TEST RESULTS OF PERSONAL PROTECTIVE GROUNDING ON DISTRIBUTION LINE WOOD POLE CONSTRUCTION

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Abstract - This paper presents the results of a series of tests to determine the most effective method of protecting distribution line workers from accidental line energization. The project scope was limited to three-phase, grounded wye, distribution wood pole construction. Voltages and currents across the work area were recorded with various configurations of temporary grounds. Several configurations provided currents which are considered lethal. The results strongly indicate that the personal protective grounding method, also called "single point grounding," provides the most effective means of protecting distribution line workers.

INTRODUCTION

Many temporary grounding methods are used by industry to protect workers from accidental energization of overhead lines. Methods range from installing no temporary grounds whatsoever, to installing temporary grounds at the remote ends of the line and on both sides of the work location. The three methods most widely used are:

Working Grounds - temporary grounding jumpers installed between the three primary conductors and the system neutral. They are installed between the source of energy and the work site.

Bracket Grounds - working grounds installed on both sides of the work site. This method is used where the line could be energized from either direction.

Personal Protective Grounds - working grounds installed on one side of the work site, with a cluster bar on the pole below the workers feet, and a jumper from the cluster bar to the system neutral.

88 SM 558-9 A paper recommended and approved by the IEEE Transmission and Distribution Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1988 Summer Meeting, Portland, Oregon, July 24 - 29, 1988. Manuscript submitted January 29, 1988; available for printing June 17, 1988.

Detailed investigation by government and private organizations [1,2,3] has shown that, in most cases, personal protective grounding during construction and maintenance of transmission lines provides the most effective worker protection. For this reason, most utility practices specify personal protective grounding.

For several reasons, few tests have been made of temporary grounding methods at distribution voltages. Because distribution lines are usually constructed on wood poles, it was thought that the pole's resistance would protect workers from electrical hazards. Also, line workers and first line supervisors have been led to believe that working grounds and bracket grounds provide absolute safety.

Working grounds and bracket grounds were thought to shunt all current around and away from the work site. However, when a worker contacts a phase conductor while standing on or touching a distribution wood pole, there is a path for current through the worker's body, even with working grounds or bracket grounds installed. The amount of current which will flow through the worker is directly related to the resistance of the pole and the impressed voltage (*Figure 1*).

Personal protective grounds provide an equal-potential zone around the worker by energizing everything above the cluster bar at the same potential (*Figure 2*).

Although personal protective grounds theoretically provide the best protection for the worker [4], questions arose relating to how a distribution transformer, a common neutral, or a pole ground would affect the grounding method.

After a fatal accident involving contact of energized distribution lines which should have been grounded, a study was begun to review existing utility practices and to recommend an acceptable temporary grounding method.

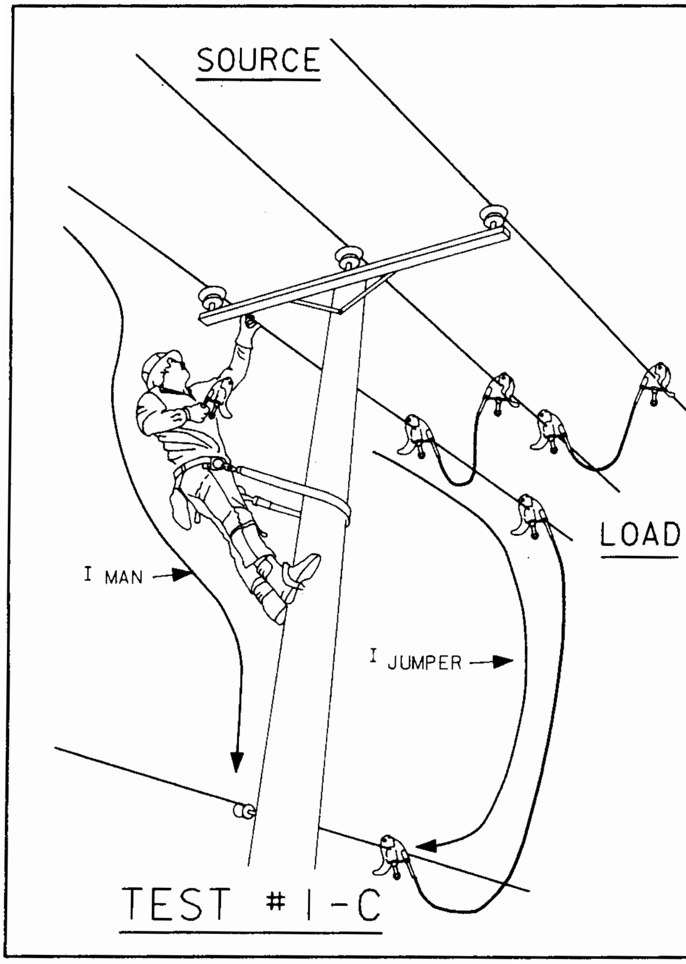


Figure 1 Working Grounds

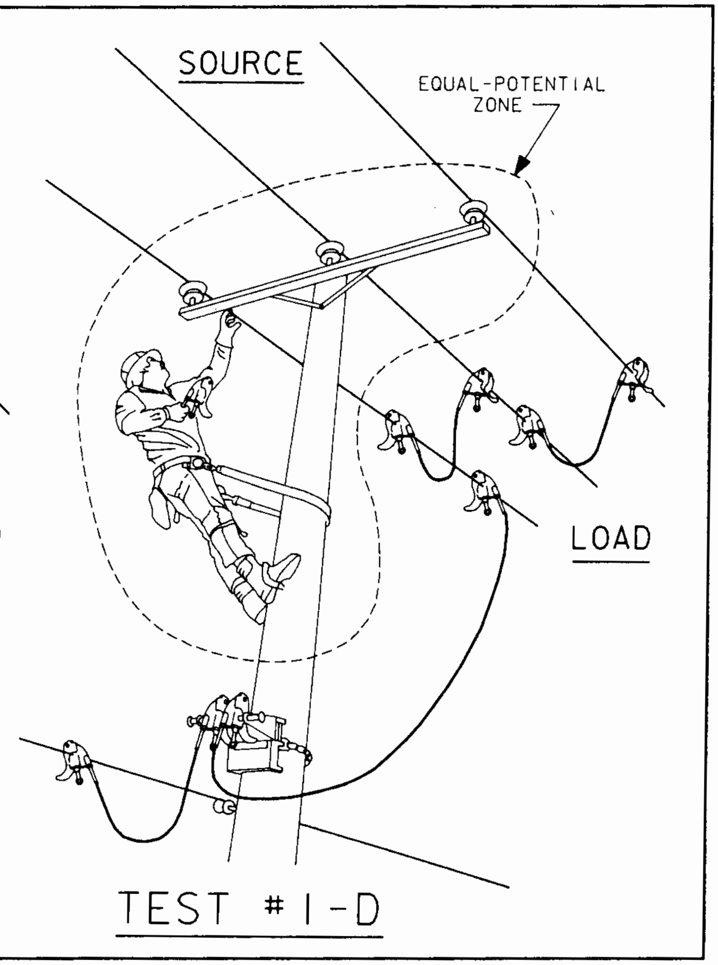


Figure 2 Personal Protective Grounds

RESISTANCE OF DISTRIBUTION WOOD POLES

The study showed that the amount of voltage and current a line worker is subjected to depends on the conductivity of the wood pole. The electrical resistance of wood varies with its moisture content. Wood resistance is greater across the grain than along it, varies slightly with species, decreases as the voltage gradient increases, and varies greatly due to surface moisture and applied treating material [5]. Tests show that a pole's electrical resistance can vary from 2500 ohms wet, to several megohms dry. Older poles are usually more resistive [6].

The three wood poles used in the test were 40 foot, pressure-treated pine poles, approximately 10 years old. Pole resistance varied from 18 000 ohms wet, to 3 megohms dry. During most of the tests, the poles had a resistance of 18 000 ohms to 2 megohms.

SURVIVABLE CURRENT LIMITS

Studies summarized in IEEE 80-1986 [7] set the human limits of electrical perception at about 1 mA, the let-go current threshold at 9 mA, and the three-second ventricular fibrillation at approximately 100 mA. Humans subjected to currents less than the ventricular fibrillation point, but above the let-go threshold for more than three seconds, are in danger of internal electrical burns as life-threatening as ventricular fibrillation.

Distribution lines are usually protected with electromechanical overcurrent relays and fuses. Many distribution circuits extend for miles, and are often constructed with small, relatively high-resistance wire near the end. Faults near the ends of these circuits may be mistaken for load by the relays or fuses, requiring long clearing times. When a worker contacts a primary conductor as the line becomes energized, the current through his body may be greater than the let-go threshold, but below ventricular fibrillation. Protective devices may not sense the fault, requiring the worker to be physically removed from the line. This may take anywhere from 15 seconds to several minutes: ample time for serious injury to occur. To assure the fastest clearing time, temporary grounds always should be attached to the system neutral conductor.

TEST PROCEDURE

The test line was built to utility standards using poles spaced 150 and 250 feet apart, nine foot wood arms, 336.4 kcmil ACSR primary conductors on 13 kV insulators, and a 4/0 ACSR common neutral on insulated secondary spools. A #4 insulated copper ground wire was connected to the common neutral from a National Electrical Safety Code (NESC)- approved copper ground plate. On the center pole, a single-phase overhead transformer was connected to the line, with its case ground connected to the common neutral. Ground resistance in the vicinity of the test line was approximately 18 ohms (*Figure 3*).

A line worker was simulated by a 911 ohm carbon resistor connected from the primary conductor to a nail driven one inch into the pole, two feet above the common neutral. Grounding jumpers used in the test were constructed of 1/0, 1064 strand, 600 V insulated, copper conductor, aluminum serrated jaw clamps, and threaded ferrules.

Four system configurations were tested. The first series of tests was conducted with the pole ground and transformer case ground disconnected. The second series had the pole ground connected to the common neutral. In the third test series, both the pole ground and the transformer case ground were connected to the common neutral. The fourth series assumed a highly conductive pole by attaching the test worker's "feet" (one end of the resistor) directly to the pole ground.

In each test, voltage across the carbon resistor was recorded on an oscilloscope. The generator voltage and current was recorded at the generator terminals. The line was energized for approximately 14 to 18 cycles.

The tests were limited to single-phase-to-ground faults at 7.2 kV, with fault currents of 4200 to 5700 A. The authors elected not to conduct three-phase tests because in most cases single-phase faults provide the largest currents. Three-phase fault current should equal near zero at the ground point.

Weather conditions varied from clear skies, 90-95 degrees F, to cloudy with rain showers and 70 degrees F.

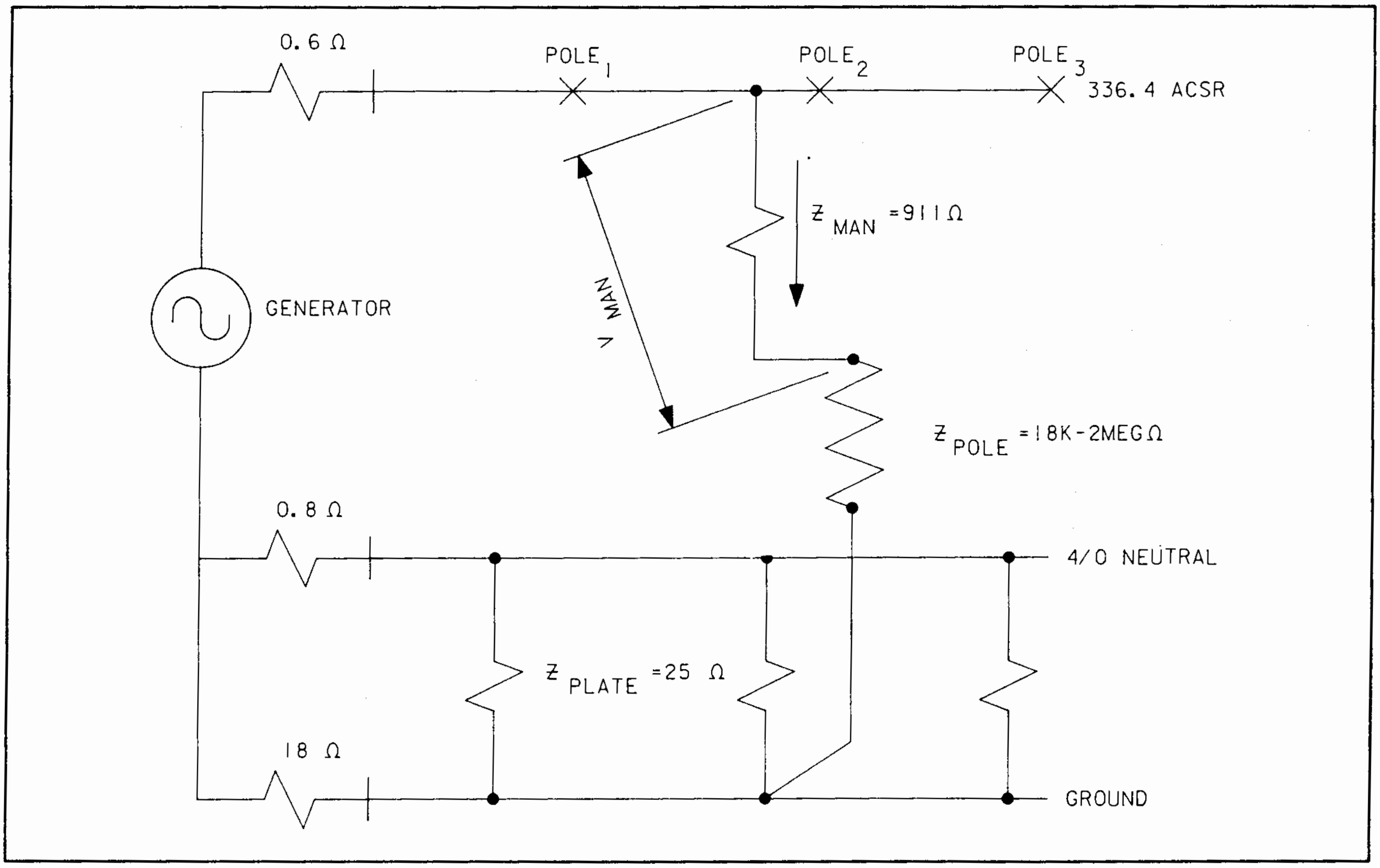


Figure 3 Test Configuration 1A

TEST RESULTS

In the first test series, the 911 ohm test worker was connected between a primary phase conductor and a nail driven into the pole, two feet above the common neutral. The pole ground was disconnected from the common neutral, the transformer cutout was open, and the transformer case ground was disconnected.

Test 1-A was conducted with no temporary grounds; 297 V and 327 mA were recorded across the resistor. In test 1-B, bracket grounds were installed on both sides of the work site; 103 V and 113 mA were recorded. A repeat of the same test provided 94.5 V and 104 mA. Test 1-C used working grounds on the load side of the work location; 52.5 V and 58 mA were recorded. In test 1-D, the personal protective grounding method was used on the load side of the work site. The voltage across the work site was reduced to 21.8 V and 24 mA (Appendix).

The first series of tests confirmed mathematical calculations showing that the least amount of voltage and current across and passing through the worker occurs when personal protective grounds are used. Similar results were seen in the other three series of tests.

Test series two and three showed that the pole ground and transformer case ground provide a "cluster bar effect" by reducing the voltage and current which the worker must endure during accidental line energization (Appendix).

The fourth series of tests created a "worst case" by jumpering out the resistance of the wood pole. In this series, the voltage and current were dramatically reduced from 1745 V and 1.88 A with bracket grounds, to 19.5 V and 21 mA with personal protective grounds installed on the pole (Appendix).

TEMPORARY GROUNDS AWAY FROM THE WORK SITE

Several tests were conducted to determine how far away from the work location temporary grounds could be installed and still provide adequate protection. In two tests, working grounds were installed 250 feet away from the work site, resulting in 34.4 V and 38 mA, and 32.5 V and 37 mA, respectfully. When a cluster bar and jumper to the common neutral were installed on the pole with the test worker, recordings were lowered to 21.8 V and 24 mA, and 21.2 V and 23 mA.

STEP AND TOUCH POTENTIALS

Step and touch potentials were recorded two, ten, and twenty-five feet away from the base of the pole, with both working grounds and personal protective grounds. Both the pole ground and transformer case ground were attached to the common neutral during this portion of the test. As seen in the table below, the step and touch potential differences between the two grounding methods were very slight. However, the test pole showed a high resistance to ground. It is suggested that ground personnel be trained to limit their contact to the pole, or to use rubber gloves or pole guards, when any temporary grounds are in use.

DISTANCE FROM POLE	WORKING GROUNDS	PERSONAL PROTECTIVE GROUNDS
2 feet (touch)	3.6 V	4.6 V
10 feet (step)	1.9 V	2.9 V
25 feet (step)	0.0 V	0.0 V

TEMPORARY GROUNDING AND BUCKET TRUCKS

Testing different configurations of temporary grounds with the test worker inside an insulated bucket truck was not attempted, because it would only confirm the insulating integrity of the truck's boom. If the boom is insulated for the available voltage, the electrical circuit through the worker's body changes from hand-to-foot to hand-to-hand. The authors maintain that personal protective grounds provides the best protection for distribution line workers operating from insulated bucket trucks.

If line workers are operating from an uninsulated boom truck, they are working outside of the equal-potential zone provided by the personal protective grounds. Additional protection, such as protective rubber goods, should be used.

CONCLUSION

The test results confirm that the personal protective grounding is superior to any other method of temporary grounding of distribution lines for worker protection. Currents recorded during the tests were well below ventricular fibrillation, and usually below the let-go threshold. However, voltage and current levels will vary at each work site. The worker is best protected by installing jumpers between the phase conductors, from a phase conductor to the system neutral, and from the neutral to a cluster bar on the pole below the worker's feet. If the lines were to become energized while the worker is in the equal-potential zone, everything within the worker's reach will be at the same potential.

When bucket trucks are insulated for the available voltage, personal protective grounding can be an effective method of protecting the worker from accidental line energization.

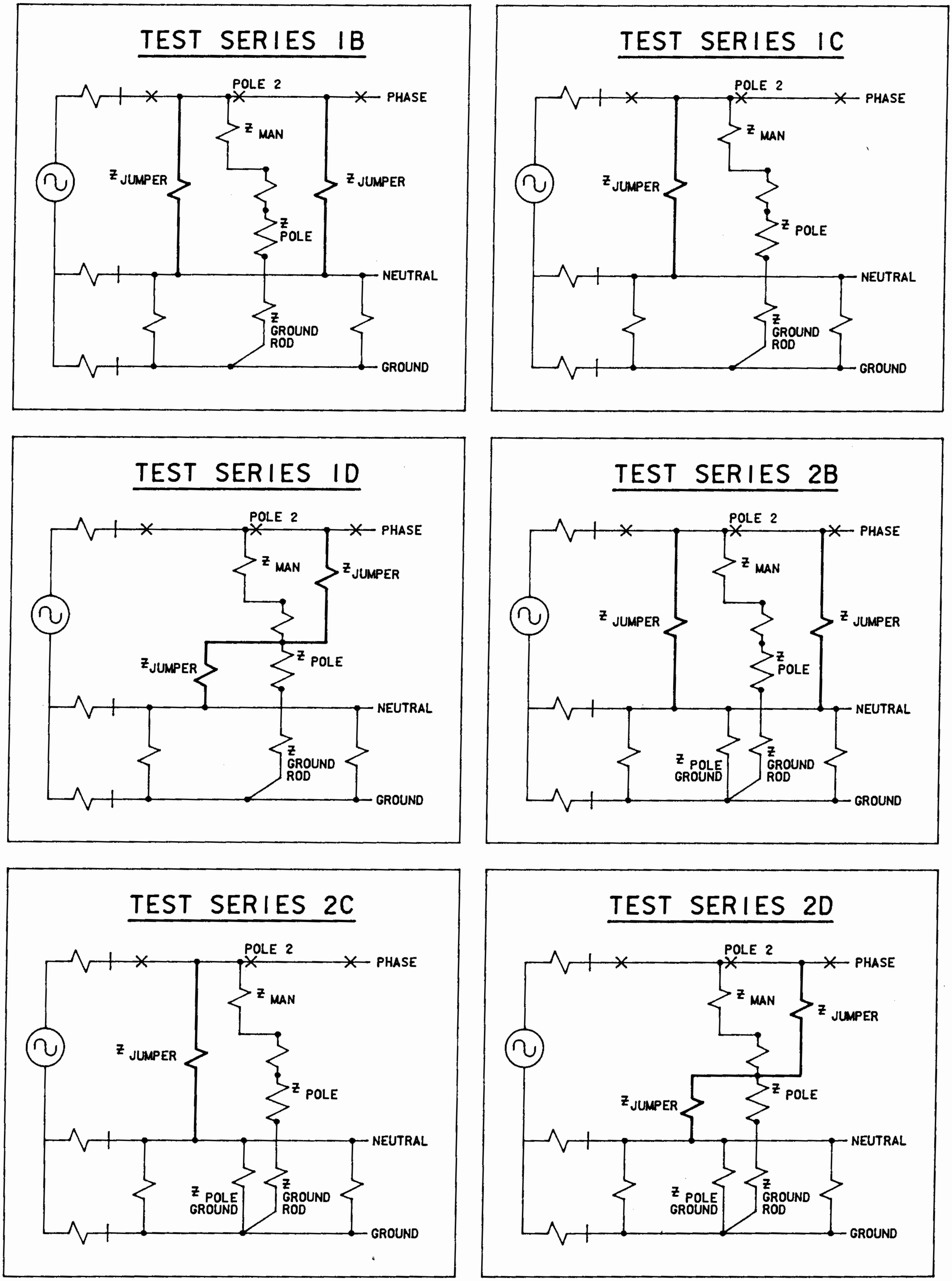
When work is to be done outside the equal-potential zone created by personal protective grounds, additional protection, such as rubber gloves or ground mats attached to the system neutral, should be considered.

A second testing program attempted to determine why the voltage and current nearly doubled from working grounds to bracket grounds in every series of tests (Appendix 1). However, weather conditions and equipment malfunctions rendered the results inconclusive. It is hoped that future tests will explain this deviation.

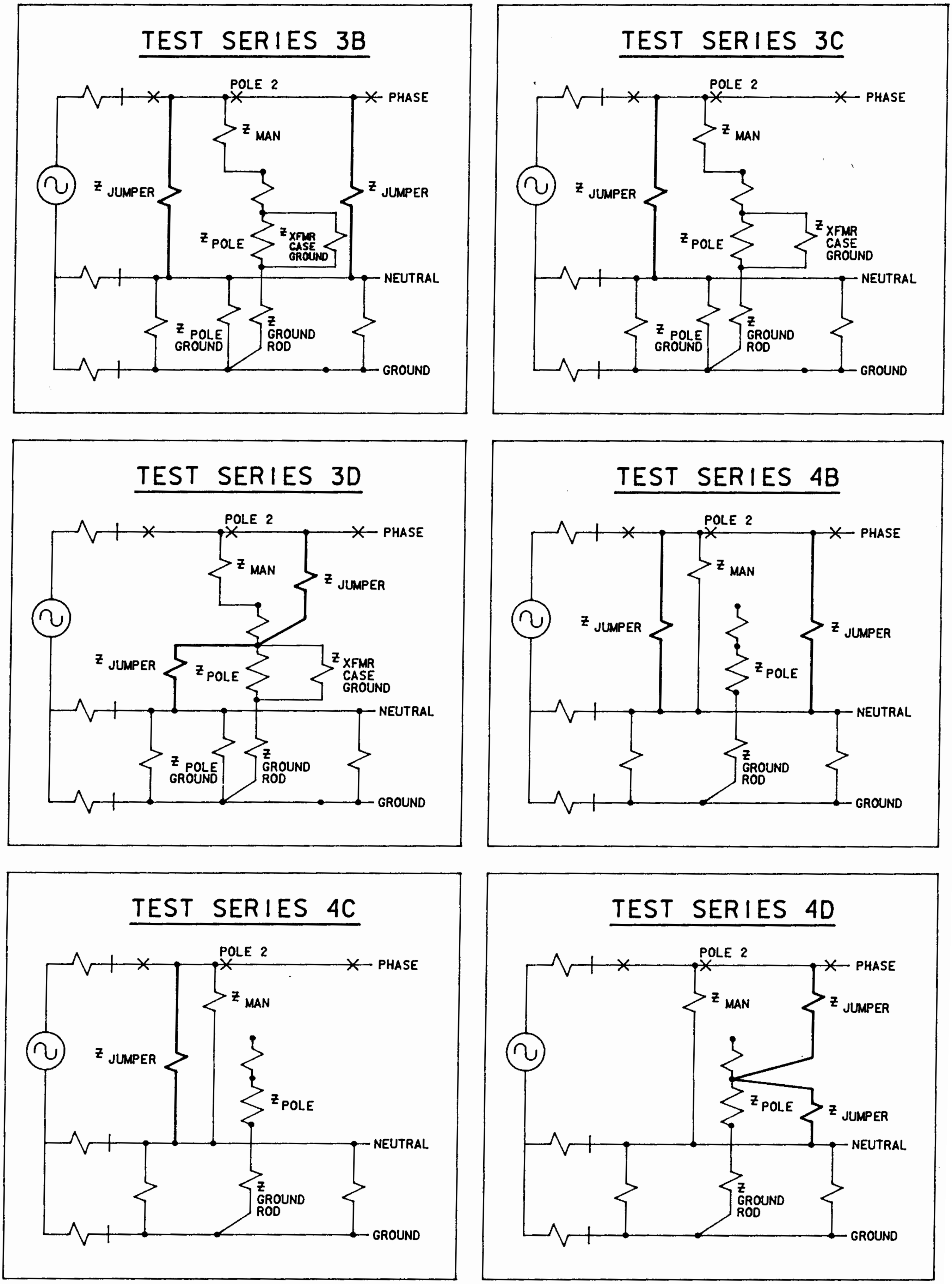
<table>
<tr><th></th><th></th><th colspan="2">SERIES 1
Without pole grnd
Without case grnd</th><th colspan="6">SERIES 2
With pole grnd
Without case grnd</th><th colspan="3">SERIES 3
With pole grnd
With case grnd</th><th>SERIES 4
Without pole grnd
Without case grnd
Worker on grnd</th></tr>
<tr><td rowspan="4">TEST A
No Grounds</td><td>V_{MAN}</td><td colspan="2">297 V</td><td colspan="6"></td><td colspan="3"></td><td></td></tr>
<tr><td>I_{MAN}</td><td colspan="2">326 mA</td><td colspan="6"></td><td colspan="3"></td><td></td></tr>
<tr><td>V_{GEN}</td><td colspan="2">7300 V</td><td colspan="6"></td><td colspan="3"></td><td></td></tr>
<tr><td>I_{GEN}</td><td colspan="2">326 mA</td><td colspan="6"></td><td colspan="3"></td><td></td></tr>
<tr><td rowspan="4">TEST B
Bracket Grounds</td><td>V_{MAN}</td><td>103 V*</td><td>94.5 V*</td><td colspan="3">49.5 V*</td><td colspan="3">32.5 V*</td><td colspan="3">26.7 V</td><td>1745 V</td></tr>
<tr><td>I_{MAN}</td><td>113 mA</td><td>104 mA</td><td colspan="3">54 mA</td><td colspan="3">36 mA</td><td colspan="3">29 mA</td><td>1.88 A</td></tr>
<tr><td>V_{GEN}</td><td>4148 V</td><td>4214 V</td><td colspan="3">3915 V</td><td colspan="3">3849 V</td><td colspan="3">4015 V</td><td>3684 V</td></tr>
<tr><td>I_{GEN}</td><td>5578 A</td><td>5473 A</td><td colspan="3">5315 A</td><td colspan="3">4968 A</td><td colspan="3">3830 A</td><td>4765 A</td></tr>
<tr><td rowspan="4">TEST C
Working Grounds</td><td>V_{MAN}</td><td colspan="2">52.5 V*</td><td colspan="2">47.4 V*</td><td colspan="2">40.2 V*</td><td colspan="2">30 V</td><td colspan="3">13.9 V</td><td>1524 V</td></tr>
<tr><td>I_{MAN}</td><td colspan="2">58 mA</td><td colspan="2">52 mA</td><td colspan="2">44 mA</td><td colspan="2">33 mA</td><td colspan="3">15.3 mA</td><td>1.65 A</td></tr>
<tr><td>V_{GEN}</td><td colspan="2">3915 V</td><td colspan="2">3982 V</td><td colspan="2">3982 V</td><td colspan="2">3948 V</td><td colspan="3">3650 V</td><td>3885 V</td></tr>
<tr><td>I_{GEN}</td><td colspan="2">5147 A</td><td colspan="2">5705 A</td><td colspan="2">5368 A</td><td colspan="2">5150 A</td><td colspan="3">5214 A</td><td>4816 A</td></tr>
<tr><td rowspan="4">TEST D
Personal Protective Grounds</td><td>V_{MAN}</td><td colspan="2">21.8 V</td><td colspan="6">21.5 V*</td><td>13 V</td><td>10.1 V</td><td>8.8 V</td><td>19.5 V</td></tr>
<tr><td>I_{MAN}</td><td colspan="2">24 mA</td><td colspan="6">24 mA</td><td>14.3 mA</td><td>11 mA</td><td>10 mA</td><td>21 mA</td></tr>
<tr><td>V_{GEN}</td><td colspan="2">3814 V</td><td colspan="6">4048 V</td><td>3816 V</td><td>3916 V</td><td>3983 V</td><td>3885 V</td></tr>
<tr><td>I_{GEN}</td><td colspan="2">5145 A</td><td colspan="6">5578 A</td><td>4741 A</td><td>4293 A</td><td>4482 A</td><td>5100 A</td></tr>
</table>

* Test conducted during wet conditions.

Appendix 1 Temporary Grounding Test Results



Appendix 2 Test Configurations



Appendix 2 Test Configurations

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