TRANSFORMERS

WHY TRANSFORMERS ?

A transformer is a highly efficient device for changing ac voltage from one value to another, for example 240V to 6V.

The transformer is one of the most useful electrical devices.
It can:

- Raise or lower the voltage or current in an ac circuit,
- Isolate circuits from one another, and
- Change the impedance of the load as seen by the source, thus enable load matching which results in maximum power transfer.

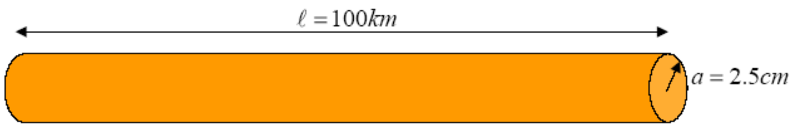
Transformers come in all sizes, from the enormous transformers used in power stations to the small transformers used for doorbells.

WHY TRANSFORMERS ?

- Without transformers, electricity as we know it today would be almost unusable.
- For every aspect of electricity generation, transmission and distribution, there is a range of optimum voltage that the transformer enables us to use. In general, the higher the voltage, the more insulation and switching costs, but less current used, so lower I^2R loss and greater efficiency results.
- It enables us to transmit electrical energy over great distances and to distribute it to the end-users in factories and homes.

Power Transmission

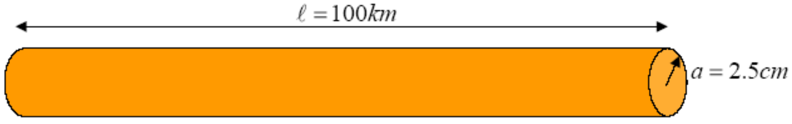
- Typical power requirement for a small city: 1000MWMaximum voltage provided by typical generator: 30 KV Thus need a current of $3.3*10^4$A
- Suppose generator is 50 km from city. Copper transmission line 2.5 cm in radius.



Note that the total wire length is 100 km, and the weigh of such a wire is 1,749,474 kg.

Power Transmission

- Resistance over length of transmission line length: 0.86Ω.
- Power loss in wire conduit: 950MW
- Leaves about 50MW for city.
- Need very large core to handle this current without saturation.



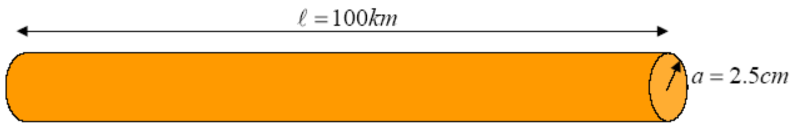
$$R = \frac{\rho \ell}{A} = \frac{\rho \ell}{\pi a^2} = 0.86\Omega$$

$$\rho = 1.7\,\mu\Omega cm$$

$$I^2 R = 950MW$$

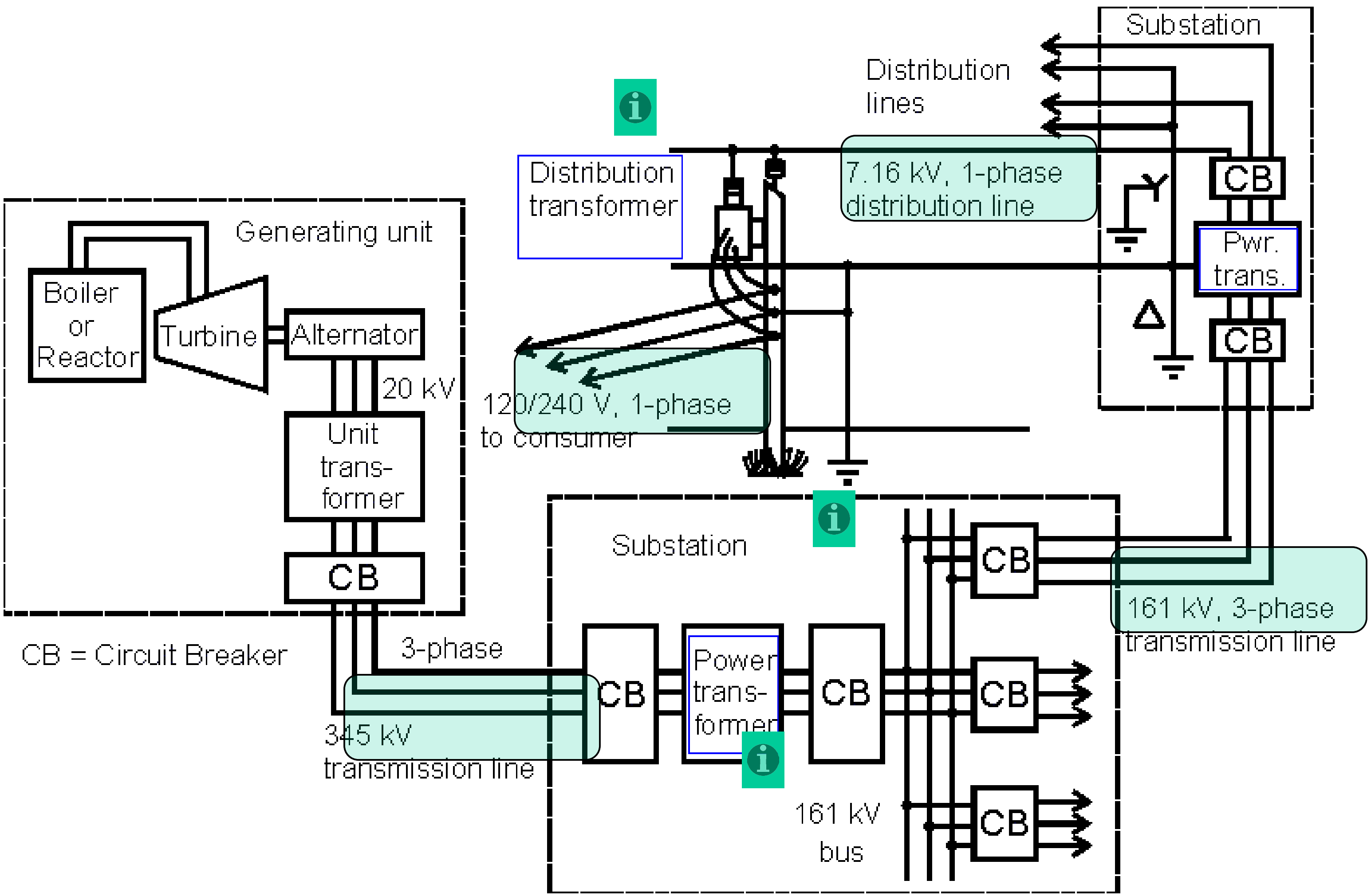
Power Transmission

- Solution is to step up the voltage and thus reduce the current and power loss in copper conduit.
  - Typical AC high voltage line: 765 kV
  - Current required: I = 1000 A
  - Power loss in wire conduit: 0.86MW
  - Leaves about 999.14MW for city.



$$I^2 R = 0.86 MW$$

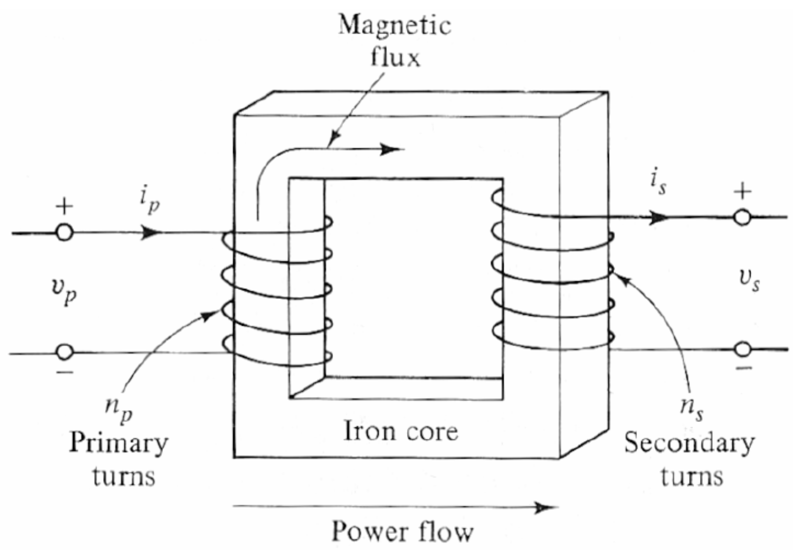
Power System Network



Three-Phase Power Transformer

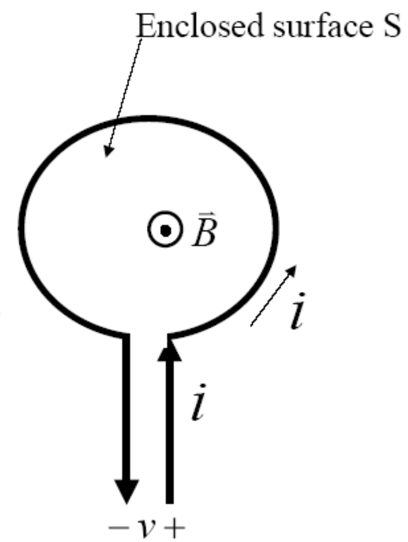
SELF INDUCTANCE

- A transformer is a device in which the current in one circuit induces an EMF in a second circuit through the changing magnetic field.
- To understand how current in one circuit induced EMF in another, we will first examine how a current in a circuit can induce an EMF in the same circuit.



SELF INDUCTANCE

- Consider a single wire loop Current in loop produces a magnetic field B, giving a flux through the loop.



$\vec{B} \propto i$

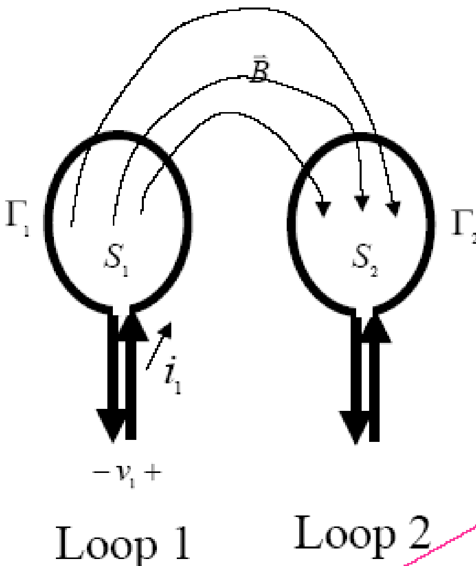
Thus: $\Phi \propto i$

WRITE: $\boxed{\Phi = -Li}$

$\boxed{\boldsymbol{L} \text{ is the self inductance of the loop}}$

$$\boxed{v = -\frac{d\Phi}{dt} = L\frac{di}{dt}}$$

MUTUAL INDUCTANCE



Suppose current i_1 flows in loop 1, creating a flux Φ_1 in the loop and a flux Φ_{12} in loop 2. We will set the source current i_2 zero for now.

$$\boxed{\Phi_{12} = \int_{S_2} \vec{B}_1 \bullet d\vec{a}_2}$$

Integral over loop 2 surface

Magnetic field of loop 1 in the region of loop 2

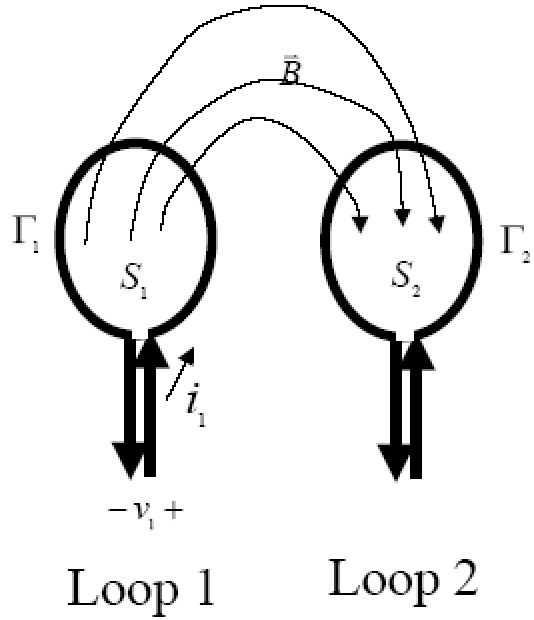
Flux of loop 2 produced by current in loop 1

MUTUAL INDUCTANCE

$$\boxed{\Phi_{12} = i_1 \frac{\mu_o}{4\pi} \int_{\Gamma_2} \oint_{\Gamma_1} \frac{d\vec{\ell}_1 \bullet d\vec{\ell}_2}{r_{21}}}$$

$$\boxed{\Phi_{12} = -i_1 M_{12}}$$

Constant that depends on loop geometry

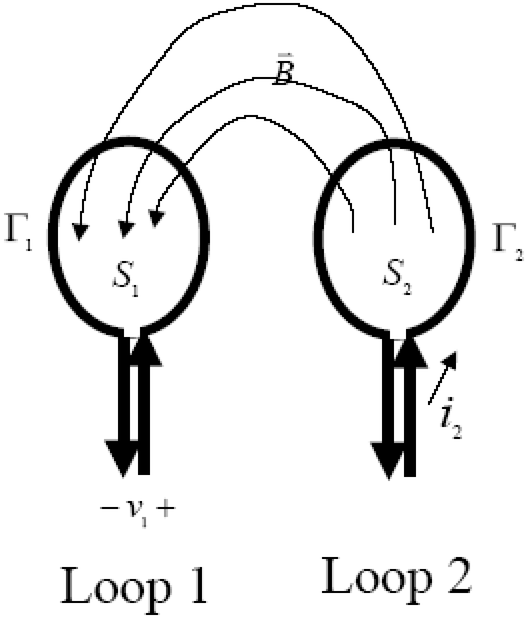


MUTUAL INDUCTANCE

$$\boxed{\Phi_{21} = i_2 \frac{\mu_o}{4\pi} \oint_{\Gamma_1}\oint_{\Gamma_2} \frac{d\vec{\ell}_2 \bullet d\vec{\ell}_1}{r_{12}}}$$

$$\boxed{\Phi_{21} = i_2 M_{21}}$$

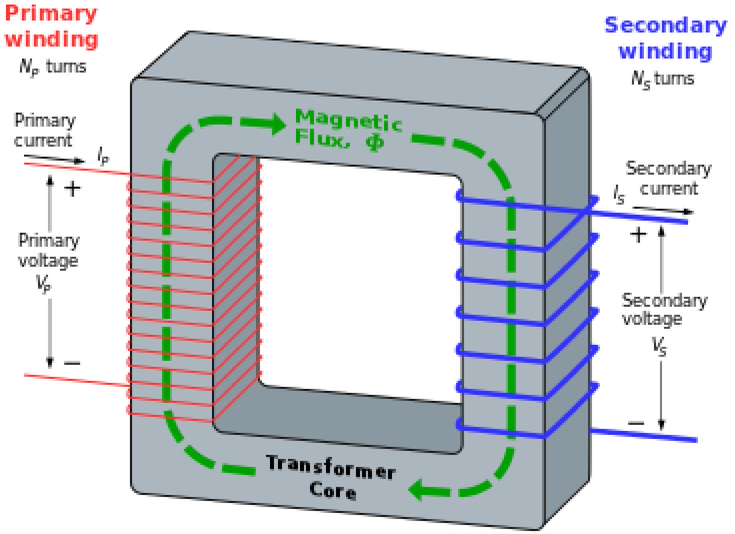
Constant that depends on loop geometry



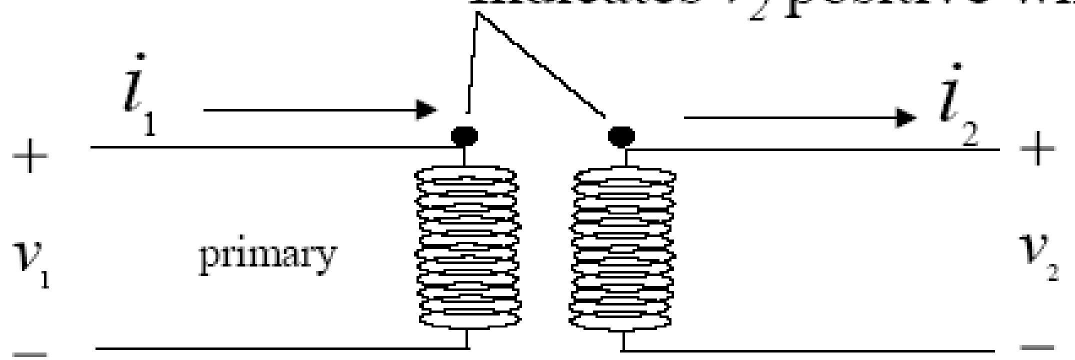
MUTUAL INDUCTANCE

$$v_1 = -\frac{d\Phi_1}{dt} - \frac{d\Phi_{21}}{dt} = L_1\frac{di_1}{dt} - M\frac{di_2}{dt}$$

$$v_2 = -\frac{d\Phi_2}{dt} - \frac{d\Phi_{12}}{dt} = M\frac{di_1}{dt} - L_2\frac{di_2}{dt}$$



Indicates v_2 positive when v_1 is positive



THE IDEAL TRANSFORMER

- The core permeability is infinite; the reluctance of the core is zero.
- No magnetic flux leaks out between the two windings (that is, all the flux links all the turns)
- The winding resistance is zero
- There is no hysteresis or eddy-current power loss in the core