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TEST RESULTS OF GROUNDING UNINSULATED AERIAL LIFT VEHICLES NEAR ENERGIZED DISTRIBUTION LINES

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Abstract – This paper presents results of a test conducted to provide information on job site hazards when uninsulated aerial lift vehicles contact energized overhead distribution lines. Touch and step potentials were recorded with various vehicle grounding and protection methods. Used alone, none of the methods provide a totally safe work enviorment, but a combination of several practices may reduce the potential hazard to workers and the public.

Keywords – Grounding, vehicle grounding, aerial lift equipment grounding, step and touch potential, temporary grounding.

INTRODUCTION

The utility industry uses various methods of protection for workers near aerial lift vehicles and equipment operating near energized lines [2] [3]. Methods range from insulated booms, vehicle barricading, grounding and bonding, and/or requiring workers wear insulating gloves or boots. No one method or approach to the problem is widely accepted by the industry. The subject is controversial not only between utilities, but within the operating structures of many companies. Current work practices were created using past experience, basic engineering reasoning, and limited testing of the subject.

This paper mainly addresses aerial lift vehicles with uninsulated booms. One test was conducted using the fiberglass third section of the vehicle's boom.

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The practice of grounding aerial lift vehicles to a system neutral or driven ground rod has been considered by some to be a safe practice in itself. However, results of this test show this procedure may not be totally safe.

Many serious and fatal accidents have been reported of workers contacting ungrounded aerial lift or conductor stringing equipment when the equipment contacted an energized line. However, the author could find no report of injury or fatality involving workers contacting intentionally grounded aerial lift or stringing equipment during electrical contact.

This study was conducted to provide information on the most effective means of providing worker protection around aerial lift and conductor stringing vehicles operated near energized distribution lines.

SURVIVABLE VOLTAGE AND CURRENT LIMIT

IEEE 80–1986 [1] emphasizes the importance of the ventricular fibrillation threshold and suggests methods be designed to keep shock currents below this value. Assuming a body resistance of 1000 ohms, Dalziel's Formula sets minimum ventricular fibrillation for 0.5% of the population at approximately 116 mA and 116 V for 1.0 second, 396 mA and 396 V for 0.1 seconds. Tests and experience show that the chance of severe injury or death is greatly reduced if the duration of a current flow through the body is very brief; this allows the maximum body current magnitude to be based on relay clearing time.

Distribution lines are often protected with ac time overcurrent relays, which operate on preset time- versus-current curves. When current in the line exceeds the minimum pick-up of the relay, often set between 600 and 1000 amperes for a given time interval, a trip signal is sent to the line's protective device, clearing the disturbance. The time interval is dependent upon the amount of fault current the relay senses. The larger the fault current value the faster the relay operating time. If system protection schemes are used in conjunction with personal protective safety procedures, the relays must be provided with the maximum amount of fault current available. Vehicle grounding was found to provide highest return currents, allowing for fast relay operation.

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TEST PROCEDURE

The test was conducted using 1969 Ford C-600 Cab-over digger-derrick line truck. A grounding point was welded to the stiffleg frame located on the rear passenger side of the truck. No other modifications were made to the truck since its removal from daily service.

The second steel section of the truck's three-section hydraulic boom was either placed in direct contact with an outside phase conductor, or swung into the outside phase of a three-phase, grounded wye distribution line. The line was built to utility standards using nine foot wood arms, 336.4 kcmil ACSR primary conductors on 13 kV insulators, 4/0 ACSR common neutral on insulated secondary spools, and #4 insulated copper ground wire connected to the common neutral from an NESC-approved copper ground plate on each pole. Ground resistance in the vicinity of the test area was 18 ohms.

The first line worker was simulated by a 918 ohm carbon resistor connected between the truck's front bumper and a weighted, one foot square metal plate, representing the worker's feet, placed on the ground below the bumper. The second worker was located off the back deck of the line truck using a 929 ohm resistor, also connected to a weighted one foot square metal plate on the ground. Grounding equipment used in the test included a 50 foot 1/0 copper grounding jumper, aluminum serrated jaw grounding clamps, and a six foot copper ground rod.

Four methods of worker protection were tested. The first series of the test was conducted with no grounds attached to the truck. The second test series connected the truck to a driven six foot ground rod installed thirty feet from the truck. In the third series the truck was grounded to the ground wire of the distribution pole located five feet from the rear of the truck. The fourth test was conducted with the truck grounded to the system common neutral conductor.

In each test, voltages across both carbon resistors were recorded on an oscilloscope. Generator voltage and returning fault currents were recorded at the generator terminals with the line energized for 10 to 12 cycles. The test circuit was energized at 7.2 kV with available fault current of 6000 A.

TEST RESULTS

The first test series was conducted with the truck ungrounded. Voltage and current through the workers ranged from 5397 V and 5.8 A, to 5856 V and 6.3 A, well above survivable limits. Fault current for the series ranged between 18 and 251 A, well below the pick-up point of most time-current relays. Arcing at the contact point of the boom and phase conductor was difficult to detect. During the test with the stifflegs directly on earth, steam was seen at the stifflegs.

TEST 1
TRUCK UNGROUNDED

Conditions	Fault Current (Amperes)	Front Worker Volts Across	Front Worker Amperes Through	Rear Worker Volts Across	Rear Worker Amperes Through
Tires insulated Stifflegs uninsulated	120	5601	6.1	5601	6.0
Tires uninsulated Stifflegs uninsulated	182	5516	6.0	5431	5.8
Tires uninsulated Stifflegs insulated	18	5728	6.2	5856	6.3
*Tires uninsulated Stifflegs uninsulated	251	5482	6.0	5397	5.8
*Tires uninsulated Stifflegs on wood	72	5516	6.0	5567	6.0
Tires uninsulated Stifflegs on wood Fiberglass boom out	------- No Measurable Readings -------				
Tires uninsulated Stifflegs on wood Nylon boom line out	------- No Measurable Readings -------				

The second series included grounding the truck to a driven ground rod installed 30 feet from the truck. Voltage and current across and through the workers ranged from 5304 V and 5.8 A, to 5601 V and 6.0 A. Fault current ranged from 402 to 726 A At these levels, it is questionable whether the relays could detect that an accident had occurred. Again, the voltages and currents were well above survivable limits. Both the voltage and current levels across the workers were nearly identical to the first test series, in which the truck was ungrounded, showing that the ground rod provided little protection. Arcing or noise was again difficult to detect at the boom-conductor contact point. Some smoke or steam was noticed rising from the ground near the ground rod following several tests.

TEST 2
TRUCK GROUNDED TO TEMPORARY GROUND ROD

Conditions	Fault Current (A)	Front Worker		Rear Worker	
		Volts Across	Amperes Through	Volts Across	Amperes Through
Tires insulated Stifflegs uninsulated	402	5431	5.9	5601	6.0
Tires uninsulated Stifflegs uninsulated	726	5304	5.8	5177	5.6
Tires uninsulated Stifflegs on wood	614	5474	6.0	5431	5.8

Test series three grounded the truck to the #4 pole ground wire, which was connected to the common neutral from an NESC-approved copper ground plate. This series saw voltage and currents (between 221 and 255 V and 0.24 and 0.28 A, respectively) across and through the workers drop to levels that could be survivable, depending on the duration. Fault current returning back to the station ranged from 4422 to 5487 A, well within the range of the protective relays' ability to clear the line within cycles.

TEST 3
TRUCK GROUNDED TO #4 CU POLE GROUND WIRE

Conditions	Fault Current (A)	Front Worker		Rear Worker	
		Volts Across	Amperes Through	Volts Across	Amperes Through
Tires uninsulated Stifflegs uninsulated	4422	221	0.24	221	0.24
Tires uninsulated Stifflegs on wood	5100	255	0.28	246	0.26
Tires uninsulated Stifflegs insulated	5487	255	0.28	238	0.26

The fourth series grounded the truck directly to the common neutral. Results were nearly identical to test series three, with the exception that the voltage and currents across the workers were even lower providing possibly safe values. During test series three and four, large electrical flashes, with the potential of going phase-to-phase, and loud bangs occurred at the contact point of the boom and the phase conductor. Workers within six feet of the contact point could sustain flash burns or be struck with molten conductor fragments.

TEST 4
TRUCK GROUNDED TO COMMON NEUTRAL

Conditions	Fault Current (A)	Front Worker		Rear Worker	
		Volts Across	Amperes Through	Volts Across	Amperes Through
Tires uninsulated Stifflegs uninsulated	5040	212	0.23	204	0.22
Tires uninsulated Stifflegs on wood	5336	207	0.23	21	0.23
Tires uninsulated Stifflegs up Plate on leather boots	4633	199	0.22	-No Reading-	
*Tires uninsulated Stifflegs on wood	5200	204	0.22	186	0.20
*Tires uninsulated Stifflegs uninsulated	5050	199	0.22	186	0.20
Tires uninsulated Stifflegs on wood Fiberglass boom out		-------- No Measurable Reading --------			
Tires uninsulated Stifflegs on wood Nylon boom line		-------- No Measurable Reading --------			

* Boom was moved into the line

Several other tests were conducted to evaluate the insulating capability of the boom's fiberglass section and the boom line. Using the boom's fiberglass third section, the phase conductor was placed one foot above the end of the second steel section of the boom. No voltage or current was recorded at either worker. To the best of the author's knowledge, the boom had never been cleaned, maintained, tested, or waxed since it was new.

A test of the insulating value of the one inch nylon boom line was also conducted. Although the line was damp and dirty, no voltage or current was recorded at either resistor.

The insulating value of a dry pair of journeyman's line boots was also tested. The boots were placed on the ground with the weighted metal plate connected to the 929 ohm resistor, which was placed on top of the boots. Again, no voltage or current was recorded.

CONCLUSION

The test project confirmed that contacting ungrounded aerial lift vehicles at the same moment it contacts an energized distribution line can be fatal to unprotected workers and general public. The test showed protective devices most likely would not sense an electrical contact by the vehicle and the line would remain energized creating increased hazards at the job site. With the vehicle grounded to a temporary ground rod, again no protection was provided to the worker.

When the truck was grounded to the common neutral or pole ground, nearly maximum fault current was generated, allowing for very short clearing time and lower body current. The possibility of surviving the accident due to the fast clearing time and low body current makes grounding vehicles a consideration. However, the electrical flash and smoke created at the contact point of the truck's boom could have produced electrical flash injury for workers within several feet of the contact point.

If vehicle grounding is used additional safety equipment should be used including insulated booms and/or conductor cover-ups. Vehicle barriers or personal protective tools including rubber gloves or boots could be other options.

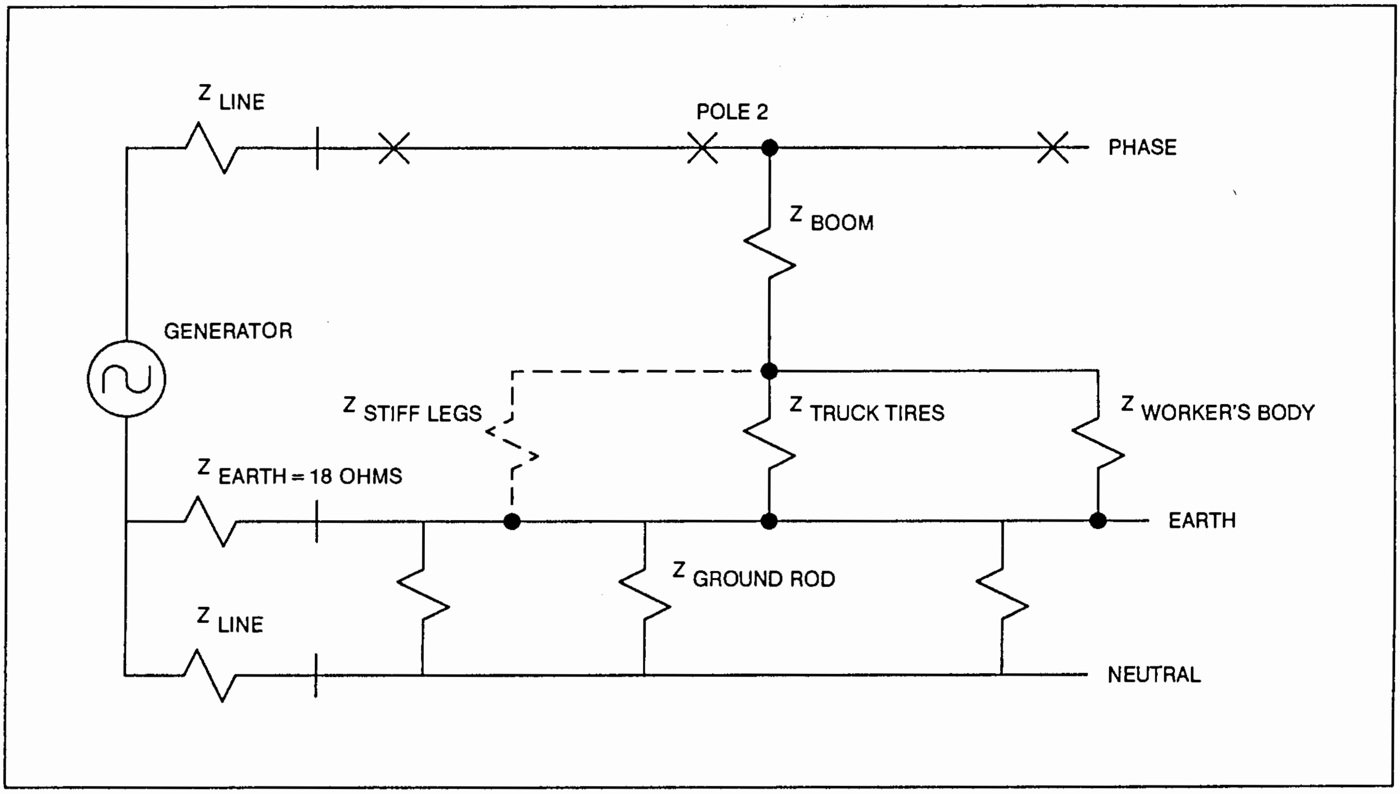

Figure 1 Test Series 1

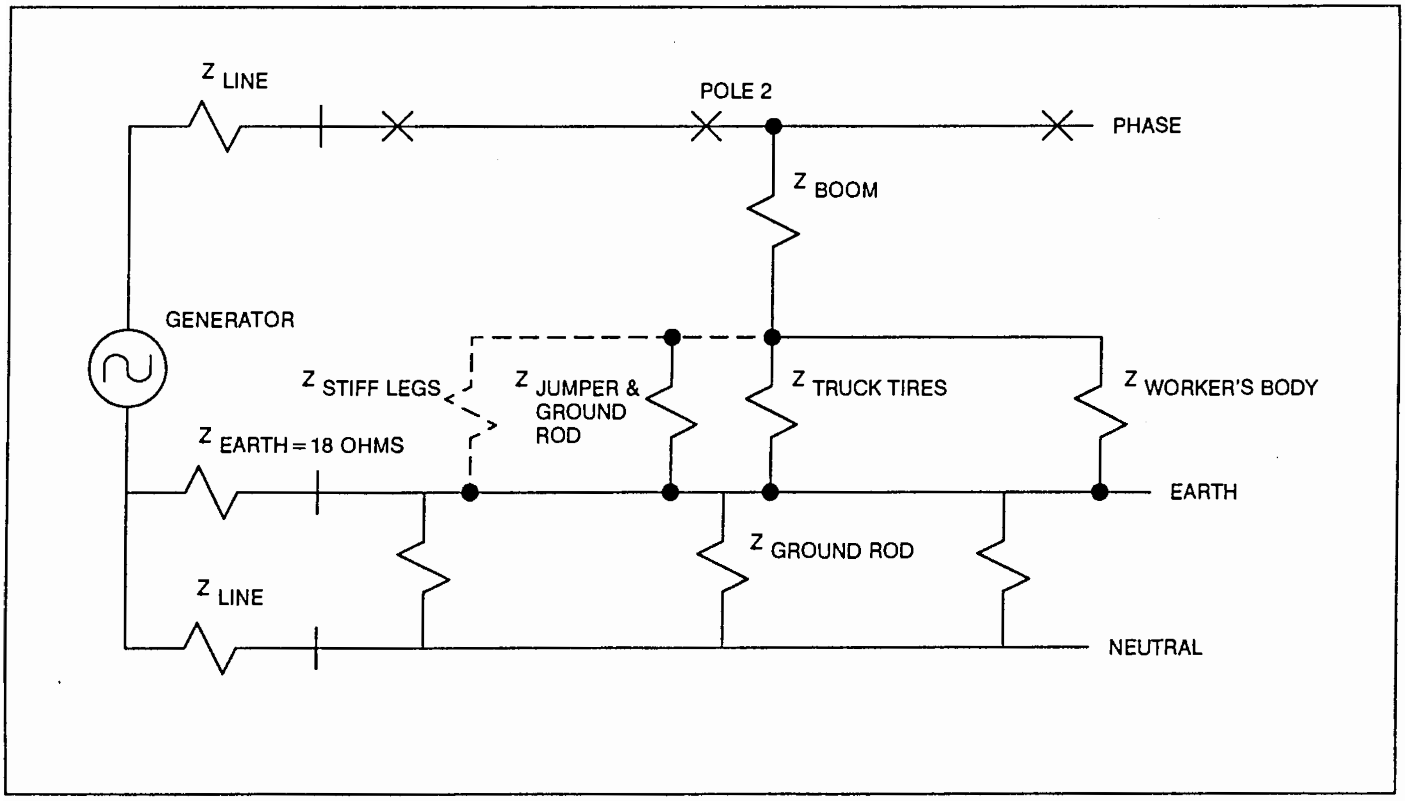

Figure 2 Test Series 2

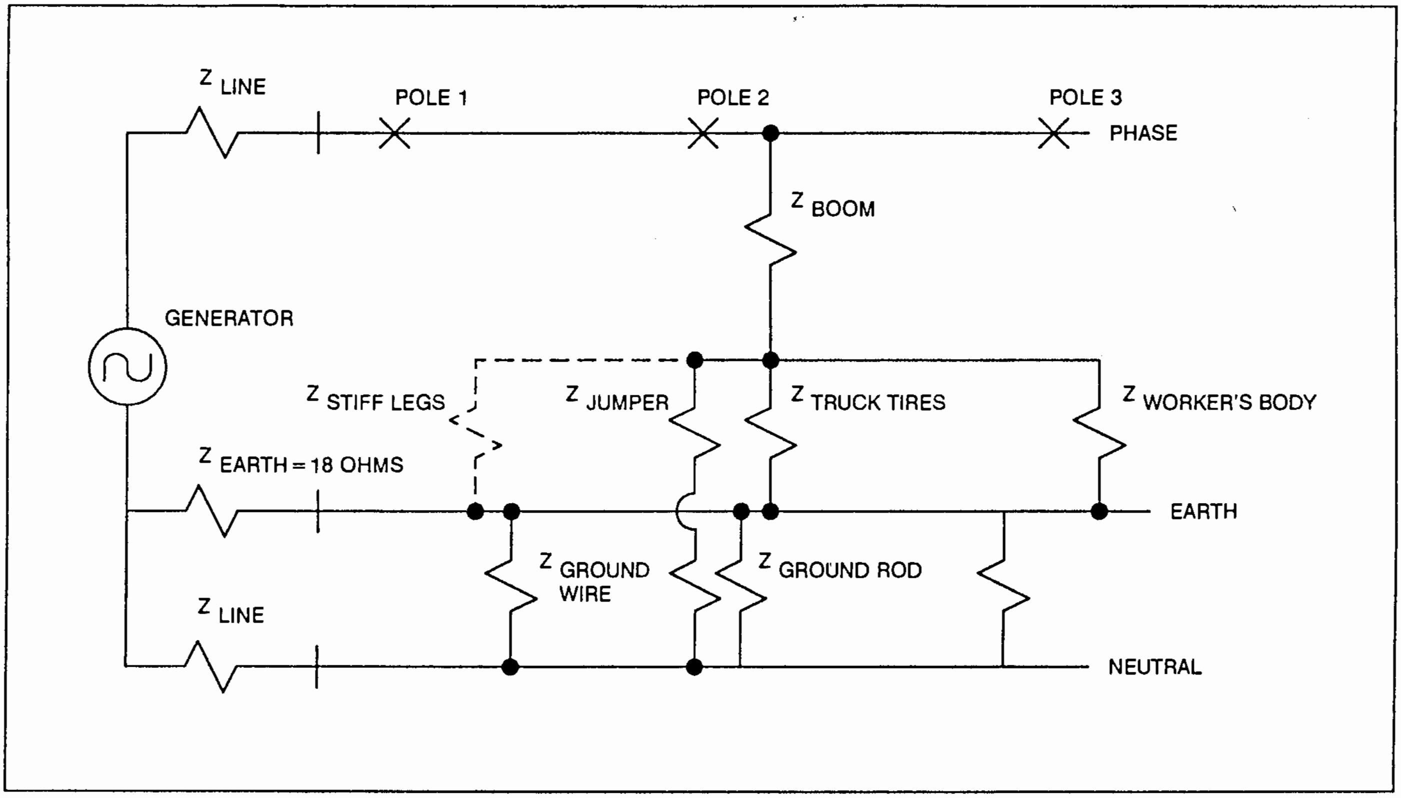

Figure 3 Test Series 3

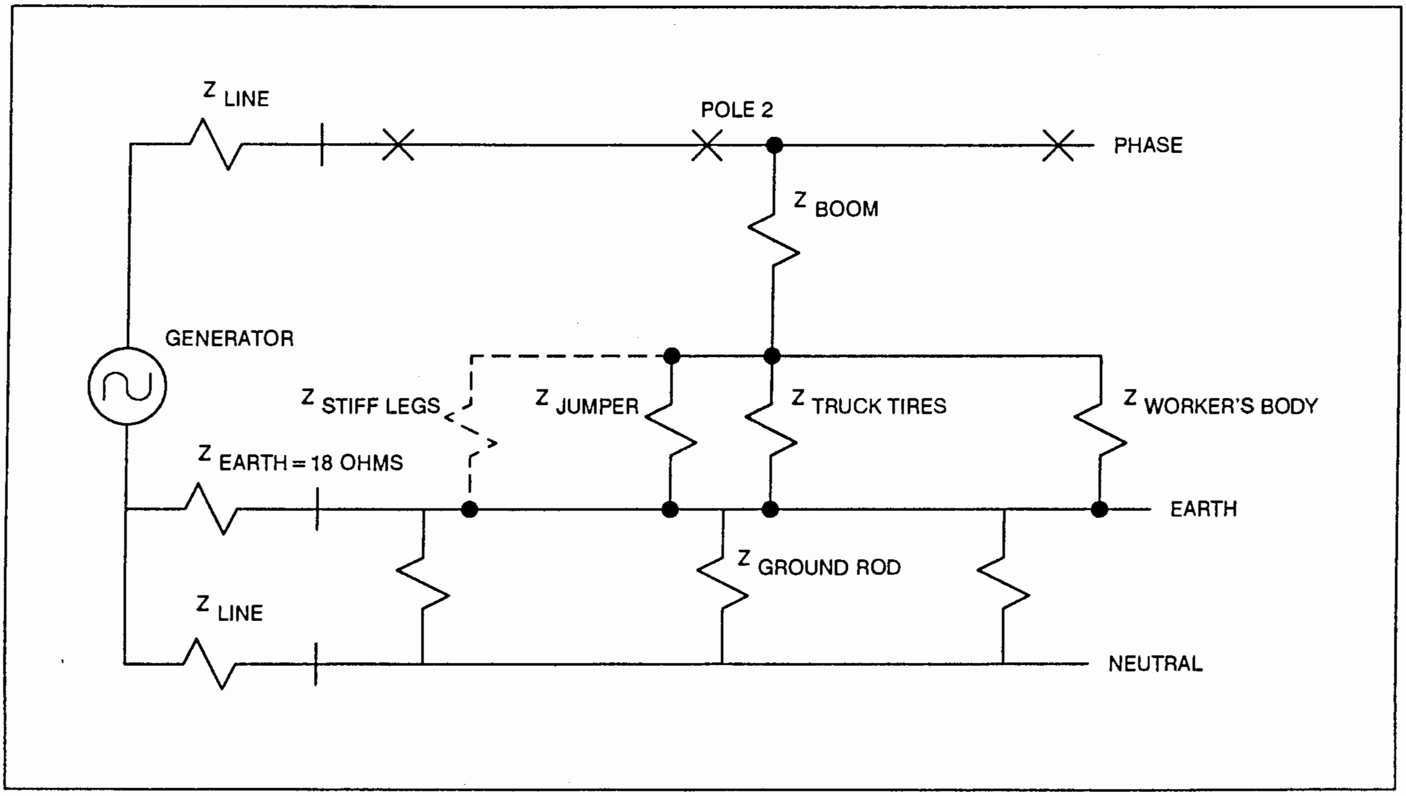

Figure 4 Test Series 4

REFERENCES

[1] IEEE Substation Committee, IEEE Guide for Safety in AC Substation Grounding, IEEE Standard 80-1986, New York, IEEE Press, 1986.

Brian Erga (M) was born in Bellingham, Washington, and received a B.S. degree in electrical engineering from the University of Washington in 1978.

He joined Puget Sound Power and Light Company in 1978. He has written work practices for five years, and has been involved in all types of personal protective grounding since 1985.