BASIC ELECTRONICS FOR FIELD MEASUREMENT
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Introduction

Since Thomas Edison invented the light bulb, Electricity has become the life blood of industrialized nations. Today, we depend on it for every aspect of our lives. Electricity is used for everything from powering motors, to running the most complicated computer systems, factories and defense systems, to charging our iPods and iPhones.

This paper will focus on the use of electric circuits that apply to the devices used in the oil and gas industry.

Basics

Electricity is made-up, in part by electrons and protons. Electrons have a negative charge and protons have a positive charge. Electrons repel each other, protons repel each other, but electrons and protons are attracted to each other. The heart of all this is the electron movement. This electron movement is enabled by electric circuits.

There exists what are called Alternating Current (AC) circuits, and Direct Current (DC) circuits. An in depth discussion of these topics and the differences between them are out of the scope of this document. Only DC circuits will be discussed.

Three elements that are always present in an electric circuit are:

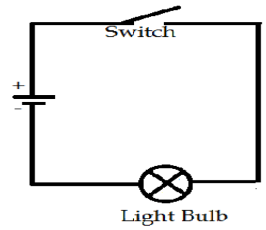
Current. A progressive movement of free electrons along a wire or other conductor. Current is expressed in Amperes or Amps (A).

Electromotive Force. This is also known as voltage. This is the force that pushes or pulls electrons (current) through the circuit. Voltage is expressed in Volts (V).

Resistance. Any opposing effect that hinders free-electron progress (current flow) through wires when an electromotive force (voltage source) is attempting to produce a current in the circuit. Resistance is expressed in Ohms or (Ω)

The simplest of circuits (Figure 1) consists of the following:

1. A voltage source, such as a battery.
2. A load, such as a light bulb.
3. Connecting wires.



A basic diagram of a circuit

4. Control device (switch).

Ohm’s Law

One of Georg Ohm’s major contributions was the establishment of a definite relationship between voltage, current, and resistance in a closed (complete) circuit. Ohm stated this relationship as: Current is directly proportional to voltage and inversely proportional to resistance.

Ohm’s law can be expressed mathematically as: $I = E/R$ (Equation 1)

Where: I = current (amps)
E = voltage (volts)
R = resistance (ohms, Ω)

Solving for voltage can be accomplished by multiplying both sides of the equation by R. This will create the equation: $E = IR$ (Equation 2)

With this equation, if you divide by I the Ohm’s law formula becomes $R=E/I$ (Equation 3)

These variations of the formula make it possible to determine current if voltage and resistance are known (Equation 1), voltage if current and resistance are known (Equation 2), and resistance if voltage and current are known (Equation 3). Figure 2 demonstrates a graphic method of remembering each equation.

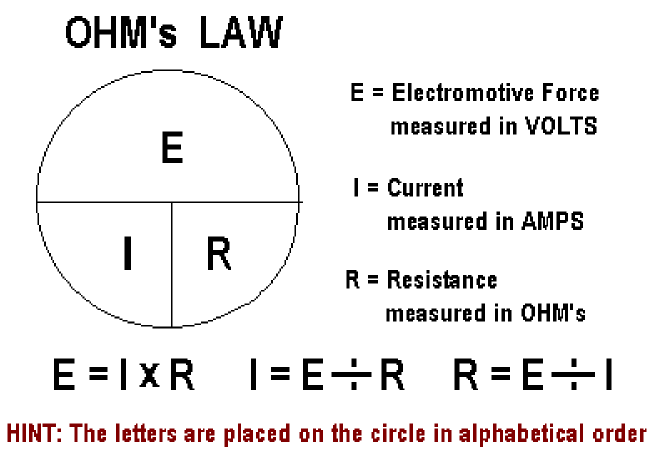


FIGURE 2. Ohm’s Law expressed graphically.

Circuit Components and Basic Circuit

Conductors are basically the wire or etching path on a circuit board that make the path for the circuit. Although there are no conductors with zero resistance, for practical purposes they are considered to be zero ohms. Silver, copper and gold are considered some of the best conductors. Figure 3 shows the symbol for a conductor.

FIGURE 3. Conductor

Insulators are the opposite of conductors. They have a very high resistance and are used to insulate. An example would be insulating between two conductors with a rubber coating or sleeve.

There may be a need to reduce the magnitude of current flow in a circuit to protect a device. This is accomplished by manufactured resistors. Figure 4 shows the symbol for a resistor.

FIGURE 4

A battery is a common source for creating a DC voltage. Power supplies also create voltages for DC circuits. In most cases, a power supply will convert the AC voltage provided from a wall socket to a DC voltage. Figure 5 shows common symbols often used to distinguish DC voltage sources whether from a power supply or battery. Figure 6 demonstrates a basic schematic diagram of a battery powered DC circuit.

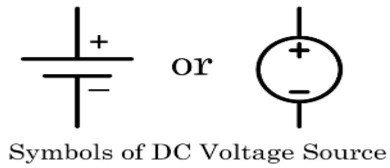


FIGURE 5. DC Voltage Source

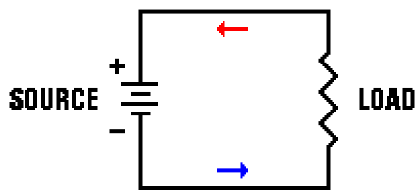


FIGURE 6. Schematic of a basic circuit.

Power

Voltage is the pressure which causes current through resistance. Power is a measure of the energy used per unit time. The unit of measure for power is the watt. When one amp of current passes through a one-ohm resistor, energy is dissipated at the rate of one watt. Figure 7 shows the power equations where P is power, E is voltage, and I is current.

Power equations

$$P = IE \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

FIGURE 7. Power Equations

Series Circuits

The circuit in Figure 8 is known as a series circuit. In this circuit, the current is constant, and the voltage drop across each resistor will equal the supply voltage.

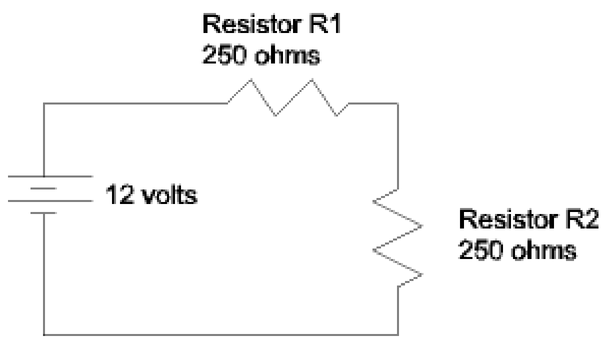


FIGURE 8. Series Circuit

To determine the current in Figure 8 using Ohm’s law, use the equation below.

I = E/R = 12v/500 ohms = .024 amps or 24 milliamps

In this example R will be the total resistance of R1 + R2. Since the current is constant in a series circuit, the voltage across R1 can be computed by using the equation below.

E1 = I*R1 = .024 amps * 250 ohms = 6 volts.

Since R2 is the same resistance value, the voltage drop across it is equal to 6 volts. This confirms that the voltage drop of each resistor equals the supply voltage.

Vsupply = E1 + E2 = 6 volts + 6 volts = 12 volts.

Parallel Circuits

The circuit in Figure 9 is known as a parallel circuit. In this circuit, the voltage is constant and the total current is equal to the sum of currents in each branch. The total resistance is not additive, but a reciprocal of the reciprocals. Figure 10 shows the formula.

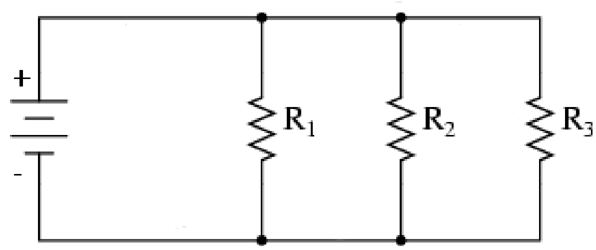


FIGURE 9. Parallel Circuit

$$R_{total} = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \ldots + \frac{1}{R_n}}$$

FIGURE 10. Parallel Resistance Formula

If the supply voltage is 12 volts, then there will be 12 volts across R1, R2 and R3. The current will be calculated per branch and will vary depending on the value of the resistors. Assuming R1 is 100 ohms, R2 is 10000 (10K) ohms and R3 is 25K ohms, the current for each leg will utilize the equation: I = E/R.

Compute the current (I) for each branch:

I1 = 12/100 = 0.12 amps or 120 milliamps (mA)

I2 = 12/10000 = 0.0012 amps or 1.2 milliamps (mA)

I3 = 12/25000 = 0.00048 amps or 0.48 milliamps (mA)

The total current = I1 + I2 + I3 = .12 + .0012 + .00048 = 121.68 milliamps (mA)

Using the resistance formula in Figure 10, the total resistance is 98.62 ohms. As a rule, the total resistance in a parallel circuit will be less than the smallest value resistor.

Practical Applications

Batteries

One of the most common batteries is the wet cell, consisting of a mixture of water and acid. Automobiles use this type of battery. Generally, a lead acid gel cell is what is used for electronic devices in the oil and gas industry. This type of cell uses an acid paste or gel. Individual lead acid cells make up a battery. The cells have a nominal 2.1 volts output. A 12 volt battery would have six cells, providing a nominal output of 12.6 volts.

The capacity of a battery is rated in discharge current for a specific time period, 8 amp hours (Ah) for example. This means the battery should be able to deliver one amp for 8 hours. The amp hour capacity is increased by adding more cells in parallel. When battery cells are wired in series the voltage increases. When wired in parallel, the current, or capacity increases. If six

2.1 volt cells in series provide 12.6 volts at 8 amp hours, then adding six more cells in parallel would double it to 16 amp hours but the output voltage would remain the same. To summarize, cells wired in series increase voltage, cells wired in parallel increase capacity.

Battery Charging

The most commonly used charging method is called Float Charging. This means the charger, battery, and loads are tied together and the voltage floats. The charging source should put out about 15 volts for a 12 volt battery. Two common charging sources are solar panels and power supplies.

Solar panels are made up of multiple photovoltaic (PV) cells. A PV cell consists of one or two layers of semiconductor material, usually silicon. When light shines on the cell it creates an electric field across the layer causing electricity to flow. The PV cells are wired in series, so the rules of a series circuit apply (Figure 11). If the panel gets too dirty, or some of the cells are covered completely, the total voltage will drop to the point it becomes ineffective.

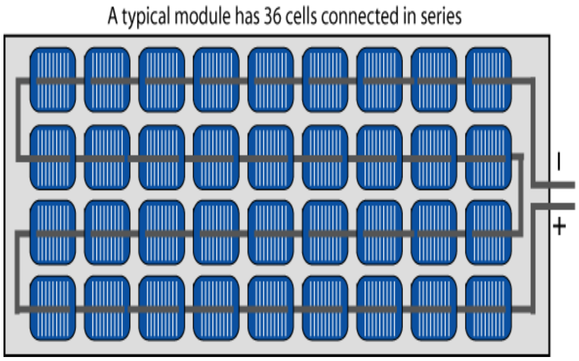
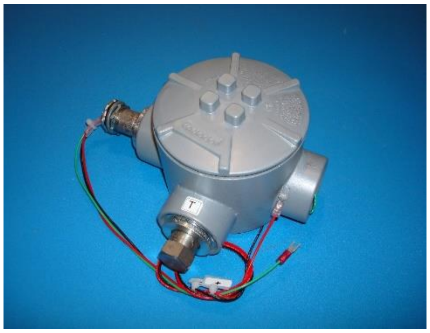


FIGURE 11. Solar Panel Cell Layout

A battery charger can be used to charge batteries where electricity is available. The one pictured is equivalent to a ten watt solar panel providing 0.5 amps of current.

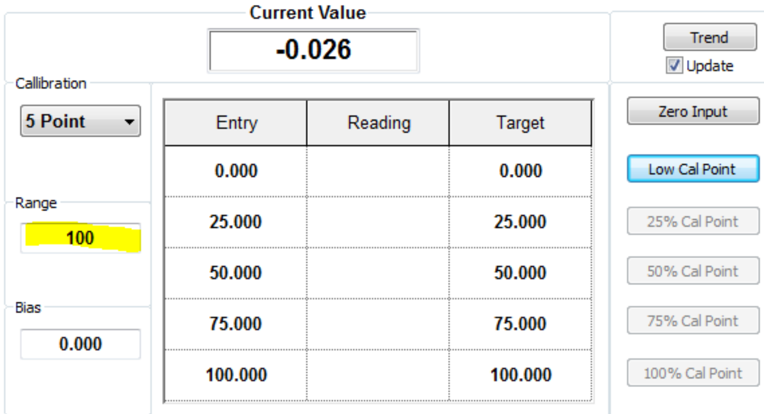


Current Loop

A 4 – 20 mA current loop is a common method of transferring information. Sometimes referred to as an analog output, the 4-20 mA device develops this output using a 250-ohm resistor and is connected to a device with an analog input. Most receiving devices read the information as 1 – 5 volts. This works by a method that can be explained by Ohms Law:

E low = I * R = 4mA * 250 Ohms = 1 volt.
E high = I * R = 20mA * 250 Ohms = 5 volts.

A practical application for this method would be a 4 – 20 mA pressure transmitter. If it were a 100 PSIG (Pounds per Square Inch Gauge), then 4 mA would equate to 0 PSIG and 20 mA would equate to 100 PSIG. If it were a 1000 PSIG pressure transmitter, then 4 mA would still equal 0 PSIG, but 20 mA would equate to 1000 PSIG.
The Analog input of the device is calibrated accordingly. See example:



Valve Control (Analog)

A 4 – 20mA current loop can be used for valve control. Valve control is utilized in industry to control how much product, natural gas for example, is flowing. There is a device called an I/P (Current to Pressure) controller. A step increase in the current loop will open the valve, a step decrease will close the valve.

Digital Inputs and Outputs

Very common in the oil and gas industry is the use of digital signaling to indicate an alarm condition as well as for control of equipment. Digital control is normally accomplished by one of the following methods.

Mechanical contact switching is common in largescale equipment where there is plenty of power to activate a mechanical switch by motor operated cam or by energizing a coil on a relay. For signaling or control, the making or breaking of a mechanical switch interrupts one leg of a circuit supplying power to a device. Testing a circuit like this is simply a matter of measuring the resistance across the switch during activation when the load and power source are disconnected. A normally open switch will show infinite resistance before activation and low resistance after activation. A normally closed switch will be just the opposite and break contact on activation.

Mechanical switches can switch a large variety of loads. Mechanical “dry contact” switches exhibit a phenomenon called switch bounce. This is a situation where the mechanical contacts make multiple connections for each opening and closing operation. This may not be a concern in some applications like turning on lights or resistance heaters.

Transistor control is very common in today’s low power computer-controlled equipment. This type of control uses a solid-state device to switch a small amount of current. This is ideal for connecting to other computer equipment but may not be enough for directly controlling a pump or motor. In this case, transistor control can be used to activate mechanical switches (relays) or other solid-state devices.

A technician cannot rely on being able to use a multimeter measuring resistance to test the cycling of a transistor digital output. Transistors require power on their load side to operate. The best way to test a transistor circuit is to apply a voltage to the circuit and measure the voltage as the circuit is switched on and off. An ammeter may be used also to measure current flow as the circuit is switched.

Digital input circuits can either accept contact closures, dry contact (mechanical switches) or they may require a voltage to be applied. It is important to know what your equipment requires when working with a control or monitoring system. Many devices today can accept both types of inputs, however wiring requirements may be different. There are even single devices that can be wired either as digital inputs or outputs.

Switch bounce is a concern when connecting a mechanical switch to a digital input. For signaling, multiple contacts may indicate multiple events. This is of concern if you are trying to count the pulses from a device for measurement. Software or hardware designs must take switch bounce into account. There are schemes of hardware filtering and software filtering. Each of these methods will reduce the maximum frequency input of the system.
Some computer-controlled devices have an option built in that will enable or disable software filtering for switch bounce. This is many times called a “de-bounce” feature.

Valve Control (Digital)

Valve control was mentioned earlier using a 4 – 20 mA current loop and an I/P converter. Valve control can also be implemented using digital circuits. A type of valve control device known as a stepper motor or valve actuator is used. Each digital pulse steps the valve open or closed. The valve control application will determine the length of time the pulse activates. This will determine how long each valve step lasts.

Conclusion

This paper touches the surface of electronics and how it is used in the oil and gas industry. Almost every device used for measurement is now electronic in some way. It may be a simple multimeter used to measure voltage, current and resistance, to a measuring device powered by a microprocessor. A computer in other words. In recent years a new type of data storage has emerged, the “cloud” where data collected from measuring devices is shared to any computer device, PC, tablet, or smart phone. The sky is the limit.

References

Grob, Bernard 1986. Direct and Alternating Current
Circuits. McGraw-Hill Book Company