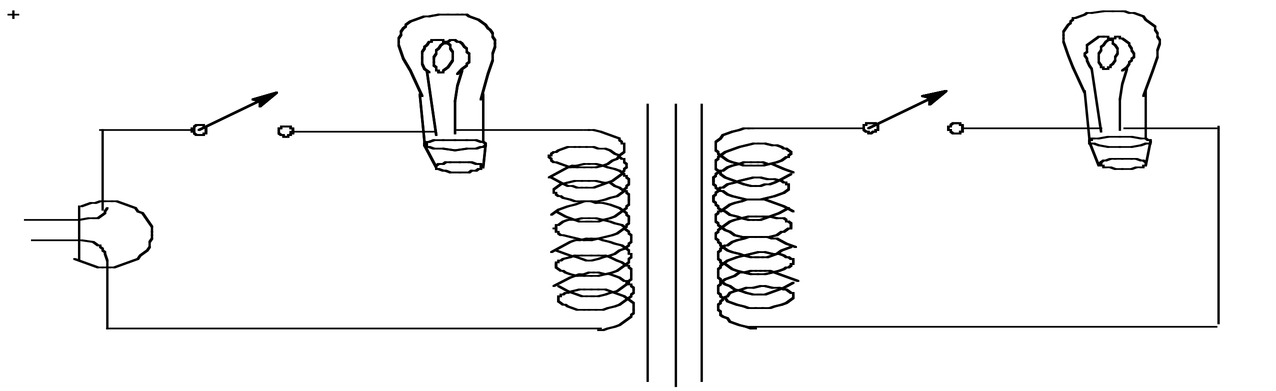
Transformer reflection of impedance   Nov. 4 meeting of SCAAPT

Place on the board an illustration of a transformer with a light bulb in series with the primary and a similar light bulb across the secondary. Since I will be using an isolation transformer, the two bulbs will be the same.



Initially both switches are closed and both bulbs are lit. Ask what will happen if the switch on the left is opened?

With both switches closed again, ask what will happen if the switch on the right is opened?

Demonstrate the above and request that those who have seen the demonstration before, let the others answer first before any discussion.

This is a demonstration of impedance matching. Originally the secondary had a small resistance which was reflected back to the primary. When the switch on the right was opened, a very large impedance appeared in the secondary that was reflected back to the primary. This high impedance in series with the low impedance bulb limited the current so much that the bulb appeared to go out.

(The demonstration might be repeated with an AC meter across the bulb on the left.)

How a transformer acts to match impedance

In the following discussion I assume the source is a strong AC across the primary of a transformer (no series bulb) that can produce an AC voltage (no doubt sinusoidal) that will maintain the same rms value during each step in the following discussion. The secondary of the transformer has a small finite impedance across it.

I assume each of the following steps occur in sequence in a very small time. At the instant of the following discussion, let's say the current in the primary is momentarily increasing.

1. As the current in the primary increases, it causes an increase in the magnetic flux in the primary.

2. This increase in flux in the primary also produces an increase in flux in the secondary that produces an increase in current in the secondary.

3. This increase in current in the secondary (by Lenz's law) must produce a magnetic flux that opposes the initial magnetic flux passing through it.

4. This acts to decrease the magnetic flux in the primary, decreasing the back emf of the primary to the source voltage and allowing more current to flow in the primary.

5. The AC source will produce nearly the same voltage (all of this takes place in a very small time) against the now decreased back emf increasing the current in the primary and the ratio of this source voltage to the adjusted current now flowing in the primary is the impedance it now sees.

Notice that I have avoided writing any mathematical symbols in the above discussion. It is my opinion that if a presentation too quickly resorts to a mathematical model and then too quickly to an argument involving correct mathematics, the math can be seen to be correct even if it does not correctly address the physics involved. Most introductory college physics texts that discuss transformers and their impedance matching, will do the simple algebraic derivations that show:

1. The voltage across the primary = the turns ratio times the voltage across the secondary: $V_P = (N_P / N_S)\ V_S$ by assuming the flux change in the primary equals the flux change in the secondary.

2. The impedance seen by the primary = the turns ratio squared times the impedance across the secondary: $Z_P = (N_P / N_S)^2\ Z_P$ using the definition of impedance and the assumption that the power in the primary equals the power in the secondary.

Both of these results are easy to derive and can be found in many college texts.

To review again what happened in the original demonstration with the bulb in series with the primary and a bulb across the secondary, it is obvious why opening the switch on the left turns off both bulbs but it is not so obvious why opening the switch on the right also turns off both bulbs since it seems the primary bulb is still connected. When the switch on the right is opened, the impedance in the secondary goes from a small finite amount to a very large amount. This is reflected back to the primary as a very large impedance, lowering the current in the primary. Now there is a much larger back emf across the primary. The remaining much smaller current through and voltage across the series bulb causes it to glow so dimly that it appears to go out.

A caution about using transformers, particularly good transformers:

1. Never short the output. This will reflect a very low impedance into the primary and may burn it out.

2. Never leave an open secondary transformer open for long. This is a little more difficult to explain but since the primary now sees no load, it will continue to cause a change in flux in the secondary that in turn will cause the voltage across the secondary windings of the transformer to increase with no current through it. This voltage could rise to a very large value and since usually a coating of lacquer only insulates the windings of the secondary, the higher voltage may cause them to short.

James Lincoln and Bill Layton Collaborated on a Video showing this demo and more related to transformers as part of the AAPT Films Video Demonstration Project.

https://www.youtube.com/watch?v=y0WrKT45ZZU