COPPER SHEATHED CABLE-
SHEATH CURRENTS

SINGLE CONDUCTOR CABLE

Single conductor cables present certain application considerations that do not arise in multiconductor cable installations. These considerations apply to both single conductor mineral insulated copper sheath cables and polymer insulated cables having an aluminum or copper armor or sheath. Sheath voltages in single conductor cables arise as a result of three physical principles:

1   All electric currents, AC or DC, generate a magnetic field

As shown in Fig. 1, the magnetic field generated by the flow of current surrounds the conductor completely and radiates laterally outward, becoming weaker with increasing distance. In the case of a DC circuit, the magnetic field is constant and has a strength determined by, among other factors, the magnitude of the DC current.

Neither the strength nor direction of the magnetic field is constant in the AC current case. Rather, the field reacts to the current's changing nature by itself alternating in strength and direction.
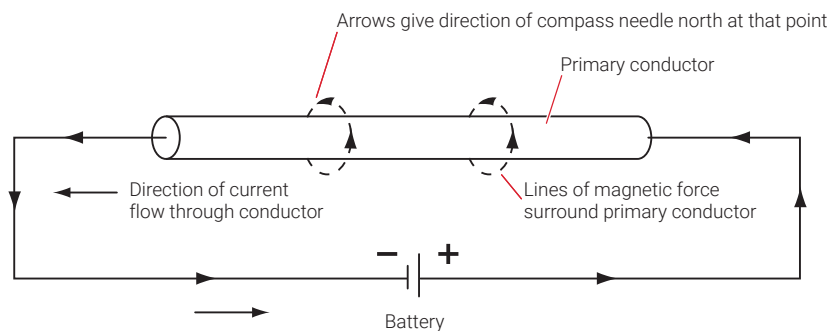

Arrows give direction of compass needle north at that point

Primary conductor

Direction of current flow through conductor

Lines of magnetic force surround primary conductor

Battery

Fig. 1   Magnetic field generated by current flow

2   Faraday's Law of Induction

Faraday found that a changing magnetic field will induce a voltage by which a current can flow. A magnetic field generated by a DC current cannot induce a steady-state voltage, as the field does not change. An AC current, with its attendant alternating magnetic field will, however, induce a voltage which, if a closed path is available, will cause a current to flow.

3   Lenz's Law

Lenz added to Faraday's work on the induction principle by developing a theory that explained the direction or polarity of the induced voltage. He found that the direction of the induced current, which flows as a result of the induced voltage, is such as to oppose the magnetic field which created it (see Fig. 2)
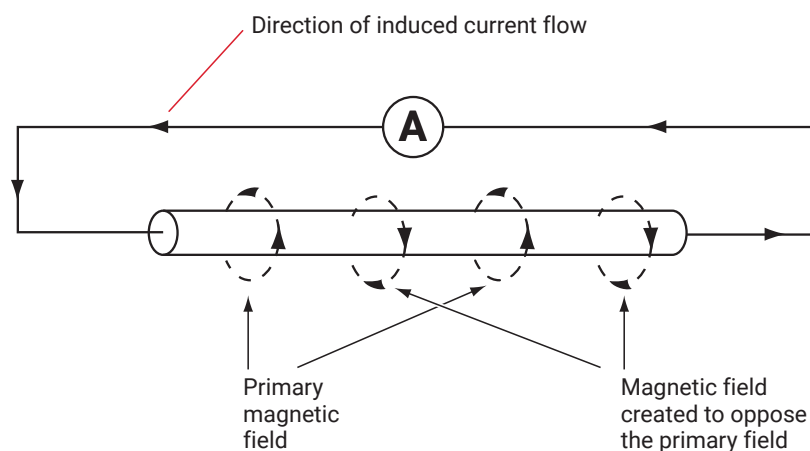
Direction of induced current flow

A

Primary magnetic field

Magnetic field created to oppose the primary field

Fig. 2 Lenz's Law: opposing polarity of magnetic fields

Sheath voltage available to drive current

Primary current flow

If a closed circuit is available, an induced or secondary current will flow in this direction
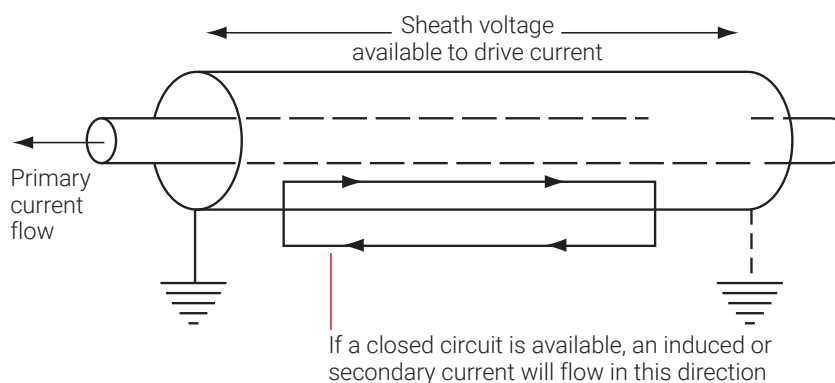
Fig. 3 Induced current in sheath

Fig. 3 shows the net result of the induction effect as applied to any metal-sheathed, single conductor cable.

The 60 Hz alternating current flowing in the conductor itself (termed primary current) generates a changing magnetic field which surrounds the entire cable assembly. That field then acts to induce a voltage in the metal sheath of the cable. If the metal sheath is grounded at more than one point, a closed circuit is available and the induced sheath voltage will cause an electric current to circulate through the sheath and grounding system.

The direction of the circulating sheath current is at all times in opposition to the flow in the primary conductor as a result of Lenz's Law.

Sheath voltages cannot be prevented. They arise from Faraday's Induction Principle and can be minimized only by proper grounding of the cable sheath. That, however, leads to sheath circulating currents as multiple grounds provide closed paths for sheath current to flow.

Sheath current magnitude is not dependent on cable length. Rather, it is a function of primary current magnitude, cable diameter, and sheath material. As length increases, so does the induced sheath voltage, and, in a compensatory manner, the total sheath electrical resistance. Since both voltage and resistance are directly proportional to length, the resulting sheath current, by Ohm's law, remains constant.

Sheath voltages can reach significant values, usually in the order of a few volts to tens of volts. Although not normally life threatening, the potentials can be sufficient to cause sparking under certain circumstances and can pose a serious danger in explosive atmospheres (Class I, II, or III hazardous locations). Even in nonhazardous environments, incidents of sheath-to-ground sparking can be unnerving to maintenance personnel and should be avoided.

Proper grounding of the sheath will minimize induced sheath voltages and prevent occurrences of sparking, but circulating currents will flow through the metal sheath via the grounding paths and can produce 1^2R heating of the cable sheath itself. In addition, the energy loss involved in producing the sheath heating effects are manifest in slightly increased voltage drop on the circuit that is supplied by the cables in question. (Sheath heating due to circulating currents can be a serious problem. Derating may be necessary if conductor temperatures are to be kept to less than 90°C.)

Sheath voltages and currents tend to increase with increased spacing between the conductors of a circuit. This effect results from the concept of field cancellation: the closer together the conductors, the better the cancellation of the fields and the weaker the overall resulting magnetic field which surrounds all circuit conductors. Refer to Fig. 4.

Maximum cancellation occurs, of course, when the cables' sheaths are in actual contact. However, mutual heating effects of each conductor on the others must then be considered.
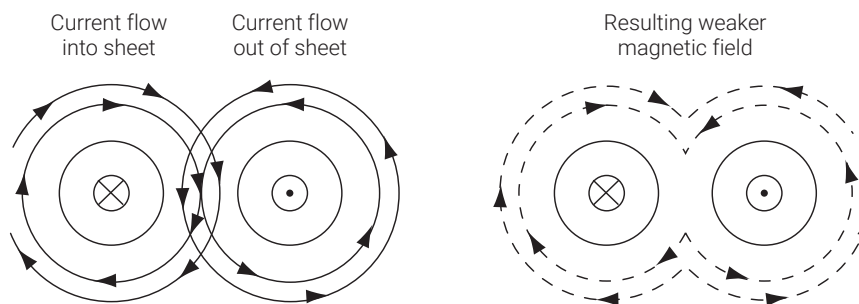
Current flow into sheet

Current flow out of sheet

Resulting weaker magnetic field

Fig.4 Overlapping fields result in weaker magnetic field

OTHER MAGNETIC EFFECTS

Induced voltages resulting from alternating magnetic fields are the cause of a second type of circulating current. These currents (termed "eddy" currents) flow in the metal plates through which single conductor cables may enter a switchgear enclosure and result when voltages that generate secondary magnetic fields are induced by Faraday's Law. Refer to Fig. 5.
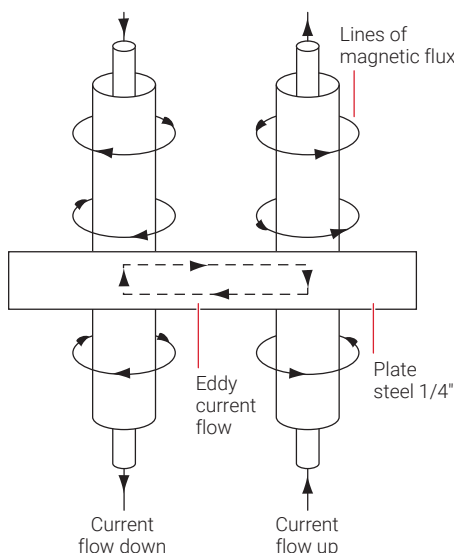
Lines of magnetic flux

Eddy current flow

Plate steel 1/4"

Current flow down

Current flow up

Fig.5 Single conductor feeders with magnetic fields

Eddy currents do contribute to heating of the metal plates through I^2R losses. In this type of application, however, the losses tend to be low as a result of the relatively small cross-sectional area of the metal enclosure and need not be directly addressed. (In other applications, like those involving ferromagnetic cores, eddy current losses can be very large and are an important factor in total "iron" losses.)

Hysteresis loss is the third and final type of heating effect arising as a result of the changing magnetic field surrounding a single conductor cable.

Here, the magnetic field (alternating at two times 60 Hz) creates a similarly alternating magnetic field within the ferromagnetic metal (normally steel) making up the wall or plate through which the conductors enter an enclosure. In each cycle of magnetization, the molecules comprising the structure realign themselves in the direction of the impressed field, and it is this realignment, with attendant frictional losses, that results in hysteresis heating.

The magnitude of the hysteresis loss is determined to a large degree by the magnetic flux density which exists within the metal. Magnetic flux density is a measure of the strength of the magnetic field; losses can be greatly reduced by limiting the flux density.

Note that hysteresis losses can occur only in ferromagnetic metals (e.g. iron, steel, nickel) as only these materials have magnetic permeabilities great enough to allow significant flux densities to develop. It is for this reason that metal-sheathed single conductor cables always incorporate sheaths of nonmagnetic material, copper in the case of MI cable, and copper or aluminum in the case of armored cable.

Steps can be taken to prevent hysteresis heating of cable entry plates:

• A nonmetallic plate made of an insulating material can be used in place of the usual steel entry.

• A replacement plate of nonmagnetic material (aluminum or brass) can be installed. Only ferromagnetic metals are subject to hysteresis heating; other metals cannot be magnetized and do not suffer losses.

• An air gap can be introduced into the magnetic circuit in which the magnetic flux exists. Its effect, because air has a very low magnetic permeability, is to drastically reduce the flux density in much the same manner as a large resistance limits current flow in an electric circuit. As discussed earlier, hysteresis losses are greatly dependent upon the magnitude of the flux density and they are, therefore, significantly lowered.

INSTALLATION RECOMMENDATIONS

The NEC and CEC both allow bundled single conductor MI cable to be sized according to the free air tables provided a spacing of 2.15 cable diameters is maintained between bundles.

The following recommendations regarding the installation of single conductor PYROTENAX MI cables are based on manufacturer's test data and on many years of in-service experience. For additional installation information contact nVent.

• Single conductor cable is subject to 90°C (free air) ampacity rating. The 90°C ampacity rating may not be appropriate for all applications; for example, applications where there are high ambient temperatures or where jacketed cable is being used. Contact nVent for additional information.

• Cables should be run in triangular or square bundles containing one conductor from each phase. Sheaths should be in contact throughout the run length. The neutral conductor in four-wire systems may be located within the bundle, or run separately. Cables are best bundled using stainless steel adjustable bands or banding kits, available from the manufacturer. Cables should be banded between supports according to the installation instructions shipped with the cable.

• Less preferable, but acceptable, are installations in which the conductors are laid flat under a common securing clip with sheaths in contact. Field cancellation is not as complete as in the case of triangular or square bundles and higher sheath voltages and circulating currents will result. In general, however, the incremental effect will be very small. Most important is that a common clip be used to maintain sheath contact.
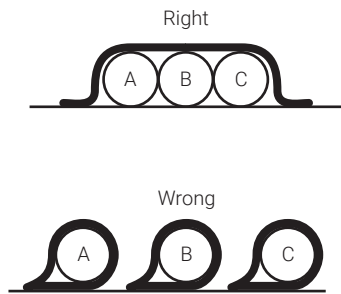
Right

Wrong

Fig. 6   Clips to maintain sheath contact

- To eliminate hysteresis heating effects, one of the following precautions must be taken (in the CEC, these rules apply only when conductor current exceeds 200 amperes):
  - Nonferrous metal entrance plates can be used at each end of the run. A 1/4-in thick brass plate with threaded entries is available, for MI cable, from nVent.
  - In dry locations, slots can be cut between each of the phase conductors, such that all entry holes are joined by an air gap.
  - Nonmetallic entrance plates can be used at each end of the run. To provide proper equipment grounding, a separate bonding conductor must then be run, as the normal bonding route of the copper sheath will be isolated from the switchgear enclosure.
- Where either nonferrous or nonconducting entry plates are employed, bushings and locknuts must also be made of a nonferrous material to avoid hysteresis heating of the accessory. Mineral insulated cable gland connectors must also be made of a nonferrous material.
- For installations involving polymer jacketed cable, consult the manufacturer for specific instructions regarding cable spacing and derating factors to be applied.
- In hazardous locations, it is vital that sparking between cable sheaths or between sheath and ground does not occur. Therefore, it is recommended that either:
  - Cables be run with metal sheaths in contact and grounded at both ends to minimize sheath voltages.
  - Cables be jacketed and grounded at one end only to prevent circulating currents. Because sheath voltages cannot then be eliminated, the jacket must be continuous so that accidental shorting of the voltages cannot occur.

PARALLELING OF SINGLE CONDUCTOR CABLES

It is often necessary to employ more than one conductor per phase when dealing with very large current loads for reasons of conductor size, ease of installation, and cost. In so doing, it is incumbent upon the user to ensure that each of the conductors in a phase group carries its proportionate share of the total line current so as not to overload, and consequently excessively heat, the other conductors in the group.

The intent is to have each of the conductors in a phase group carry exactly the same current load by arranging the cables such that the AC impedance is identical from one conductor to another.

The electrical codes address the problem of ensuring balanced AC resistance in each of the conductors comprising a phase group:

- All conductors must be the same length
- All conductors must be the same size and the same material
- All conductors must have the same type of insulation
- All conductors must be terminated in the same manner

In addition, electrical codes stipulate that only cables in sizes #1/0 AWG and larger may be run in paralleled configurations.

Balancing of inductive reactance is, in general, more difficult as the effects of cable spacing, relative position, and number of conductors per phase on the interacting magnetic fields can cause large differences in reactance that will measurably affect the division of current among conductors.

In all instances, it is necessary that the current balance be checked immediately after the cables begin to carry load. Load imbalances between conductors of up to 10% are tolerable and are to be expected. Greater imbalances between conductors of the same phase are of concern and warrant investigation.

It is recommended that single conductor cables be installed in the configurations shown in Fig. 7. These cable arrangements will result in the best overall impedance balance and consequently in the best possible current division when used in conjunction with the requirements of the electrical codes.

In reviewing Fig. 7, note that the neutral conductor may be located within or outside the cable group and that the spacing between groups of bundled cables should be at least 2.15 cable diameters in accordance with the NEC (US) and CEC (Canada) to maintain free air ratings without applying de-rating factors for number of conductors in contact. Most importantly, note that each group of cables must contain one conductor from each phase so as to minimize the resulting magnetic field encircling each bundle.

Few problems are normally encountered in dealing with three or fewer conductors per phase as long as recommended configurations are utilized.

	Single Phase	Three-Phase • 3 Wire	Three-Phase • 4 Wire
Single circuit (preferred)			
Single circuit (alternative)			
Two cables in parallel per phase (preferred)			
Two cables in parallel per phase (alternative)			
Three or more cables in parallel per phase (preferred)			
Three or more cables in parallel per phase (alternative)			

Note: For free air ampere ratings, the spacing "S" between bundles should be a minimum of 2.15 cable diameters in the U.S. (NEC), and Canada (CEC). For magnetic effect purposes, the neutral may be located as shown, or outside groups in the most convenient location.

Fig. 7   Installation configurations

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