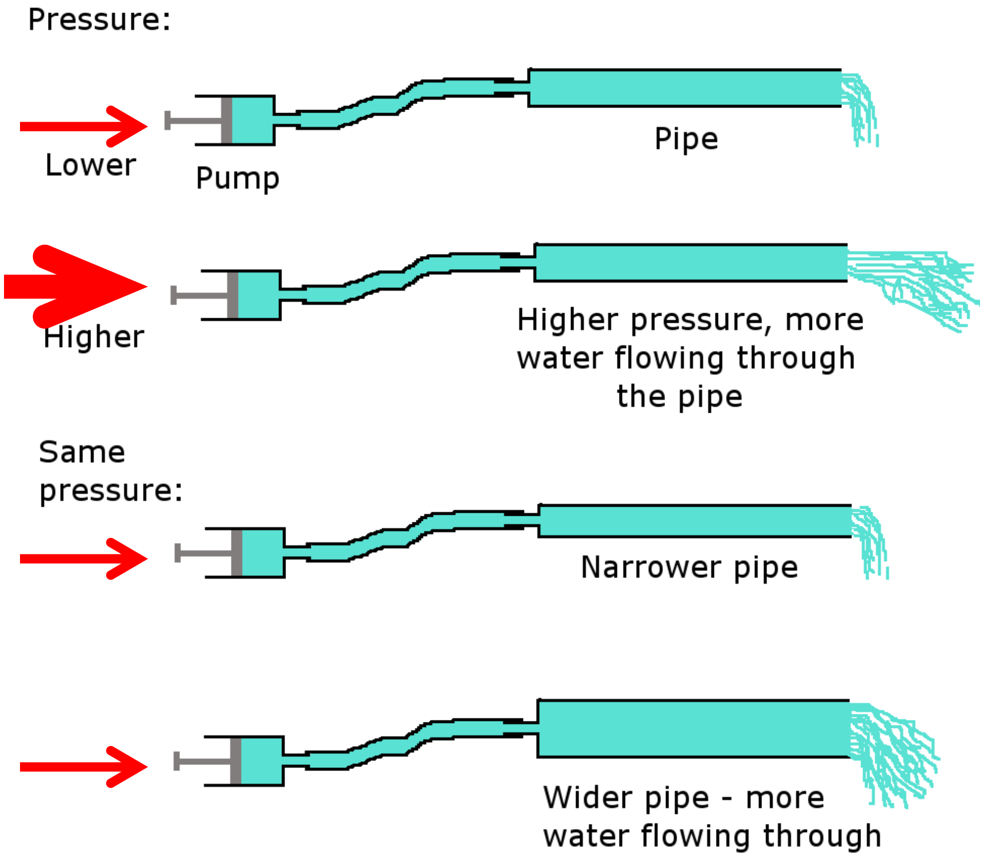
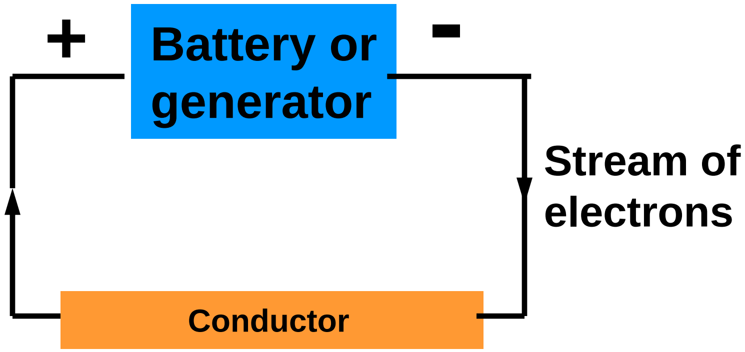
ABOUT THE “UNSUNG HERO” OF THE ELECTRICITY GENERATING SYSTEM:

THE GRID

Some analogies between the flow of current in a conductor, and and the flow of water in a rigid pipe (good to keep in mind for those who are scared by “Volts”, “Amps”, “Ohms”….):





$$(\text{Water pump}) \Leftrightarrow (\text{Current source})$$

$$(\text{Pipe}) \Leftrightarrow (\text{Conductor})$$

$$(\text{Water flow}) \Leftrightarrow (\text{Charge flow})$$

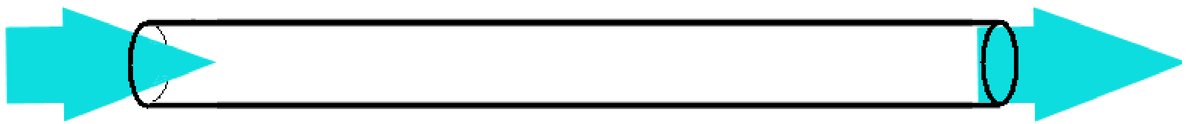
$$\begin{pmatrix}\text{Water volume flowing} \\ \text{out per second}\end{pmatrix} \Leftrightarrow \begin{pmatrix}\text{Charge flow per} \\ \text{second (Amps)}\end{pmatrix}$$

$$\begin{pmatrix}\text{Pump} \\ \text{pressure}\end{pmatrix} \Leftrightarrow \begin{pmatrix}\text{Voltage} \\ \text{applied}\end{pmatrix}$$

$$\begin{pmatrix}\text{Pipe} \\ \text{"narrowness"}\end{pmatrix} \Leftrightarrow \begin{pmatrix}\text{Conductor} \\ \text{resistance}\end{pmatrix}$$

One more thing to remember:

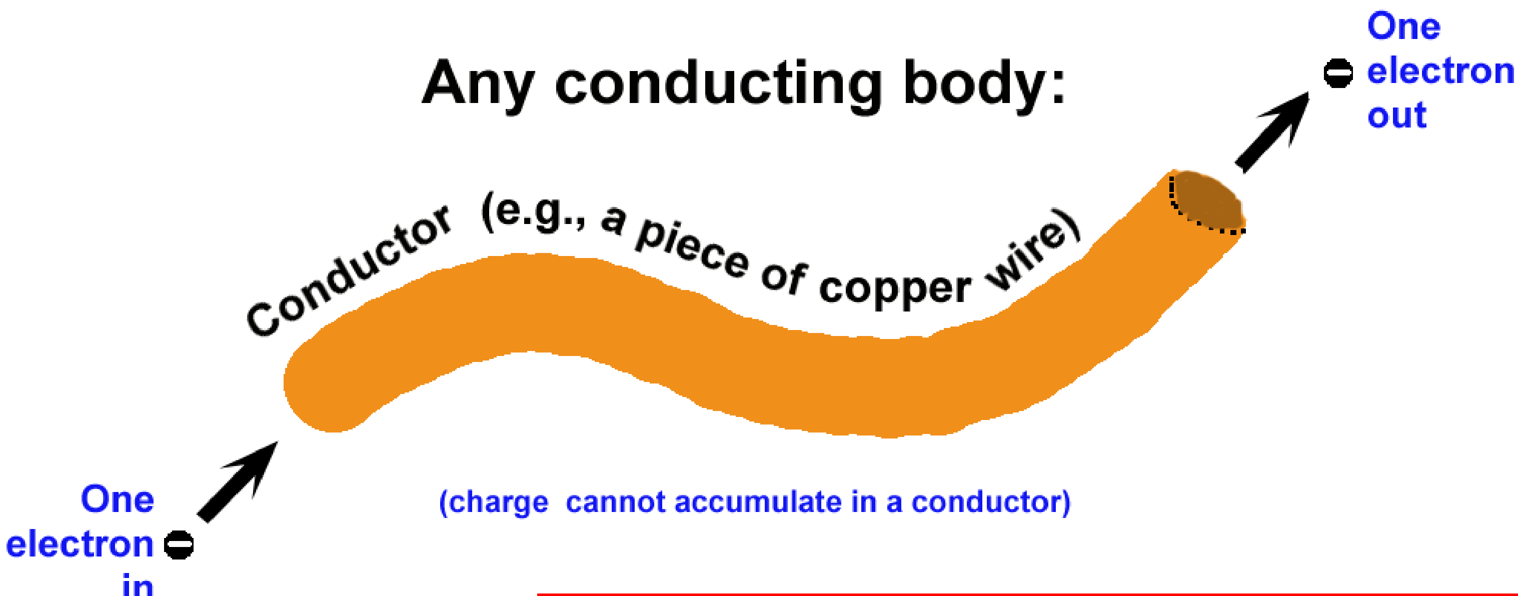
Rigid water pipe:



The volume flowing in = the volume flowing out

(water cannot accumulate in the pipe)

Any conducting body:



(charge cannot accumulate in a conductor)

Note: this is also true for any current source. Current not only flows out of a battery – exactly the same amount of charge returns by the other terminal.

Basic laws of electric current flow:

Ohm Law: $I = \dfrac{V}{R}$

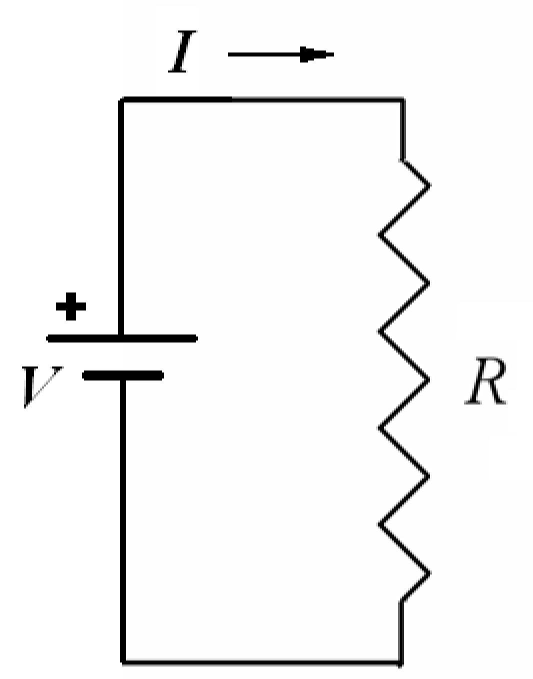
Work done by electric current I over a time period Δt: $W = V \cdot I \cdot \Delta t$

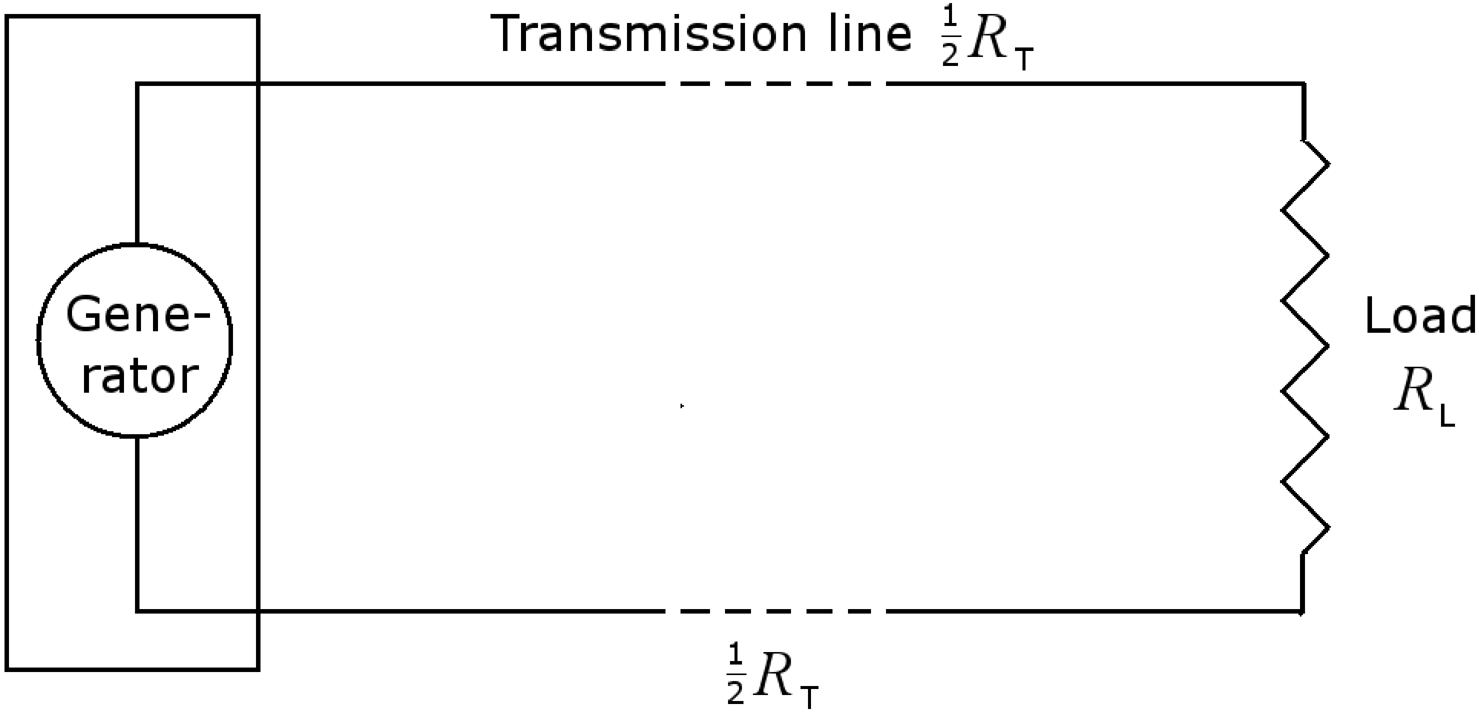
(converted into Joule heat).

Then, the power is: $P = V \cdot I$

Combining with the Ohm Law, we get:

$$P = I^2 \cdot R$$





Power recieved : $P_L = R_L \cdot I^2$

Power dissipated in transmission line : $P_T = R_T \cdot I^2$

Total power send out : $P_{total} = P_L + P_T = \left(R_L + R_T\right) \cdot I^2$

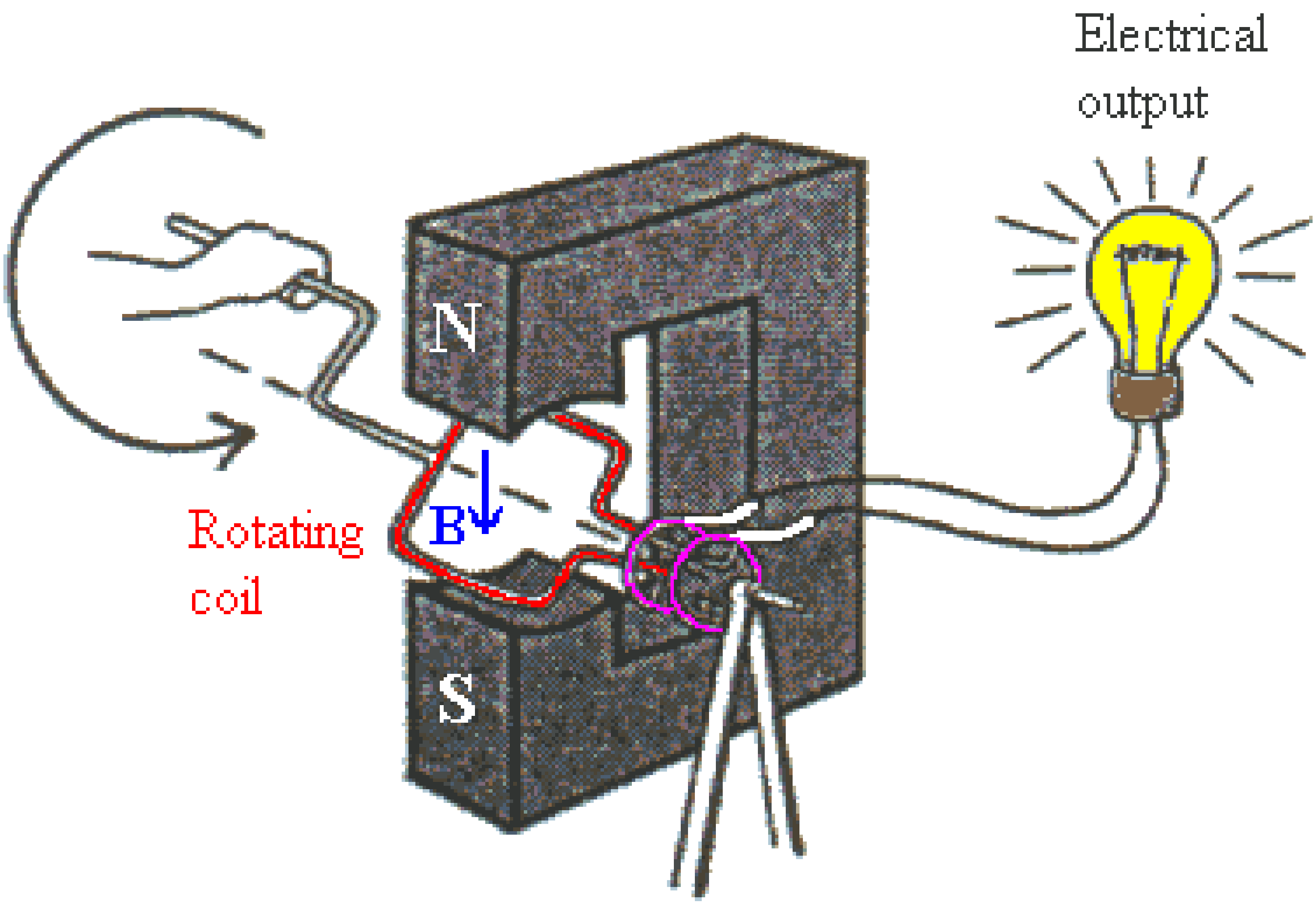
Transmission efficiency : $\varepsilon = \dfrac{P_L}{P_{total}} = \dfrac{R_L}{R_L + R_T}$

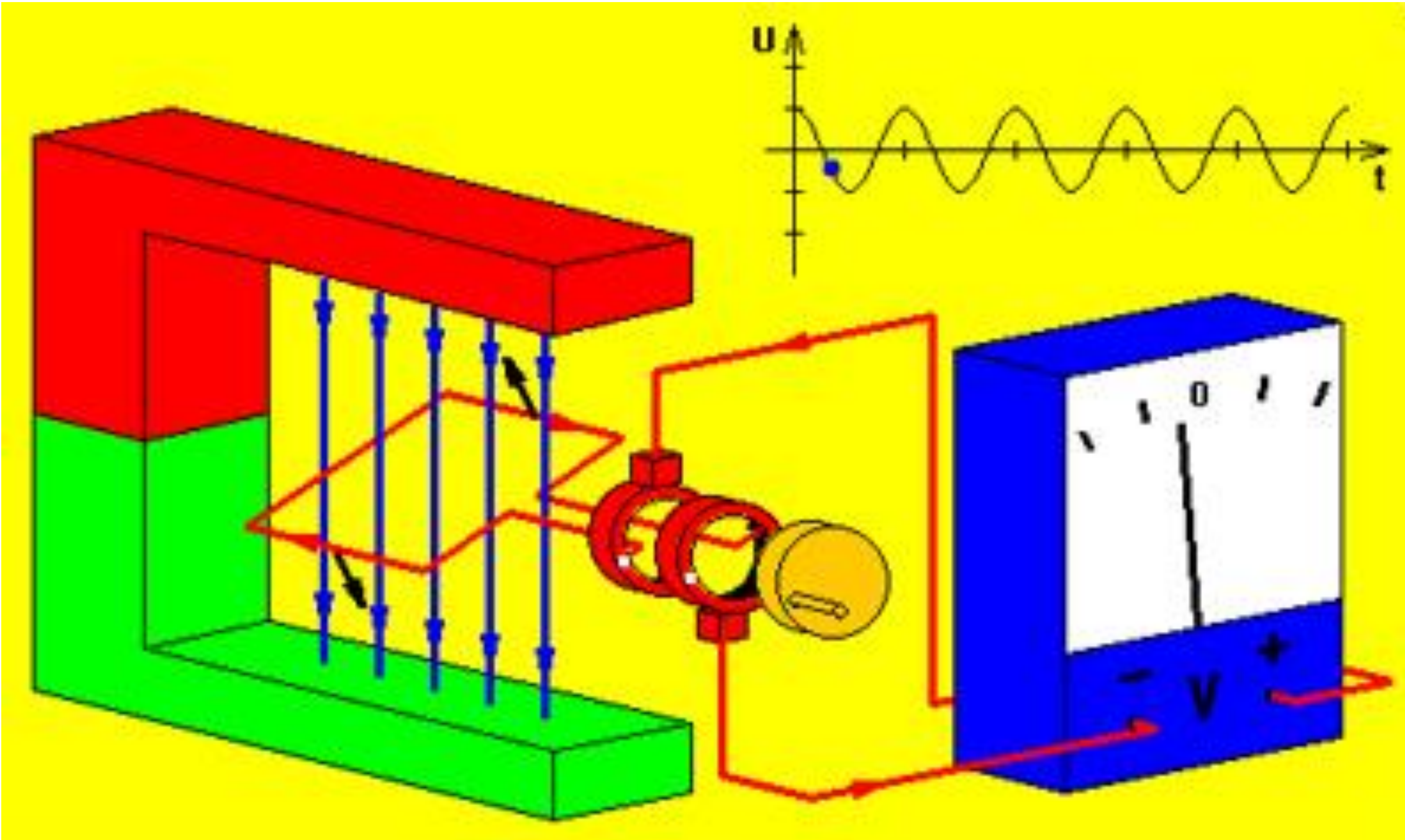
E.g., if $R_T = R_L$, then 50% of power send out is "lost" in the line

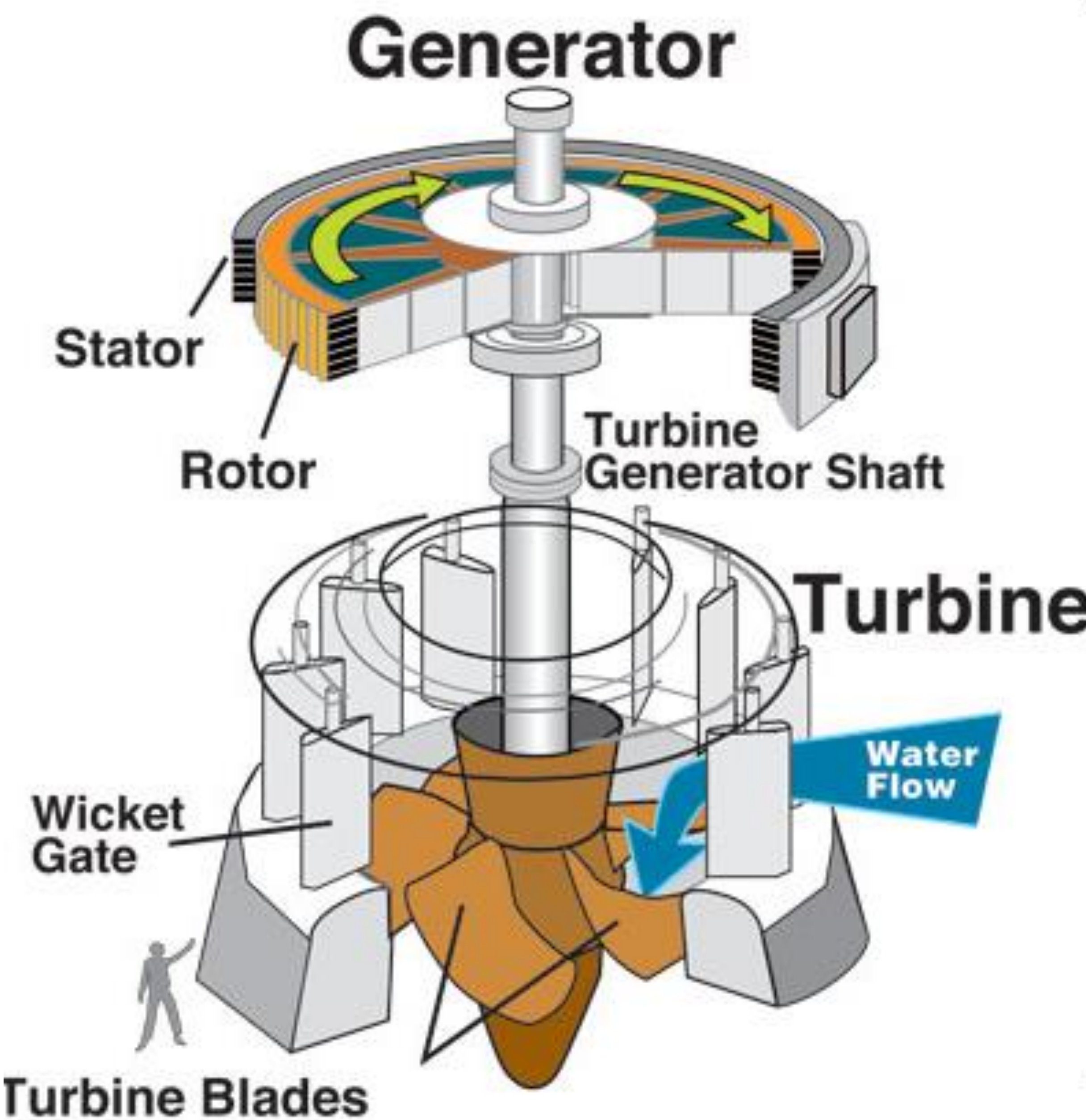
Wire resistance: the American Wire Gauge (AWG) standard.

Wire gauge chart, AWG calculator and theory.

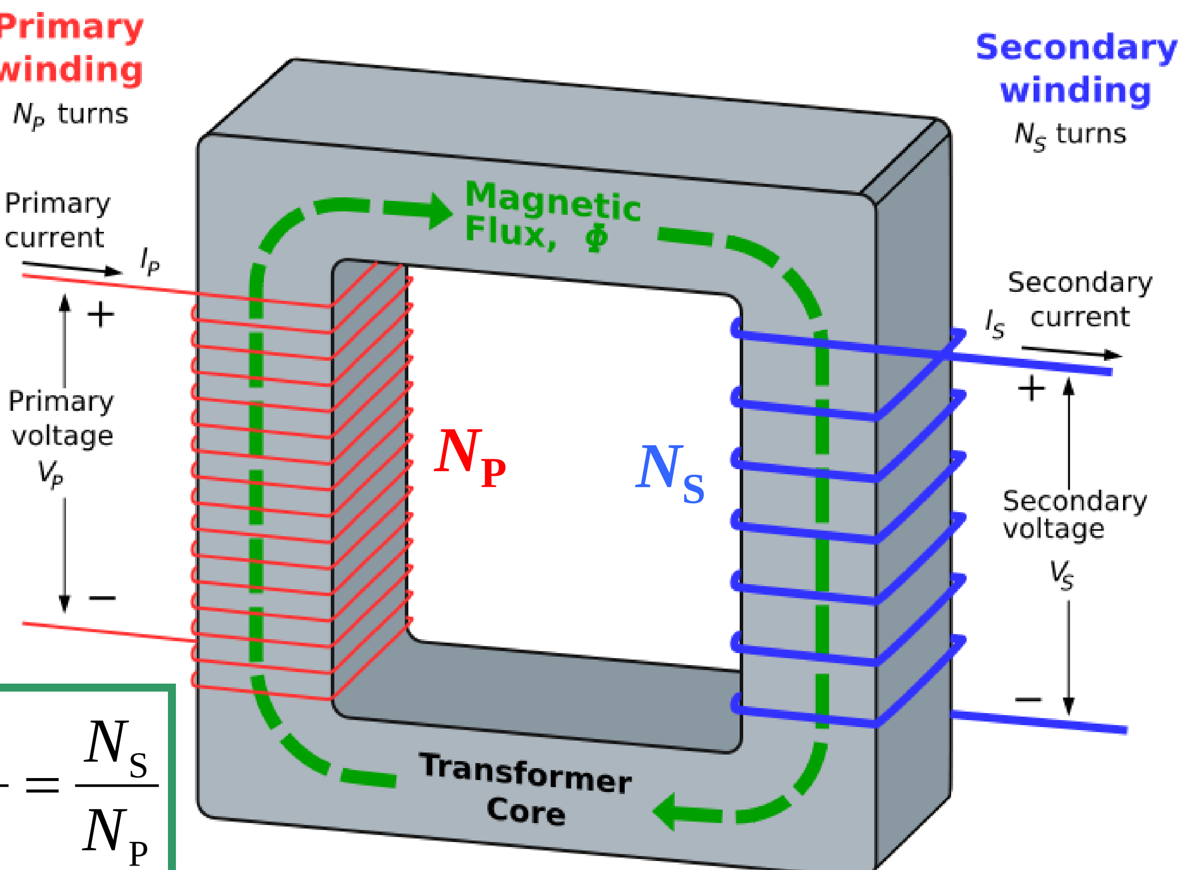
Another AWS table & calculator, more details.

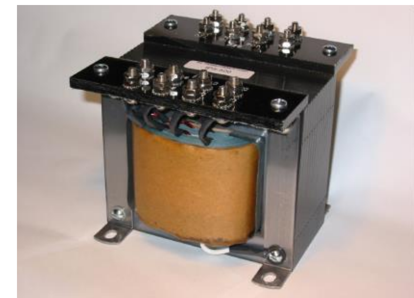

Electrical
output
N
B
S
Rotating
coil


U
t
0
V


Generator
Stator
Rotor
Turbine
Generator Shaft
Turbine
Water
Flow
Wicket
Gate
Turbine Blades

Remedy: alternating current + transformers





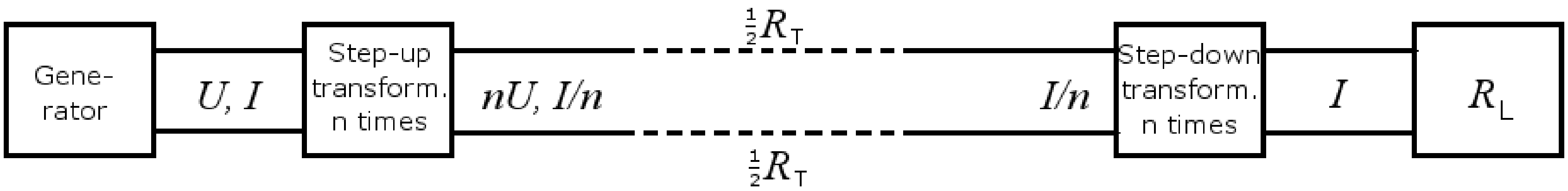
$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Ideal transformer:

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} \Rightarrow \underbrace{V_P \cdot I_P}_{\text{input power}} = \underbrace{V_S \cdot I_S}_{\text{output power}}$$

Real transformers: the efficiency may reach 97-98%

The same "consumer" as before, but now we use transformers:



Power delivered: $P_L = R_L \cdot I^2$

Power dissipated: $P_T = R_T \cdot \left(\dfrac{I}{n}\right)^2$

Total power sent out: $P_{total} = P_L + P_T = \left(R_L + \dfrac{R_T}{n^2}\right) \cdot I^2$

Efficiency: $\varepsilon = \dfrac{P_L}{P_L + P_T} = \dfrac{R_L}{R_L + \dfrac{R_T}{n^2}}$

Take, e.g., $R_T = R_L$ and $n = 10$:

$$\varepsilon = \frac{R_L}{R_L + \dfrac{R_L}{10^2}} = \frac{R_L}{1.01 \times R_L} \approx 0.99 = 99\%$$

But the transformers are not 100% efficient; suppose that the efficiency of each one is 97%. Then:

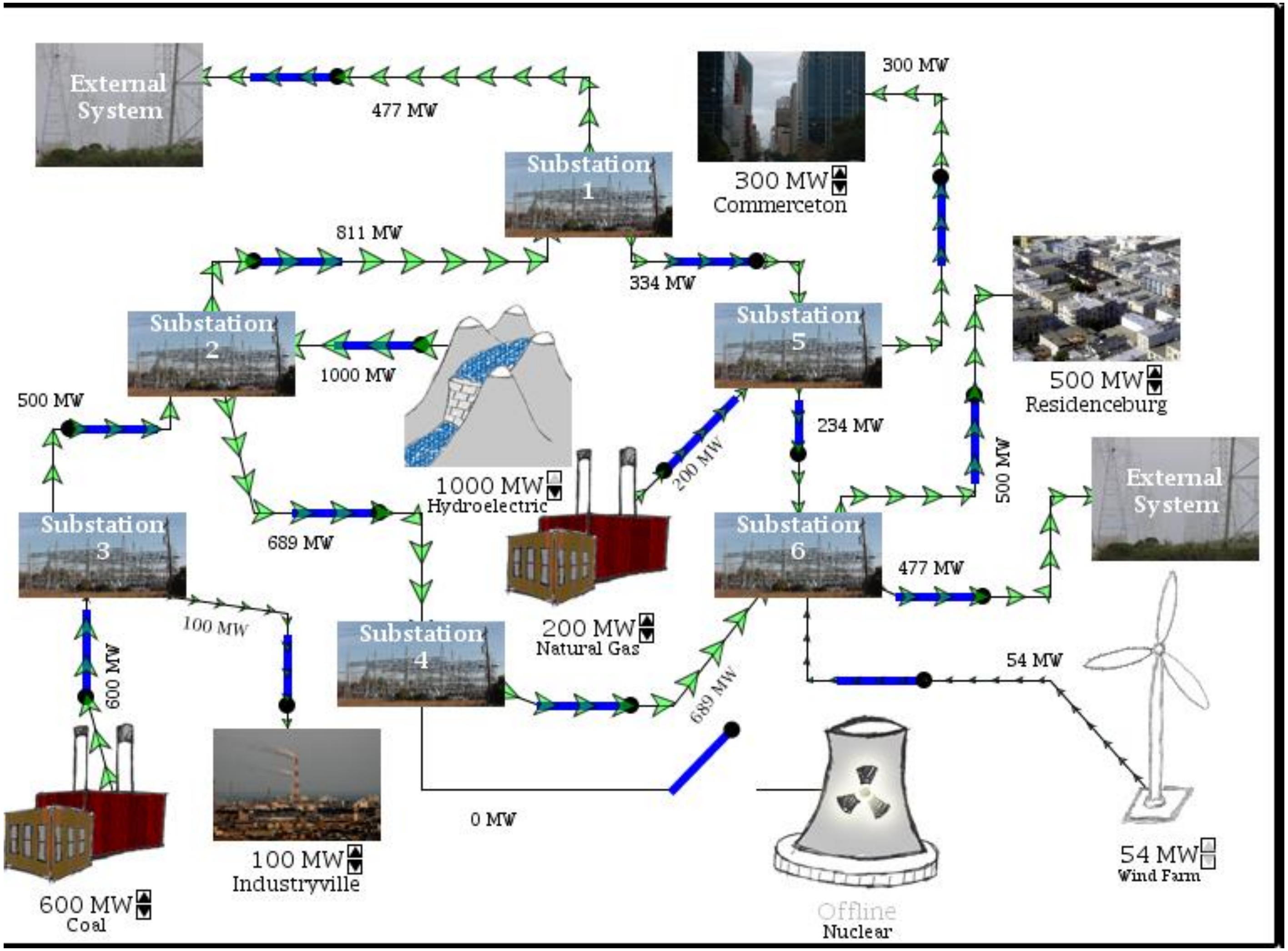
$$\varepsilon = 0.99 \times (0.97)^2$$

$$= 0.93 = 93\%$$

Without transformers, we had only 50%, and now we have 93%! Transformers give incredible efficiency improvement!


Now it's clear why we use all those
high-voltage transmission lines,
right?

Power grid:



[Java Applet showing how this grid works]

[Good Wiki article about the smart grid]

[US Department of Labor Web Page]