University of Utah
Electrical & Computer Engineering Department
ECE 3600

AC Meters & Power Factor

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NOTE: Bring your lab notebook to all labs!

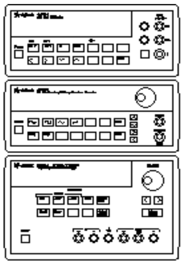
Objectives

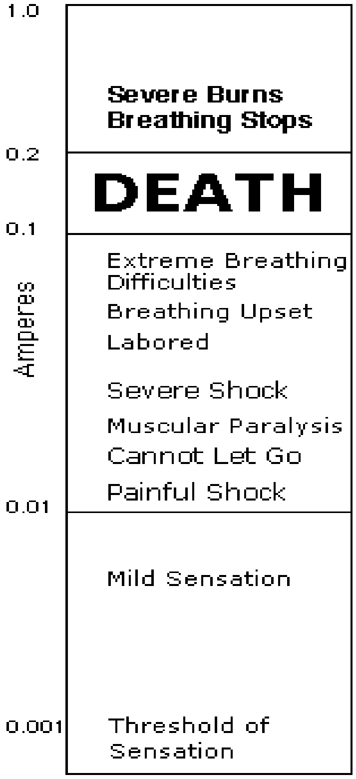
1. Learn safe lab practices.
2. Compare peak and RMS voltages of a sine wave.
3. Learn about the characteristics of AC voltmeters.
4. Investigate power factor and correction.
5. Learn a little about induction motors in the process.

Equipment and materials to be checked out from stockroom:

- Power wire kit
- Digital multimeter (APPA 95 if possible)
- Note: if your workbench does not have a stack of Agilent devices, also check out a function generator and Fluke DVM. Substitute as needed in the lab.
- Wattmeter
- Power strip
- “Suicide” cord
- Single-phase induction motor
- 3-phase induction motor

Bring all this equipment to one of the benches along the west or north wall of the lab.


Agilent Stack



Electrical Safety

Material contained here comes from The Department of Electrical Engineering, Massachusetts Institute of Technology and from a bulletin published by Graymark International entitled "Graymark Cares About Your Safety"

The Fatal Current

It's the **CURRENT** that **KILLS** and does other harm.

Offhand it would seem that a shock of 10,000 volts would be more deadly than 100 volts but this is not necessarily so. Individuals have been electrocuted by appliances using ordinary household 110 volts and by electrical apparatus in industry using as little as 42 volts direct current. The real measure of a shock's intensity lies in the amount of current (amperes) forced through the body, and not the voltage. Any electrical device using more than 42 volts can, under certain circumstances, transmit a fatal current.

A current as little as 10 mA (.01 amp) is capable of producing a painful shock and 50 mA can be a severe shock. Currents between 100 and 200 mA (.1 - .2 amp) can be lethal.

Currents above 200 mA (0.2 amp), while producing severe burns and unconsciousness, do not always cause death if the victim is given immediate attention. Resuscitation consisting of artificial respiration will usually revive the victim. Artificial respiration must be applied immediately if breathing has stopped.

The Physiological Effects of Electric Shock

The figure on the previous page shows the physiological effects of various current densities. Note that voltage is not a consideration. Although it takes a voltage to make the current flow, the amount of shock-current will vary depending on the body's resistance between the points of contact.

As shown in the chart, shock is relatively more severe as the current rises. At values as low as 20 milliamperes breathing becomes labored, finally ceasing completely at values near 75 milliamperes.

As the current approaches 100 milliamperes ventricular fibrillation of the heart occurs - an uncoordinated twitching of the heart's ventricles. Fibrillation is the most life-threatening condition caused by electrical current and is very difficult to correct without specialized medical equipment (a defibrillator). There is a defibrillation unit mounted near the north-west entrance of MEB.

Above 200 milliamperes, the muscular contractions are so severe that the heart is forcibly clamped during the shock. This clamping protects the heart from going into ventricular fibrillation and the victim's chances for survival are good. In fact, this is how a defibrillator “resets” the heart rhythm.

DANGER! - LOW VOLTAGE!

Victims of high voltage shock usually respond to artificial respiration more readily than the victims of low-voltage shock. The reason may be the merciful clamping of the heart, owing to the high current densities associated with high voltages. 200 volts can be more lethal than 2000 volts.

The actual resistance of the body varies depending upon the points of contact and the skin condition (moist or dry). Skin resistance may vary from 1000 ohms for wet skin to over 500,000 ohms for dry skin. Internal resistance (doesn’t include skin resistance) isn’t as high or as variable. Between the ears, for example, the internal resistance is only 100 ohms while from hand to foot it is closer to 500 ohms.

What to Do For Victims

Cut voltage and/or remove victim from contact as quickly as possible--but without endangering your own safety. Use a length of dry wood, rope, blanket, etc., to pry or pull the victim loose. Another strategy which can be particularly effective in the lab is to short the power on a neighboring bench and cause the breaker to cut the power. In general, if you don’t know where the power switch or breaker is, don't waste valuable time looking for it. In the lab, I’d like you to always be aware of the switch and plug locations. The resistance of the victim's contact decreases with time, so the current flow will increase with time. The fatal 100 to 200-milliampere level may be reached if you delayed action.

After separating the victim from the power, check that the victim is conscious and breathing, if not, check for a pulse and start artificial respiration or CPR at once. Do not stop resuscitation until the victim begins breathing on his own or a medical authority pronounces the victim beyond help. It may take as long as eight hours to revive the patient. There may be no pulse and a condition similar to rigor mortis may be present, however these are the manifestations of shock and are not an indication the victim has died.

General precautions to be used when working with electric circuits

1. Do not work alone! The more you know about electrical equipment, the more heedless you're apt to become. Don't take unnecessary risks.
2. Unless you absolutely have to, do not work on electrical circuits when the power is on. Kill all power and ground all high-voltage points before touching wiring. Make sure that power cannot be accidentally restored.
3. Keep one hand in your pocket while investigating live electrical equipment, such as making voltage or current measurements. If two hands are in contact with the circuit or if one hand is in contact with the circuit and the other hand is in contact with ground, (such as a metal panel or the case of a piece of test equipment), the current path is across the chest where the heart and lungs are located. This is extremely dangerous as you need to have your heart and lungs working at all times.
4. Electrolytic and other large capacitors can hold a charge for several hours after the power is turned off. Make it a habit to check that they have fully discharged by shorting them with a screwdriver or clip lead before working on a circuit.
5. Do not work on electrical equipment while standing on a damp floor or when leaning on or touching any metal object. Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.
6. When working around electrical equipment, move slowly. Make sure your feet are firmly placed for good balance. Don't lunge after falling tools. Don't examine electrical equipment when you are mentally or physically fatigued.
7. Be sure equipment is in proper working order before you use it. Replace frayed, cracked cords.
8. When moving tall objects, even objects you wouldn’t normally consider conductors, be aware of and avoid overhead power lines. Don’t dig in areas with underground power lines.
9. Certain components such as resistors get quite hot. Give them time to cool before removing them.
10. Make it point to know the location of the fire extinguisher and how to use it.

In Our lab

1. Do not work in the lab if your hands are wet. Do not allow any drinks to be set on your bench, spills can lead to shorts and/or shocks. As long as your skin is dry, the voltages we will use in the lab are unlikely to cause life-threatening shocks. However, if you touch the 208V phase-to-phase voltage and your body and skin resistance is less than 10 kΩ, you may not be able to let go. The resulting sweating and skin damage can lower the resistance enough to get the fatal current.
2. Put bandaids on your abrasions and cuts before working in the lab. Without insulation, these can be low-resistance paths through the skin.
3. Keep the wiring on the bench as neat and orderly as you can. Choose your wires and

connectors carefully to minimize the number of exposed connections, especially the electrically “hot” connections. Always keep in mind that the metal cases of the computer and test instruments are grounded and provide ready return paths to complete circuits from a hot connection though your body to ground. Also be aware that the scope and function generator grounds are connected to the electrical power ground.

4. Don’t wear loose clothing or jewelry around spinning motors.

Lab Notebook

You are required to keep a lab notebook in the ECE 3600 lab. We will pay particular attention to the following things:

- Work in your lab notebook at lab time—no scribble sheets for data so that you can “write it down neatly later.” Take measurements and make calculations directly in your notebook. Mistakes should be crossed out and redone.
- No cutting-and-pasting from the lab handout. You are supposed to be learning how to keep a notebook of your own.
- Write clearly and follow the guidelines on the “Lab Notebook” handout for procedures, data, and conclusions.
- Use lots of drawings, tables, and graphs, and label them well. Often these are both easier to create and better than written text. Draw a schematic or drawing of each circuit that you build in lab.
- When you are asked a question in the lab handout or asked for a comment, please respond with at least one full sentence in your notebook. This sentence should make sense by itself, without reference to the handout.
- Whenever you read some section like “Electrical Safety” as part of the lab, you should include some description or synopsis in your notebook.

My main objectives are that you to work in your notebook as you do the lab, and that you make that work useful for later reference.

Check-off:

When you are finished with your lab, you should call your lab TA over to check you off. At this time, you should be able to demonstrate a working circuit, answer questions about what you did, and show your finished notebook. Some or all of your notebook may be graded at this time and you may get part or all of your lab grade right on the spot. Check-off becomes a problem if you ever miss your normal lab time, so try not to. If you have to miss a lab, make arrangements with your TA to make it up. Most TAs will accept the check-off from another TA or from me.

Experiment 1, Meter Responses

This part of the lab will not involve any dangerous voltages.

Sinusoid: Set the Agilent or HP 33120A function generator 60 Hz and 5 Vpp (will actually output 10 Vpp). Observe this sine wave on the oscilloscope and measure it’s peak-to-peak voltage. Calculate the RMS voltage of this sine wave.

Set your two voltmeters (the Agilent or HP 34401A and the other meter you checked out) to AC volts (sometimes meters show a small sine-wave symbol instead of “AC”). Now measure the function generator voltage with both voltmeters. Do the both meters show the RMS value?

Almost all AC voltmeters are designed to show the RMS voltage if the input is a sine wave. However, most meters do not actually read the true RMS value of an AC waveform. Instead, they read the *rectified average* (V_{RA}) of the AC waveform and then multiply that by 1.111 to display an estimate of the RMS (V_{RMS}) value. The multiplication factor works out exactly for a sinusoidal waveform but not for other waveforms. That's because the the factor would be different for different waveforms and the meter cannot tell one waveform from another. Meters that measure the "true RMS" of any waveform are more complicated and more expensive.

Sinusoid: $V_{RMS} = \frac{V_p}{\sqrt{2}} = 0.707\,V_p$ $\quad V_{RA} = \frac{2}{\pi} V_p = 0.6366\,V_p$ $\quad V_{RMS} = 1.111\,V_{RA}$

Square: Observe the scope and change the function generator output to a square wave. Measure this voltage with each of the voltmeters again. Do the meters show the RMS of this wave correctly?

Square: $V_{RMS} = V_p = V_{RA}$

Again, the majority of inexpensive meters actually measure the rectified average (V_{RA}) of the waveform. The rectified average is the average of the absolute value of the voltage (take all the negative parts and make them positive). They measure this V_{RA} and multiply it by 1.111 to display a V_{RMS}. This works fine for a sine wave, but not for any other waveform. In this case, if a meter measured the V_{RA} of your square wave and multiplied it by 1.111, what would it display? Does this correspond to what you see on either of the meters? Do either of the meters read the "true RMS" of the square wave.

Does the 34401A meter actually measure, V_{RMS}, or V_{RA}? Does the other meter actually measure, V_{RMS}, or V_{RA}?

DC Offset Effects

Now let's see what the meters do if we add some DC into the mix. Set the function generator back to sine wave and adjust the DC offset to 2.5 V (will actually offset the output by 5 V). Now you have a sine wave that swings between 0 V and 10 V.

Sinusoid + DC: $V_{RMS} = \sqrt{V_{RMS(AC)}^2 + V_{DC}^2}$

Do any of the meters read correctly now? Do any of them even respond to the added DC? Actually, most meters filter out the DC before measuring the AC. Do these meters do that?

Frequency response

The final meter characteristic we will look at in this lab has nothing to do with RMS. I want you to find the frequency response of each meter. So far we have only measured waveforms at about 60 Hz. All AC meters should measure sine waves correctly at t 60 Hz because that's the power frequency. Most will also work well up to 400 Hz because 400 Hz is common in aircraft. Meters vary greatly in how well they work above 400 Hz, some work well but many do not.

Remove the DC offset from your sine wave and turn up the frequency until the 34401A starts to read a little off (say 5% high or 5% low). Write down the frequency as the upper limit of that meter. Now turn the frequency back down and repeat this for the other meter. Also look for weird effects (especially the APPA 95) and note them. Some AC meters do strange things, like read way too high at higher frequencies.

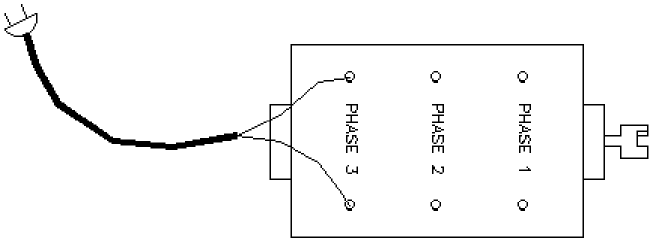
Experiment 2, 3-phase Voltages

You should find a 3-phase power box on your lab bench. Turn on the breaker and carefully measure the line-to-neutral voltages and the line-to-line AC voltages with your choice of meter. (If these are zero, go to the check-out window and ask that the 3-phase power be turned on.) Do your measurements agree with and indicate a common 3-phase power and what is it called? Turn off the breaker.

Experiment 3, Power factor

Induction motor load

The 3-phase induction motor is the larger of the two motors that you checked out. You will run it as a single-phase motor in this lab. Connect it as shown, plug the cord into the power stip and turn it on. Notice that the motor doesn't turn. This is because one phase can only produce a magnetic field that swings back and forth 60 times per second, but does not rotate. Without a rotating magnetic field, the rotor may hum a bit, but it will not start rotating. Give the motor shaft a spin in either direction to get it started. Now it will continue to rotate because the rotor gets get a little kick each time the magnetic field changes direction. After the motor spins up to full speed, turn off the power and let it come to a stop. Turn on the power again and manually start the motor in the opposite direction. Notice that it will work equally well in either direction, depending only on how it is started. This is typical of a single-phase induction motor. Describe what you have just done in your lab notebook.



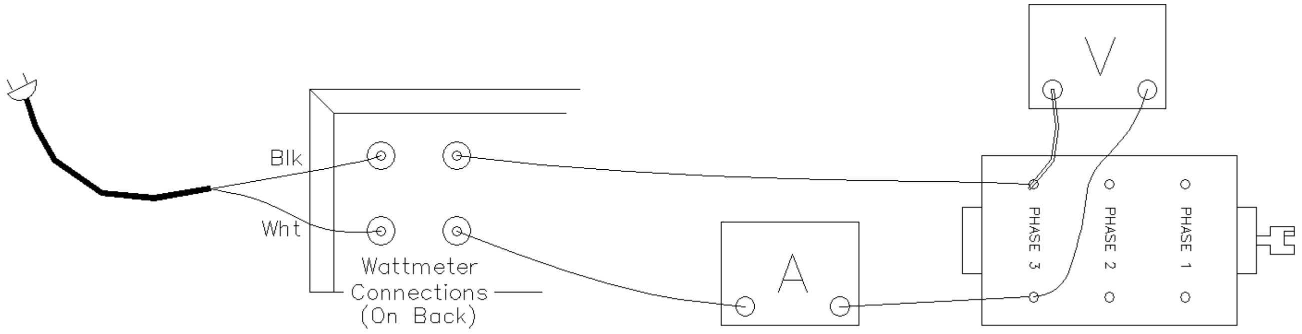
If you were to hook up another of the motor phases to the same voltage source the motor would act about the same. It still would not start on its own. Although the second motor winding is placed at an angle relative to the first, when the two currents in the two windings are in phase the combined effect will be a magnetic field that swings back and forth with no rotation, just like before. If, however, you were to add another circuit element in series with the second winding (say a capacitor) to change the phase of the current in the second winding, you could produce some rotating magnetic field. This could get the rotor started and this is exactly how single-phase induction motors work. A capacitor-run motor uses a second winding and a capacitor which are always connected in parallel to the first winding. A capacitor-start motor uses a cheaper, thinner second winding and a cheaper capacitor which are connected in parallel to the first winding only during starting. When the motor reaches a certain speed (usually about 75% of the rated speed) a centrifugal switch disconnects the second winding. A resistance-start motor works like the capacitor-start motor except that the phase difference is achieved by a second winding with higher resistance and lower inductance than the first. It's cheaper, but has a lower starting torque. In all these motors the direction of rotation can be changed by changing the polarity of either winding but is usually done by changing the polarity of the second winding, also called the start or auxiliary winding.

If you are interested in learning more about electrical motors, look into the motors class. In this class we will only discuss the 3-phase synchronous machine (motor/generator) in any detail and occasionally use some other motors as loads (like in this lab) or as mechanical input to a generator.

Determination of the power factor

The power factor is rarely determined by measuring the phase angle between the voltage and the current. Instead, you'll measure the voltage current and power and use those to calculate the power factor. It is an easy calculation because multiplying the voltage and current gives you the apparent power and the power factor is simply the ratio of the real power to the apparent power. Set up one of your multimeters to read AC current and one to read AC voltage.

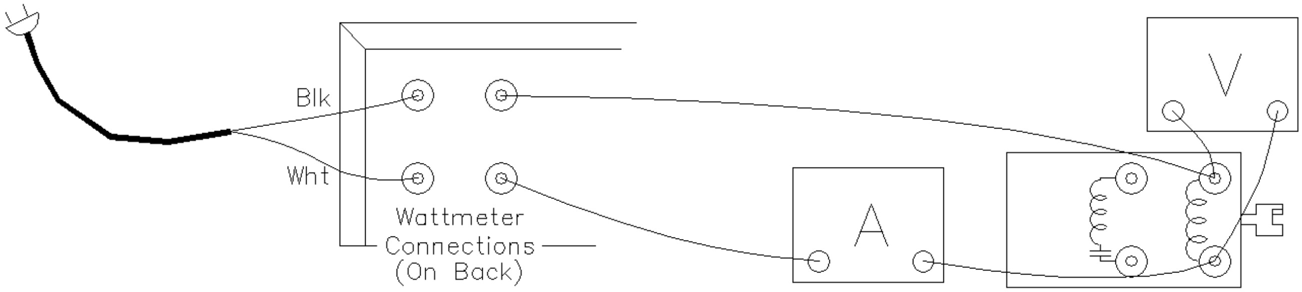
A wattmeter simultaneously measures the voltage and current and combines the two to give a measurement of the real, average power. The wattmeter has four terminals– two for power input and two for load. Connect the power line, wattmeter, ammeter, voltmeter and motor as shown. This will be an awkward wiring job because the wires you have won't match your needs very well. You'll need to use some of the jumpers that are hanging on the wall. Be careful to make as clean and stable a wiring job as you can. Whenever you make a circuit like this you should draw a schematic in your lab notebook and add some description.



Power up the wattmeter before applying power to the rear terminals (pugging in the motor). Plug in the motor and manually start it rotating. When things have stabilized, read the three meters and record all the readings. The ammeter and voltmeter should match the amps and volts shown on the power meter, if not, use average for further calculations. Unplug the motor.

Calculate the power factor and calculate the capacitance needed to correct the power factor. Why is it reasonable to assume that the load is inductive and the power factor is lagging? Obtain a capacitor of approximately this value with a voltage rating of at least 320 VDC. There are an assortment of capacitors that you can check out, but you may have to use several in series and/or parallel to get the right value. Hook this capacitor in parallel with the motor and determine the power factor again. Have you corrected the power factor? Note how much the current reading changed. Why is this change desirable?

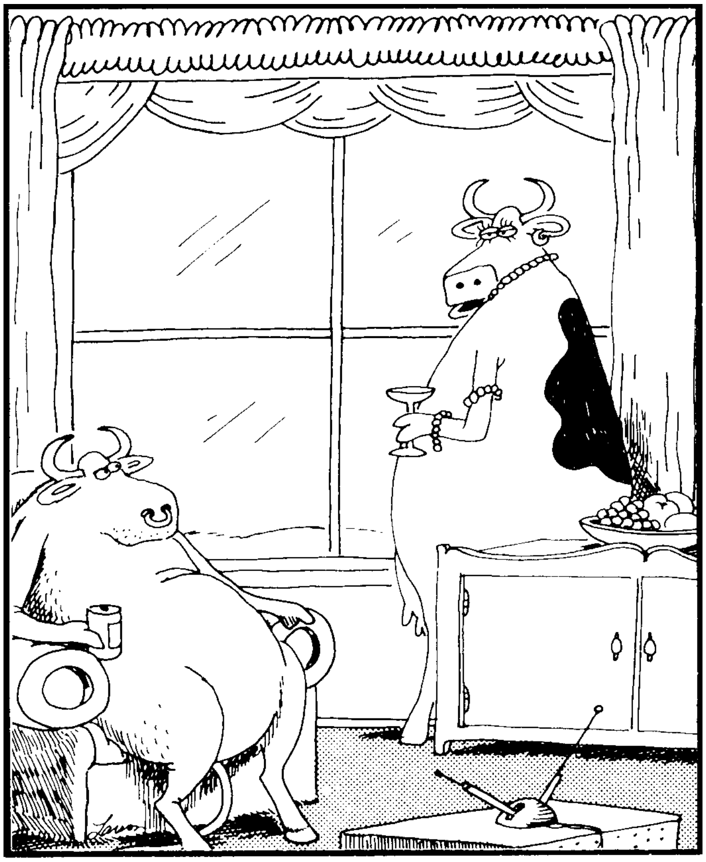
Repeat the power factor measurement and correction on the single-phase motor with only the first winding connected (the one without the capacitor).



Measure the power factor of a single capacitor alone. Is it possible to determine weather a power factor is leading or lagging by this measurement alone? Why is it usually reasonable to assume that the power factor is lagging?

Conclude

As always, check off and write a conclusion. In particular, draw some conclusions about how the AC meters work and about power factor corrections.



"Wendell . . . I'm not content."