UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-22-17C

March 2022

Effective Grounding Of Lightning Conduction Systems Around Trees

Dr. Kim D. Coder, Professor of Tree Biology & Health Care / University Hill Fellow
University of Georgia Warnell School of Forestry & Natural Resources

Of all major lightning conduction system components, grounding is most critical for effective performance. Charge exchanges generated by lightning are composed of extremely short duration electron flows which can be effectively neutralized in the soil (grounded). The purpose of the grounding (earthing) rods are to effectively conduct lightning current into contact with soil materials and water which then dissipate the energy. Adequate grounding volume availability is more important than simple low resistance measures. (Uman 2008)

Earthing

Tree protection systems cannot fulfil design objectives and meet safety criteria if not grounded correctly. It is important tree protection specialists understand how grounding components of a lightning conduction system function under different circumstances.

As the massive impulse current and smaller constant current within a tree lightning conduction system occurs, the ground must be able to effectively conduct and allow dissipation of energy. Ground rods provide a means of low resistance access to soil. Ground rods provide the primary interface between a lightning conduction system and soil, where soil represents a large reservoir of charge potential. Electric energy is dissipated by soil water, soil atmosphere, and soil solid materials (both minerals and organics) through rapid changes in their electronic configurations, chemical transformations, and heating. A certain minimal volume of soil is required for any amount of electronic dissipation.

Soil Resistance

The lower the resistance value to electron movement, the more effective a tree lightning conduction system. Many standards provide grounding recommendations that theoretically represent the lowest resistance for a particular grounding configuration. These grounding recommendations are targeted at effectively conducting current and generating a grounding resistance low enough to defend tree tissues and growing space. It is important that grounding resistance estimates be verified by actual measurement. Resistance is measured in units called "ohms" with lower numbers representing lower resistances and more efficient movement of electricity.

Soil resistance ranges are estimated by soil type in Figure 1. Generally, the coarser the soil, the greater soil resistance, due primarily to lack of contact between: soil solids; water filled pore spaces; and, grounding rod surfaces. Grounding rods driven into native soils tend to have better contact with soil than rods buried and packed into soil. Figure 2 graphically demonstrates the relationship between soil resistance values and soil types across various moisture contents. (Saraoja, 1977)

Water Resistance

Moisture content of soil plays a dominate role in electrical resistance. Figure 3. Note soil moisture contents above 16% by volume do not vary significantly in resistance. Soil moisture contents below 16% by volume vary greatly in resistance depending upon texture, organic matter, sand and gravel components, soil amendments, temperature, salt content, and bulk density. Resistance of just the water held within a soil can vary greatly. Figure 4 provides soil resistance values over a range of different soil water resistances and moisture content volumes. Soil resistance was calculated using the Hummel formula:

$$\textbf{Soil Resistance in ohms}_m =$$

$$[(1.5 \;/\; \text{relative volume of water in soil}) - 0.5] \quad X \quad \text{resistance of water in soil in ohms}_m$$

As soils dry, resistance to electron flow increases rapidly. Dry soils can have large electrical resistance. Caution in grounding is needed where moisture contents can fluctuate greatly and pass through periods of very dry conditions. Soils modified to protect foundations from water, or where artificial components of soil allow low moisture contents to be reached, greatly increase resistance. All of these high resistance soil situations must be overcome by expanding grounding potentials of a lightning conductance system. One high resistance problems is low temperatures. Figure 5 provides resistance values for soils which may be frozen or have permafrost. Note there is more than doubling of resistance as water moves from liquid to frozen state at 32^oF.

Don't Spare the Rod

To provide adequate grounding (soil volume contact) for a tree lightning conduction system, special metal rods are usually driven vertically into the soil. The number of rods used depends upon reaching a low electrical resistance (i.e. <10ohms). These ground rods are normally composed of copper, copper-bronze, copper clad stainless steel, or stainless steel. Mixing different metals in a conducting system can facilitate metal corrosion.

Ground rods of any composition vary by length and diameter. Calculations demonstrate increasing rod diameter adds small increments in lowering resistance while increasing length of ground rods greatly reduces resistance. In application, longer rods are much more effective than larger diameter rods, as long as they can be driven into the soil and not buckle. A specialized thin-rod slap-hammer driver or a power driver can be used to push ground rods into soil.

Distance Apart

The value of each individual ground rod inserted depends primarily upon its length and closeness to other ground rods. For example, Figure 6 lists for various rod lengths, the distance away from the first vertical rod position where conducting and grounding values for a second rod is 66%, 80%, 90%, 95%, or 99% of its total grounding value. Ground rod effectiveness is proportional to the volume of soil impacted. The longer the rod below the soil surface, the greater soil volume available for grounding.

For example, two feet long rods are at 90% grounding effectiveness when placed four feet apart, which represents a small soil volume impacted. Eight feet long rods are at 90% grounding effectiveness when placed 12.6 feet apart, representing a relatively large soil volume impacted. Calculate grounding effectiveness distance for any length ground rod using the formula:

$$\textbf{Distance From Ground Rod} = \frac{\{\text{rod length} \;/\; [\log_e\left(\left(8 \times (\text{rod length})\right) / \text{rod diameter}\right) - 1]\}}{(1 - (\%\ \text{effectiveness}))}$$

Spreading grounding effectiveness over large soil volumes, not clustering or concentrating grounding in one small area is ideal. Remember in many soils under many conditions, only one grounding rod can generate an acceptably low electrical resistance for a tree lightning conduction system. In high resistance soils and on sites with grounding constraints, multiple ground rods may be required.

Rod Length

Figure 7 lists the grounding effectiveness in percent for different length rods which are either 8, 10, or 12 feet away from another vertical ground rod. Values were calculated using the following formula:

$$\textbf{Rod Grounding Effectiveness Percent} =$$

$$\{1 - ([\text{rod length} \;/\; (\log_e((8 \times (\text{rod length})) / \text{rod diameter}) - 1)] \;/\; \text{rod length})\} \times 100$$

For example, a second added eight feet long rod reaches 90% effectiveness when placed vertically beyond 12 feet from the first rod. At 10 feet away from the first eight feet long rod, the second rod effectiveness in grounding is 87%.

Figure 8 shows a grounding resistance curve for rods of various lengths when soil resistance is 100 ohms and rod diameter is 0.5 inches. This figure suggests rods greater than 14 feet in length are not continuing to lower resistance significantly, and may not be cost-effective. Rods lengths of 8-10 feet perform most efficiently.

Citation:

Coder, Kim D. 2022. Effective grounding of lightning conduction systems around trees. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-17C. Pp.11.

soil type	soil resistance (ohms$_m$)
clay	25 - 75
sandy clay	40 - 300
organic soil	50 - 250
sand	1,000 - 3,000
gravely loam	1,000 - 10,000

Figure 1: Range of soil resistance values for several soil textures. (from Saraoja, 1977)

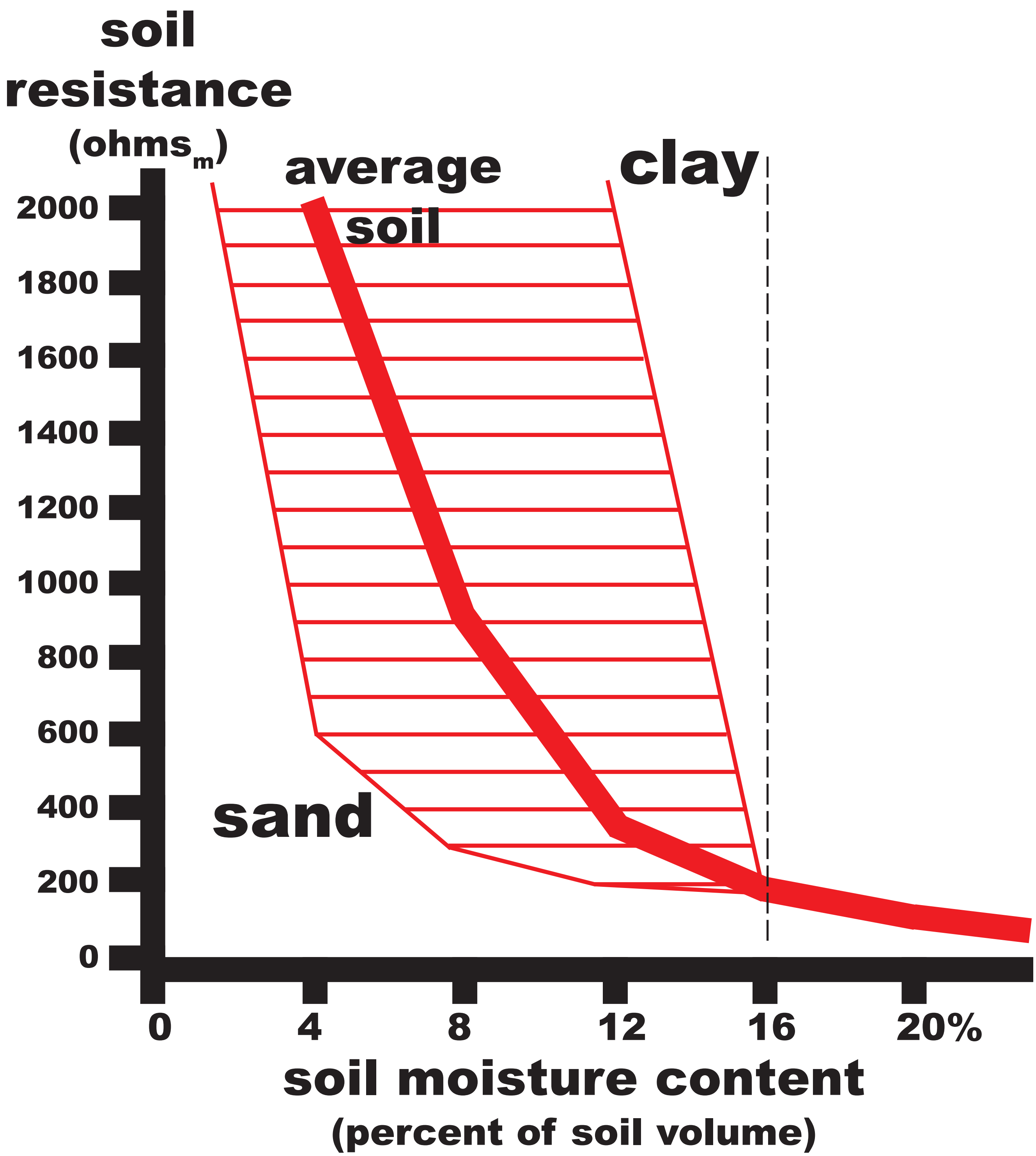

Figure 2: Influence of soil moisture content (percent in soil by volume) on soil resistance (ohms$_m$).
(from Saraoja, 1977)

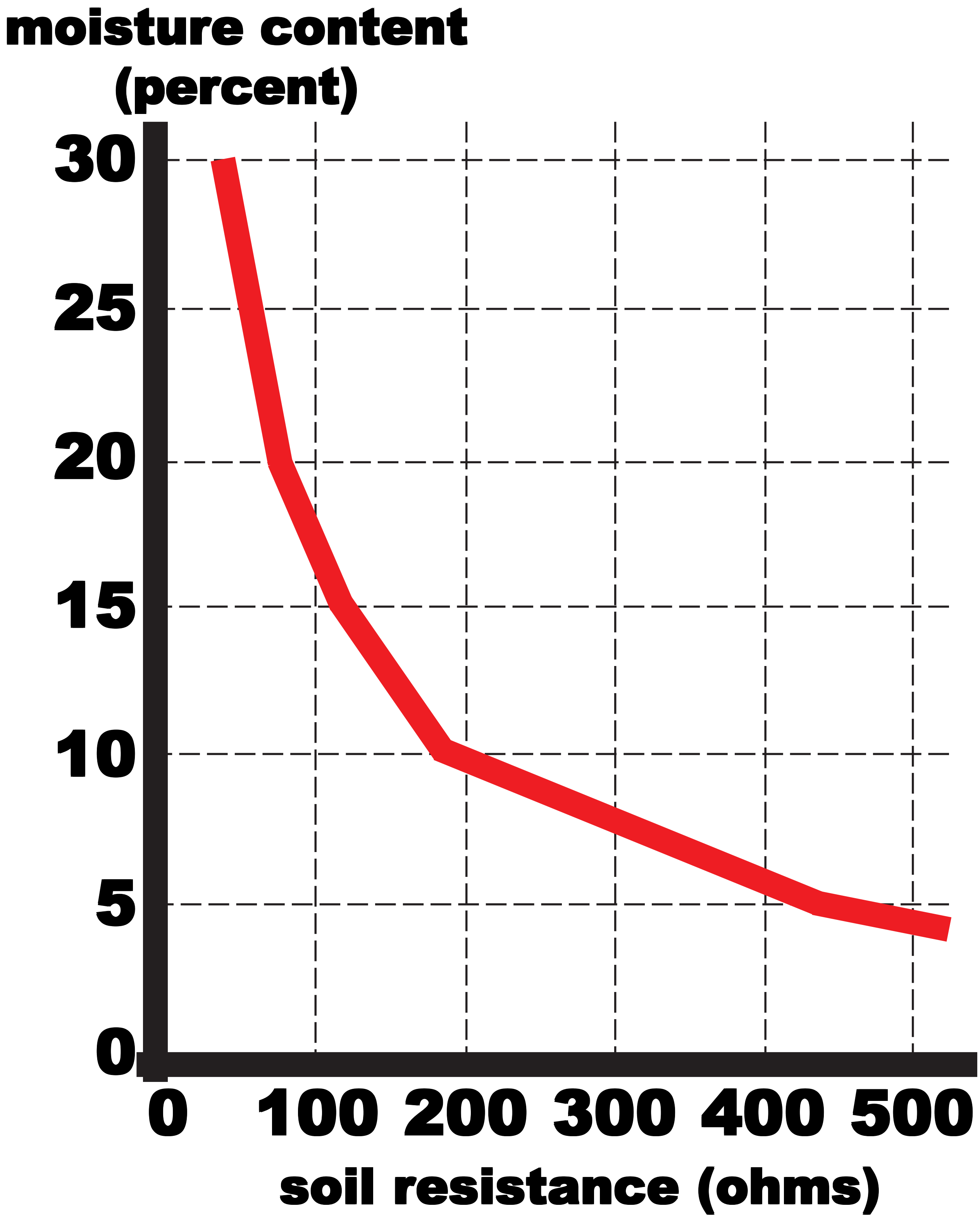

Figure 3: Soil resistance by percent moisture content by weight in soil.

percent of water by volume in soil (%)	resistance of water in soil ($ohms_m$)				
	50	100	150	200	250
2.5%	2,975	5,950	8,925	11,900	14,875
5.0	1,475	2,950	4,425	5,900	7,375
7.5	975	1,950	2,925	3,900	4,875
10	725	1,450	2,175	2,900	3,625
15	475	950	1,425	1,900	2,375
20	350	700	1,050	1,400	1,750
25	275	550	825	1,100	1,375
30	225	450	675	900	1,125
40	163	325	488	650	813
50	125	250	375	500	625
60	100	200	300	400	500
70	82	164	246	329	411

Figure 4: Total soil resistance values ($ohms_m$) based on percent of water in soil by volume across various soil water resistance ($ohms_m$) values. (Hummel formula)

Figure 5: Water resistance (ohms) at different temperatures (°F)

MULTIPLE GROUND RODS

rod length (feet)	ground rod effectiveness				
	66%	80%	90%	95%	99%
2	1.2ft	2.0	4.0	8	40
4	2.1	3.5	7.1	14	71
6	2.9	5.0	10	20	99
8	3.7	6.3	13	25	126
10	4.5	7.6	15	31	152
12	5.2	8.9	18	36	178
14	6.0	10	20	41	203
16	6.7	11	23	46	228

Figure 6: Horizontal distance (in feet) at soil surface away from a vertical ground rod (0.5 inches diameter) of various lengths where another rod has reached a given grounding effectiveness percent. (Saraoja 1977)

rod length (feet)	distance away from other rod (feet)		
	8 ft.	10	12
2	95%	96	97
4	91	93	94
6	88	90	92
8	84	87	90
10	81	85	87
12	78	82	85
14	75	80	83
16	72	77	81

Figure 7: Various length ground rod effectiveness in percent at horizontal distances of 8, 10, and 12 feet away from another vertical ground rod. Note grounding effectiveness is on a per rod basis. (Saraoja 1977)

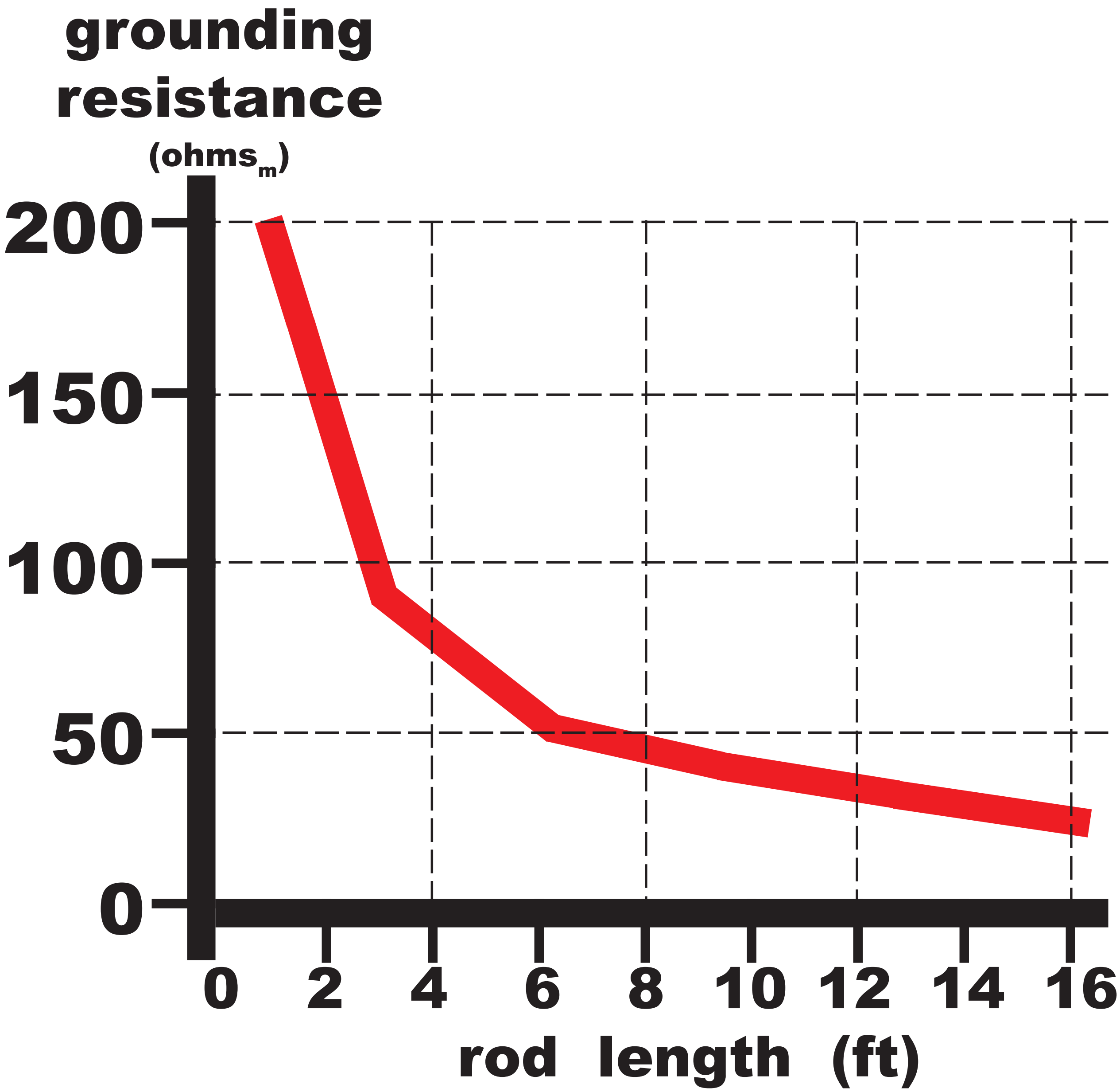

Figure 8: Grounding resistance changes as rod length changes. Soil resistivity is set at 100 ohms$_m$ and rod diameter is 0.5 inches.