AC Single Phase Energy

An Online Continuing Education Course for Engineers

Course Number: E-3001

Credit: 3 Hours / 3 PDH / 3 CPD

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1 Introduction

This course presents an introduction to single phase, ac circuits from an intuitive and illustrative standpoint rather than presenting a rigorous development of the definitions and equations. The objectives are to understand and calculate power and energy in basic single-phase ac circuits typically found in manufacturing and electrical power distribution systems.

The presentation assumes that the reader has been introduced to trigonometric definitions, can add vectors and can convert vectors between polar and Cartesian form.

2 Definitions

In working toward the objective of calculating the cost of energy consumed by various loads, we will first introduce the units used for voltage, current, load, power and energy. We will then present the equations necessary to compute current from voltage and load and then the equations to compute power and energy.

2.1 Units

The following electrical attributes and their associated units will be necessary to develop the circuit and energy calculation concepts used in later sections.

2.1.1 Voltage

Voltage or potential difference is the electromotive force that causes electric current to flow. The Meter-Kilogram-Second system (MKS) units are volts. Generators, alternators and batteries are examples of electromotive devices that supply energy to circuits. Voltage is always expressed as a difference of potential between two points (or across a component) in a circuit. It is very important to connect the idea that the voltage ***across*** a component causes current to flow ***through*** the component.

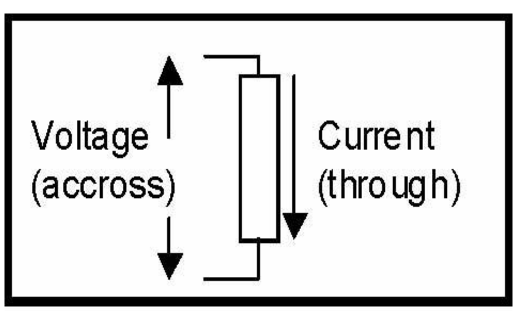


Figure 2-1 Voltage and Current

2.1.2 Current

Electric current flows in response to the voltage applied and is expressed in ampere (denoted as 'A'). The ampere is one coulomb per second. The coulomb, a term not in common use, is the SI unit of electrical charge. In circuits of concern to us, current will increase as voltage is increased and vice versa. Current is analogous to the rate of fluid flow in a hydraulic circuit—the ampere is analogous to gallons/minute.

2.1.3 Load

The load is any device that *resists*, or *impedes*, the flow of electrical current and serves to convert or store electrical energy. Examples of energy converting loads are:

Heater - Electrical to heat energy.
Motor - Electrical to rotational kinetic energy.
Light - Electrical to light energy.
Battery - Electrical to chemical energy.

The SI unit of electrical *resistance* or *impedance* is the ohm (Ω). The simplest loads, e.g. heaters, motors, etc., convert electrical energy into the desired forms based on the application. In the cases of these simplest loads the current is, always, proportional to the voltage.

There are two basic types of loads—resistive and reactive. These terms will be more fully described later. But for now, purely resistive loads permanently remove energy from a circuit, analogous to friction in a piping system. Purely reactive loads move energy out of and into a circuit with no net loss, analogous to a spring. Loads can be purely resistive, purely reactive or a combination of the two. A combination load is shown below:

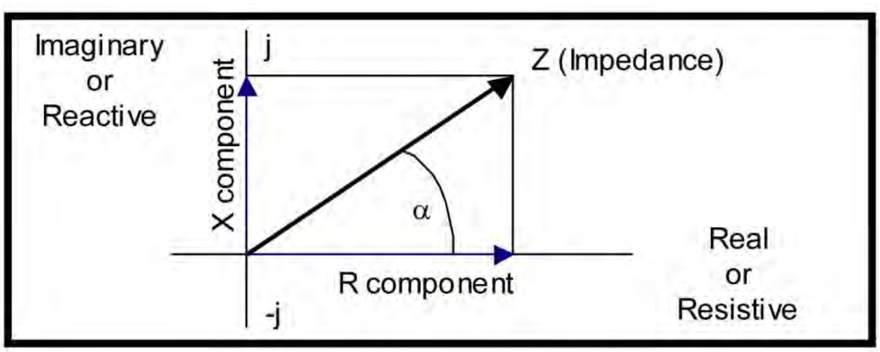


Figure 2-2 Impedance Diagram

The Resistive component of any load always points along the positive Real axis or East. The Reactive component is always directed along the Imaginary axis either North or South. The direction depends upon the type of reactor. The North and South direction is indicated with the lower case "j" and is a notation for $\sqrt{-1}$* . Impedance vectors of concern to us will be in either the first or fourth quadrants. Its components depend upon the magnitude of the resistance in the load and the magnitude and type of reactance.

The notation in common use is:

$$Z = R \pm jX = \sqrt{R^2 + X^2}\,\angle\alpha$$

Where $\alpha = \tan^{-1}\left(\frac{X}{R}\right)$

In the above expression, 'R' denotes resistance and 'X' denotes reactance of the circuit.

2.1.4 Power

The rate at which energy is delivered or used is called power and is expressed as units of watts (Real Power), VARS (Reactive Power), VA (Apparent Power) in electrical power distribution.

2.1.5 Energy

Energy is the capacity to do work or the amount of work accomplished and is frequently expressed in units of watt-hours (Wh) or kilowatt-hours (kWh) in electrical power distribution systems (1kWh = 1000 Wh). We will be especially interested in calculating the energy used by various loads to determine the electrical operating cost. The procedure will generally be to compute the power delivered to a load at an instant of time and then add these values to find the energy used over some period.

2.2 Circuits

A circuit is a connection of electrical elements that allows energy to flow from the source to the load(s). To be complete, a circuit must be connected to allow the electrical current leaving the source to pass through the load(s) and return to the source. This section defines and illustrates the concept of an electric circuit along with the associated components and attributes:

- Circuit connections.
- Voltage and current.
- Load.
- Energy and power.

* Typically denoted by "i" other areas but would conflict with the notation for current in the electrical areas.

2.2.1 Basic Circuit

The following figure illustrates a simple electrical circuit consisting of a voltage source, a load and wires to connect the voltage source and the load. This is analogous to assembling a hydraulic circuit consisting of a pump, hydraulic motor and connecting pipes. In both cases the energy flows from the energy generator (the source) to the load. The current (electric charge in one case and hydraulic fluid in the other) flows from the source, through the load and then back to the source, thus making a complete circuit.

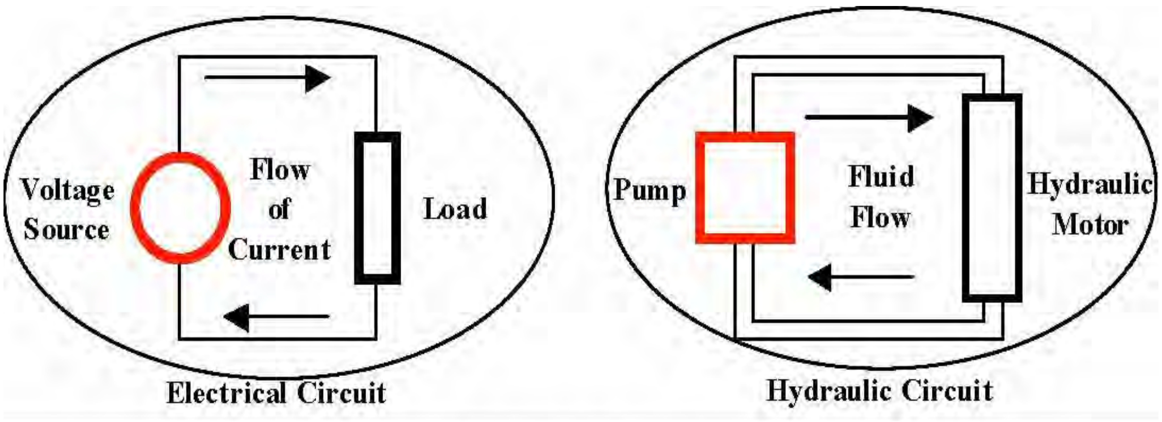


Figure 2-3 Electrical and Hydraulic Circuit Schematics

The voltage source, like the pump, is the source of the energy that is to be delivered to the load. Voltage is a measure of the electrical pressure causing the current to flow and is always specified as the voltage across, or between, two points. The larger the magnitude of the voltage, the greater the flow of current.

2.2.2 Series and Parallel Circuits

Most of the circuits in this course will consist largely of parallel connections. A figure illustrating both parallel and serial connections follows:

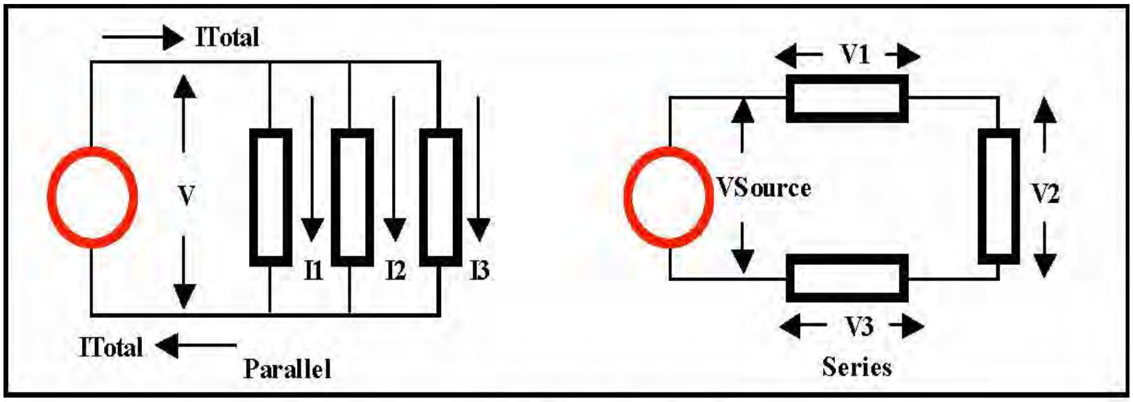


Figure 2-4 Parallel and Series Circuits

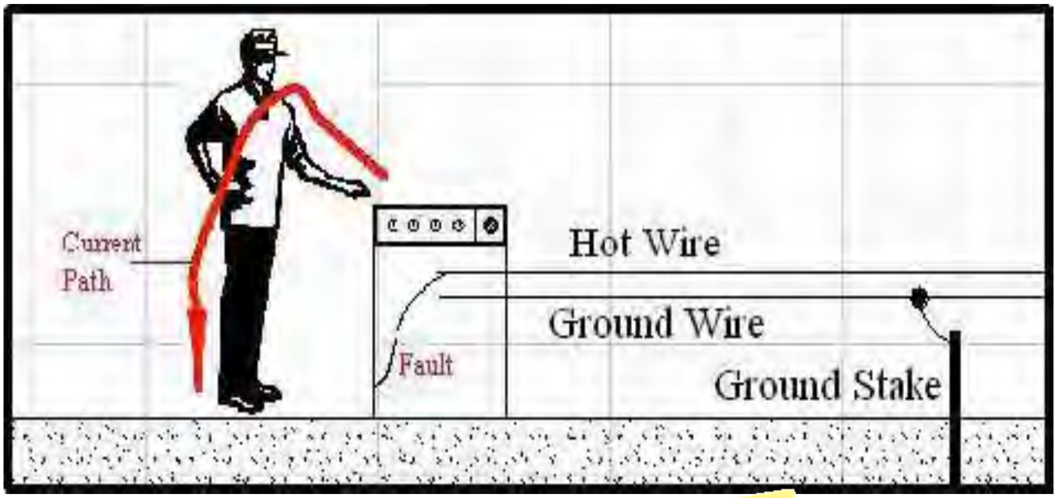
The purely parallel circuit (no serial elements) has only two connections between which the voltage is measured. In the case of this figure, those connections are the wires connected to the two terminals of the voltage source, thus there is only one voltage—that measured across the source. The current leaving the source divides between the three loads and then recombines to return to the source. The returning current would be of the same magnitude as the current leaving the source.

Now consider the series circuit. Here there is only one path for the current to follow. The magnitude of the current leaving the source is equal to the magnitude of the current measured through any of the three loads. In the series circuit illustration there is one current and four voltages measured where in the parallel illustration there is one voltage and four currents to measure.

The circuits of interest in this course will be mainly parallel circuits.

2.2.3 Ground

Note that in the parallel circuit one of the two conductors connected to the source is usually called ground and is used as the reference. This is a safety issue. Consider the following illustration:



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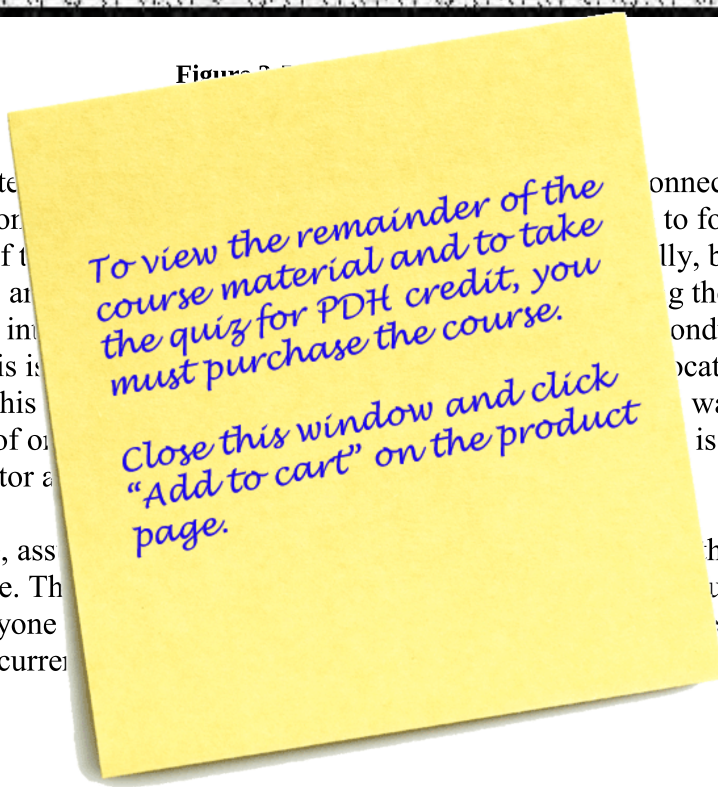

This illustrate… …onnection to an appliance. Simplification… …to focus on the safety issue. One of t… …lly, by the electric company, to ar… …g the wire to conductive stake driven in… …onductive building element. This is… …ocations around the residence. This … walls, etc.—close to the voltage of o… is called the ground or cold conductor a…

In the figure, ass… …the case or chassis of the appliance. Th… …ugh mistakes, damage or wear. Anyone … …een the hot wire and the ground, curre… …al shock.