Cutting Current to Size

Measuring large ac currents can be difficult unless you know a trick or two. W7CRY explains how.

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Have you ever tried to measure large ac currents and found your trusty VOM somewhat short? Welcome to the club. I was stuck with the problem of finding the current used by an electric hot water heater but no way of measuring it.

I also found my wallet short after letting my fingers walk through several instrument catalogs. Several hours of thrashing around the workbench yielded a simple and, best of all, inexpensive way of measuring large ac currents using an ordinary 88-mH choke, a trick or two, and Ohm's law.

Theory

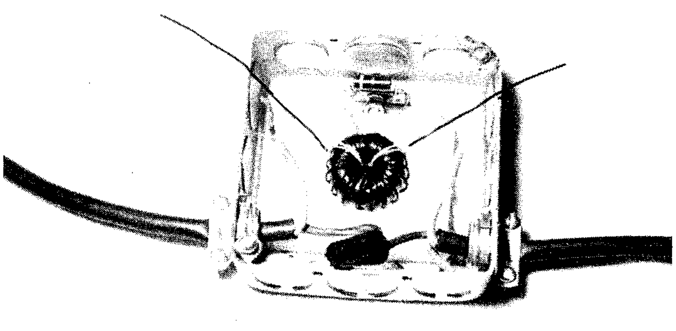
Perhaps a little transformer theory should be covered before Ohm's law and the tricks are applied. By definition, a transformer is exactly what its name implies: It transforms one voltage (or current) to a different level. The major differences between a voltage transformer and current transformer are the turns ratio and power-transfer characteristics. Depending on design, the voltage transformer has a low turns ratio, i.e., approximately 19 to 1 (118/6.3) for a filament transformer. The current transformer, on the other hand, has a turns ratio from around 300 to greater than 10,000 to 1, depending on the burden (load) on the secondary.

The current transformer always has the burden specified along with the current ratio. For example, a typical 50-Amp to 5-Amp current transformer will require a burden of .25 Ohms. If the secondary burden were to open or be removed, the transformer would be destroyed because the voltage developed across the resulting open circuit would cause arcing within the windings.

An additional consideration is that the current transformer should not introduce significant changes in the circuit being measured.

Hybrid Current Transformer Design

Fig. 1 shows the basic technique in utilizing the 88-mH choke as a current transformer. The term hybrid is used because in using the choke, a "halfway in-between" turns ratio will result. The approximate number of turns is determined by measuring the resistance of the coil, finding



The almost-completed ac current transformer. The transformer is mounted on a piece of styrofoam™ which is glued to the box. Contact or rubber cement can be used for both the foam and transformer. The signal wires (not shown) can be routed out through any of the knockouts.

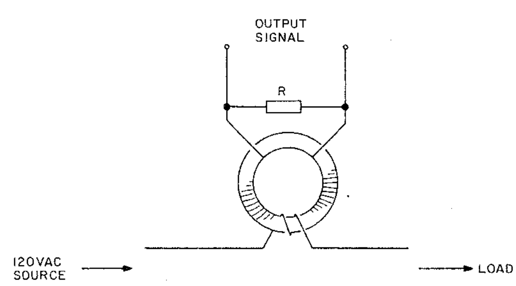


Fig. 1. Basic hybrid current transformer.

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the wire size, and, from a wire table, finding the resistance per foot. By taking the average diameter of the donut and average cross section, a rough turns count can be calculated.

For those not willing to take the time to play with the math, a quick test can be found in the calibration section. If the ratio is found to be in excess of about 300, the choke is a good candidate.

Apparently, there are several so-called surplus 88-mH-type chokes. I found some with and some without center tap. I have also found some with two separate windings. These can be used if the windings are connected in series adding. Even though the choke defined here was intended for the audio frequencies, it works well at 60 Hz if the power levels are kept low.

Construction

The only construction required is covering the existing windings with tape. Once the value of R is determined, it can be soldered to the windings and taped to the body of the coil or mounted as shown in Fig. 3. The signal wires are attached across the resistor and routed where necessary. Wire length is not critical, but wires should be routed away from high-noise areas.

Calibration

Fig. 2 shows the test setup used to calibrate the current transformer. It is not necessary to use the 120-volt, 60-Hz line to do the calibration. As shown, a low-voltage, high-current voltage transformer with an adjustable input is the quickest and safest.

For calibration purposes, R can be a quality pot. The 100-Ohm resistor is used to prevent shorting the transformer, but is part of the burden. The source and load will depend on what is available. Use the following steps to calibrate the transformer:

1) Make sure that there are ten complete turns of #18 insulated wire wound as shown in Fig. 2.

2) Adjust the load for 10.0 Ohms.

3) Adjust the voltage to the load for 10.0 V ac.

4) Adjust R (1k pot) for an even value of voltage—preferably 0.1 V ac. Remove power.

(If 0.1 volt was not obtainable, replace R with a 2k pot. If the measured voltage was higher than 0.1 V ac, set the value to any even value above 0.1 V, e.g., 0.3 V ac.

(The current ratio is calculated as follows: $I = E/R$, where E was set to 10.0 V ac and R was set to 10.0 Ohms. Therefore, $I = 10\ V/10\Omega = 1$ Amp.

(Then 1 Amp through 10 turns equals 10 Amp/turns which is also equal to 10 Amps with 1 turn through the transformer. With one turn in the primary and the measured value across R of 0.1 V ac, the ratio becomes 10 to 0.1. By Ohm's law, E is equal to I times R, and if R is held constant, then E must be proportional to I.

(What this boils down to is that the current through the transformer will generate a proportional voltage across R as long as R stays constant. If the ratio has been set correctly, adjusting the load to 1.0 Ohms and again adjusting the voltage across the load to 10.0 V ac, a value of 1 V ac should be measured across R.)

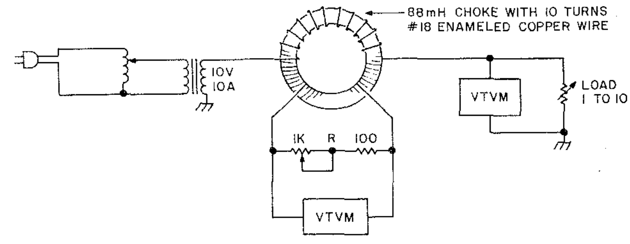

Fig. 2. Calibration test setup.

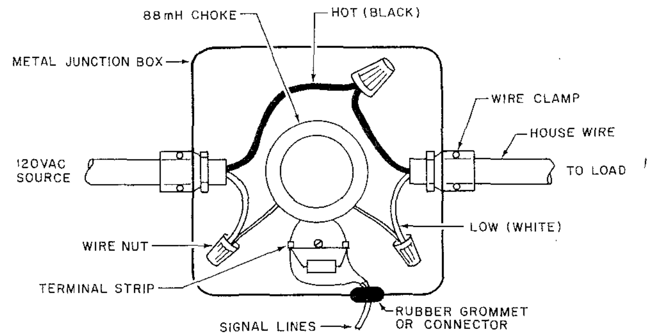

Fig. 3. Mounting fixture.

5) Determine the wattage for R by measuring the value of R and calculating as follows: $P_{Watts} = E^2/R$. Generally, a ½-Watt resistor will be more than sufficient. Replace the pot and 100-Ohm resistor with a fixed value equal to the combination of the two in series.

Application

Obviously, this combination can be used with any current range. It is limited only by the size of wire capable of being wound (1 turn) through the donut. Note that at least one turn is necessary to excite the transformer core. Passing the wire through the hole is not sufficient. Practically speaking, a #5 (solid enameled) wire is about the maximum-size wire which can be formed into one turn around the donut. This limits the upper current range to around 50 Amps.

The number of turns wound on the current transformer will depend on the current range to be measured and wire size. As an example, suppose a motor rated at 15 Amps (running) is to be monitored. We know from our calibration that 10 Amps gave us 0.1 V ac across R. Therefore, one turn of #12 wire through the donut should give us 0.15 V ac across R. The #12 was chosen because it is the smallest size generally used for motors in this range.

Another example is the case where only 1 Amp is to be measured. In this case, the wire size (assumed to be #14) is too large to pass a large number of turns through the donut. If you can assume also that nothing larger than approximately 5 Amps will be

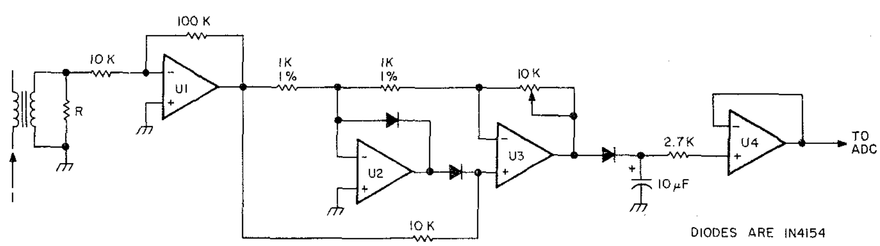

Fig. 4. Precision rectifier/buffer.

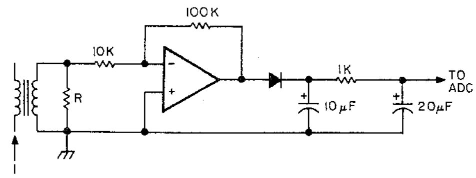

Fig. 5. Half-wave rectifier.

passed through the donut, then ten turns of #18 (solid enameled) will generate 0.1 V ac across R. In most cases, the number of turns will be determined by the measurement requirements.

Installation

According to most electrical codes, any splices of power lines must be located in a box. An outlet or junction box will work equally well. The transformer should not touch the metal box, and make sure that only the circuit being measured is in the box. It is best to use the low side (white wire) because the voltage between the low side and ground will not exceed the voltage rating of the enameled wire.

When measuring a 220-V ac line it will be necessary to use either of the two hot (red or blue) lines. In this case, the donut should have at least one layer of electrical (plastic) tape between the two sets of windings. Fig. 3 shows one method of mounting the donut and resistor R. Any method which meets your local code requirements will work.

Use

Now that you have a current transformer, how can it be used? The answer to that depends on why it was built. The easiest use of the current transformer is with an ac voltmeter. In my case, it is being used in a computer-controlled power system. Since a computer does not know ac from dc (or much else), the ac signal across R must be signal conditioned. There are many ways to signal-condition, but the method I chose was determined by the analog-to-digital converter (ADC) used with my computer. It has ±15 V dc available, so that the use of operational amplifiers seemed to be the best solution.

Fig. 4 is an example of how the ac signal is conditioned from ac to dc for the ADC. It is beyond the scope of this article to dissect the operation of Fig. 4 except to note that U2 and U3 form an absolute value (precision-rectifier) circuit. U1 is an inverting amplifier and U4 is used as a unity-gain buffer. U1 and U4 are in one LM747 and U2 and U3 are in another. Any general-purpose operational amplifier will work. (More information on this particular absolute-value circuit may be found in the November 8, 1979, issue of *Electronic Design*, page 94.)

A simple amplifier and diode arrangement also will work if accuracy and response time are unimportant. Fig. 5 is the method used in this case.

Summary

No matter what the requirement, a simple arrangement such as described here will provide a reasonably accurate measurement of ac line current. Sources of 88-mH chokes are found in the back of most electronic magazines and cost around $3.00.

Now I need to look into a method of measuring the gas pressures in my heat pump! ■

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