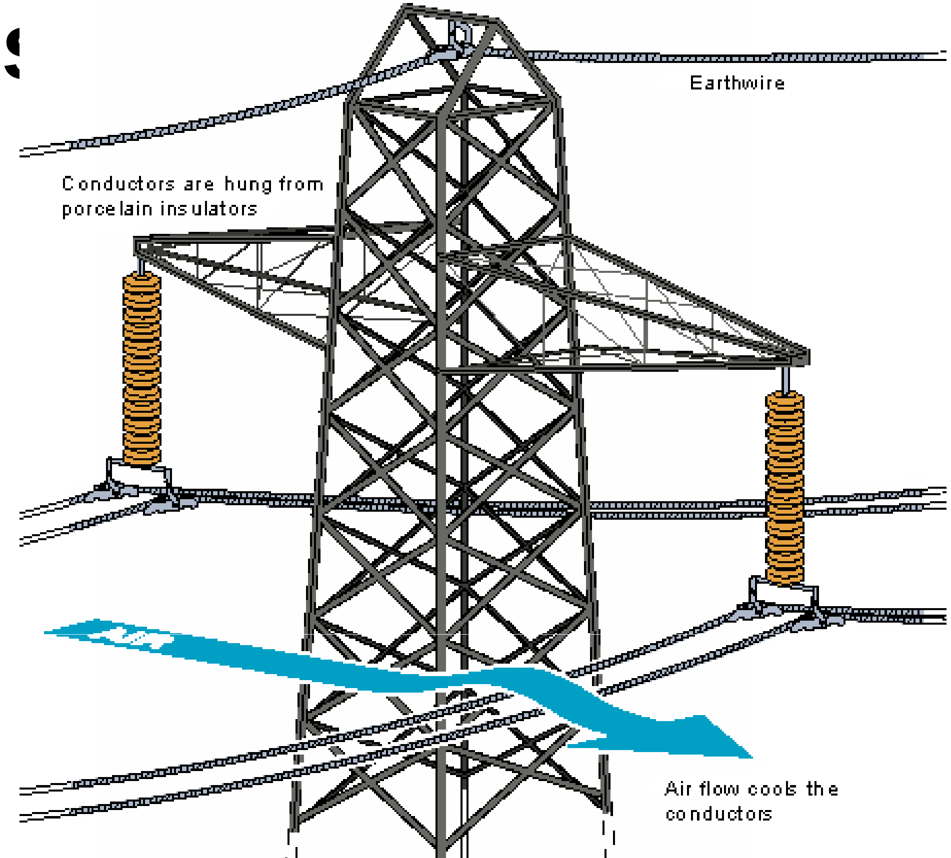
275kV

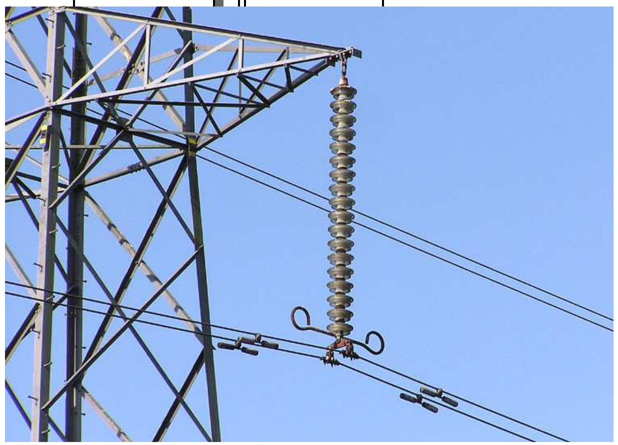
Higher voltages used in other countries with longer transmission distances

e.g. 765 kV in US

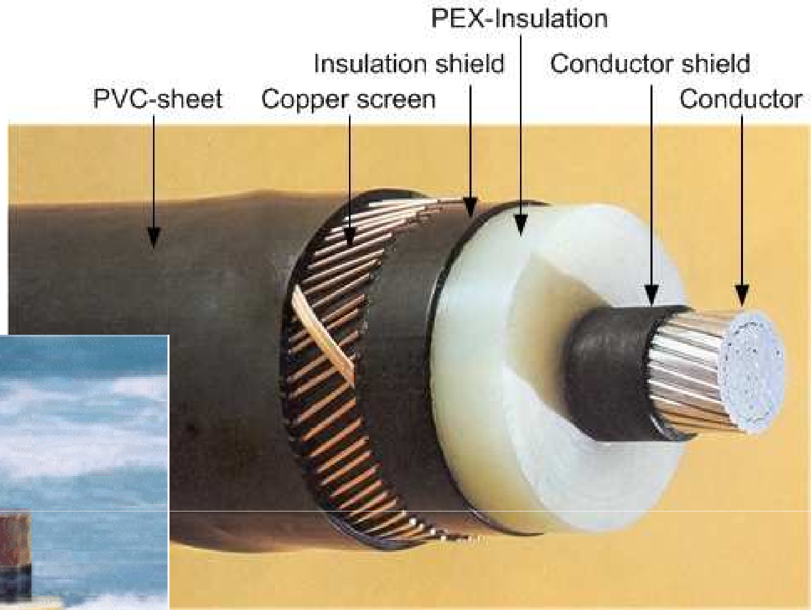
Transmis

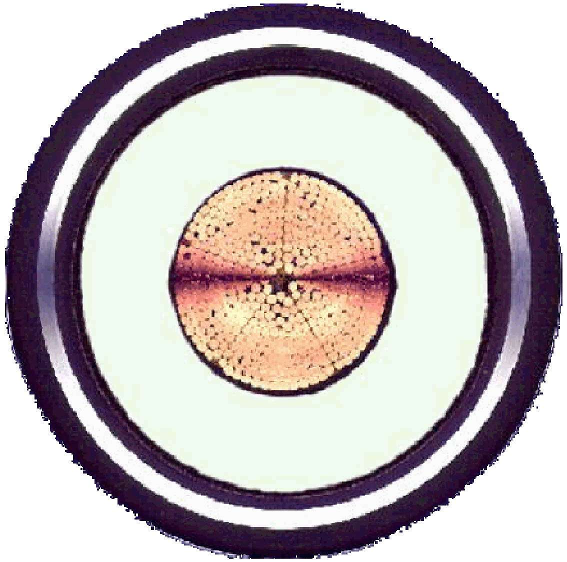

Shield conductor
Insulator
Phase conductor
Tower
69kV Line


Earthwire
Conductors are hung from porcelain insulators
Air flow cools the conductors

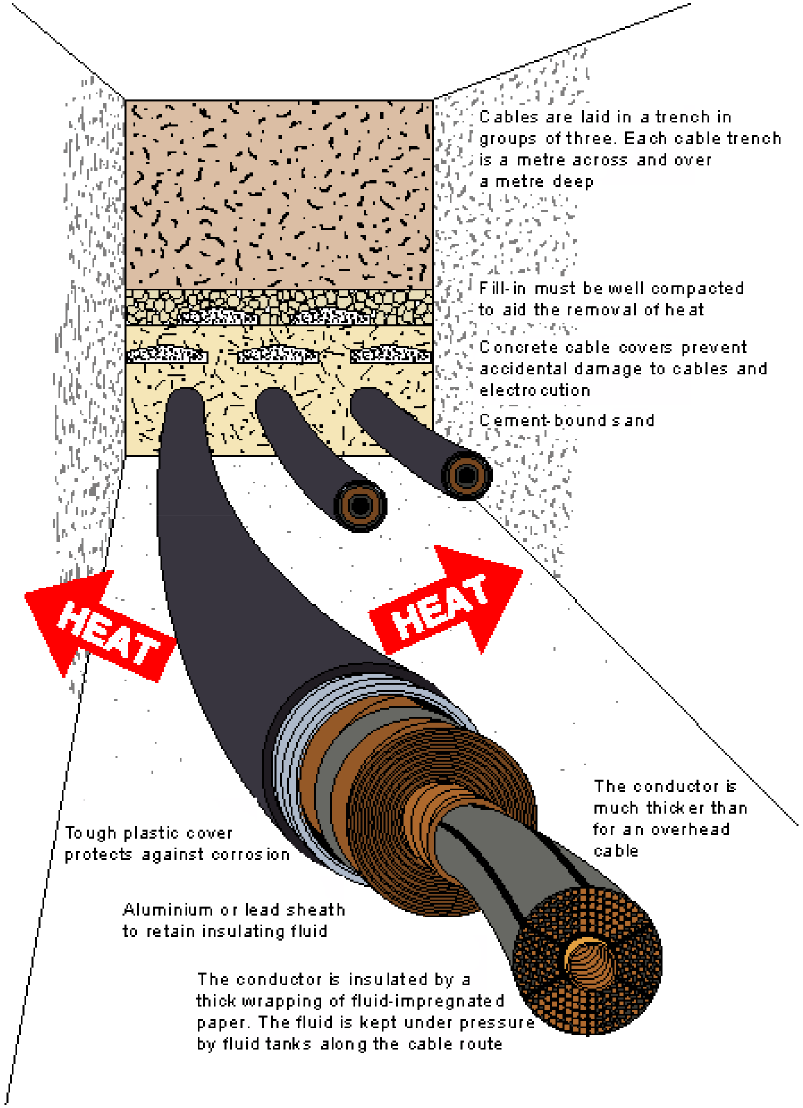


Underground Cables

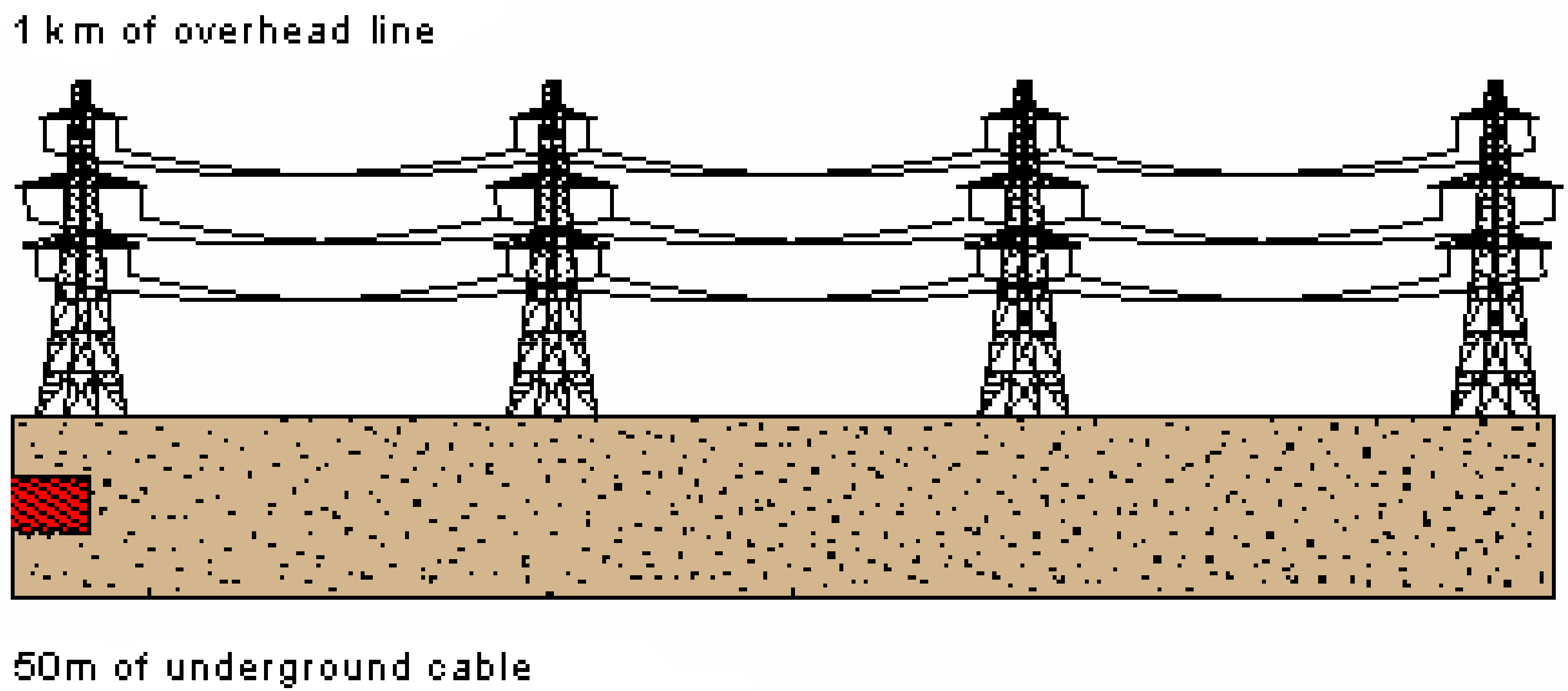




Underground Cables

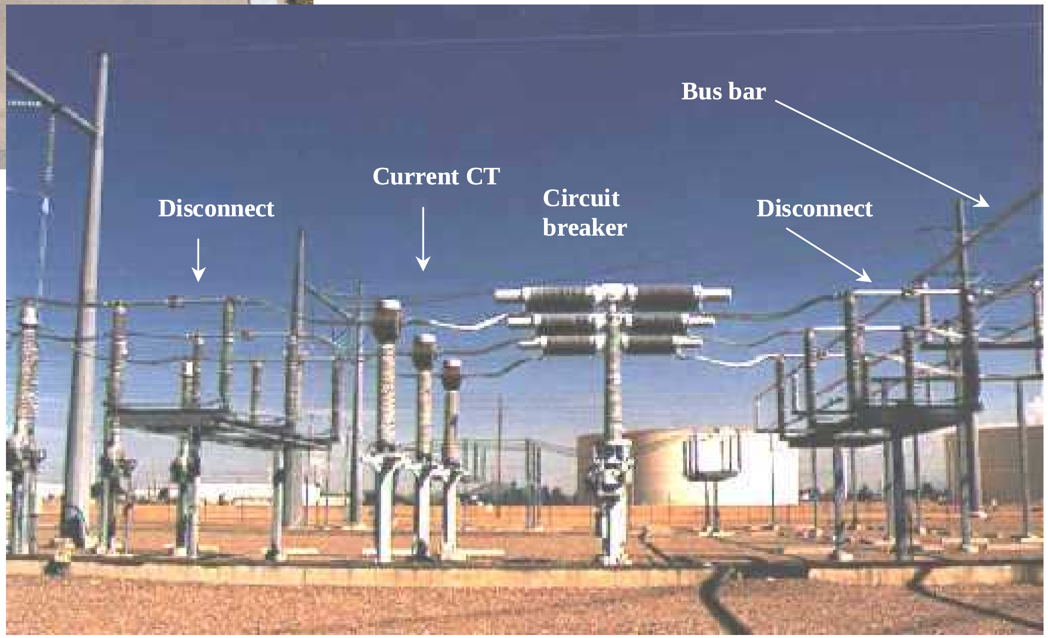


Overhead vs Underground



£500,000

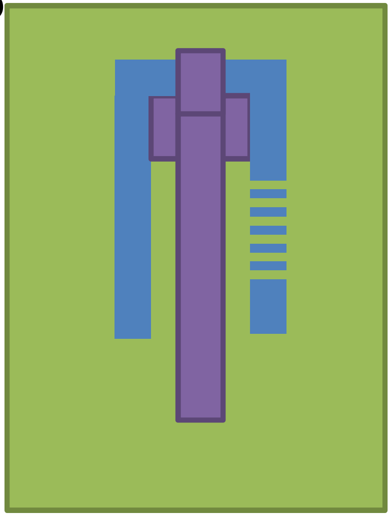
Substations / Switchgear



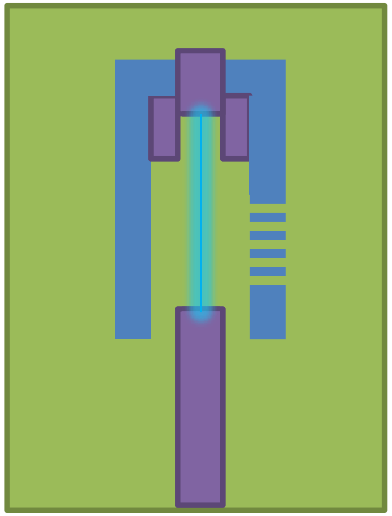
Circuit Breakers

Oil Circuit Breaker

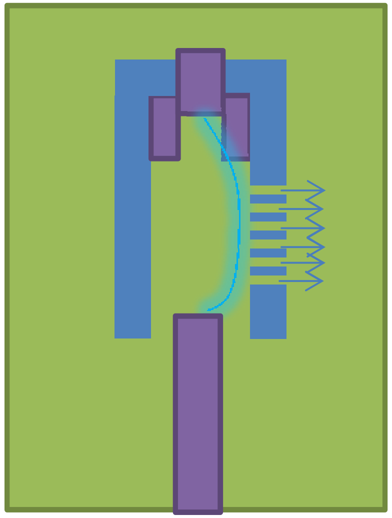
Sulphur hexafluoride (SF6)



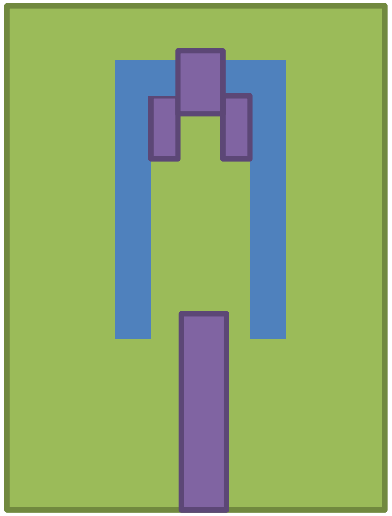
Lower contact moves down to break the circuit



An arc ignites due to the huge voltage and current



The arc is so hot (30,000K) that is separates hydrogen from the oil



The hydrogen flow disrupts the arc. Current ceases to flow.

Security of Supply:

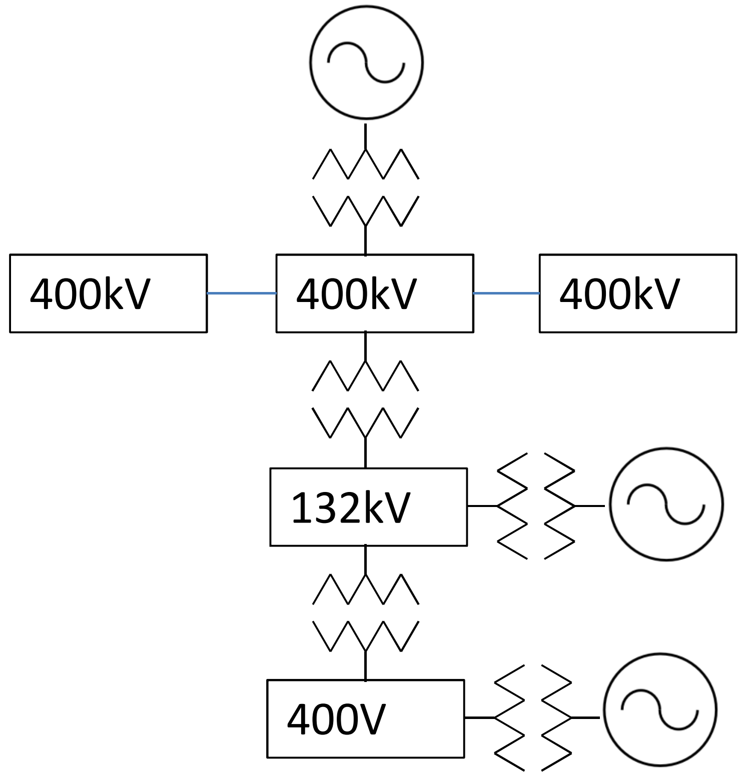
Redundancy

- AC power transmission networks today provide redundant paths and lines for power routing from any power plant to any load centre.
  - based on the economics of the transmission path
  - the cost of power
  - and the importance of keeping a particular load centre powered at all times.
- Generators (such as hydroelectric sites) can be located far from the loads.

1926 National Grid

1904-1948 Standardisation

- 1926: Central Electricity Board (Act of Parliament) to establish a *grid* of best 500 power stations
- 1948: More boards
  - *area* boards: distribution and customer service
  - *generation* boards: generation and HV grid
- 1989-90: Privatisation
  - National Grid Company (HV)
  - 12 Regional Electric Companies



UK Transmission Network

nationalgrid

7000 km of overhead line

600 km of underground cable