LONG DURATION GROUND ELECTRODE PERFORMANCE PROGRAM

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Abstract

Requirements for today's modern facilities dictate an elevated stringency in electrical grounding. This has led to the implementation of a long duration testing program focused on the evaluation of commonly used and commercially available ground electrodes. The program, conducted in two phases, will provide performance data over a period of at least ten years for a variety of soil and climatic conditions. Test results from Phase 1 of the program, completed at the end of 1997, are presented. Results include 19 different types of electrodes at five sites. The program for Phase 2 is discussed.

Introduction

A test program is being conducted in North America to evaluate the long-term performance of numerous types of ground electrodes in a variety of soil conditions. The need for long term performance data of commercially available ground electrodes is essential to engineers and designers of electrical ground systems to enable them to provide designs that will be reliable and effective for the long life of the installation. The need for an effective ground has been recognized for decades by power utilities, but the emergence of electronics has resulted in the increase in the requirements for power and lightning ground systems for equipment used in wireless telecommunications, data processing and other commercial installations. Modern electronic devices are highly susceptible to the effects of electronic disturbances transmitted over power and data lines. The performance of the devices used to protect electronic equipment, particularly transient voltage surge protection devices, are highly dependent on the existence of an effective low impedance ground system.

The objective of the test program is to evaluate the performance and physical integrity over time of the electrodes, as determined by resistance measurements, under varying soil conditions including geological, moisture content and temperature. The type of connection used to attach the ground conductor (test lead) to the ground electrode is also under evaluation.

The program was initiated in 1992 by a small group of electrical inspectors, members of the International Association of Electrical Inspectors, in Clark County, Las Vegas, Nevada, USA. The test program was originally planned to last five to ten years. Four years into the program, the local inspector group could no longer sponsor the program and enlisted The National Fire Protection Research Foundation (NFPRF) to manage the program. The NFPRF then invited interested companies and organizations to join and fund the project as a Technical Advisory Committee (TAC) to the project, now called the National Electrical Grounding Research Project (NEGRP). With this new organization, the test program has continued at the Nevada sites (Phase 1) and is expanding to include several new sites (Phase 2) being installed across North America. The authors are members of the TAC.

Approach

The electrodes tested in the program fall into three basic categories. The first are NEC® [1] required electrodes, the second are proprietary electrodes, and the third contain electrodes not required by the NEC nor are proprietary in nature. Table 1 describes the electrodes used in both Phase 1 and Phase 2. Phase 2 of the program has some electrodes that were not included in Phase 1, and a number of electrodes evaluated in Phase 1 of the program were not included in Phase 2. Test sites have been selected to provide a variety of different soil and climatic conditions. Phase 1 of the program includes five test sites in the Las Vegas valley area of Nevada. Phase 2 of the program includes continued testing at four of the five Phase 1 sites and an additional five sites across the United States. The nature of the soil at each site is evaluated prior to inclusion into the test program.

Phase 1 of the test program included from 17 to 19 different grounding electrodes installed in similar schemes at five different sites in Nevada. Samples R and S were only installed at one and two of the five sites respectively. Two samples for each electrode under test were installed at each site. The electrodes tested in Phase 1 had two test leads attached, one with a mechanical bolted connector and one with an exothermically welded connection. The test leads used are 13.3mm^2 (#6 AWG) THW insulated copper wire. The leads from each electrode are routed through conduit to a centralized pull box where they are attached to individual terminals to facilitate ground impedance readings. At no other location is an individual electrode bonded to another electrode. Figure 1 shows a typical Phase 1 site layout. The distance maintained between adjacent electrodes was 1.5m. In Phase 2 of the program, a third test lead was added, attached with a compression connection. Figure 2 shows a typical Phase 2 site layout. The minimum separation distance of electrodes in Phase 2 is 3m.

Apparent soil resistivity measurements are made using the equally spaced Four-Point Method [2]. The Three Point Fall of Potential Method [2] is used to measure the ground impedance of each electrode tested. The apparent soil resistivity and ground impedance are measured on a monthly basis at each site. Permanent test probes are installed to facilitate these measurements. The probes for the ground impedance measurements are installed at a fixed distance from the pull box. At each site, the current probe is installed at a distance of 30.5m and the potential probe is installed at 18.9m. The probes for the resistivity measurements are installed at equal distances of 3m. A number of different earth test instruments have been donated and used during the program. Each instrument is factory calibrated and readings are periodically duplicated with other instruments to verify the accuracy of the readings [3]. The instruments utilize a test frequency below 160 Hz.

Additional data will be taken for Phase 2 of the program. It will include temperature and moisture at several depths within the soil. Side studies have also been added to Phase 2 that include corrosion evaluation of discrete ground electrodes.

Results and Discussion

The Phase 1 sites varied in soil type and moisture content. Table 2 lists the installation date, soil description, and the high, low, and average soil resistivities through 1997.

The (USA) National Electrical Code [1] requires a single electrode to be 25 ohms or less or a second electrode must supplement it. Therefore, 25 ohms was considered a pass/fail indicator. Other codes and guides NESC [4] and IEEE [5] do not give a maximum electrode resistance, but rather a system performance requirement.

Table 3 and Table 4 list the results of the ground resistance measurements for all the Phase 1 electrodes. Presented are the average resistance values based on the monthly values sampled over the duration of the five year program. In addition, the highest and lowest resistance values measured are also presented.

Electrode resistance readings through December 1997 for Phase 1 indicate that some electrodes were not capable of meeting the 25 ohm resistance criteria. As a result, a number of these electrodes will not be included in the Phase 2 installations. Future readings will indicate if a trend toward resistance increase is taking place for some or all of the electrodes. Of all the electrodes tested in Phase 1, only one electrode, E did not have at least one resistance reading over 25 ohms at any of the five sites over the test period. In addition, the E electrode exhibited the most stable resistance values of all the electrodes tested for all five sites, based on the deviation between minimum and maximum resistance values. The greatest deviation in the resistance of the E electrode occurred at the Balboa site, where the resistance measurements ranged between 12.2 and 23.0 ohms (Table 4).

The three most effective electrodes for grounding in high resistivty soil, based on average resistance values measured at the Balboa site were the E, L, and R electrodes. All three electrodes are proprietary. All three electrodes were installed in 229mm (9in) diameter augured holes. The E electrode is a 2.4m (8ft) long copper-bonded ground rod encased in ground enhancement material manufactured by Erico Inc. with the trade name GEM™. Electrodes L and R are categorically considered electrolytic (chemical type) electrodes, in that they leach salts into the surrounding soil to lower the resistivity of the adjacent soil. The L electrode is a vertical 3.0m (10ft) long chemical type electrode manufactured by Lyncole XIT Grounding with the trade name of XIT. The R electrode is a vertical 2.4m (8ft) long chemical type electrode manufactured by LEC Inc. with the trade name of Chem-Rod®.

Figure 3 shows the resistance readings over the test period for the two most effective electrodes E and L, installed at all five test sites. The E electrode is the 2.4m long copper-bonded ground rod encased in GEM (ground enhancement material). ERICO GEM, is a very low resistivity material (0.12 ohm-meter or less) that is either installed dry (and allowed to absorb moisture from the surrounding earth) or premixed in slurry (similar to concrete). It is then poured into an augured hole of given diameter with a standard copper-bonded ground rod centered in the hole. The GEM sets up permanent like concrete and does not leach any compounds into the surrounding soil. The L electrode consists of a 54mm diameter, thin wall copper tube, filled with salts, capped at both ends and with holes at the top and the bottom of the electrode. The electrode is installed in an augured hole and back-filled with a bentonite clay type product to just below the top holes. A protective cap is placed over the top of the electrode. The manufacturer claims that the salts absorb moisture from the air and changes in the atmospheric pressure cause a pumping action forcing the salt laden moisture out of the bottom holes and into the earth.

The three least effective electrodes, based on performance at the highest resistivity site (Balboa), are G, K, and Q. Figure 4 shows the graph of the resistance values of these three electrodes at both the highest resistivity site, Balboa, which had the highest average resistivity of 93.6 ohm-m, and Pawnee, which had the lowest average resistivity of 15.0 ohm-m.

The first Phase 2 test site was installed in Staunton, Virginia, during the summer of 1997. There are three additional sites scheduled for installation during 1998, they are located in Nothbrook, Illinois, Dallas, Texas, and Poughkeepsie, New York.

Conclusion

Several electrodes commonly used and even specified as acceptable electrodes by several code bodies have proven to be ineffective at meeting the 25 ohm requirement and are acceptable only in the lowest resistivity soils. In very high resistivity soil, only the proprietary electrodes, vertical chemical type (L, S) and the vertical ground rod encased in GEM (E), provide an excellent alternative to large number and/or deep driven ground rods when system resistance below 25 ohms is required. The E electrode demonstrated the most stable resistance values of all the electrodes tested in the five test sites from Phase 1 of the program.

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References

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[2] ANSI/IEEE Std 81-1983, “IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System,” Institute of Electrical and Electronic Engineers, pp12-24, 1983.

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[5] ANSI/IEEE Std 80-1986, “IEEE Guide for Safety in AC Substation Grounding,” Institute of Electrical and Electronic Engineers, 1986.

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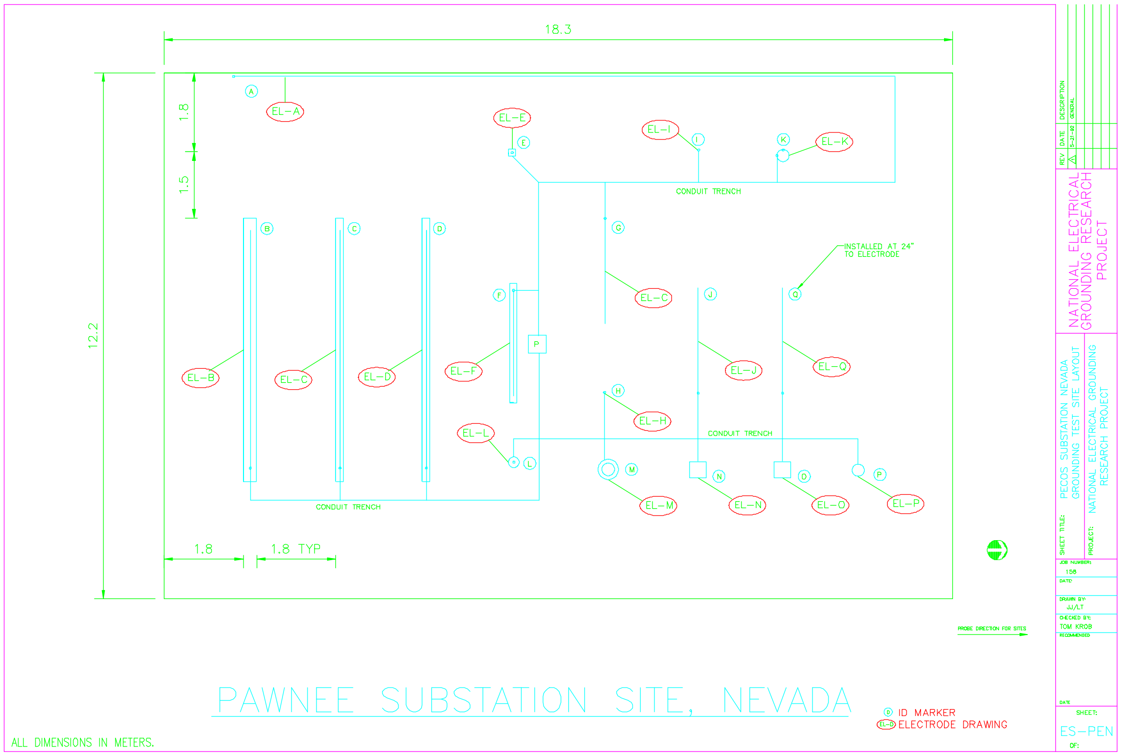

Fig. 1. Typical site layout for Phase 1 installations.

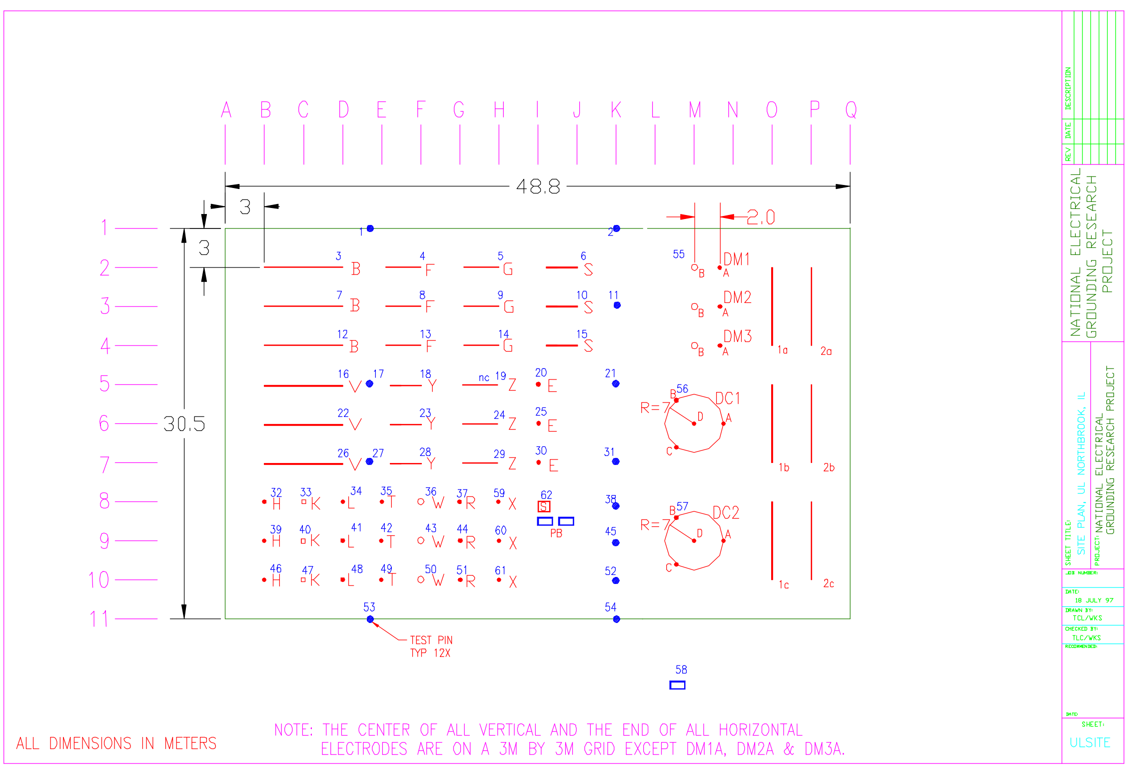

Fig. 2 Typical site layout for Phase 2 installations.

Fig. 3. Resistance graphs of the two most effective electrodes at each site from installation thru end of 1997.

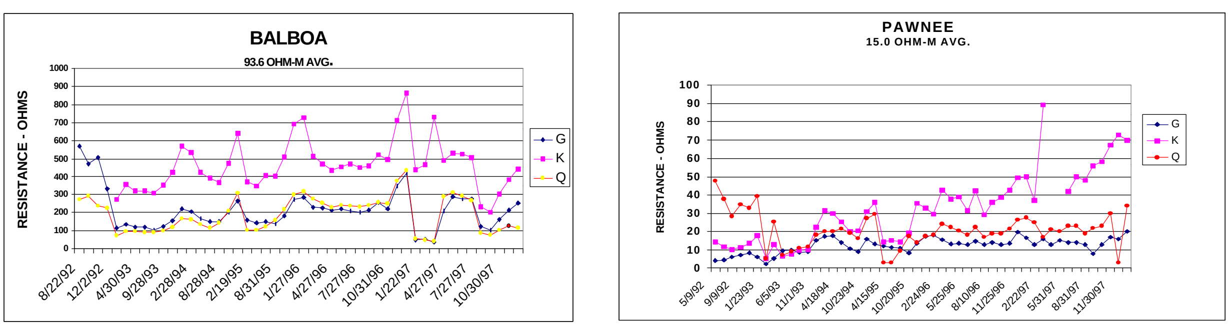

Fig. 4. Resistance graphs of the three least effective electrodes at the Balboa site which has the highest resistivity and the same electrodes at the Pawnee site which has the lowest resistivity.

Table 1. List of Electrodes used in Phase 1 and Phase 2.

Item	Description	Used In Phase	
		1	2
A	#2 AWG (33.6mm^2) Cu x 50 ft (15m) in 12 in (305mm) sand in a trench.	X	
B	½” (12mm) horizontal steel rebar concrete encased in a trench.	X	X
C	#4 AWG (21mm^2) horizontal solid Cu x 25 ft (7.6m) encased in ground enhancement material in a trench.	X	
D	#4 AWG (21mm^2) horizontal solid Cu x 25 ft (7.6m) encased in concrete in a trench	X	
E	5/8” x 8’ (16mm x 2.4m) vertical copper bonded rod in a 9 in (230mm) diameter hole encased in ground enhancement material.	X	X
F	5/8” x 8’ (16mm x 2.4m) horizontal copper bonded rod encased in ground enhancement material in a trench.	X	X
G	5/8” x 8’ (16mm x 2.4m) horizontal copper bonded rod in a trench at 30 in (760mm).	X	X
H	5/8” x 8’ (16mm x 2.4m) vertical copper bonded driven rod.	X	X
I	¾” x 10’ (19mm x 3m) vertical galvanized steel driven rod.	X	
J	¾” x 10’ (19mm x 3m) horizontal galvanized steel rod in a trench at 30 in (760mm).	X	
K	12” x 12” (305mm x 305mm) copper plate buried 30” (610mm).	X	
L	10 ft (3m) vertical chemical type electrode (XIT).	X	X
M	24 in. (610mm) square x 30 in. (760mm) reinforced concrete.	X	X
N	#4 AWG (21mm^2) x 20 ft. (6 m) coiled copper wire encased in concrete in trench.	X	
O	#4 AWG (21mm^2) x 20 ft. (6 m) coiled copper wire encased in ground enhancement material in trench.	X	
P	Copper “butt plate” on wooden pole with #6 AWG (13mm^2) spiral wrap.	X	
Q	1/2” x 8’ (16mm x 2.4m) horizontal copper bonded rod in a trench at 30”.	X	X
R	8 ft (2.4m) vertical chemical type electrode (Chemrod).	X	X
S	8 ft (2.4m) horizontal chemical type electrode (XIT).	X	X
T	¾” (19mm) x 8 ft (2.4m) vertical pipe.		X
V	4/0 AWG (107 mm^2) x 20 ft (6m) copper in a trench.		X
W	Grounding cage of 6 each 5/8 (16mm) x 8 ft (2.4m) rods encased in concrete.		X
X	5/8” (16mm) x 8’ (2.4m) stainless steel vertical driven rod.		X
Y	8 ft (2.4m) horizontal chemical type electrode (Chemrod).		X
Z	#6 AWG (13mm^2) wire mesh on 4 in. (102mm) centers, 2 ft (0.6m) x 8 ft (2.4m) in trench.		X

Table 2. Installation dates, resistivity values, and soil descriptions for Phase 1 sites.

Site	Date Installed	Resistivity, Ohm-meters			Soil Description
		High	Low	Avg.	
Balboa	Aug 92	134	46.0	83.2	Gravel, loosely compacted, normally dry
Lone M.	Jun 92	33.7	19.2	24.0	Sand & silt, normally dry
E. Charleston	Dec 92	34.5	11.5	22.1	Sand & small rocks, signs of ground salts or sulfides
Pecos	Dec 92	25.3	11.5	18.5	Dry sand and silt to 6 ft., wet clay to 12 ft.
Pawnee	May 92	16.9	7.7	13.2	Silt & clay, high water table

Table 3. Phase 1 electrodes at the three mid-range site and their resistances from installation to Dec. 1997. Resistances values are in ohms.

Electrode	Sites								
	Pecos (18.7 Ω-m)			East Charleston (20.8 Ω-m)			Lone Mountain (22.1 Ω-m)		
	Avg.	High	Low	Avg.	High	Low	Avg.	High	Low
A	23.0	***48.1***	4.9	***34.2***	***81.1***	10.5	14.4	***28.0***	2.3
B	16.0	***32.0***	4.7	14.1	***27.8***	4.6	8.4	15.0	2.4
C	10.2	17.4	3.2	***35.0***	***66.4***	6.0	5.2	13.0	1.6
D	***34.1***	***69.0***	5.2	***96.6***	***554***	9.1	10.3	18.4	3.0
E	5.0	7.0	2.0	4.0	5.8	3.0	3.8	6.1	2.5
F	5.4	8.6	2.5	7.9	15.2	4.0	4.5	8.0	2.0
G	24.3	***44.9***	5.6	***48.1***	***78.0***	11.5	***80.8***	***311***	5.8
H	6.5	11.0	3.0	12.0	20.0	6.2	6.6	11.0	2.7
I	8.3	12.0	4.5	6.4	15.0	4.7	7.0	12.0	3.5
J	12.4	20.4	4.6	22.6	***76.0***	10.9	11.2	***36.4***	3.6
K	***145.2***	***303***	7.4	***68.8***	***518***	11.5	***81.7***	***420***	5.1
L	6.3	11.7	2.2	13.5	***49.3***	5.1	20.3	***54.0***	2.5
M	24.6	***43.0***	4.9	17.8	***154.2***	9.4	***33.0***	***74.6***	4.2
N	***33.4***	***51.3***	4.8	***65.2***	***1908***	10.4	14.3	22.0	3.8
O	***26.9***	***46.8***	4.7	4.3	13.0	2.6	7.5	15.4	2.3
P	8.2	19.5	4.5	10.4	17.0	7.1	15.8	24.6	3.2
Q	***26.2***	***67.7***	4.5	***37.9***	***81.8***	11.5	***27.3***	***112***	4.2
R	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S	17.3	***32.4***	3.5	N/A	N/A	N/A	N/A	N/A	N/A

All values over 25 ohms are shown in **bold**.

Table 4. Phase 1 electrodes at the highest and lowest resistivity sites and their resistances from installation to Dec. 1997. Resistances values are in ohms.

Electrode	Sites					
	Pawnee (15.0 Ω-m)			Balboa (93.6 Ω-m)		
	Average	High	Low	Average	High	Low
A	3.6	6.5	0.5	***60.0***	***115.0***	***25.5***
B	5.7	9.0	0.6	***34.4***	***62.0***	19.7
C	***45.2***	***301***	1.1	***29.7***	***86.5***	13.0
D	8.5	14.0	5.1	***36.3***	***60.4***	24.5
E	2.5	3.1	1.6	17.5	23.0	12.2
F	2.9	5.0	1.6	***33.9***	***76.9***	20.0
G	12.9	20.0	2.3	***213.0***	***569***	***37.0***
H	8.6	13.0	2.2	***49.1***	***71.0***	***33.5***
I	3.5	6.0	1.9	***32.8***	***40.0***	22.0
J	6.0	10.0	2.5	***154.7***	***546***	***62.0***
K	***49.4***	***420***	5.2	***606.4***	***3097***	***202.0***
L	5.2	6.7	3.5	24.6	***304.0***	13.2
M	15.1	21.0	9.3	***75.6***	***123.0***	***41.8***
N	14.9	23.0	9.7	***74.9***	***119.9***	***43.0***
O	6.5	9.0	4.7	***57.9***	***100.0***	***27.0***
P	9.9	22.4	6.1	***72.1***	***110.0***	***54.3***
Q	19.4	***39.4***	3.0	***189.1***	***443***	***41.0***
R	N/A	N/A	N/A	15.0	***99.8***	8.4
S	4.5	***42.0***	1.9	N/A	N/A	N/A

All values over 25 ohms are shown in **bold**.