Impressed Current Cathodic Protection System Design

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Impressed current cathodic protection (ICCP) systems are used throughout the world to provide cathodic protection for pipelines, ship hulls, offshore production platforms, water and wastewater treatment equipment, tank farms, and of course, underground storage tank systems. The principle advantage of impressed current cathodic protection is its much greater output capacity as compared to galvanic anode systems. Therefore, whenever corrosion protection is desired for very large, poorly coated, or bare structures, impressed current is often the system choice.

ICCP systems require the use of an external DC power supply that is usually energized by standard AC current. There are many different anode materials available for use and most are capable of providing 100 to 10,000 times the amount of current provided by a galvanic anode. For existing underground pipelines, on-grade storage tanks, cast and ductile iron water pipe and buried storage tank systems, the use of impressed current cathodic protection is often mandatory as the coatings provided on these older structures is usually severely deteriorated or non-existent.

A good example of this is existing underground storage tank systems (UST's). The cut-back asphaltic coatings commonly used on the older tanks was easily dissolved by spilled gasoline and other hydrocarbons and they are almost 100% bare after a few years of service. Therefore, the amount of metal surface exposed to the corrosive environment is substantial and the amount of cathodic protection current required is typically in excess of 4 to 8 amperes for a typical service station facility. To generate a similar amount of current from a galvanic anode system, more than 100 magnesium anodes would typically be required. Thus, it is usually not practical or economic to use galvanic anodes to protect large, bare underground structure.

ADVANTAGES AND LIMITATIONS

There are several important advantages to using impressed current anode systems:

- Unlimited current output capacity. – The amount of current that can be designed into an impressed current system can be from a few amperes to as much as several hundred amperes. The amount of current available will be a function of the number of anodes provided, the rectifier voltage and amperage capacity and the soil (electrolyte) resistivity in which the anodes are installed.

- Adjustable output capacity. – The output of the rectifier power supply is easily adjusted to accommodate either changes in circuit resistance or current requirement. They can be provided with automatic control circuitry to eliminate the need for manual adjustment.

- Lower cost per ampere of cathodic protection current. Galvanic anode systems are significantly more expensive where amperes rather than milli-amperes of total current are required.

There are several significant disadvantages to the use of impressed current cathodic protection.

- They are more costly if only a few milliamperes of current are required to protect a small or very well coated structure. Impressed current systems typically have a base cost of several thousand dollars. If only a few galvanic anodes are required for protection of a specific structure, this will often be the more economic choice.

- Impressed current systems have a higher maintenance cost. Impressed current systems are inherently more prone to failure. Switches can be turned off and fuses can blow. Thus, the system needs to be monitored more frequently and some repair may be required once every several years.

- Impressed current systems may create stray current corrosion on other nearby structures. This is an inherent potential problem with any impressed current system. This can sometimes be minimized through the use of distributed anode designs where the anodes are placed nearby the protected structures.

AVAILABLE ANODE MATERIALS l

There are a number of commonly used impressed current anode materials that can be used, depending on the environment and congestion in the area where they will be installed. For example, both graphite and hi-silicon cast iron anodes are commonly used for protection of pipelines. For UST systems, precious metal oxide coated titanium rod anodes are generally preferred because of their small diameter and light weight.

There are numerous anode sizes and configurations available from various manufacturers. Today, these are almost always pre-packaged in metallic canisters containing performance enhancing, high conductivity coal or calcined petroleum coke breeze. Typical anode types, sizes, weights and canister dimensions for ICCP systems include the following:

Anode Type	Anode Size (Inches)	Anode Wt. (Lbs)	Canister Size (Inches)	Max. Amps for 20 Yr. Life
HSCI Tube	1.1 x 9	1	3 x 18	0.1
HSCI Tube	2.0 x 9	5	4 x 18	0.4
HSCI Rod	1.5 x 60	25	6 x 84	1.0
HSCI Rod	2.0 x 60	44	6 x 84	2.0
HSCI Tube	2.2 x 42	23	8 x 60	1.5
HSCI Tube	2.2 x 84	46	8 x 90	3.0
Graph. Rod	3.0 x 30	13	6 x 42	0.4
Graph. Rod	3.0 x 60	27	6 x 84	0.8
Graph.Tube	3.0 x 30	13	8 x 42	0.5
Graph.Tube	3.0 x 60	27	8 x 84	1.0
Graph.Tube	4.0 x 40	35	10 x 48	2.0
Graph.Tube	4.0 x 80	70	10 x 90	4.0
PMO-Ti Rod	1/8 x 24	<1	3 x 30	0.5
PMO-Ti Rod	1/8 x 48	<1	3 x 60	1.0
PMO-Ti Rod	1/4 x 24	<1	3 x 30	1.0
PMO-Ti Rod	1/4 x 48	<1	3 x 60	2.0
PMO-Ti Rod	1/8 x 72	<1	3 x 84	1.5
PMO-Ti Rod	1/4 x 72	<1	3 x 84	3.0

The type and number of anodes required is dictated by user experience as well as the current required to protect the structure, the anode life desired, and the resistivity of the soil in which they will be installed. Due to the complexity of designing an impressed current system, the services of a qualified Corrosion Engineer will almost always be required. Among the concerns which he must address are:

- Current Required – Generally the Corrosion Engineer will perform current requirement tests by installing temporary cathodic protection equipment and evaluating the effectiveness of increasing current output increments versus change in structure potentials achieved.

- Continuity – All metallic components that are to be cathodically protected by an impressed anode system must be electrically continuous. Other metallic components for which cathodic protection is not necessarily desired but which are in the immediate vicinity of the system anodes must also be made continuous. The Corrosion Engineer must locate and test all such metallic components for continuity. Where such continuity does not exist, electrically bonding in these components must be evaluated.

- Soil Resistivity – Essential to the design of impressed current anode systems is accurate measurement of the soil resistivity in the strata where the anodes will be located. The Corrosion Engineer normally measures the soil resistivity to a number of different depths in order to calculate the resistivity of each successive layer.
- Anode Location and Size – Impressed current anodes are typically installed at depths of 10 to 20 feet in augured holes. They are usually installed in banks on 10’ to 30’ center-to-center spacing with the first anode typically being placed 100’ to 500’ from the pipeline depending on the soil resistivity and the structure coating. To minimize stray currents in congested areas, they can be installed vertically in tandem down deep holes called “deep anode beds”. While this type system does significantly reduce the probability of serious stray current generation, it is a substantially more expensive type installation and has a higher incidence of failure.

  Another option is to distribute the anodes along the structure with each anode being placed 10’ to 20’ from the structure. This is occasionally done on large diameter bare pipelines and almost always done on UST tanks and piping where the anodes are distributed around the tank excavation and product piping. The anodes are generally distributed based on the current requirement testing and the individual current required for each metallic component to be protected.

  All of the resistance formulas previously provided in the "Galvanic Anode Cathodic Protection System Design" section of this manual equally apply to impressed current anodes. The graphs and charts provided on the pages following this narrative can be used to determine the total anode ground bed resistance for anodes pre-packaged in coke breeze contained by 3”, 4”, 6”, 8” & 10” diameter spiral seamed galvanized sheet metal tubes of various lengths. The tables provided are for anodes installed vertically in 1,000 ohm-cm soil resistivity with anodes spaced either on 10’ or 20’ center-to-center spacing. If the anodes are to be installed in 4500 ohm-cm soil, the anode circuit resistances shown should be multiplied by 4.5 since the total anode resistance is linearly related to the soil resistivity.

SHAPES, SIZES AND BACKFILL

As discussed above, both the diameter and length of the anode directly affect the anodes resistance in the earth. While increasing the anode diameter slightly reduces this resistance, increasing the anode length and number of anodes has a much more dramatic effect in reducing this resistance. All impressed current anodes are generally installed in a select backfill to enhance their useful life and reduce their contact resistance to earth. This select backfill is most commonly calcined petroleum coke breeze. The particle size and amount of material required are normally specified by the Corrosion Engineer. For the most commonly used underground anodes, the manufacturer normally pre-packages them in steel tubes with the specified coke breeze around the rod. When this packaged anode is installed, it is common practice to bore a vertical hole which is 2 to 3 inches greater in diameter to facilitate placing additional coke breeze around the anode canister after it is installed in the hole.

ANODE AND SYSTEM GROUND LEAD WIRES

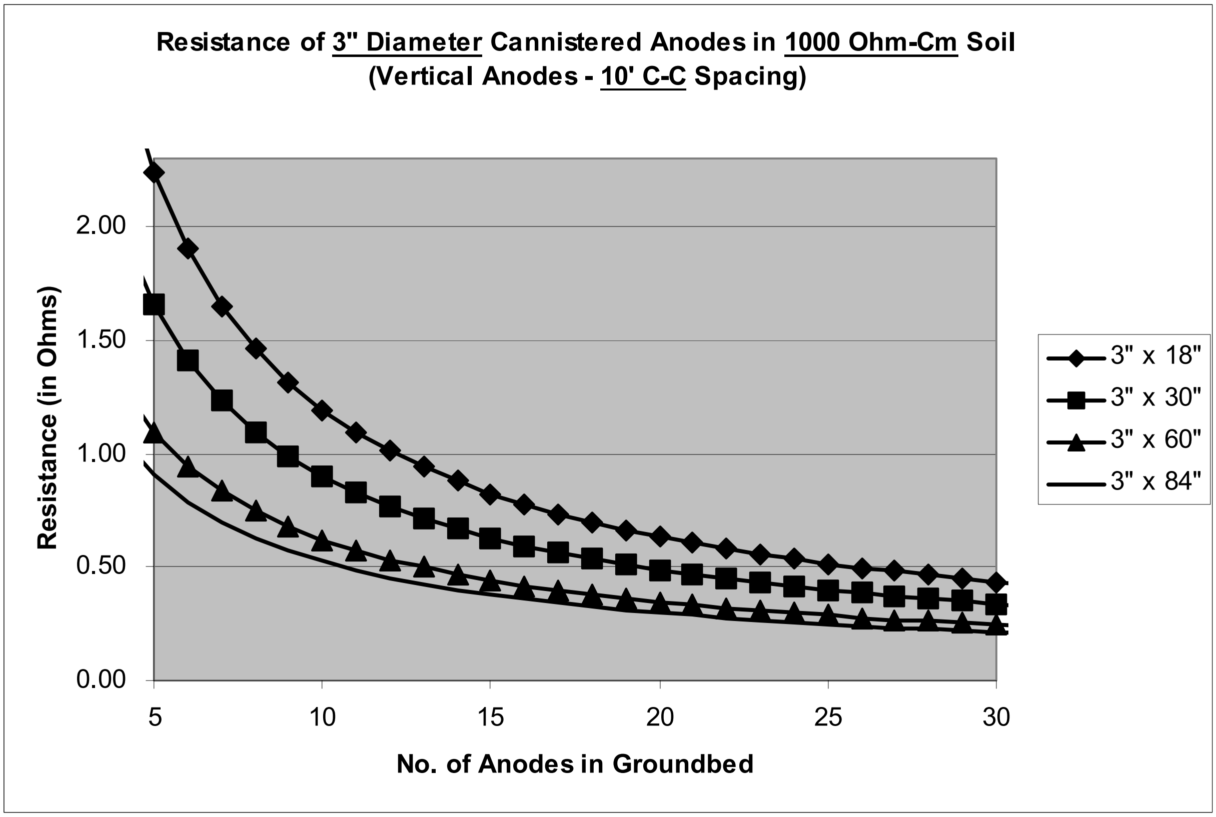
Anode Lead Wires – The insulation of the anode lead wires is critical to the long-term durability of the system. If any of the wire insulation is perforated, soil moisture will come in contact with the copper wire. This will cause the copper to corrode rapidly and failure will occur shortly thereafter. Since underground splices are a common point for such moisture ingress, they should always be avoided. Use of individual lead wires has the double benefit of eliminating the need for these splices while assuring that only one anode will become inoperative should its lead wire insulation be damaged during the installation process. The most common insulation provided for anode lead wires is High Molecular Weight, Low Density Polyethylene Type CP Cable. Other cables that are specified for more arduous situations incorporate Halar, Kynar and Hypalon insulations. The copper conductor is most commonly #8 AWG, 7 strand annealed copper.

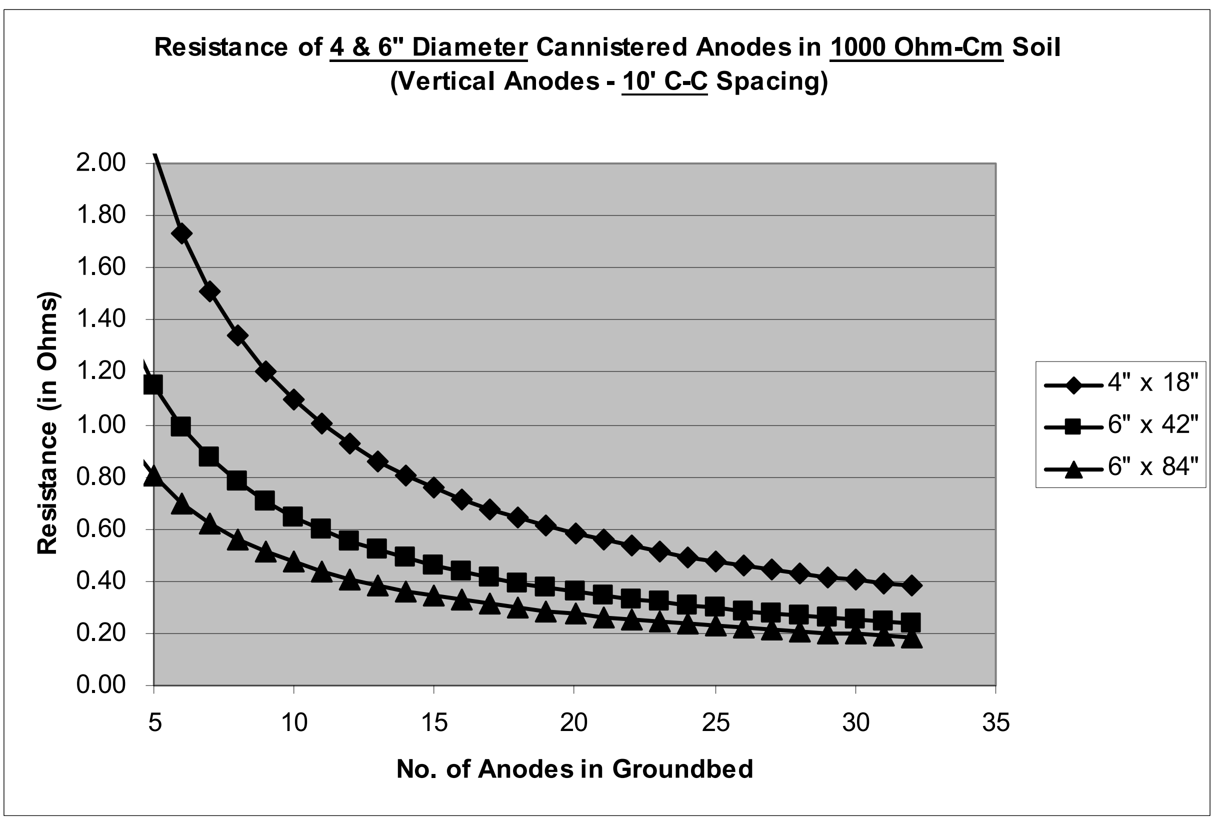
System Ground Wire – To complete the cathodic protection circuit, a ground wire must be connected from the structure to be protected to the rectifier power supply negative terminal. This connection is often made by thermite brazing of these wires directly to the metal structure or by using grounding clamps specifically designed for this purpose. (Thermite brazing should only be used where combustible gases or liquids are not in the brazing area). The Corrosion Engineer normally determines the size and wire insulation required.

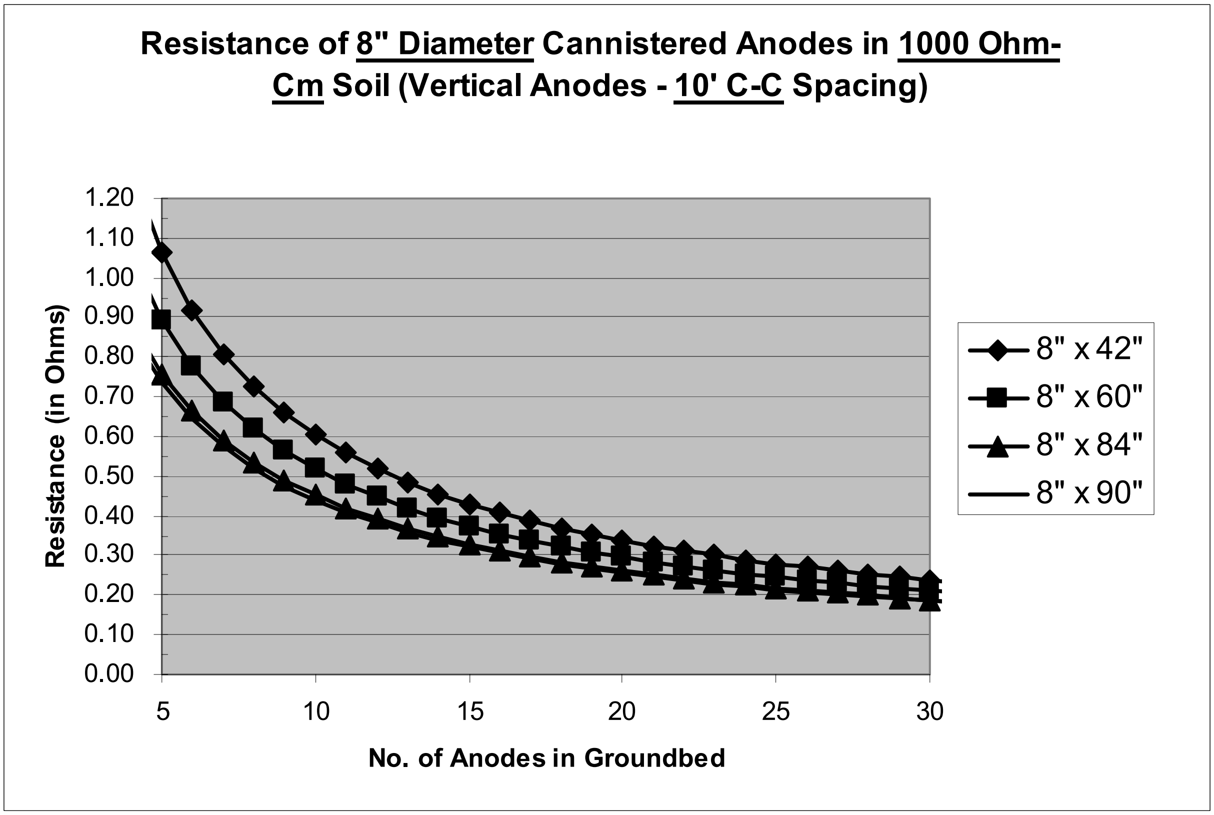
RECTIFIER POWER SUPPLY

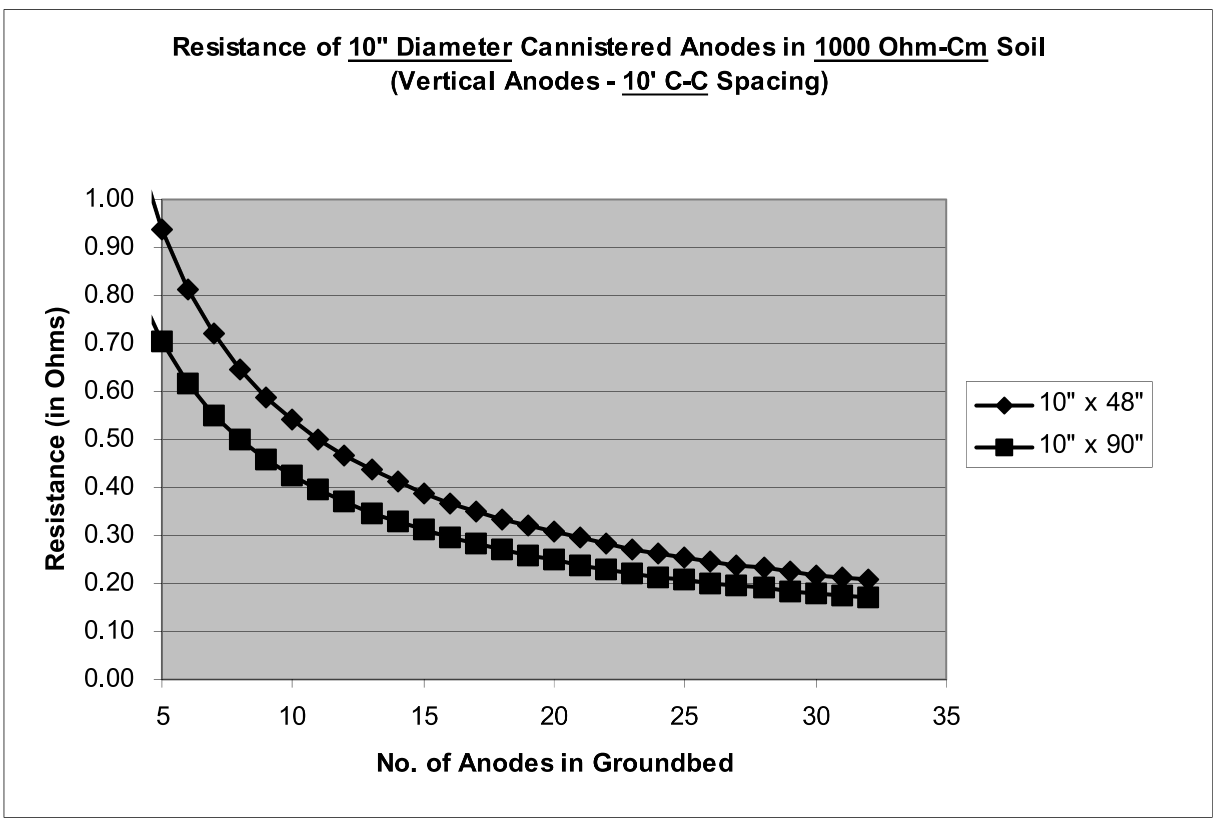
There are many options to be considered when selecting a particular power supply for a given cathodic protection system. Obviously the DC output, capacity and AC supply voltage have to be determined. In addition, the method of output control, cabinetry, monitoring devices, etc., also must be selected and clearly defined. This will be impacted by where the unit is to be installed and the frequency with which it can be regularly inspected. The Corrosion Engineer normally consults closely with the owner and/or operator in selecting the various options available.

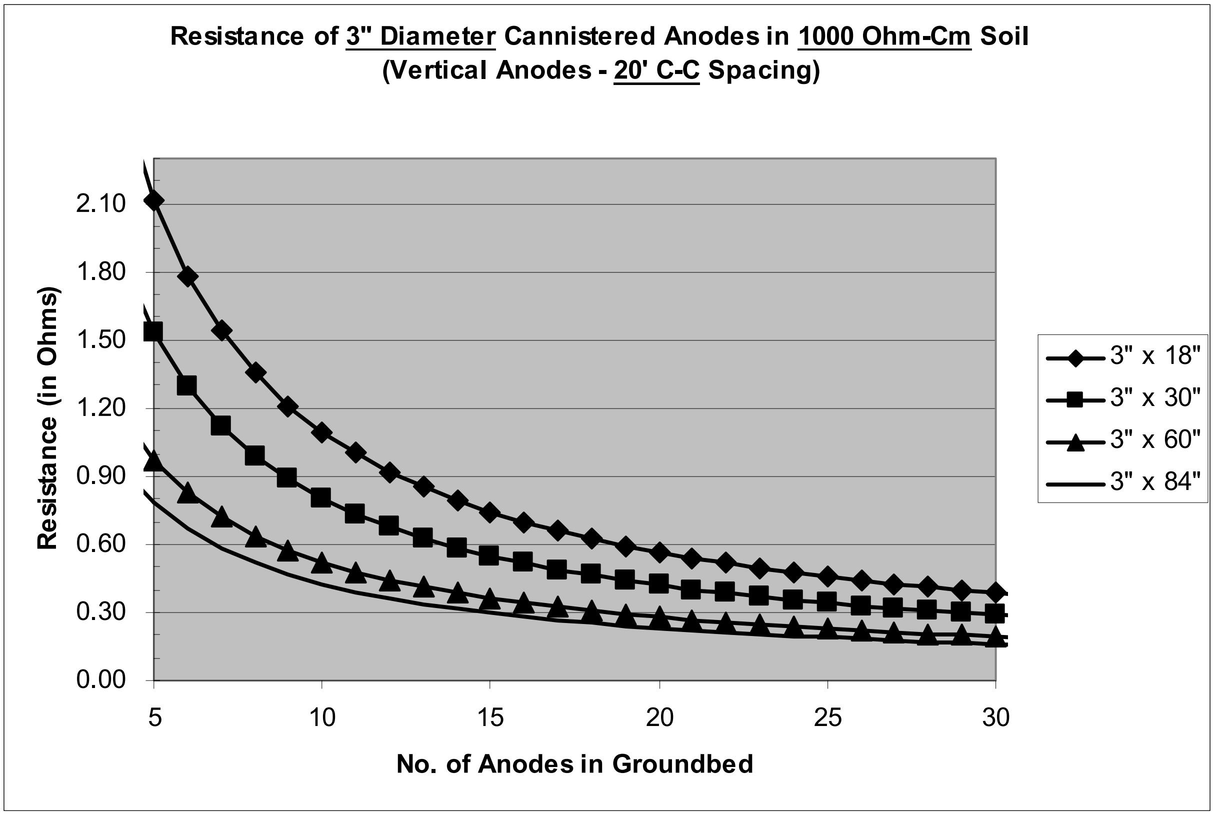
Some features which are suggested for incorporation into ICCP power supplies for underground applications are constant current control and remote monitoring with the ability to remotely request simultaneously interrupted potential readings from permanently installed reference electrodes. Alternatively, at the very least, “up time” meters that accumulate hours of operation at the desired protective level should be considered. Note that this is not just monitoring that the unit is operating, but rather that it is operating at the correct level (e.g. ±10% of current output set level). Unfortunately, most ICCP power supplies are provided simply with manual voltage adjustment and the output varies seasonally and ground moisture and temperature vary as well as with time as the anodes are consumed.

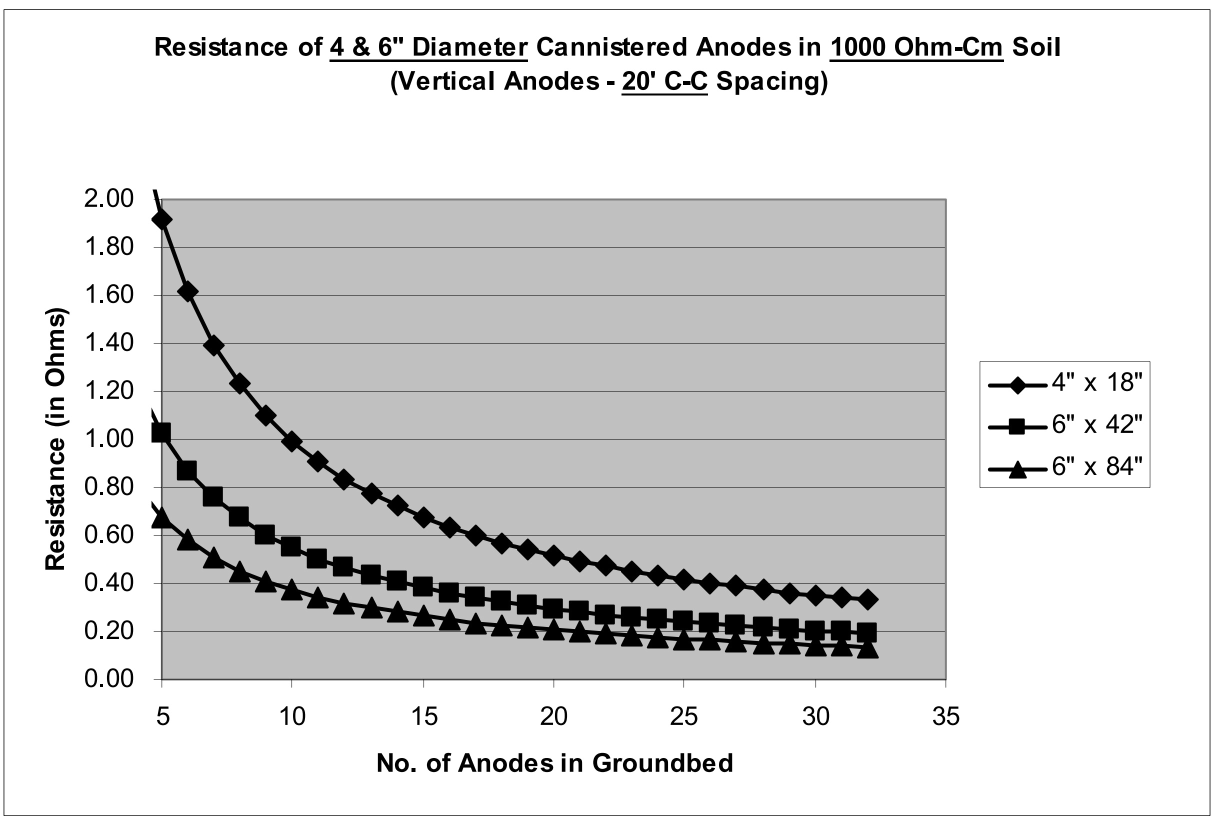

Resistance of 3" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil
(Vertical Anodes - 10' C-C Spacing)
Resistance (in Ohms)
2.00
1.50
1.00
0.50
0.00
5
10
15
20
25
30
No. of Anodes in Groundbed
3" x 18"
3" x 30"
3" x 60"
3" x 84"


Resistance of 4 & 6" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil
(Vertical Anodes - 10' C-C Spacing)
Resistance (in Ohms)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
5
10
15
20
25
30
35
No. of Anodes in Groundbed
4" x 18"
6" x 42"
6" x 84"

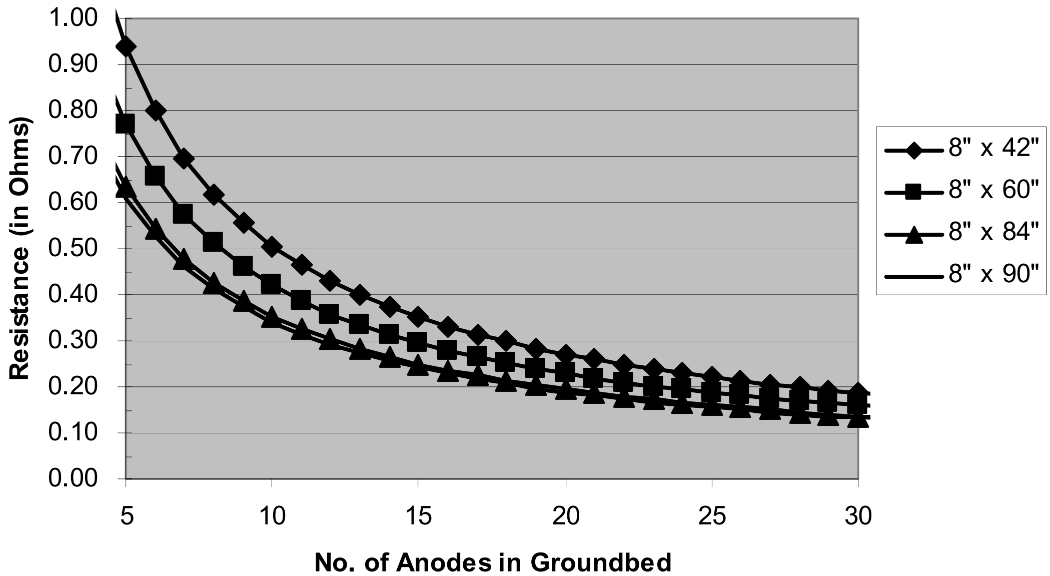

Resistance of 8" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)
Resistance (in Ohms)
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5
10
15
20
25
30
No. of Anodes in Groundbed
8" x 42"
8" x 60"
8" x 84"
8" x 90"


Resistance of 10" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)
Resistance (in Ohms)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5
10
15
20
25
30
35
No. of Anodes in Groundbed
10" x 48"
10" x 90"

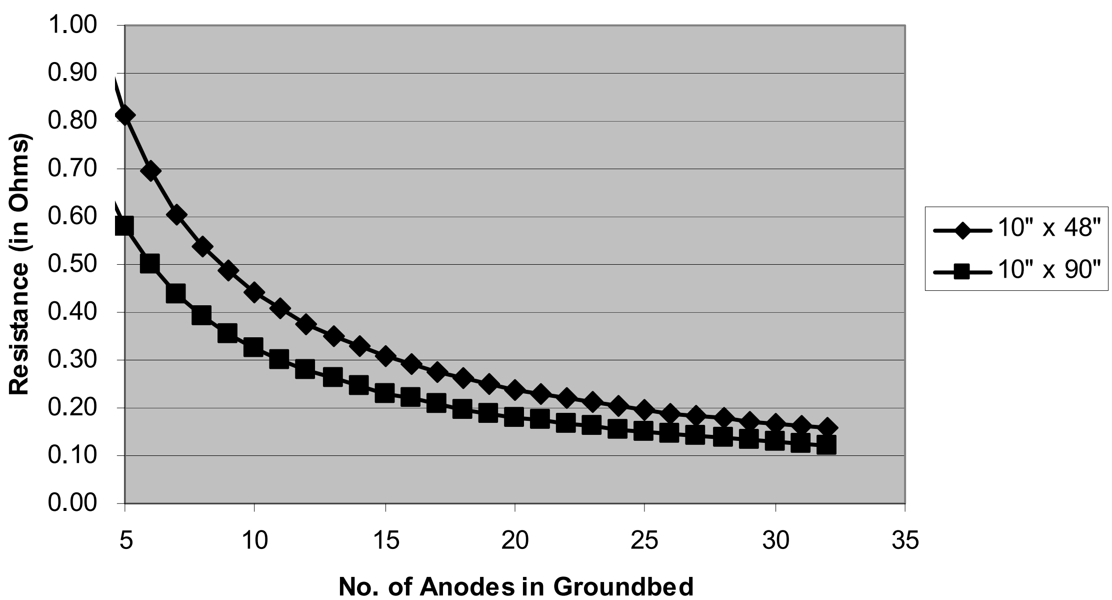

Resistance of 3" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil
(Vertical Anodes - 20' C-C Spacing)
Resistance (in Ohms)
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0.00
5
10
15
20
25
30
No. of Anodes in Groundbed
3" x 18"
3" x 30"
3" x 60"
3" x 84"


Resistance of 4 & 6" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil
(Vertical Anodes - 20' C-C Spacing)
Resistance (in Ohms)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
5
10
15
20
25
30
35
No. of Anodes in Groundbed
4" x 18"
6" x 42"
6" x 84"

Resistance of 8" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 20' C-C Spacing)



Resistance of 10" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 20' C-C Spacing)



Pre-Packaged Impressed Current Ceramic Anode Simplified Resistance and Current Output Calculations Based on Anode Cannister Size Only Computation Program by Bushman & Associates, Inc.

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Case No.: **Resistance of 3" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)**

Variables	Value	Value	Value	Value
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**	**1,000**
Anode Spec. Backfill Diameter (Inches)	**3**	**3**	**3**	**3**
Anode Spec. Backfill Length (Inches)	**18**	**30**	**60**	**84**
Anode Center-to-Center Spacing (feet)	**10**	**10**	**10**	**10**
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**
1	9.9726	7.0481	4.2463	3.2835
2	5.1278	3.6656	2.2646	1.7832
3	3.5594	2.5845	1.6506	1.3297
4	2.7445	2.0133	1.3129	1.0722
5	2.2421	1.6572	1.0968	0.9043
6	1.9001	1.4126	0.9457	0.7852
7	1.6516	1.2338	0.8335	0.6960
8	1.4625	1.0970	0.7467	0.6264
9	1.3136	0.9887	0.6774	0.5704
10	1.1933	0.9008	0.6206	0.5244
11	1.0938	0.8279	0.5732	0.4857
12	1.0102	0.7665	0.5330	0.4528
13	0.9389	0.7140	0.4984	0.4244
14	0.8774	0.6685	0.4684	0.3996
15	0.8237	0.6287	0.4419	0.3777
16	0.7764	0.5936	0.4185	0.3583
17	0.7344	0.5624	0.3976	0.3410
18	0.6970	0.5345	0.3788	0.3253
19	0.6632	0.5093	0.3618	0.3112
20	0.6327	0.4865	0.3464	0.2983
21	0.6050	0.4658	0.3324	0.2865
22	0.5797	0.4468	0.3194	0.2757
23	0.5565	0.4294	0.3076	0.2657
24	0.5352	0.4133	0.2966	0.2565
25	0.5155	0.3985	0.2864	0.2479
26	0.4972	0.3848	0.2770	0.2400
27	0.4803	0.3720	0.2682	0.2325
28	0.4645	0.3600	0.2600	0.2256
29	0.4497	0.3489	0.2523	0.2191
30	0.4359	0.3384	0.2450	0.2129
31	0.4230	0.3286	0.2382	0.2072
32	0.4108	0.3194	0.2318	0.2017

Pre-Packaged Impressed Current Ceramic Anode
Simplified Resistance and Current Output Calculations
Based on Anode Cannister Size Only
Computation Program by Bushman & Associates, Inc.

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Case No.: **Resistance of 4" & 6" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)**

Variables	Value	Value	Value
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**
Anode Spec. Backfill Diameter (Inches)	**4**	**6**	**6**
Anode Spec. Backfill Length (Inches)	**18**	**42**	**84**
Anode Center-to-Center Spacing (feet)	**10**	**10**	**10**
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**
1	8.9734	4.5035	2.7676
2	4.6282	2.3932	1.5253
3	3.2263	1.7363	1.1577
4	2.4947	1.3772	0.9432
5	2.0422	1.1482	0.8011
6	1.7335	0.9885	0.6992
7	1.5088	0.8703	0.6223
8	1.3376	0.7789	0.5619
9	1.2026	0.7060	0.5131
10	1.0933	0.6463	0.4728
11	1.0030	0.5966	0.4388
12	0.9269	0.5545	0.4098
13	0.8621	0.5182	0.3847
14	0.8060	0.4867	0.3627
15	0.7571	0.4591	0.3433
16	0.7139	0.4346	0.3261
17	0.6757	0.4127	0.3106
18	0.6414	0.3931	0.2967
19	0.6106	0.3754	0.2840
20	0.5828	0.3593	0.2725
21	0.5575	0.3446	0.2619
22	0.5343	0.3311	0.2522
23	0.5131	0.3188	0.2433
24	0.4936	0.3073	0.2350
25	0.4755	0.2967	0.2273
26	0.4588	0.2869	0.2201
27	0.4433	0.2777	0.2134
28	0.4288	0.2692	0.2072
29	0.4153	0.2611	0.2013
30	0.4026	0.2536	0.1957
31	0.3907	0.2465	0.1905
32	0.3795	0.2399	0.1856

Pre-Packaged Impressed Current Ceramic Anode
Simplified Resistance and Current Output Calculations
Based on Anode Cannister Size Only
Computation Program by Bushman & Associates, Inc.

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Case No.: **Resistance of 8" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)**

Variables	Value	Value	Value	Value
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**	**1,000**
Anode Spec. Backfill Diameter (Inches)	**8**	**8**	**8**	**8**
Anode Spec. Backfill Length (Inches)	**42**	**60**	**84**	**90**
Anode Center-to-Center Spacing (feet)	**10**	**10**	**10**	**10**
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**
1	4.0752	3.2243	2.5535	2.4312
2	2.1791	1.7536	1.4182	1.3571
3	1.5936	1.3099	1.0863	1.0456
4	1.2701	1.0574	0.8897	0.8591
5	1.0626	0.8924	0.7582	0.7338
6	0.9172	0.7753	0.6635	0.6432
7	0.8091	0.6875	0.5917	0.5742
8	0.7253	0.6190	0.5351	0.5198
9	0.6584	0.5638	0.4893	0.4757
10	0.6035	0.5184	0.4514	0.4391
11	0.5577	0.4803	0.4193	0.4082
12	0.5188	0.4479	0.3920	0.3818
13	0.4853	0.4198	0.3682	0.3588
14	0.4561	0.3954	0.3474	0.3387
15	0.4305	0.3738	0.3291	0.3209
16	0.4078	0.3546	0.3127	0.3051
17	0.3875	0.3375	0.2980	0.2908
18	0.3693	0.3220	0.2848	0.2780
19	0.3528	0.3081	0.2728	0.2663
20	0.3379	0.2953	0.2618	0.2557
21	0.3242	0.2837	0.2517	0.2459
22	0.3117	0.2730	0.2425	0.2369
23	0.3001	0.2631	0.2340	0.2287
24	0.2895	0.2540	0.2261	0.2210
25	0.2796	0.2456	0.2187	0.2138
26	0.2704	0.2377	0.2119	0.2072
27	0.2619	0.2303	0.2055	0.2010
28	0.2539	0.2235	0.1995	0.1951
29	0.2464	0.2170	0.1939	0.1897
30	0.2393	0.2110	0.1886	0.1845
31	0.2327	0.2053	0.1836	0.1797
32	0.2265	0.1999	0.1789	0.1751

Pre-Packaged Impressed Current Ceramic Anode Simplified Resistance and Current Output Calculations Based on Anode Cannister Size Only Computation Program by Bushman & Associates, Inc.

Case No.: **Resistance of 10" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 10' C-C Spacing)**

Variables	Value	Value	
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	
Anode Spec. Backfill Diameter (Inches)	**10**	**10**	
Anode Spec. Backfill Length (Inches)	**48**	**90**	
Anode Center-to-Center Spacing (feet)	**10**	**10**	
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	
1	3.4491	2.2762	
2	1.8660	1.2796	
3	1.3848	0.9939	
4	1.1136	0.8204	
5	0.9374	0.7028	
6	0.8128	0.6173	
7	0.7196	0.5521	
8	0.6471	0.5005	
9	0.5888	0.4585	
10	0.5409	0.4236	
11	0.5008	0.3941	
12	0.4666	0.3688	
13	0.4371	0.3469	
14	0.4114	0.3276	
15	0.3888	0.3106	
16	0.3687	0.2954	
17	0.3507	0.2817	
18	0.3345	0.2694	
19	0.3199	0.2582	
20	0.3066	0.2479	
21	0.2944	0.2385	
22	0.2832	0.2299	
23	0.2729	0.2219	
24	0.2634	0.2145	
25	0.2546	0.2076	
26	0.2463	0.2012	
27	0.2387	0.1952	
28	0.2315	0.1896	
29	0.2248	0.1843	
30	0.2185	0.1794	
31	0.2125	0.1747	
32	0.2069	0.1703	

Pre-Packaged Impressed Current Ceramic Anode Simplified Resistance and Current Output Calculations Based on Anode Cannister Size Only Computation Program by Bushman & Associates, Inc.

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Case No.: **Resistance of 3" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 20' C-C Spacing)**

Variables	Value	Value	Value	Value
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**	**1,000**
Anode Spec. Backfill Diameter (Inches)	**3**	**3**	**3**	**3**
Anode Spec. Backfill Length (Inches)	**18**	**30**	**60**	**84**
Anode Center-to-Center Spacing (feet)	**20**	**20**	**20**	**20**
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**
1	9.9726	7.0481	4.2463	3.2835
2	5.0571	3.5948	2.1939	1.7125
3	3.4418	2.4670	1.5330	1.2121
4	2.6188	1.8877	1.1872	0.9465
5	2.1183	1.5334	0.9730	0.7805
6	1.7811	1.2937	0.8267	0.6662
7	1.5381	1.1203	0.7201	0.5825
8	1.3545	0.9890	0.6388	0.5184
9	1.2109	0.8859	0.5746	0.4676
10	1.0953	0.8028	0.5226	0.4264
11	1.0002	0.7343	0.4796	0.3921
12	0.9206	0.6769	0.4434	0.3632
13	0.8530	0.6281	0.4125	0.3385
14	0.7949	0.5860	0.3858	0.3171
15	0.7443	0.5493	0.3625	0.2983
16	0.6998	0.5171	0.3419	0.2818
17	0.6605	0.4885	0.3237	0.2671
18	0.6255	0.4630	0.3074	0.2539
19	0.5941	0.4401	0.2927	0.2420
20	0.5657	0.4195	0.2794	0.2312
21	0.5400	0.4007	0.2673	0.2214
22	0.5165	0.3836	0.2562	0.2125
23	0.4951	0.3679	0.2461	0.2042
24	0.4754	0.3535	0.2368	0.1967
25	0.4572	0.3402	0.2281	0.1896
26	0.4404	0.3279	0.2202	0.1831
27	0.4248	0.3165	0.2127	0.1771
28	0.4103	0.3059	0.2058	0.1714
29	0.3968	0.2960	0.1993	0.1661
30	0.3842	0.2867	0.1933	0.1612
31	0.3723	0.2780	0.1876	0.1565
32	0.3612	0.2698	0.1823	0.1522

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Case No.: **Resistance of 4" & 6" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 20' C-C Spacing)**

Variables	Value	Value	Value	
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**	
Anode Spec. Backfill Diameter (Inches)	**4**	**6**	**6**	
Anode Spec. Backfill Length (Inches)	**18**	**42**	**84**	
Anode Center-to-Center Spacing (feet)	**20**	**20**	**20**	
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	
1	8.9734	4.5035	2.7676	
2	4.5575	2.3225	1.4546	
3	3.1087	1.6187	1.0401	
4	2.3690	1.2515	0.8176	
5	1.9185	1.0245	0.6773	
6	1.6145	0.8696	0.5802	
7	1.3954	0.7568	0.5088	
8	1.2296	0.6709	0.4539	
9	1.0998	0.6032	0.4103	
10	0.9953	0.5483	0.3748	
11	0.9094	0.5030	0.3452	
12	0.8374	0.4649	0.3202	
13	0.7762	0.4323	0.2988	
14	0.7235	0.4042	0.2802	
15	0.6776	0.3796	0.2639	
16	0.6374	0.3580	0.2495	
17	0.6018	0.3388	0.2367	
18	0.5700	0.3216	0.2252	
19	0.5415	0.3062	0.2148	
20	0.5157	0.2922	0.2054	
21	0.4924	0.2795	0.1969	
22	0.4711	0.2679	0.1890	
23	0.4516	0.2573	0.1818	
24	0.4337	0.2475	0.1752	
25	0.4172	0.2384	0.1690	
26	0.4020	0.2300	0.1633	
27	0.3878	0.2223	0.1580	
28	0.3746	0.2150	0.1530	
29	0.3623	0.2082	0.1484	
30	0.3509	0.2019	0.1440	
31	0.3401	0.1959	0.1399	
32	0.3300	0.1903	0.1361	

Pre-Packaged Impressed Current Ceramic Anode Simplified Resistance and Current Output Calculations Based on Anode Cannister Size Only Computation Program by Bushman & Associates, Inc.

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Case No.: **Resistance of 8" Diameter Cannistered Anodes in 1000 Ohm-Cm Soil (Vertical Anodes - 20' C-C Spacing)**

Variables	Value	Value	Value	Value
Soil Resistivity (Ohm-Cm)	**1,000**	**1,000**	**1,000**	**1,000**
Anode Spec. Backfill Diameter (Inches)	**8**	**8**	**8**	**8**
Anode Spec. Backfill Length (Inches)	**42**	**60**	**84**	**90**
Anode Center-to-Center Spacing (feet)	**20**	**20**	**20**	**20**
No. of Anodes	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**	**Package Resistance (in Ohms)**
1	4.0752	3.2243	2.5535	2.4312
2	2.1083	1.6829	1.3475	1.2863
3	1.4760	1.1923	0.9687	0.9280
4	1.1445	0.9317	0.7640	0.7335
5	0.9388	0.7686	0.6345	0.6100
6	0.7982	0.6564	0.5446	0.5242
7	0.6956	0.5741	0.4782	0.4608
8	0.6174	0.5110	0.4272	0.4119
9	0.5556	0.4610	0.3865	0.3729
10	0.5055	0.4204	0.3534	0.3411
11	0.4641	0.3867	0.3257	0.3146
12	0.4292	0.3583	0.3024	0.2922
13	0.3994	0.3339	0.2823	0.2729
14	0.3736	0.3128	0.2649	0.2562
15	0.3511	0.2944	0.2497	0.2415
16	0.3313	0.2781	0.2361	0.2285
17	0.3136	0.2636	0.2241	0.2169
18	0.2979	0.2506	0.2133	0.2065
19	0.2837	0.2389	0.2036	0.1971
20	0.2708	0.2283	0.1947	0.1886
21	0.2591	0.2186	0.1867	0.1808
22	0.2485	0.2098	0.1793	0.1737
23	0.2387	0.2017	0.1725	0.1672
24	0.2296	0.1942	0.1662	0.1611
25	0.2213	0.1873	0.1604	0.1555
26	0.2136	0.1809	0.1551	0.1503
27	0.2064	0.1749	0.1500	0.1455
28	0.1997	0.1693	0.1454	0.1410
29	0.1934	0.1641	0.1410	0.1368
30	0.1876	0.1592	0.1369	0.1328
31	0.1821	0.1546	0.1330	0.1291
32	0.1769	0.1503	0.1294	0.1255