INTRODUCTION

The use of electronics in the measurement and control of natural gas systems is now firmly established. Some subsystems are still controlled by mechanical or pneumatic means; however, the majority of control, and measurement, is by electronics. The rise of computer-controlled systems, enabling real time measurement and control, has revolutionized the natural gas industry. Central offices now have information on the entire system updated in real time. This information is invaluable in making decisions concerning system health, capacity, and safety. The responsibility of keeping this critical data flowing falls on the field personnel. An understanding of some basic principles of electronics will make troubleshooting these electronic data and control systems easier for the field technician.

THE LAW

Ohm’s law is the basic rule of electrical systems. This law, discovered by Georg Simon Ohm in 1827, correlates the basic elements of force (Voltage), flow (Current) and restriction (Resistance). Potential Difference is E (Volts), Current is I (Amps), and Resistance is R (Ohms). The formula is expressed in three algebraic forms:

\[ E = IR \quad R = \frac{E}{I} \quad I = \frac{E}{R} \]

Most questions about electronic circuit behavior can be answered by judicious use of Ohm’s law. The other important law is the formula for calculating electrical work, or power. Power (P) is expressed in Watts. This formula, for Direct Current (DC), is expressed as \( P = IE \).

THE REFERENCE

All measurements in life, and electronics, require a reference. To measure how old we are, the reference is our birth. To measure how far we travel, the reference is our starting point. To measure electronic force, Voltage, you need to designate a reference. In most cases, we designate this reference as Ground. Ground may be connected to earth, the most used reference point, or it may be floated. Floating the reference can be a useful technique, especially if the measurement is electrically noisy, or at a high voltage. Electric utilities float their measurement electronics, and ground may be at a 100,000 volt potential, or more, compared to earth. Ground, as a reference, is only absolute at the point of measurement. At all other points in the system, resistance degrades ground. Wiring, or other conductors, such as a steel skid, or even soil, may cause this resistance. Wiring is a dependable ground, as we can control the resistance with wire composition and gauge. A steel skid can be a reliable ground, but resistance of the contact point (or points) caused by corrosion, or dissimilar metals, can be a problem. Soil is extremely variable, and cannot be depended upon as a reliable reference. The basic method of earth ground, the ground rod, is almost useless in arid areas, so multiple ground rods are used, often in conjunction with a ground grid buried in soil. Rocky areas are an even bigger problem, and ground rods may have to be drilled in these areas. As problematic as earth ground is, its usefulness in being a path to dissipate electronic surges, and lightning, is unsurpassed.

THE SOURCE

All electronic systems start with a power source. We are familiar with the power line that enters our home. This power source originates with the electric utility in our area. A rotating generator, driven by natural gas or other fuel, creates this power electromechanically. This power is Alternating Current, or AC. In the early days of electrical power grids, both AC and DC (Direct Current) were used. One reason for AC being selected as the standard is a good example of Ohm’s law in action. The main purpose of the electrical grid is to deliver power (Watts) to the end user. DC was a good power source in the early days, as the main use of the power grid was incandescent lighting. DC power results in longer incandescent bulb life, compared to AC power. The problem was the transmission of the DC power. Copper power transmission wire was, and still is, expensive, and copper is prone to oxidation (corrosion) when exposed to air. Galvanized steel cable is stronger, corrosion resistant, and less expensive. The problem with galvanized steel cable is increased resistance. According to Ohm’s law, if you increase resistance, and keep voltage the same, current must be decreased (\( I = \frac{E}{R} \)). This results in less power to the end user, and larger losses to the electric utility. The solution was a simple device called a transformer. This device, made of iron pole pieces with copper wire windings, allows AC power to be stepped up, or down, in voltage with no moving parts. If you increase voltage, resistance can be increased with no effect on current (\( I = \frac{E}{R} \)), and losses will be reduced. Thus, the high voltage transmission line was born. In some cases, AC is used directly in natural gas measurement and control systems, to power motors or operate solenoids.
In most cases, AC is converted to DC in a power supply, to operate the measurement and control systems. In remote locations, power can be generated by solar panels, thermoelectric generators, or natural gas operated rotating generators. In addition to a source of DC power, most systems have a way of providing back-up power in the case of power interruption from the primary source. This is usually a storage battery. Solar primary systems must have the storage battery to provide power when sunlight is not available. In most cases, the storage battery is inserted into the primary power line, between the source of DC power and the measurement and control system equipment.

STORAGE BATTERIES

When dealing with storage batteries, no matter what the type, you must never forget that they are CHEMICAL SYSTEMS. Storage batteries function as a continuing chemical reaction. Like most chemical reactions, batteries are very much affected by ambient temperature, and they also degrade with age. The internal chemical reaction is affected by temperature. Batteries are rated in amp-hours. This is defined as how many amps the battery can supply times the hours that the current can be supplied (amps * hours, or AH), without completely discharging the battery. This rating is given at room temperature, usually 75 degrees F. When the temperature is lowered, the AH rating of the battery is decreased. At a low enough temperature, the battery stops functioning. The most common chemistry used is lead acid, although the same basic principles can be applied to nickel cadmium (Ni-cad), or nickel metal hydride (NiMH), or lithium (Li) batteries. Lead acid batteries are basically two types of lead plates separated by an electrolyte. Two basic types of electrolyte are used. The older technology, which allows the greatest power density, is liquid electrolyte. The drawbacks with this technology are: the battery cannot be mounted in various positions (upright only), and the chemical reaction produces hydrogen gas. This hydrogen gas must be vented outside enclosures, or buildings, to avoid a hazardous situation. Generation of hydrogen gas causes the water in the electrolyte to be consumed, requiring frequent servicing to top up the electrolyte level. At elevated temperatures, the water in the electrolyte is also reduced rapidly, due to evaporation. Newer technologies use a recombinant element to convert the hydrogen gas back to water, allowing the wet cell battery to be sealed, or the electrolyte is gelled, reducing the hydrogen gas generated, and allowing the battery to be sealed. The gelled type of electrolyte causes a slow down of the chemical reaction. These batteries, called gel cell batteries, are larger than equivalent wet cell batteries for a given AH rating, but have better performance over temperature, and a longer life span, than wet cell batteries. Some sealed gel cell batteries can also be mounted in any position. Both of these newer technologies reduce the degradation of operation with age, but do not stop the aging process. Never forget that BATTERIES HAVE FINITE LIFE SPANS. Part of a field technician’s responsibility is to be aware of the age of the battery systems, and replace the batteries when recommended, or when a degradation of performance is noted. Most modern flow measurement and control systems have a means of monitoring the primary input voltage, and thus recording the history of voltage over time, especially at night in solar powered systems. Batteries that routinely drop below their rated terminal voltage, are showing the effects of age, and need to be considered for replacement.

PROTECTION

Most natural gas measurement and control systems are powered, ultimately, from low voltage DC. These systems, based on microprocessors and other solid-state electronics, can be instantly damaged by higher than normal voltages. Some type of protection for the input power to these systems, the control outputs, and the measurement inputs, is required, if long life and reliability is desired. Higher than normal voltages can be generated by malfunctioning power supplies, electrical transients, static discharges, or lightning. Protection circuitry operates by routing the over voltage to ground. Protection circuitry can only operate properly when there is a LOW RESISTANCE path to ground, preferably earth ground. In some cases, a low resistance earth ground path is required by a safety listing on the measurement and control equipment. The ground wiring normally seen in the field is a solid copper ground wire, painted to resist oxidation. This is adequate for over voltages and some transients, but not the optimum wiring for static discharges and lightning. Why is this? Static discharges, and especially lightning, are actually high frequency AC events. At higher frequencies, VHF and above, electrical current does not flow in the entire cross section of a wire. The majority of current flows in the outer surface of the wire. This physical phenomenon is called “skin effect”. A more effective ground wire for static discharges and lightning is stranded wire, with tinned conductors. The more strands, the better, as the stranded wire has more area of outer surface for a given wire gauge, and the tinned finish has more resistance to oxidation than the copper base wire. In microwave systems, this is taken to the extreme, and the conductors are silver plated copper tubes. A rule of thumb is to use good quality 12 AWG tinned stranded insulated wire as a minimum conductor from the measurement and control equipment to the earth ground. There are two basic schemes for grounding multiple pieces of equipment. Figure one shows the scheme for maximization of surge and lightning protection:
Figure two shows the scheme for reduction of circulating ground currents, and electrical noise from RF sources, by using a single point earth ground:

Figure two is less effective in protection against lightning, because two of the paths to ground are longer. Because the current flow from lightning is so high, every bit of resistance you add in the path to earth ground is critical. Ohm’s law explains this: The voltage of the lightning event is fixed, so is the current. If you increase resistance in the ground path, current through the conductor must be reduced (I=E/R). The remaining lightning current will have to find another path to ground, usually through the measurement equipment, resulting in damage to the equipment. The lightning events discussed here are classified as near strikes. A direct lightning strike contains such a large amount of energy, only a well engineered, and expensive, protective system can cope with the energy load. A good example of this is a microwave relay tower. The tower is constructed of steel, and the steel legs are grounded directly to an earth ground grid by large copper straps. Even this system can sustain damage to the structure in lightning strikes, although the tower usually does it’s job, and protects the sensitive microwave antennas, and radios. Another system, that offers enhanced lightning protection, is the steel pole building, with properly engineered lightning rods, connected to an earth ground grid by copper straps, and housing the measurement and control electronics.

INPUTS

Inputs to natural gas measurement and control instrumentation include measurement transducers, discrete inputs, and pulse inputs. Low power transducers can have analog or digital outputs. In either case, they are sensitive to electrical noise, and loading. These transducers operate on low voltages (usually 12 VDC or less), and consume low amounts of current (2-15 mA typical). Their low current consumption also means they cannot drive a low resistance load at the input to the measurement and control instrumentation. Typical loading is 10,000 Ohms (10 K Ohms) or greater. If a low power transducer works great by itself, but will not work in the circuit, look for a loading issue. A leaking filter capacitor, or leaking surge protector can cause an increase in loading. With a 10K output load, any noise introduced at the transducer output will affect the output signal. Ohm’s law explains this: with a high resistance on the output, a small amount of noise current makes a significant output voltage change (E=IR). Low power transducer output integrity depends on proper shielding of the output cable connection to the input of the measurement and control instrumentation. Shielding should be single point, with the cable shield usually connected to the measurement and control instrumentation ground.

To reduce the noise issue in low powered transducers, especially in long cable runs, 4-20 mA transducers are used. Transducer output loading at the input to the measurement and control instrumentation is typically 250 Ohms with the 4-20 mA transducer. Noise currents are less likely to cause output voltage swings with this low load value. These transducers do require higher drive voltages, typically 24 VDC, and usually a separate power supply. Problems with these transducers are typically caused by high load resistance in the loop, or insufficient current output from the 24 VDC power supply, or a drop in the power supply voltage. Excessive loop load resistance can be caused by the wire gauge being too small, or corroded terminals, or too many devices on one loop. The maximum loop resistance is a function of Ohm’s law: 20 mA = 24 VDC/1200 Ohms (I=E/R). The input to the measurement and control instrumentation typically uses a 250 Ohm precision resistor to generate a 1-5 VDC actual input to an analog to digital converter. This leaves only 950 Ohms for the transducer impedance, and any other loop devices. Exceeding the 950 ohms will cause the output to fail to reach full scale (20 mA output). Wire gauge is the most frequent factor in excessive loop resistance, especially in long runs. If the wire run is 4000 feet total in the loop, and you use 24 AWG stranded instrumentation wire; the wire resistance is 110.8 Ohms (27.7 Ohms max per 1000 FT). This additional loop resistance is frequently not taken into consideration.
Discrete inputs to measurement and control instrumentation are usually used for fault sensing, or status. These inputs usually have high impedance, causing problems similar to the low powered transducers, in the areas of noise and shielding of the signal. The use of shielded cable, and the proper single point shield to ground connection, is highly recommended. Unlike low powered transistor inputs, these inputs are usually detecting an on or off event, such as a limit switch. Pay close attention to the measurement and control instrumentation input specification, specifically the voltage required to establish the off condition, and the voltage required to establish the on condition. Typical values are below 0.5 VDC in one condition, and above 4.5 VDC in the other condition. Excitation current, either provided by the measurement and control instrumentation, or an outside source, is typically very low. In the sensing loop, just a small amount of leakage to ground, or leakage to power, can cause the sensing element to miss the target voltages, and therefore cause the measurement and control instrumentation to miss the event. The discrete inputs usually have some type of input filter, to minimize the impact of noise in the sensing loop. Be very aware of the measurement and control instrumentation maximum frequency discrete input specification, as an event that is faster than the maximum will not be recorded, due to the input filter. Pulse inputs are similar to discrete inputs, in the areas of high input resistance, and input filtering. The use of shielded cable, and the proper single point shield to ground connection, is highly recommended. Where pulse inputs differ, is in input amplification, and input filtering. Pulse inputs can be highly amplified by the measurement and control instrumentation, especially if the pulse input is a turbine meter magnetic pickup. In this case, shielding the wiring from the pickup to the instrumentation is critical, as is the wire length and gauge. See the manual of the measurement and control instrumentation, for wiring recommendations, and maximum frequency allowed.

OUTPUTS

Outputs from natural gas measurement and control instrumentation include discrete, and 4-20 mA control loops. Discrete outputs from measurement and control instrumentation, used for control, are usually in the form of relays, solid-state relays, or transistors. Mechanical relays have the advantage of isolating the measurement and control instrumentation from any problems in the control loop, and the ability to handle both DC and AC currents. They do have drawbacks, in the form of speed of operation, and fixed mechanical life span. Mechanical relays have to be hermetically sealed if used in a Class 1, Division 2 hazardous area, making them an expensive alternative. Solid-state relays are not as versatile as the mechanical relays, but have very long life spans, are fast in operation, and also isolate the measurement and control instrumentation from the control loop. Solid-state relays can be designed to handle AC control currents, or DC control currents. Careful attention must be given to the specifications of the solid-state relays. Damage to the relay will result if the maximum voltage or maximum current specifications are exceeded. The longest-lived devices are simple transistors or FET’s. Isolation of the measurement and control instrumentation from the control loop may be designed into the circuit for transistors, or it may not. In most cases, the control current is limited to DC only, and careful attention must be given to the measurement and control instrumentation specifications for proper polarity of the control voltage, maximum voltage allowed, and maximum current allowed. Damage will result if the specifications are exceeded.

4-20 mA outputs may be used for control, or recording. These outputs have the same circuit considerations as the 4-20 mA inputs discussed previously. Isolation of the control circuit, from the measurement and control instrumentation, may sometimes be required. Isolation for the control loop may be built into the measurement and control instrumentation, or added externally.

COMMUNICATION

Almost all natural gas measurement and control systems have some type of communication capability built in, either local communication, or remote communications. Communications are usually asynchronous, and are typically RS232 or RS485. These communication signals can be direct (local), or be connected to Internet, radios, or other modems. The RS232 specification is for direct connection, no multi-drop, full duplex (simultaneous transmit and receive). The minimum voltage levels are –3 VDC to +3 VDC. Suggested maximum cable length for a data rate of 19.2 Kbps is 50 feet. Some common problems with RS232 include noise, a cable run that is too long, and the use of a modem splitter. Noise can cause communication error, so proper shielded cable, with the shield grounded at one end only, is highly recommended. In trying to use too long a communication cable, the real problem is not resistance of the wire, but capacitance of the cable. Because of the fact that digital communications are really high-speed square waves, the capacitance in the cable acts as a filter. The more capacitance, the lower the allowable frequency. The longer the cable, the greater the capacitance. Modem splitters allow more than one communication port to use a radio or modem. The problem with modem splitters lies with how they operate. To keep the two, or more, communication ports from interfering with one another, the modem splitter isolates the ports with diodes. This has the effect of allowing only the positive going waveform to pass through. The negative going waveform is blocked. The standard specifies a minimum of –3 VDC negative going waveform, but what gets through is only –0.7 VDC typical. Some modern RS232 receiver Integrated Circuits (IC’s) only require a –0.5 VDC to +0.5 VDC waveform to operate properly. These modern units can handle a modem splitter without major problems.
YOU CANNOT COUNT ON ALL RS 232 DEVICES TO OPERATE WITH A MODEM SPLITTER. The RS485 specification is for direct connection, multi-drop, differential driver, 32 transceivers maximum. A typical configuration is 4-wire, which allows full duplex operation. RS485 can also be 2-wire, where the transmit and receive share the line, and is called half-duplex operation. Suggested maximum cable length for a data rate of 100 Kbps is 4000 feet. Some common problems with RS485 include noise, a cable run that is too long, improper termination, and multi-dropping too many devices. Noise can cause communication error, so proper shielded cable, with the shield grounded at one end only, is highly recommended. RS485 communication systems are robust, but trying to extend the 4000 feet maximum length is not recommended. At 4000 feet, wire resistance is a factor, so use 18 AWG shielded cable, as a minimum. The biggest problem with RS485 is improper termination. The recommended cable connection diagram is called a daisy chain, and looks like Figure 3:

![Figure 3](image)

The recommended termination is a called a DC load, and is applied at the start of the daisy chain (RS485 master), and at the end of the daisy chain (RS485 end device). The DC load is typically a resistor of 120 ohms, placed across the line. In the real world, the cable connection diagram can look like Figure 4, and is called a star configuration:

![Figure 4](image)

In this configuration, there is a parallel-wired cable junction, and different cable lengths going to each device.

The problem with Figure 4 is that each wire run is actually a transmission line, and can set up reflected data called standing waves. These standing waves can cause communication to fail. The recommended termination of the daisy chain, a DC load, cannot be used on a star configuration. A termination called an AC load must be used. This is a capacitor, usually between 0.1 uF and 0.01 uF, placed in series with a resistor, typically 120 Ohms, and then the assembly is placed across the line. This AC load must be used at each RS485 device.

CONCLUSION

Rapid changes in the natural gas industry are placing a larger burden on field technicians. Some knowledge of electronics, and basic electronic troubleshooting, is now required. Hopefully, this paper has given some insights into basic electronics, and basic electronic troubleshooting, for natural gas measurement and control instrumentation.

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