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Grounding

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Rev. 5/00

Grounding

TiPS

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Safety

A major difficulty in developing a safe and working grounding safety plan is the variety of construction practices. There are single circuits, presence and absence of neutrals, with and without protective static wires; double circuits with at least the variables listed above; lines parallel to, at right angles to, crossing over or under the line being serviced; corner or tangent configurations; no place to drive a ground rod; and underground distribution. All are variations that require different approaches. But, the common requirement is the need to maintain a very low voltage drop across workers and to provide a fast clearing of faults which may occur.

Charles Dalziel, a prominent electrical researcher in the 1940s and '50s, studied the body's reaction to different circuit levels. His research used student volunteers at low current levels and for short time durations. He learned the average 60 Hz perception level of a 155 pound man is 1.2 mAmps (perception level being the least current that can be detected by a person touching an energized object). The painful shock threshold, but below the let-go threshold, was found to be 9 mAmps. The let-go threshold was found to be 16 mAmps. The person would experience difficulty in breathing at 23 mAmps and above. Dalziel found at 1,000 mAmps of current flow through the chest cavity for 30 mSec the heart goes into fibrillation. Fibrillation also can be caused at the reduced current level of 100 mAmps with current flow duration of 3 seconds.

Dalziel's research pointed out two important variables: Current level and the duration of current flow through the body. The amount of current flowing through a body is a function of the voltage applied and other variables. Some of these are the presence or absence of work gloves, resistance of work shoes, the amount of moisture or calluses on a worker's hands, or the conductivity of the soil where the worker stands.

Ohm's Law provides the mathematical relationship between voltage, current and resistance just as it does in any electrical circuit. For planning purposes, many standards today use the value of 1,000 ohms as man's resistance. While this value is subject to many variables, at 1000 ohms it requires only a voltage differential of 25 volts to cause heart fibrillation. Normally, a worker has a higher resistance due to boots, gloves, etc., and is working near far higher voltages than 25 volts. Because fault currents are thousands of times larger, the worker obviously must take extreme precautions.

This relationship is expressed as:

$$I = \frac{K}{\sqrt{T}}$$

I = Fibrillating current in milliamperes.

T = Duration of shock in seconds.

K = 116 (110 lb. man)
99.5% chance of no fibrillation

K = 185 (110 lb. man)
99.5% chance of fibrillation

Grounding a line involves making a connection to earth. It provides a path for the fault current to return to its source. This path may not be the lowest resistance path, but it usually provides sufficient current to signal the system's protective equipment that a fault has occurred. This causes the breakers or fuses to operate in a short time period, thereby removing the flow of fault current. Since no current flows to ground during a phase-to-phase fault on a perfectly balanced system, many researchers have limited themselves to the single-phase fault-to-ground case. Both are common and dangerous to workers.

Jumper installation provides a low-resistance path around the worker or return to the source if a neutral is available. The intent is to provide such a low-resistance path that most of the current bypasses or is shunted around the man. For establishing a safe work procedure, it is critical to know the approximate value of available fault current at the work site and the jumper resistance to select the proper equipment. The voltage drop across the man will never exceed the product of fault current through the jumper times the resistance of the jumper. This is a basic application of Ohm's law dealing with parallel circuits.

Grounding configurations

One configuration has a bracket (see Figure 1) or double point grounding at the work site. Bracketing consists of a jumper set on each side of the worker, either at or removed from the work site. There is also double-point grounding (see Figure 2) remote from the work site. While bracket grounds at the work site may be beneficial in handling large fault currents, which are in excess of a single cable's rating, bracket grounds lose credibility when discussing the directional characteristics of current flow.

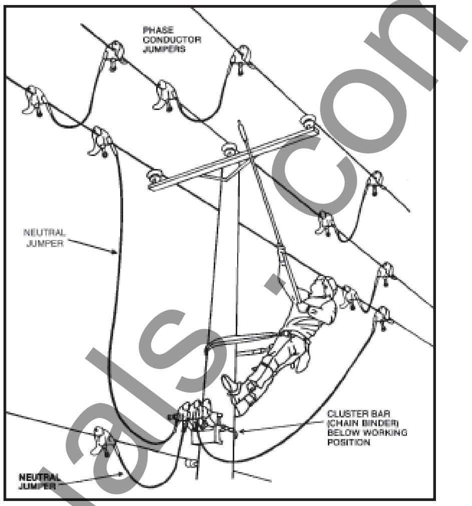


Figure 1
Double point, bracket grounding at worksite.

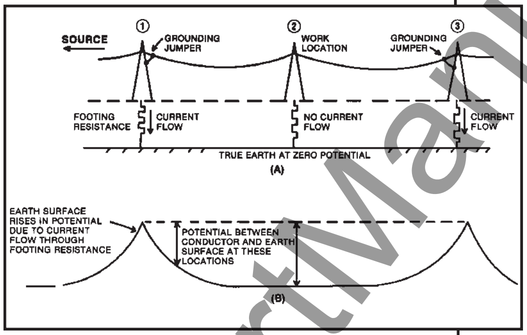
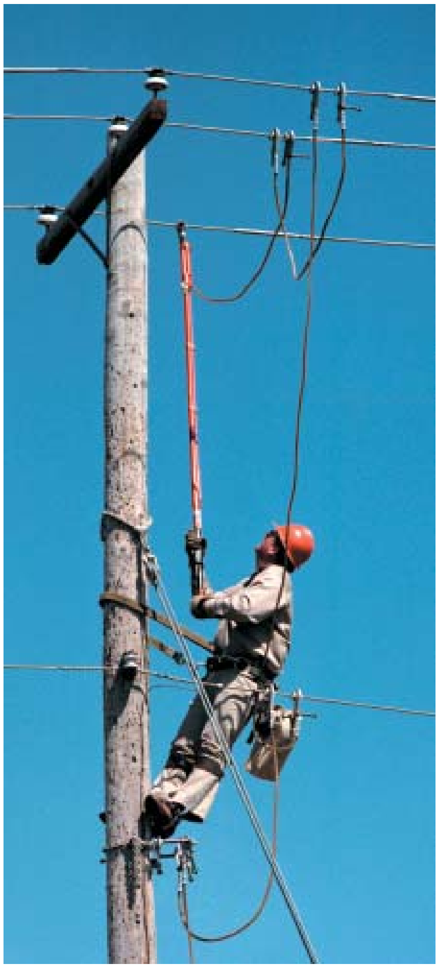


Figure 2
Double point, bracket grounding remote from worksite

Some current flows in every available path. The amount of flow depends upon the resistance of the path. There is no such thing as the jumper on the right protecting the man from a current coming from the right, and the jumper on the left protecting a man from current coming from the left. He is not protected because he is between the jumpers. The two parallel paths afford an extremely low resistance shunt. Remote double-point grounding, without jumpers at the work site, increases the worker's freedom of movement between the installed ground sets (see Figure 2). If the worker is on a conductive structure, however, it places him at maximum risk. Whatever voltage the line achieves during the fault will be felt across his body since his feet will be at near voltage zero. In some cases, the use of personal shunt around the worker instead of a full three-phase grounding set at the work site may be appropriate. In the double-point grounding scheme, current flows through all three paths available to it. Most of the current flows through the two jumpers to the earth and the amount that flows through the worker, while small, may be fatal. Remember, 25 mAmps for an extended time can cause heart fibrillation. For example, consider these conditions: If the line voltage should rise to 5,000 volts and the earth presents the only return path



Single-point grounding at worksite.

to the current source and is valued at 25 ohms, available fault current will be 200 amps at each remote site. Fault current flowing through the 1,000 ohm man will be 4.9 amps. With jumpers, current through the man could be reduced to 1mAmp, a definite improvement in worker safety.

Equipotential single-point or personal grounding consists of one set of jumpers connecting all phases together and to both the neutral, if available, and a cluster bar mounted below the worker's feet. If sized correctly, it is easier to install since fewer structures are involved. This approach provides safety at the work site, takes less time to install and overcomes the hazards of remote bracket grounding (see Figure 3).

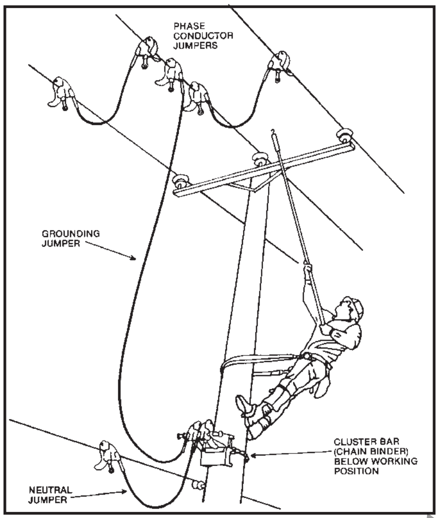
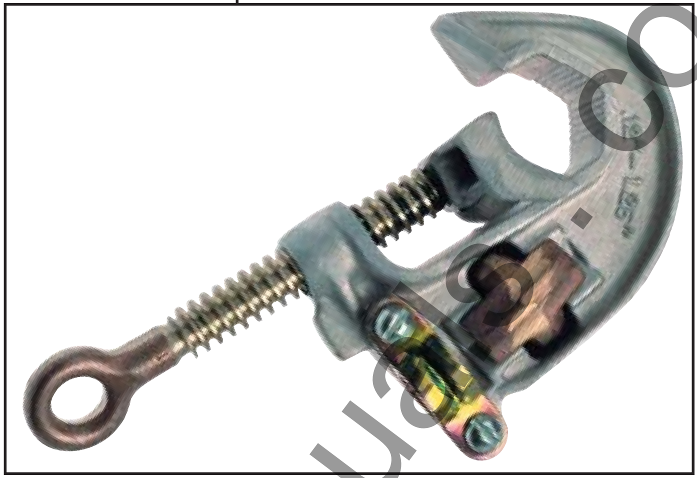


Figure 3
Single-point grounding at worksite.



Chance C-Type ground clamp C600-2276

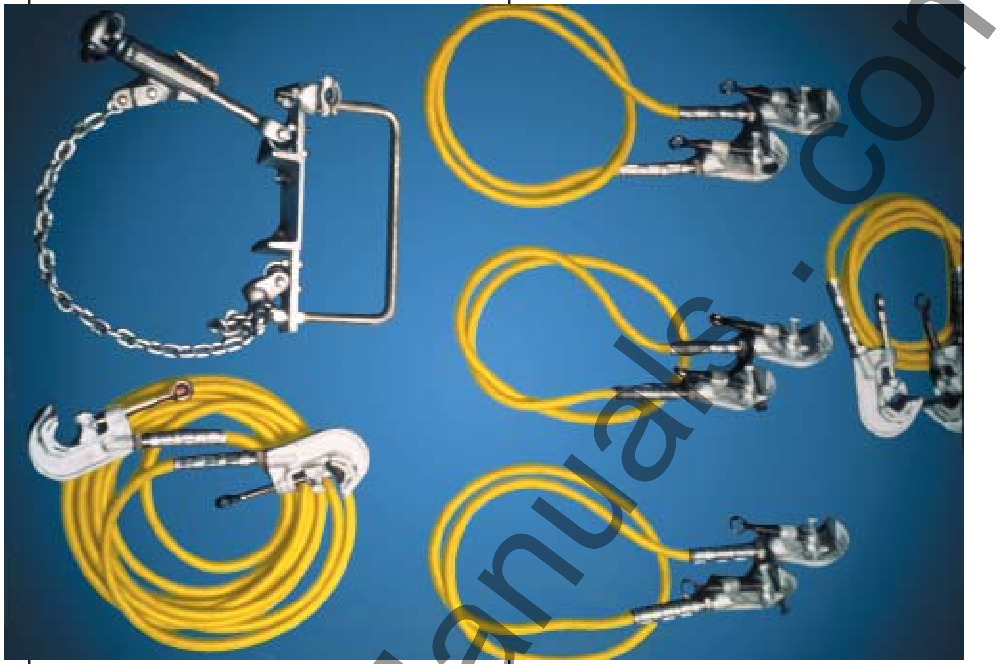
During August 1987, Brian Erga of Puget Sound Power and Light, arranged for a test program at the Chance Research Laboratory at Centralia, MO. A short section of line was built to Puget's construction specifications. The test-line poles were spaced 150 and 250-feet apart and 9-foot wooden crossarms with 336.4 kcmil ACSR primary conductor on 13 kV insulators with 4/0 ACSR common neutrals on insulated secondary spools were used. A #4 insulated copper ground wire was connected to the common neutral from NESC approved copper pole-ground butt plate. On the center pole, a single-phase overhead transformer was mounted using a thru bolt and connected to the line with its case grounded and connected to the common neutral. Ground resistance in the vicinity of a test line was approximately 18 ohms.

Three series of tests were conducted. The first was with both the pole ground and the transformer case ground removed. The second series consisted of only the case ground removed with pole grounds connected. The third series was with both pole and case grounds connected. A non-inductive resistor was used to simulate the worker. The resistor's value was approximately 1,000 ohms. The worst case was the first test with the man on the pole without jumpers or grounds., Bracket grounds on the wood pole reduced the current to 15.3-113 mAmps. It varied with jumper location and ground configuration. The personal protective grounds maximized the protection. The worker's current varied from 10-24 mAmps and varied with ground configurations.

Variables to consider in any grounding program are the size and distance of both primary and neutral conductors from the source or jumper set, conductivity of the structure, presence or absence of insulated or bare pole-down wires, mounted system hardware, driven grounds, available fault currents, sizing of jumper conductor and clamps, and the placement of these.

In all cases, the connection of the phase-to-neutral presented the lowest current flow through the man. The low-resistance path provided by the jumper and neutral carried most of the current, and maintained a minimum voltage drop across the man. As the jumper set is moved toward the voltage source, the resistance in series with the man slightly increases. The conductor and neutral resistances are added to that of the man. The change may or may not be appreciable depending upon the distance moved, the fault current present, the presence of a cluster bar and its connections and the conductor resistances.

If the single set of jumpers is placed on the load side, the same variables are present; however, they become much more important. If the jumpers are close to the work site, the man can be adequately protected. As they are moved farther from the man and away from the voltage source, the conductor and neutral resistance is now added in series with the jumper resistance. This resistance can be appreciable when compared to the extremely low value of the jumper. This can vary the man current to a dangerous level. If no neutral is present, it is more difficult to protect the worker. A cluster bar below his feet reduces the voltage difference across the man. While the difference is not zero, it is very small compared to the voltage being protected against, hence the term "equipotential zone." The protection may be satisfactory,



Jumper set with clamps and cable

depending upon the variables. Some of these variables are the poles conductivity, the presence of a low-resistance path to earth (such as a pole-down wire), a low resistance connection to earth (such as butt plate or driven ground), and the value of earth resistance to source at the pole.

The analysis of the Puget program resulted in Puget's adoption of the personal grounding system. It is their recommended method in all cases that some situations may require other configurations.

Puget allows, based upon their fault currents, conductor sizes and so forth, bracket grounds remote from the work site if they do not exceed 250-feet from the worker. Beyond the 250-foot mark, it is necessary for the worker to use a personal ground in addition to the remote grounding sets for full protection. This personal ground consists of a cluster bar below the worker and connections to both the neutral and the phase being worked. The use of this method must be determined based upon the variables of an individual utility. They should not adopt the Puget system without further analysis.

During any high-current fault, if there is a connection to earth, either by way of separate driven ground or pole-down wire, a hazard exists at the pole base. The voltage at the point of earth entry reaches approximately the same level as the line voltage. This creates a large voltage gradient at ground level which can cause possible ground worker injuries. This hazard is known as "Step Potential," and represents another hazard to consider.

The voltage drop with respect to distance from the current's point of entry into the earth is non-linear. A rough rule of thumb is that the voltage will halve for each $2^{1}/_{2}$ to 3-feet distance from this point. For example, an 8 kV system voltage transferred to a driven ground rod will yield a 4 kV level approximately 3 feet from the ground rod; with a voltage of 2 kV, when it is 6 feet from the ground rod.

This potential difference represents a "Touch Potential" hazard from the ground man who may be standing at some distance away with his feet at a low voltage level and touching a point connected to the much higher voltage. Both step and touch potential hazards are prominent in maintenance involving trucks. In either case, a ground man can be protected by standing on a conductive mat and bonding that to the ground lead with a short connection. This keeps both of his feet at the same potential. Further, it keeps his feet at the same potential as any object he may touch with his hands. An alternate protective scheme is to place the worker on an insulating mat, thereby eliminating the current flow path through his body.

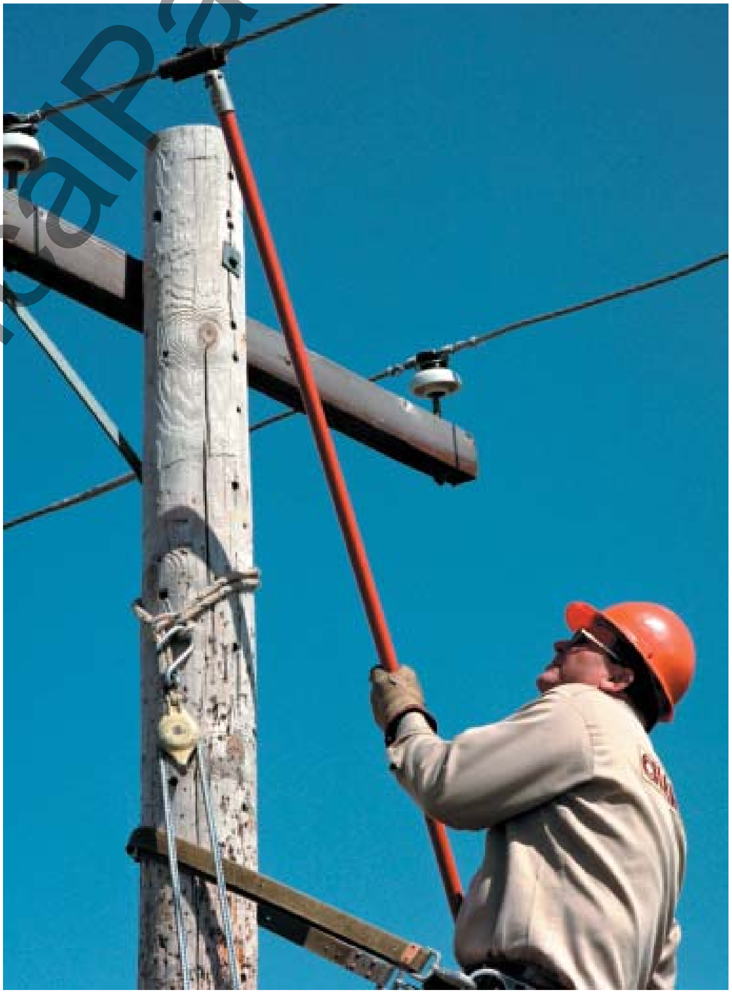
Since there are so many variables to consider and many different work site situations, worker safety must be studied thoroughly and carefully. It is of great benefit to actually draw the electrical circuit at and near the work site. Every possible current path should be included. Some may be deleted later, such as a low-resistance jumper in series with a high-resistance wood pole, but this will give the reviewer a much clearer picture of the possibilities.

Do not disregard a conductor just because it is known to be of low resistance. When dealing with current in the tens of thousands of amperes, very small resistance can develop a dangerous voltage drop. Study each case using your conductor sizes, fault currents, span spacings, presence of grounds and earth resistances, etc.

To ensure maximum worker protection during de-energized overhead line maintenance, clamps with sufficient current rating both for short and long duration current flows should be used. Clamps should have sufficient mechanical strength to resist the tremendous mechanical forces associated with a high-current fault. Do not attempt installation of a single ground clamp on more than one conductor. Clamps are designed for: One clamp - one conductor. Flexible grounding cables of sufficient size to conduct the current without fusing or becoming so hot as to allow the mechanical forces to separate it at the hot spot should be used. This requires knowledge of the approximate value of fault current to be expected at the work site.

The approximate time required for the backup equipment to operate in case of high-current faults should also be known. The worker must determine that the line is truly de-energized before attempting to place safety grounds. The grounded end should be attached first and an insulated "shotgun stick" should be used to position the clamps. All connections should be cleaned and properly tightened to prevent the loss of the protective equipment during a fault. The most important items in the application and use of safety jumper equipment are to exercise extreme caution, training and common sense.

Grounding set with support stud helps in placement on lines.



Before applying ground clamp, always clean conductor. Chance conductor-cleaning brush C403-0451 cleans a 6" area.

Underground Grounding Sets

Essential tools for 15kV, 25kV and 35kV gear

Even state-of-the-art deadfront transformers and switchgear require hot-line tools for proper operation and maintenance.

But, too often, temporary grounding is not designated as part of the procedures. Without it, safety remains subject to the risks of human error and equipment failure.

That's why Chance offers pre-assembled ground sets, each system-rated for available fault ccurrent. Hot-line tool sets for underground distribution systems just wouldn't be complete without them.

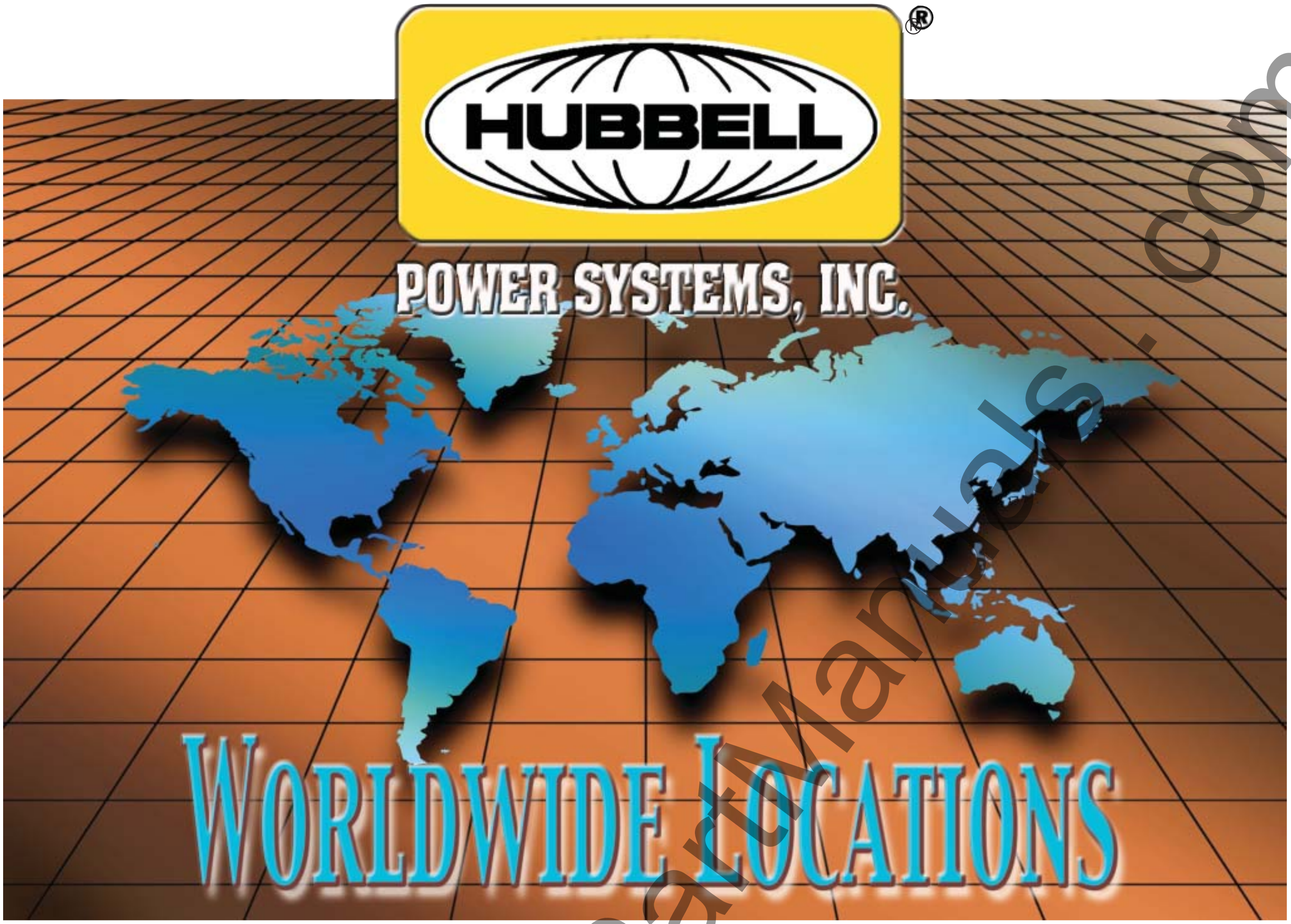
(Top, at right) Three-phase sets are available with only 15kV or 25kV elbows.

(Center, at right) Single-phase sets are availaable with elbows for 15, 25, or 35kV bushings.

At each bushing where applied, these units provide grounding for the associated underground cable span to the next location.

(Bottom, right) Grounded parking bushings are available in 15 and 25kV sizes.

Each assembly provides a grounded location for parking a loadbreak elbow after it's removed from a deadfront bushing and tested to be de-energized.



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