NEC Article 725—Cost-Effective Control Wiring

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***Abstract*—Article 725 is one of the less obvious but powerful sections of the *National Electrical Code*. The limitations imposed and the advantages provided by the section are discussed. Application in conjunction with hazardous environments is presented. The installation, application, and transient protection of communications cable for instrumentation circuits is outlined.**

Introduction

MANY of the articles of the *National Electrical Code* (NEC) are subject to interpretation by the user and the enforcing authority. This creates difficulty in properly applying the article to commercial and industrial installations. The quandary is greater involving those sections that are not general purpose and are used infrequently.

One of these interesting sections is Article 725. The scope of the article indicates its purpose and application: "This article covers remote-control, signaling, and power-limited circuits that are not an integral part of a device or appliance [1]".

Despite many years of experience working with electrical systems, we did not encounter this area until redesigning a chemical process plant that had extensive computer control and process instrumentation. Designing and modifying an existing plant with minimum interruption to the continuing process operation motivates creative insight and a search for alternative approaches. The circumstances forced an evaluation of Article 725.

In another application for a classified environment, the wiring density and cost precipitated an evaluation of wiring methods different from conventional Article 500 techniques. The invocation of Article 725 permitted the use of cable with small wire size and much lower cost.

The application of the article is appropriate for many instrumentation applications. It will permit the use of less expensive equipment and wiring methods. However, the constraints imposed by the NEC are very stringent.

A Requirement?

The first decision a designer must evaluate is whether the article is a requirement for installation or whether it is an option. The descriptive classification for the article does not provide much additional clarity [1]:

> A remote-control, signaling, or power-limited circuit is the portion of the wiring system between the load side of the overcurrent device or the power-limited supply and all connected equipment, and shall be Class 1, Class 2, or Class 3 as defined in (a) and (b).

If the article is a requirement, then many pieces of equipment are constrained. The power supply must be restricted and the wiring must be separated from some other types of wiring.

An explanation of the different groupings and classification of circuits referenced in Article 725 is necessary to understand the impact of attempting to apply this article to industrial plants. The article covers remote control, signaling, and power-limited circuits. Circuits in a plant can be classified according to the groupings shown in Fig. 1.

Power: Motor control circuits that derive power from the load side of the short-circuit protective device and function to control the motor(s) connected to that branch circuit are included (Article 430-72). All these circuits could be mixed in a raceway (Article 300-3).

Functional Associated Power Control: Motor control circuits with a separately derived power source are considered (Article 725-12). These are Class 1 circuits. If grouped with a motor power circuit, each control circuit must be functionally associated with the motor. Therefore, a separate raceway is required for each motor (Article 725-38).

Class 1: All remote control and signaling circuits that are not required to be power limited and do not exceed 600 V are Class 1. The insulation on conductors must be suitable for 600 V. These circuits can be mixed with other Class 1 circuits in a raceway. They can only be mixed with power circuits as noted above or in factory/field-assembled control centers (Article 725-15).

Class 2: These are power limited circuits that basically have a maximum nameplate power rating of 100 VA. The circuits can be short circuited or *broken without introducing any shock or fire hazard.* This may include any remote-control, signaling, or power-limited circuit.

Class 3: These circuits limit fire hazard but not shock hazard (Article 725-31, 1974 commentary to preprint). They may operate at levels up to 150 V with current limits of 1 A if the power supply is not inherently limited. Otherwise, they have the same criteria as Class 2 circuits.

Is the use of Article 725 a requirement for control environment? The NEC permits but does not require classification of circuits under Article 725. The article is used when it is desirable to limit hazards and to use less restrictive wiring construction. The use of the classifications is optional, but the

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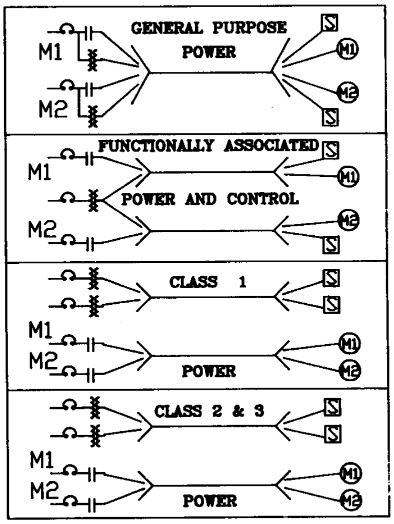

Fig. 1. Wiring classifications.

restrictions must be followed precisely if the lower class ratings are ever used.

The NEC does not require a classification that is different from the general wiring except for certain safety circuits. The following are examples of areas that require use of more constrictive circuits than general-purpose ones.

1) If circuits are within a computer room then classification is more restrictive.

2) Any wiring through an air handling or plenum area must be classified and use special insulations, such as Telfon.

Class Usage

Class 1

Class 1 circuits may have two different ratings. These are power-limited circuits as well as remote-control and signaling circuits. Power-limited circuits have a rated supply of not more than 30 V and 1000 VA.

Remote-control and signaling circuits are the more generally applied circuits. The circuits *may not exceed 600 V.* Most Class 1 circuits are common 600-V construction. Remote control circuits to safety control equipment must be Class 1 if the failure of the equipment would introduce a direct fire or life hazard.

Class 2

Class 2 circuits are designed to provide protection from electric shock. This is accomplished by a combination of limiting the voltage and the power of the circuits. The circuits are primarily for applications such as doorbells and thermocouples on heating/cooling equipment.

The wiring is much smaller and less expensive than power conductors. No restrictions are placed on the wiring or insulation as long as it is suitable for the application.

These circuits can be mixed only with Class 3 circuits in raceways (Article 725-38). If mixed, the insulation must be adequate for the highest voltage circuit (Article 725-39).

Open wiring must be separated from other class wiring by 2 in, unless the other class is in conduit or cable (Article 725-38). An exception permits power for a Class 2 device to be brought into the same box as the circuit (Article 725-38a2).

The power supply must be marked to indicate the class (Article 725–34). UL permits two transformer types: energy-limiting with short-circuit current not to exceed 8 A and non-energy-limiting with a rating of 100 VA or less. Special insulations must be used.

All 4–20 MA and resistance temperature detector (RTD) circuits as well as properly fused 24-V control circuits meet the criteria for Class 2 when power-limited. At the discretion of the design engineer, the circuits may be specified and operated as Class 2.

Class 3

Class 3 circuits are designed to provide fire protection but not necessarily shock protection. These are the circuits that require slightly more power or higher voltage than the thermocouple type circuits in Class 2. Therefore, there are a few minimum requirements for the conductors. Single conductors are not smaller than AWG 18, while cabled conductors are not smaller than number 22.

Experimental Tests of Power-Limited Sources

One of the major constraints imposed by Article 725 circuits is power limitation on the supply. The most fundamental aspect of power limitation is that it cannot be accomplished with current protection devices. Fuses are not an adequate method of limiting current for these circuits.

Current limitation is defined as "the maximum output after one minute of operating under any non-capacitive load, including short circuit, and with over-current protection bypassed if used." Similarly, the maximum volt-ampere capability of the circuit is defined as "volt-ampere output regardless of load and over-current protection bypassed if used [1]."

Power constraints cannot be accomplished using welder-tye power supplies. Transformers rated for less then 250 VA provide the necessary limitations on available power. Transformers with ratings up to 350 VA capacity may be used if the load voltage is less than 15 V. An excellent example of this type of limitation is the doorbell transformer which has a nominal rating of 20 VA at 24 V.

Actual performance on commonly available control power (machine tool) transformers and doorbell transformers used for power systems have been tested to determine their applicability for Class 2 and Class 3 serivce. Standard transformers were used. A bolted fault was applied to the secondary of each transformers. The available fault current was measured well after transients were settled. For the 24-V, 100-VA control transformer, fault I = 23 A after 1 min; for the 24 V, 20-VA doorbell transformer, fault I = 3 A after 1 min.

Neither transformer was destroyed, although significant heating occurred. As can be observed from these tests, standard voltage supply transformers can provide adequate limitation for establishing power-limited circuits.

Class 2/3 in Hazardous Locations

There are other applications that are very similar to the restricted levels of Article 725. These should not be confused, but much of the same equipment can be used for both applications.

Intrinsically Safe

Intrinsically safe installations are defined in Article 500—Hazardous (Classified) Locations [1]. Intrinsically safe equipment and wiring does not have sufficient electrical or thermal energy even under abnormal conditions to cause ignition of a specific flammable or combustible atmosphere even in its most easily ignitable concentration.

Although Class 2 and Class 3 equipment have limitations to reduce thermally induced fire, they do not have the restriction to prevent spark-induced fire. The inductance and capacitance in the Class 2 and 3 circuits may store adequate energy to ignite some flammable mixtures. Class 2 and 3 circuits can be used in hazardous environments in association with intrinsically safe construction but are not intrinsically safe.

A major benefit of using the Class 2 and 3 wiring on intrinsically safe circuits occurs in the hazardous environments. Eliminating the necessity of using conduit and associated hardware reduces the cost and complexity of some installations. Furthermore, access to instrumentation and end devices is greatly enhanced.

Simply classifying a circuit as intrinsically safe maintains all the other restrictions of the wiring methods of Articles 300 and 500. The benefit of restrictive wiring methods can only be derived by further classifying the circuit as Class 2 or 3 under Article 725.

Communication Cable in Control

There are numerous benefits from the application of communication cable to control systems that have been limited to Class 2 or 3. Communications cable does not have adequate insulation or wire size for use in general-purpose electrical construction. Therefore, the current and voltage available to the circuits must be restricted.

Communications

Communication circuits apply to telephone, radio, and outside wiring for fire and burglar alarms. These circuits are primarily intended for extended distances. As such, they are low-power, low-cost installations.

The design and installation of these circuits is governed by Article 800—Communications Circuits [1]. The circuits are similar to Class 2 and 3 circuits in many ways. Moreover, Class 2 and 3 circuits are permitted to occupy the same raceway as communications cable.

Communication cable is a very appropriate wiring material for use in the power-limited circuits. The cost and ease of use is very beneficial during system installations. The cable is produced in such large quantities for telephone application that there is no more cost-effective solution for providing low-power circuits.

Methods of installation, wiring materials, and transient protection have been developed over the past 50 years to minimize the cost and to maximize the reliability of the communications circuits. Using this technology for remote control and monitoring is the epitome of efficient use of cross-technology transfer for control engineers.

Direct Burial

In environments where direct burial cable can be used, communications cable is an excellent system for power-limited circuits. The cable is double-jacketed, gopher-shielded and gel-filled. The gel filling provides unparalleled environmental immunity even if the jackets and shield fail.

The cable provides telephone company reliability. The cable benefits from quantity manufacturing for the phone service. Hence the cost is less than $0.30/ft, for a 12-wire direct burial cable.

A significant advantage for remote locations is the availability of the cable and ancillary equipment in virtually any community. A very wide parts and service network exists to support the telecommunication industry.

Lightning Protection

Article 800 requires that every communication circuit have transient protection. Consequently, inexpensive and effective protection devices have been developed. The primary protection device is the gas tube, which is relatively slow. However, it can handle substantial surges. Regardless of the more sohpisticated transient protection devices used, the gas tube has proved indispensable.

Metal oxide varistors (MOV's) are often used to obtain faster transient response. However, the follow-through voltage can be devastating. A 24-V circuit would require a 36-V rated MOV. The continuous voltage that would be passed to the protected circuit could be 100 V for the duration of the transient.

The MOV begins conducting very quickly but does not limit the voltage adequately during extreme transients. Furthermore, the amount of energy it can dissipate is limited. The best solution for transient protection is to use a gas tube upstream of a MOV-protected device. An example is shown in Fig. 2.

The operation of the protection network illustrates its merits. First, the MOV begins conduction. Next, the circuit will ignite the gas tube using the inductance of the leads between the MOV and the gas tube. The voltage at the gas tube will be inductively raised by the MOV current:

$$V_g = L di/dt.$$

Hence the protected device never experiences a level as high as the gas-tube firing voltage

$$V_d = V_{\text{mov}}.$$

After the gas tube fires, the voltage is clamped to the tube maintenance voltage

$$V_m \sim 0.6 V_g.$$

The gas tube is a much lower impedance device than the MOV.

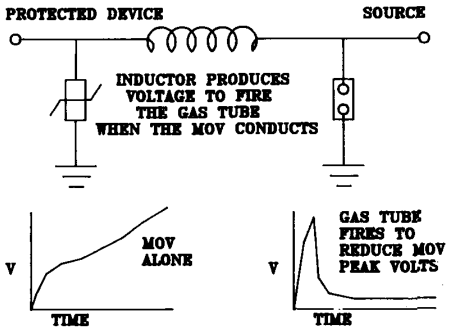

Fig. 2. Transient protection.

The gas tube protectors can be purchased mounted in a junction box for little more than the cost of the junction box alone. The MOV is connected at the terminals of the protected device, not in the junction box. The short distance between the gas-tube junction box and the protected device is needed to obtain the inductively induced gas-tube firing voltage.

Noise Immunity/Bandwidth

Class 2 and 3 circuits must be removed from the vicinity of power circuits as specified in Article 725. Power circuits are potentially noisy from motor switching and other transient inducing operations.

Many control and instrumentation signals operate at very low levels. Any extraneous noise may cause data error. An example is the extra counts that may be coupled onto a turbine meter line. The isolation of the circuits provides substantial signal quality benefit.

The shielding of the cable is significant when provided properly. If the shield is used as a ground, only one end should be connected. Otherwise, ground loops will be created. Experiences has shown that leaving both ends of the shield unconnected is an effective method to provide radiated signal protection. Without connections, no significant current can flow through the shield.

The cable conductors are twisted in pairs to prevent interchannel communication. The direction and rate of twist mitigates both capacitive and inductive coupling between the circuits. The long experience history of the telecommunications industry has optimized the technology associated with the cable. The cable can be beneficially applied by control engineers even though they are not experts in communications circuit design.

Because of the configuration of the circuits, a minimum of 750-kHz bandwidth is available. This provides adequate resolution for most instrumentation signals. A 9600 Bd signal can be passed easily on the cable. A turbine meter or pulse transducer signal of up to 600 000 pulses/min can also be processed. Few analog signal will exceed the bandwidth of the cable.

Installation and Application

Article 725 circuits are very appropriate where signals from remote devices in a hazardous environment must be transmitted to a central process controller. A typical example is the wellhead monitoring and instrumentation that is used in petroleum production.

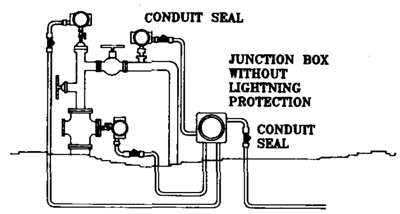

Fig. 3. Classified area wiring, conventional.

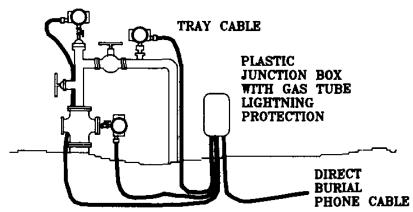

Fig. 4. Classified area wiring, limited power.

A conventional installation in a hazardous environment requires a number of sophisticated wiring techniques. In the traditional technique, buried conduit would be run from the controller to the wellhead. Since the distance may be as much as 300 ft, the installation is tedious. This is illustrated in Fig. 3.

By use of intrinsically safe devices with Class2/3 wiring methods, all conduit and associated expense is eliminated. The significant difference is that rigid condut, fittings, and seals are not required. However, a junction box is used outside the classified area to prevent migration of flammable gases. The difference is apparent by comparing Fig. 4 with the previous figure.

A major requirement for wellhead installations is the ability to remove the electrical equipment when work is required on the mechanical system. Cabling to end devices permits the easy relocation of the electrical components during the mechanical well work.

The design has been used for a number of years. To date not a single failure has resulted from lightning problems, whereas in the past, other type installations in the Gulf coast region were plagued with these problems.

Summary

NEC Article 725 provides for the installation of power-limited circuits. If the supply is limited, less restrictive wiring methods may be used. Furthermore, fire hazards and safety are improved.

Class 2 circuits can be broken without introducing shock or fire hazards. Class 3 circuits limit fire hazard but not shock hazard.

The use of power-limited circuits with intrinsically safe equipment significantly reduces the complexity and cost associated with hazardous (classified) environments. Inexpensive communication cable can be used for power-limited controls. Direct burial cable has excellent performance and wide bandwidth. Lightning and transient protection can be very effective, and installation is simple and reliable.

References

[1] *National Electrical Code*, Nat. Fire Protection Assoc. Boston, MA, NFPA 70-1984 (NEC), 1984.

[2] *Electronic Computer/Data Processing Equipment*, Nat. Fire Protection Assoc., Boston, MA, NFPA 75-1981, 1981.

[3] *Guideline on Electrical Power for ADP Installations; FIPS 94-1983*, Federal Information Processing Standards, U.S. Dept, of Commerce. Nat. Bur. Standards, Washington, DC, 1983.

[4] *Intrinsically Safe Process Control Equipment for Use in Class I Hazardous Locations*, Nat. Fire Protection Assoc. Boston, MA NFPA 493-1975, 1975.

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