Bob's TechTalk #29
by Bob Eckweiler, AF6C

Capacitors - Part III of IV

Power Factor in Capacitors:

Now that you're an expert on capacitors, let's talk about *power factor* as it relates to capacitors. The capacitors we've talked about in previous columns were considered "perfect" or "ideal" capacitors. Unfortunately, in the real world capacitors also have inductance and resistance associated with them. The inductance is due to the leads and construction and has little effect until you get to the higher frequencies; so we will ignore it. The series resistance is due mostly to the dielectric material. The lead resistance is small; for mica, ceramic and polymer capacitors the dielectric resistance is also small, but for electrolytic capacitors the resistance caused by the dielectric can be appreciable.

One handy piece of test equipment that's been around my shack for many years is a Heathkit IT-11 capacitor checker. This checker uses an AC Wheatstone bridge to measure an unknown capacitance by comparing it to a known standard. Figure one shows the basic schematic of the bridge when used to measure an electrolytic capacitor. The capacitor Cx is the one to be measured. The standard capacitor is a high quality 2µf polymer capacitor and is shown as Cs. The bridge is excited by a low voltage 60 cycle AC signal. The detector, not shown, is a "magic eye tube" preceded by an amplifier and rectifier. When the "eye tube circuit" has an AC signal present, the eye closes. To measure a capacitance, set R14 to minimum resistance and adjust R13 until the eye opens as far as possible. The capacitance can then be read directly from the scale on R13. The ratio of the unknown capacitance to the standard capacitance is the same as the ratio between the two parts of R13. (When measuring large value electrolytic capacitor, a resistor is added to one leg of R13 to extend the ratio).

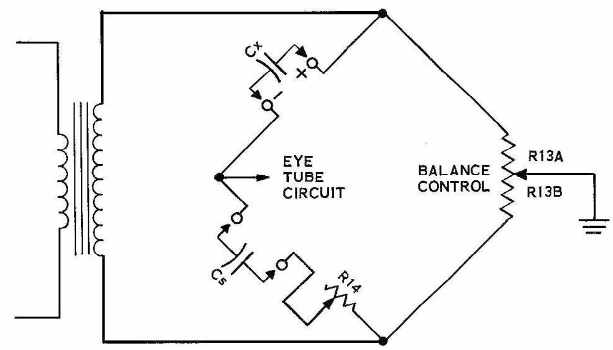

Figure 1: Heathkit IT-11 Capacitor Bridge circuit concept schematic showing how electrolytic capacitors are measured for their capacitance and power factor.

Now that the capacitance is known, the electrolytic can be checked for power factor. This is accomplished by adjusting R14. R14 further balances the bridge by balancing any series resistance in the unknown capacitor. It should be increased slowly until the eye tube reaches its maximum opening. The power factor as a percentage can then be read directly from the scale on R14. The scale is calibrated for a frequency of 60 Hz, but corrections can be made easily if an external excitation voltage of a different frequency is used.

So what have we done here? And how does that relate to what we've been learning? The definition of the power factor of a capacitor is just the resistance divided by the reactance.

$$\%P.F. = \frac{R}{X_C}$$
$$= 2\pi fRC$$

(remembering that: $X_C = \frac{1}{2\pi fC}$)

Power factor has no actual units (it's ohms / ohms). It may be expressed as a percentage, where 100% is when the resistance equals the reactance – a very bad capacitor indeed! Some capacitor manufacturers no longer use power factor, but specify the *effective series resistance* (ESR) instead.

What's bad about a capacitor with high power factor? Last month we talked about power in a circuit with a capacitor and resistor in series. When the resistance is zero and only capacitive reactance is present then no power is dissipated. However, if there is series resistance internal to the capacitor then that resistance does dissipate power, commonly in the form of heat. Electrolytics tend to age and the electrolyte may dry out or change from the environment it's experienced. This change will not only affect the capacitance, it tends to also increase the capacitor's power factor.

Heat from a high power factor will accelerate the demise of electrolytic capacitors. Older large electrolytic capacitors used as filters in power supplies at 60 Hz or 120 Hz tend to fail by a combination of high series resistance and a lowering of capacitance. Their big size helps dissipate heat and they also have a built-in vent in case the pressure inside gets too high. Today's miniature electrolytic capacitors have vents too; they also have scribed lines that will open under explosive pressure. These newer capacitors are significantly smaller and by shear volume cannot dissipate nearly the heat of older capacitors. Luckily, the design has improved over the years, and they tend to have lower ESR. But they can fail with a startling "bang"

Power Factor in Electrical Devices:

Power factor also comes into play in electric circuits. Any load you plug into an AC outlet might appear as either an inductor or capacitor in series with a resistance to the generator back wherever the power is being generated. While we're talking about capacitors, inductive loads (motors especially) are the more common type of load encountered.

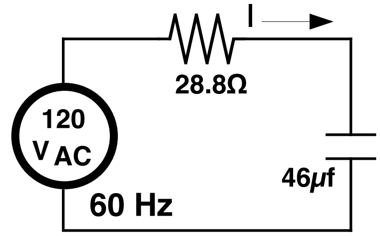

Figure 2 – Circuit for our example

Figure two shows a simple RC load circuit that might appear across your AC line. It's composed of a 28.8 ohm resistive load in series with a 46 μf capacitor. At 60 Hz the capacitor has a capacitive reactance of:

$$X_C = \frac{1}{2\pi f C}$$
$$= \frac{1{,}000{,}000}{2 \cdot 3.1416 \cdot 60 \cdot 47} = 57.6\Omega$$

The total impedance of the circuit is:

$$Z = \sqrt{R^2 + X_C^2}$$
$$= \sqrt{28.8^2 + 57.6^2}$$
$$= \sqrt{829.44 + 3317.76}$$
$$= 64.4\Omega$$

The series current is then (from Ohm's law):

$$I = \frac{E}{Z} = \frac{120}{64.4} = 1.86 \text{ amps}$$

Let's look at the power in each component. For the 28.8Ω resistor:

$$P_R = I^2 R = 1.86^2 \cdot 28.8$$
$$= 100 \text{ watts}$$

And for the capacitor, which you will recall from last month stores power from the circuit for part of each cycle and returns it back to the circuit for the remainder of the cycle (and thus does not dissipate power), we get:

$$P_C = I^2 X_C = 1.86^2 \cdot 57.6$$
$$= 200 \text{ var}$$

Since the capacitor cannot dissipate power, engineers use the term *var* for *volt-amperes reactive* to show that it is reactive power. Remember that the voltage across the resistor is in phase with the current, but the voltage across the capacitor is lagging the current by 90°.

The total power supplied from the AC line can be determined by:

$$P_{VA} = I^2 Z = 1.86^2 \cdot 64.4$$
$$= 223.6 \text{ VA}$$

Since this power incorporates both the real and reactive components, it is given the term VA which stands for *volt-amperes*. You'll see a lot of appliances marked with VA instead of watts, especially devices with motors. Figure 3 shows the relationship between the power, var and VA given in the above example.

Power factor (PF) in AC circuits is sometimes expressed as an angle. That angle is shown in figure 3. It is more often given as a number between 1 and 0, which is just the cosine of the angle. A PF of one says all the power is being delivered to the resistance.

In the example we're effectively using only 100 watts. But the power company must deliver the full 1.86 amps of current to produce that power. Many new appliances have devices built in that correct the power factor to save energy and add to the product's reliability. While our example used capacitance, a majority of the high PF devices are inductive. The power company can correct the PF to some extent by placing capacitors in the line. You can often spot these large capacitors on high voltage power poles.

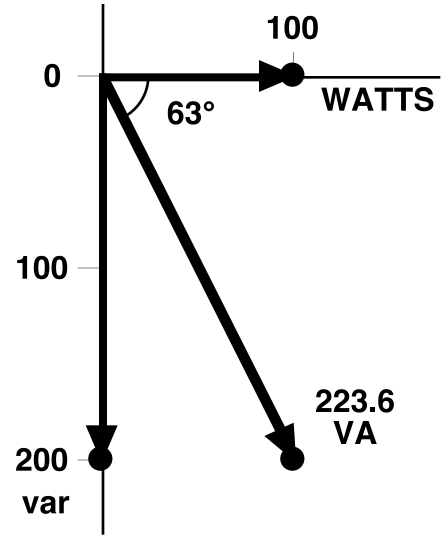

Figure 3: Point 'A' is the power in the resistor. 'B' is the power in the capacitor and 'C' is the overall circuit power

This pretty much concludes capacitors and power factor. I haven't decided on a topic for next month. Any ideas? I have one, and it will be a change of pace for this series. Till next month, I'll keep you guessing.

73, from AF6C

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