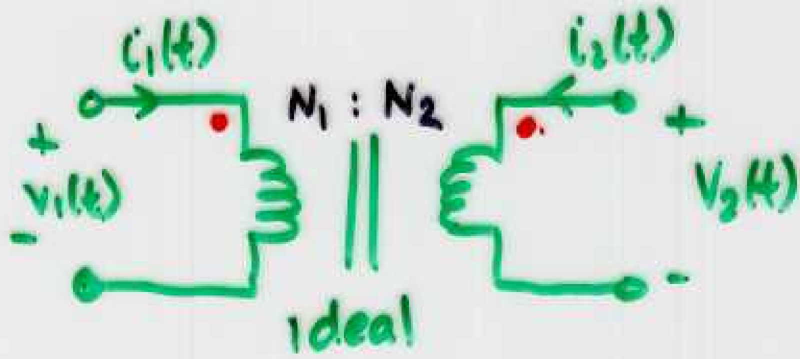
TRANSFORMERS

* Have the ability to "step up" or "step down" voltages in AC power systems
* Typically used to step-up voltages of around 10 kV at generation to 200 kV for distribution, then down again for local distribution, then down to 220 or 110V for consumer use
* 

The double vertical stroke is used to represent the fact that the transformer has an iron core. (Air core transformers are rarely ideal!)

* Since the transformer is ideal, we can calculate the voltages + currents without using M, L_1 and L_2
* Ideal transformers are usually drawn with the source attached to the left circuit (primary) and the load to the right circuit (secondary)

* Since the transformer is ideal,

$$v_2(t) = n\,v_1(t)$$

$$i_1(t) = -n\,i_2(t), \quad \text{where } n = \frac{N_2}{N_1} = \text{turns ratio}$$

* Similarly, in the phasor domain

$$\underline{V}_2 = n\underline{V}_1$$

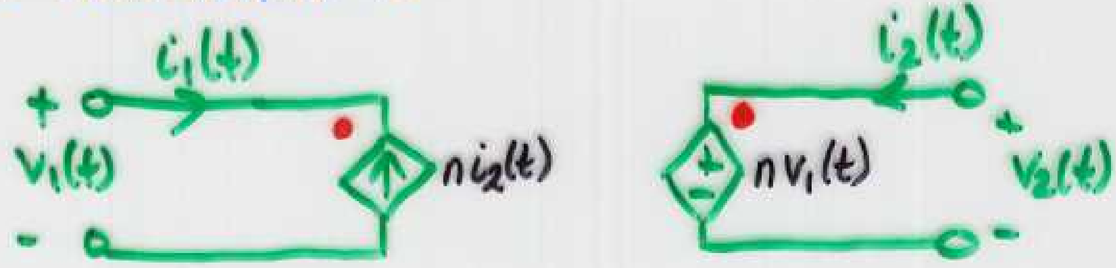
$$\underline{I}_1 = -n\,\underline{I}_2$$

* The instantaneous power absorbed by the ideal transformer is

$$p(t) = v_1 i_1 + v_2 i_2 = -v_1 n i_2 + n v_1 i_2 = 0.$$

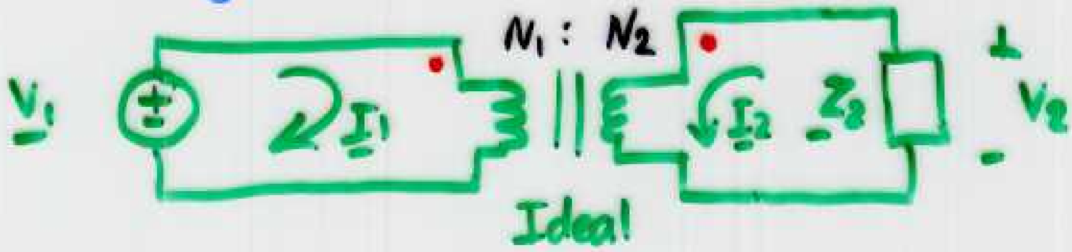
Similarly the ideal transformer absorbs no average, complex or reactive power.

* A useful equivalent circuit model for an ideal transformer is



Input impedance of a transformer circuit.

Find the input impedance $\underline{Z}_1 = \dfrac{\underline{V}_1}{\underline{I}_1}$ for the following circuit



Ideal Transformer $\Rightarrow$ $\underline{V}_1 = \dfrac{\underline{V}_2}{n}$

$\underline{I}_1 = -n\,\underline{I}_2$

Given the sign convention

$\underline{V}_2 = -\underline{Z}_2 \underline{I}_2$

$$\Rightarrow \underline{Z}_1 = \frac{\underline{V}_1}{\underline{I}_1} = \frac{\underline{V}_2/n}{-n\underline{I}_2} = \frac{1}{n^2}\left(\frac{-\underline{V}_2}{\underline{I}_2}\right)$$

$$= \frac{1}{n^2}\underline{Z}_2$$

Hence the transformer reduces the impedance seen by the source by a factor of n^2!

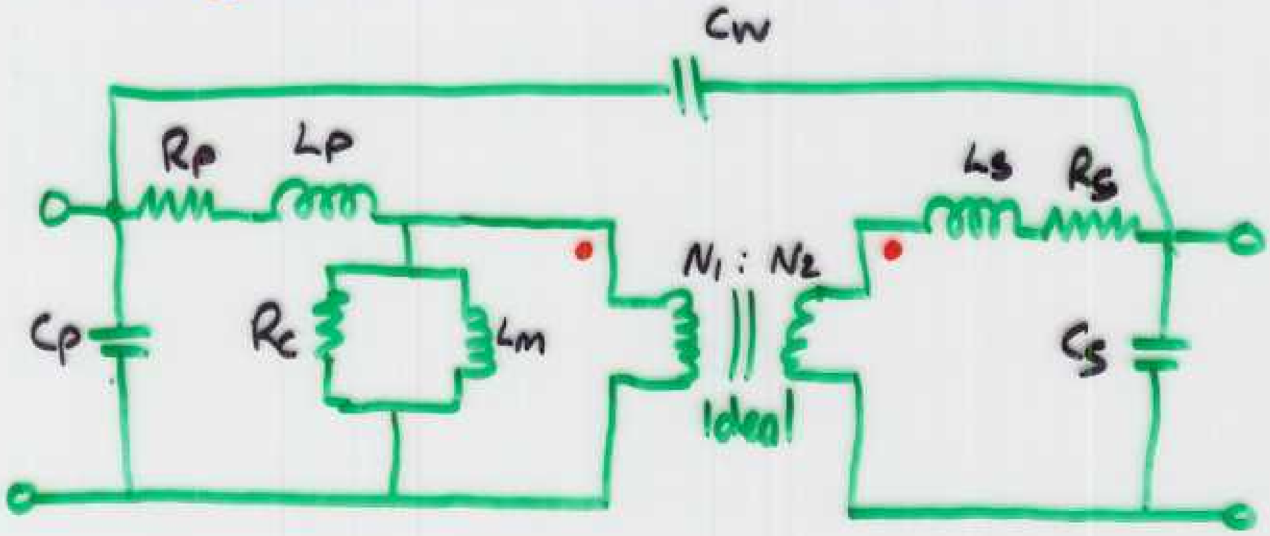
NON-IDEAL TRANSFORMERS

* Whilst some transformers are close to ideal in certain operating ranges, we need to take into account their non-idealities when we want to build + design real circuits

* Often the first phase of the design assumes an ideal transformer. Then in the second phase we model the important non-idealities. This is very similar to what we did for op-amps.

* Like the case of op-amps, models for non-ideal transformers often include an ideal transformer. This simplifies the node/mesh analysis of the resulting circuit.

Here is a typical circuit model for a non-ideal transformer



R_p, R_s - resistances of the wires which form the primary + secondary coils

L_p, L_s - represents the effect of leakage flux that is flux which is not coupled to the other coil

R_c - represents losses due to non-linearities and "eddy currents" in the iron core

L_m - magnetising inductance, which is associated with establishing the flux in the core

C_p, C_s - capacitance between wires in the coils

C_w - capacitance between the coils

In most power systems, R_p, R_s, L_p and L_s are the dominant terms.

Suggested Problems

11.3 - 3-5, 8

11.4 - 1, 2

11.5 - 1, 3, 4, 5, 7, 10

11.6 - 1-3, 7, 10, 11, 15

11.7 - 1, 2

11.8 - 1-4, 7

11.9 - 1, 3, 6

11.10 - 2, 3, 5-7, 11