Use a Smart Power Meter to add Practical Labs in AC Electronics

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Abstract

Students lose their interest in some electronics classes for of several reasons. Most labs, for example, are only related to theories without any examples in real life. Moreover, some theories cannot be verified in the lab due to the limitations of lab equipment. Most meters used to test these AC power systems are expensive and hardly used in lab in concern for safety issues. There are, however, some new electronics devices on the market that can be adopted in these classes to solve these problems at a lesser cost.

This paper describes an example of the applications of a smart meter to verify the theory of a parallel resistive-capacitive (RC) circuit in an AC electronics class. The parallel RC circuit cannot be tested using an oscilloscope, which only shows signal voltage, in lab as there is no difference between voltages in a parallel RC circuit. Most lab books change the parallel circuit a little bit in order to use an oscilloscope; this may confuse students because the resulting circuit is no longer an RC parallel circuit anymore. This paper describes how a smart meter measures a parallel RC circuit. The meter is a power meter from the market with functions to measure AC voltage, current, frequency, real power, apparent power, as well as energy in kWh. All variables read from the meter are used to calculate the real problem according to the theory from textbook, which shows students real-life examples. The result also explains some theory about power factor as well as some considerations in power transmission. The method is safe for students to use 120VAC power system in lab.

Introduction

AC electronics is one of the most difficult and fun basic classes in the electronics field for a number of reasons. Compared with a DC power supply, an AC power supply provides a changing voltage or current rather than a constant one. Sine waves are used in the theory to simplify the problem by using RMS value (constant value) rather than changing instant value, which makes it hard to be understood. Labs can provide good explanation and support to theories, which can motivate students in learning, especially those labs demonstrating real-life examples.

The most commonly used equipment in an AC lab includes oscilloscopes, multimeters, and function generators. A function generator is used as a power supply while an oscilloscope as a meter to measure voltage in a circuit. Although an oscilloscope provides a vivid picture to show how voltage changes in a circuit, there is not such an affordable equipment to show current and powers in a similar way. A digital multimeter can measure AC current and voltage, but it is only used to measure voltage and current with low frequencies. Power and power fact are calculated according to theory and are seldom measured directly by using meter in lab.

Most times, students are excited when they see waves on the screen of an oscilloscope. Oscilloscopes only show different voltages at different time. They can show the phase shift of voltages in an AC serial circuit. However, parallel circuits, such as shown in Figure 1b cannot use an oscilloscope to be verified because all voltages are the same in a parallel circuit. The current meter, such as a digital multimeter, cannot show the phase shift of current in parallel circuit either. To show the current phase shift, current sensor resistors with small resistance are added in the parallel circuit, as shown in Figure 1a, making it not a parallel circuit any longer. This method sometimes confuses students because of the difference between two circuits shown in Figure 1. Parallel AC circuits, such as power systems used in our home, are common in our daily life. Most students are curious about the real parallel AC circuits rather than the modified ones with current sensor resistors.

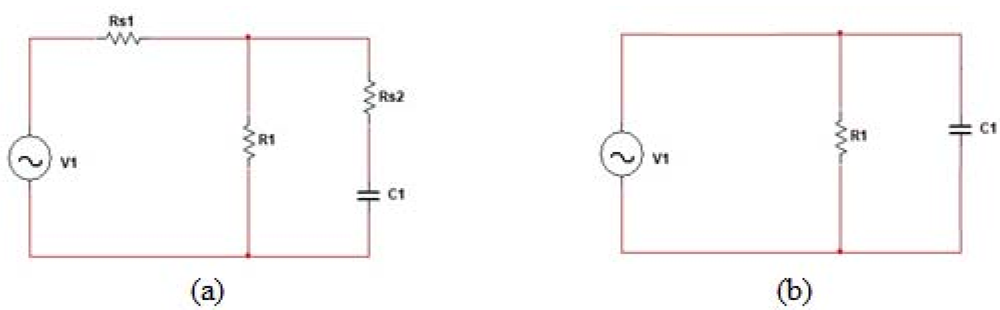

Figure 1. Parallel RC circuit with current sensing resistors Rs1 and Rs2 (a) vs. real parallel RC circuit (b).

Most AC labs do not use 120VAC as the power supply for safety reasons. A common question asked by students after a lab is "Can we get the same result if a 120VAC power is used in this lab" because everyone wants to say the real-life application rather than theory. Labs using 120VAC power supply can help students to realize that all theories in textbooks are used in real life.

Lab maintenance and upgrade cost much money. An economic way might be buy some untraditional equipment as supplementary to traditional lab equipment.

A smart meter provides a possible economic solution to all those problems. It is used for 120VAC system. The price is about $30. It can measure voltage, current, real power, apparent power as well as power factor. This paper gives an example using a smart meter to test a parallel AC circuit with 120VAC power supply as a supplemental AC lab to verify the parallel theory.

The smart meter used in this paper is introduced following the detailed description of the lab setup as well as calculations according to AC parallel circuit theory.

Kill Power Smart Meter

The smart meter used in the paper is shown in Figure 2.

Figure 2. Smart Power Meter P3.

It is a cheap device that can be used to monitor how much power is used by a device in our daily life, for example, energy consumed by a computer in sleep mode. The result will let people know which device uses more energy and how they can reduce their power bill and save their power consumption, such as turning off a computer rather than just leaving the computer in sleep mode.

It is easily applicable and safe. The device under test (DUT) is simply plugged into the front socket, and the smart meter will show voltage, current, real power, apparent power, frequency, power factor, as well as energy used by the DUT.

In this paper, a parallel resistive and capacitive circuit serves as an example to use a smart meter in an AC electronics lab class. The following section describes the detailed setup of the RC circuit.

A Parallel RC Circuit under Test

The lab setup is shown in Figure 3. An 120VAC, 60W incandescent light bulb is used as a resistor R1 and a 3.75μF AC motor running capacitor as capacitor C1. The capacitance is about 3.83μF, which is read from a digital capacitor meter. Both components are connected to a power cord with a plug. A power strip is used to connect the lamp and the capacitor as a parallel circuit.

Figure 3. A parallel RC circuit.

The following test process was used in lab:

1. Discharge the capacitor and connect it with a power cord.
2. Connect a lampholder with a power cord and install the bulb.
3. Plug the capacitor and lamp's power cords into the power strip.
4. Plug the power strip cord into a power socket to make sure the lamp is on, which means the connection of the circuit is good.
5. Unplug power strip cord and plug the power strip cord into the socket of the smart meter.
6. Plug the smart meter into the power socket and make sure the lamp is on again.
7. Press the related button on the smart meter and record all variables for the RC parallel circuit. The results are related to the variable from the AC power supply.
8. Unplug the power strip's power cord from smart meter and remove the smart meter from the power socket. Plug the power strip's power cord into the power socket directly, and the lamp is on again.
9. Unplug the lamp's power cord and plug it into the smart meter's socket.
10. Plug the smart meter into the power strip's socket. The lamp should be on again.
11. Press the related button on the smart meter and record all variables for the lamp, e.g. resistor R. All results are related to the resistor branch.
12. Unplug the smart meter from the power strip.
13. Unplug lamp's power cord from the smart meter and plug into the power strip.
14. Unplug the capacitor's power cord and plug it into the smart meter socket.
15. Plug the smart meter into the power strip.
16. Press related button on the smart meter and record all variables for the capacitor C branch.

Table 1 shows the test result in one group.

Table 1. Measurements of a parallel RC circuit.

Smart Meter Position	Voltage (VAC)	Current (A)	Real Power (W)	Apparent Power (VA)	Frequency (Hz)	Power Factor
Power socket	121.6	.53	59.6	64.5	60	.92
Capacitor	121.9	.17	.8	21	60	.03
Lamp	121.8	.49	59.8	59.8	60	1

Analysis and Discussion

The test results are analyzed in two ways: 1) verify Ohm's law; 2) verify parallel equations.

Ohm's law verification for AC power supply:

- V_T = 121.6V

- I_T = 0.53A
- Apparent power $P_T = V_T I_T$ = 64.4 VA, which is close to the measurement result 64.5VA.
- Total Impedance $Z = \frac{V_T}{I_T}$ = 229.4Ω. This result will be verified by the calculation results for the parallel circuit in the following section.

Ohm's law verification for the capacitor C (here C is treated as an ideal capacitor):

- V_C = 121.9V
- I_C = 0.17A
- Capacitive reactance $X_C = \frac{V_C}{I_C}$ = 717 Ω, which is close to the result according to equation $X_C = \frac{1}{2\pi f C}$ = 692.6Ω where C = 3.83μF.
- Reactive power $P_C = V_C I_C$ = 20.7VAR, which is close to the test result 21VA.
- According to the AC circuit theory, power is not dissipated in a purely reactive load, such as an ideal capacitor; it is alternately absorbed from and returned to the source. The test result shows that there is 0.8W power dissipated by the capacitor branch. The small power is dissipated by the wire resistor (about 1Ω) and leakage resistor capacitor. The real power 0.8W is much smaller than the capacitor branch power 21VA according to the test result, so the capacitor branch can be treated as an ideal capacitor. The power factor is about 3%, which is close to the ideal result 0.

Ohm's law verification for the resistor R branch:

- V_R = 121.8V
- I_R = 0.49A
- The real power $P_R = V_R I_R$ = 58.7W, which is closest to the measured result 59.8W as well as the rated value 60W.
- The resistance $R = \frac{V_R}{I_R}$ = 248.6Ω. Because the resistance of an incandescent light bulb changes according to its temperature, it is hard to measure using a multimeter.
- Impedance $Z = 1/\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}$ = 234.9Ω, which is close to the result according to the Ohm's law in previous calculation.

Verification for parallel RC circuit:

- Voltage drops on a capacitor and resistor are almost the same as AC power supply voltage.
- $I_T = \sqrt{{I_R}^2 + {I_C}^2}$ = .52A, which is close to the measured result .53A
- Apparent power $P_T = \sqrt{{P_R}^2 + {P_C}^2}$ = 63.2VA, which is close to measured result 64.5VA.

- Power factor PF = Real power / apparent power = 58.7W/63.2VA = .928, which is close to the measured result .92

Different capacitors and lamps are used in class by different groups. Every group came up with similar analysis. The test results closely match the calculated results according to the theories.

In this setup, it is safe to measure current because the circuit is not opened. Voltage, current, real, and apparent power can be measured after the power cord is plugged into the smart meter.

Test results for capacitor branch also show the real-life result rather than the theoretical result by the nonzero power factor. The ideal capacitor should not consume energy, and real power for capacitor branch should be 0 and the power factor should be 0, too. Students are encouraged to discuss why the power factor of the capacitor branch is not 0 and which part dissipates that 0.8W power. Power dissipated on transmission lines as well as the reason for adjusting power factor close to 1 in real life is also discussed.

Conclusion

This paper presents an example of using a smart meter in AC lab. This smart meter can also be used in other labs related to AC power application. For example, it is easy to see the change of power factor after a running capacitor is added to an AC motor. Compared to other AC equipment, this smart meter is cheaper and easier to use in a safe way. It can provide more information in AC circuits, especially in 120VAC power system. Some variables are hard to be measured using oscilloscopes or digital multimeter, such as real power and apparent power. All these variables can be measured by the smart meter at the same time. It is a good test equipment for an electronics lab.

Biographies

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