EPRI

History of Residential Grounding

Technical Report

History of Residential Grounding

1005490

Final Report, September 2002

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

History of Residential Grounding, EPRI, Palo Alto, CA: 2002. 1005490.

REPORT SUMMARY

This report describes the development of residential electrical service grounding practices in the United States. The report focuses on the history of the *National Electrical Code* (*NEC*), which prescribes standards for wiring practices in residences, including grounding of the building electrical service.

Background
Grounding of the electrical service in a home results in an electrical connection between the building wiring and the water plumbing. This connection can cause a flow of current in water pipes and small voltage differences between pipes and nearby metal objects that are connected to ground. The grounding of secondary electrical distribution systems as practiced today (and required by the *NEC*) was settled only after long and intense discussion in professional meetings and in the technical literature. Human and fire safety arguments were put forth to favor grounding. At the same time, the water authorities were reluctant to allow grounding to water pipes because of previous experience with corrosion of their pipes from electrolysis due to stray currents from electric streetcar lines. Discussion went on from about 1890 to 1920, but the advantages of grounding were widely accepted by 1913, when the *NEC* required grounding of secondary distribution systems.

Objectives
To review the early development of the *NEC* and related technical literature; to determine the time frame for the establishment of grounding practices; and to understand the arguments put forth to favor and to oppose residential electrical grounding.

Approach
Most of the editions of the *NEC* and some earlier codes are preserved in the library of the National Fire Protection Association, the sponsor of the code. A missing edition was located in the collection of Yale University. Transactions of the American Institute of Electrical Engineers, proceedings of waterworks associations, and trade magazines (which cover electrical engineers, electricians, plumbers, and water-supply agencies) are scattered through university and state libraries. This literature was located and analyzed to determine the development of grounding provisions in the *NEC* and the nature of the discussions that were carried out as the code matured.

Results
Prior to 1899 the *NEC* and its predecessors appear to prohibit intentional grounding of low-voltage distribution systems. In 1901 the *NEC* was changed to recommend—but not require—grounding of low-voltage distribution systems, and in 1913 it was changed to make grounding mandatory. In 1918 the *NEC* explicitly required grounding either at the building service or near

the transformer, and in 1923 the code required grounding at each building service unless specifically authorized otherwise by the local inspection agency. Grounding to water pipes was permitted from the start, and emphasized more with the passage of time.

EPRI Perspective

The issue of possible health effects from exposure to electric and magnetic fields (EMF) has involved understanding sources of magnetic fields. The work described in this report is part of an ongoing EPRI effort to assess the sources and levels of magnetic fields associated with residential electrical wiring. Previous EPRI activities have included measurements and studies of residential magnetic fields as they are related to different types of residential wiring. Grounding systems in residences have been shown to be a significant source of magnetic fields. To reduce grounding-system fields, it is important to know exactly where they originate. This report explores this question in following the development of grounding systems and provides a historical record of how grounding systems came to be wired as they are today.

Keywords

Codes
National Electrical Code
Grounding
Electrical Safety
Electrical Fires

ACKNOWLEDGMENTS

The investigation performed for this report involved the location and collection of numerous source documents, including early editions of the *National Electrical Code* and contemporary books, magazines, and conference records. Assistance in locating this source material was provided by numerous libraries and their reference librarians. Especial thanks are due to Teresa Frydryk, librarian of the Morgan Technical Library of the National Fire Protection Association; Betsy Rock, interlibrary-loan librarian of the Schenectady County (New York) Library; and Mark Graham of the EPRI library. Thanks to Chris Hooper of Enertech Consultants for assistance in the preparation of report figures and to Gail Lundell of EPRI for technical editing.

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1
INTRODUCTION

Grounding of residential electrical services to water pipes in American homes goes back to at least 1887, the dawn of the electrical age. Arguments for and against grounding in general, and grounding to water pipes in particular, were carried out in professional meetings and in the technical literature for the next thirty years. Discussion continued through the period after 1901, when the *National Electrical Code (NEC)* made grounding permissible [1], and after 1913, when the *NEC* made grounding mandatory [2]. Much of the discussion was carried out or reported in the pages of magazines of the day. *Electrical World and Engineer* and *Electrical Review and Western Electrician* served the electrical industry; *Fire and Water* and *The Metal Worker, Plumber and Steam Fitter* served the plumbing- and water-supply interests. The *Transactions of the American Institute of Electrical Engineers* presented papers and discussion from the electrical side, with men of the stature of the great electric power engineer Charles Steinmetz contributing. The *Journal of the American Water Works Association* and the *Journal of the New England Water Works Association* weighed in for the water interests.

Grounding of the secondary neutral conductor forces the voltage on building electrical wiring to be close to the voltage on the earth and anything conductive that might be connected, however poorly, to the earth. Figure 1-1 shows an accidental connection between the primary distribution line and a secondary circuit supplying a residential customer. This type of connection may occur because of a failure inside the transformer, or because of a tree branch coming down on the primary wire. If the secondary were not grounded, the voltage on the secondary wiring would reach the voltage of the primary circuit, possibly damaging insulation on either the building wiring or connected lights and appliances. A person touching the secondary or a device containing failed insulation would be subject to a shock at primary voltage. Moreover, the lack of a current path would lead to fault current insufficient to blow the primary fuse, thus possibly sustaining the dangerous condition for a long period of time. On the other hand, if the secondary were grounded, the building wiring would remain near its normal operating voltage. The ground path would result in a large fault current, blowing the primary fuses and rapidly clearing the fault.

Questions raised during the debate over grounding involved not only the advantages and disadvantages of grounding itself, but also the location and number of secondary electrical system grounds. Multiple grounds have the advantage of redundancy, that is, failure of a single ground connection will not leave the secondary system ungrounded. Also, more grounds in parallel decrease the overall resistance to earth, reducing the possible voltage rise under fault conditions. Grounding practice thus came to include grounding at both the supply transformer and each customer's service entrance, providing a current path from the electrical system in the house through the earth, and anything conductive connected to the earth, to the supply transformer. Figure 1-2 (taken from a handbook prepared for use with the *NEC*) illustrates this current path between the secondary electrical system service entrances and two customers [4]. A consequence of multiple ground paths is the possibility of current returning to earth through all the ground connections that are connected together.

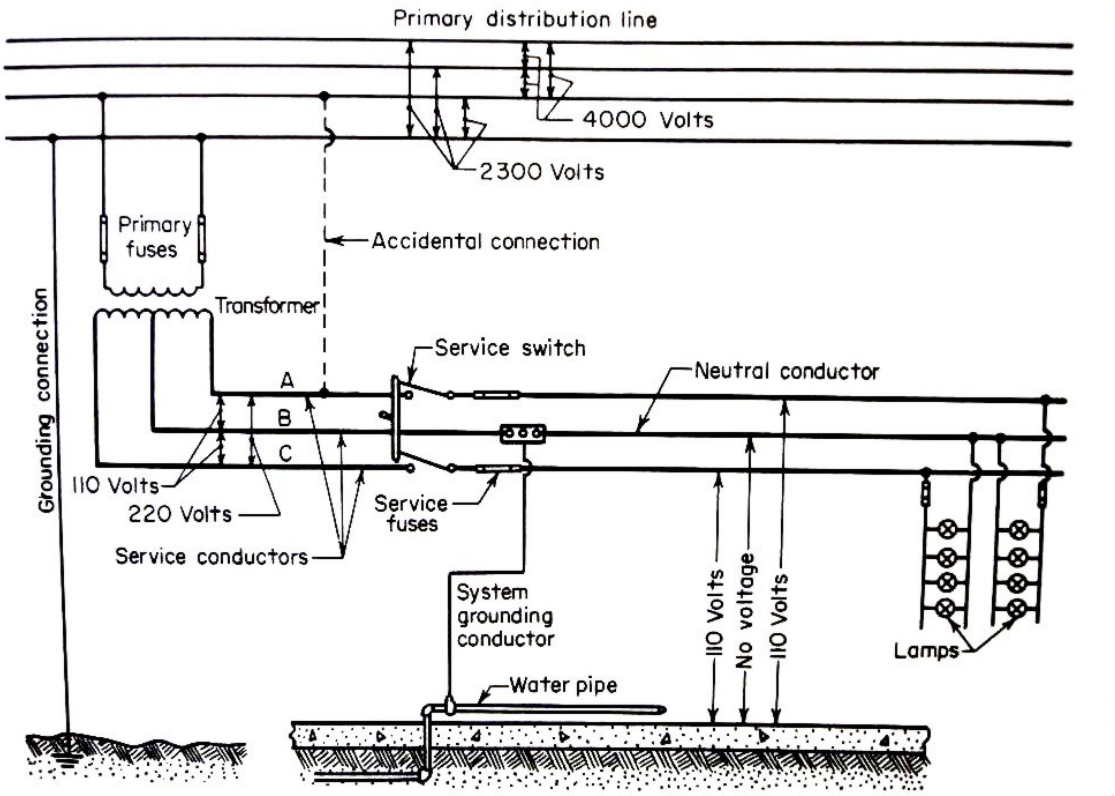


Figure 1-1
Crossed Primary and Secondary Wires [3].

From Croft and Summers, *American Electricians' Handbook*, McGraw-Hill 1996. Reproduced with permission of The McGraw-Hill Companies.

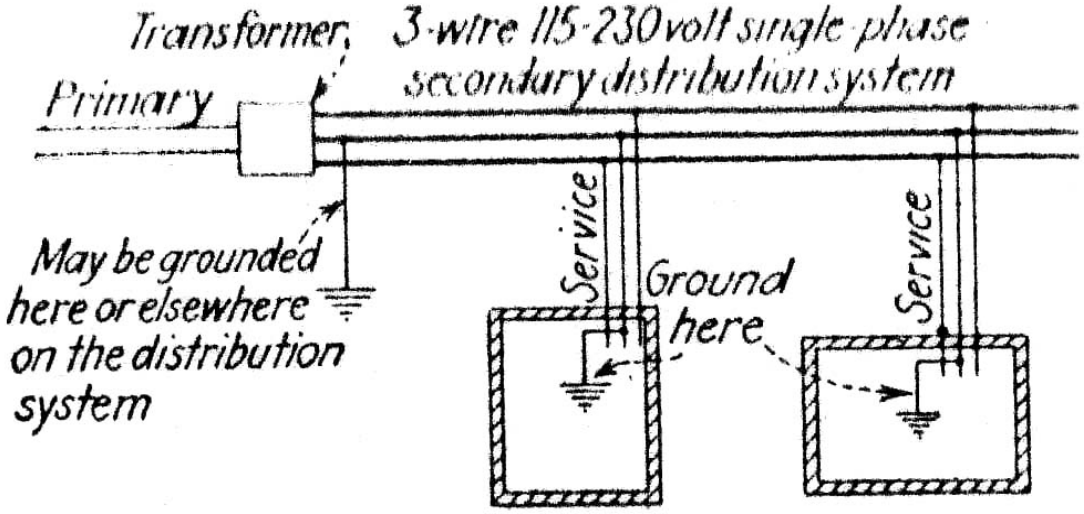


Figure 1-2
Ground Connections at Transformer and Customer Service Entrances [4].

From Abbott, *National Electrical Code Handbook*, McGraw-Hill 1943. Reproduced with permission of The McGraw-Hill Companies.

In the arrangement shown in Figure 1-2, a short circuit to ground in one of the houses (from an insulation failure in a washing machine, for example) would result in a closed current path through the ground connections back to the supply transformer. The resulting high current would clear a fuse or trip a circuit breaker, cutting off the power to the point of failure. The lower the grounding resistance, the higher the fault current and the faster the operation of the fuse or circuit breaker. On the other hand, if the system were designed to be ungrounded (without the ground connections shown in Figure 1-2), an insulation failure in the washing machine would not close a current path and cause the fuse or circuit breaker to operate. This continuation of service was cited as an advantage of ungrounded systems during the debate on grounding. However, the effects of leakage resistance and capacitance were not well understood at that time, and touching 120 volts was then considered safe. Because touching 120 volts is no longer considered safe, means such as grounding have been devised to ensure that the public cannot contact such a voltage [5].[1]

The continuing validity of the major arguments for secondary grounding is illustrated by the wording of Section 250.4.A.1. "Electrical System Grounding" of the 2002 edition of the *NEC*: "Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation" [6].

This report describes the addition of provisions to the *NEC* to permit and later require grounded neutrals on residential electricity service. It also summarizes the arguments for and against grounding as expressed by both electricity and water interests at the time when these provisions were being considered. Boldface type is used to call attention to important statements, and is not necessarily found in the original documents quoted. Quotations have been cited with sentence structure and grammar as they were found in the source. Paraphrases of source material in the text were written to try to reproduce sentence structure, hyphenation, and word usage as found in the original documents.

During the conduct of this study, the importance of the grounding issue was brought home to the author quite literally when a tree brought down by a windstorm caused a primary wire to fall against the secondary wires near his home. Proper grounding ensured that no damage was sustained as a result of the contact, although electric service was unavailable for almost thirty hours.

[1] Assuming a resistance of 1000 ohms for interlimb resistance of a sweating or wet person, contact with 120 volts would result in a current of 12 milliamperes, higher than the threshold of let-go for 50% of women, but below the level required for heart fibrillation. The same contact with 7200 volts resulting from a crossed primary and secondary connection without secondary grounding would result in 7.2 amperes, well above the hundreds of milliamperes required to cause heart fibrillation.

2
HISTORY OF RESIDENTIAL GROUNDING IN THE NATIONAL ELECTRICAL CODE

2.1 Summary

Electrical codes in effect prior to 1901 appear to prohibit intentional grounding of low-voltage distribution systems. In 1901 the *National Electrical Code* permitted grounding of low-voltage distribution systems [1], and in 1913 it was changed to make grounding mandatory [2]. At first grounding was required only at the transformer and at intervals along a secondary feeder. In 1918 grounding was explicitly required at the building service or near the transformer [7], and in 1923 grounding was required at each building service unless specifically authorized otherwise by the local inspection agency [8].

Grounding to water pipes was permitted from the start and was given more emphasis with the passage of time.

2.2 Background

In 1881 Thomas Edison wrote a letter (shown in Figure 2-1) to the New York Board of Fire Underwriters stating that all necessary measures had been taken to make the use of electricity safe [9]. However, rapid deterioration of electrical insulation and other factors led to an increasing incidence of electrically caused fires. Various bodies attempted to deal with this situation through development of codes, starting with the first installation requirements in 1881 by the New York Board of Fire Underwriters and the National Association of Fire Engineers [10].

The first meeting of the National Conference on Standard Electrical Rules was held March 18 and 19, 1896 at the Hall of the American Society of Mechanical Engineers in New York City. It was billed as a joint conference "Of Electrical, Insurance and Allied Interests, looking toward the Adoption, Promulgation and Enforcement of a National Code of Rules for Electrical Construction and Operation." Attendants represented the American Society of Electrical Engineers, the American Street Railway Association, the National Board of Fire Underwriters, the Postal Telegraph Company, Western Union Telegraph Company, the American Institute of Architects, the International Association of Fire Engineers, American Bell Telephone Company, General Electric Company, Westinghouse Electric and Manufacturing Company, the Underwriters National Electric Association, the National Electric Light Association (NELA), the Philadelphia Board of Fire Underwriters, the Pittsburgh Bureau of Electricity, and Factory Mutual Insurance Company of Boston. This meeting adopted *The National Electrical Code* [11], which, after review, was unanimously approved at the next meeting in June 1897 [10]. The 1897 document was published by the National Board of Fire Underwriters [12], and was the first of a continuous sequence of editions to the present time, although a code with the same name had been published in 1895 [13].

The Edison Electric Light Company,

65 Fifth Avenue.

Norvin Green, Pres
S D Eaton, Vice-Pres
E P Fabbri, Treas
C Goddard Sec'y

New York, May 6th. 1881

To the New York Board of Fire Underwriters.

No. 115 Broadway, New York City.

Gentlemen:-

Referring to a publication in the New York Evening Post of yesterday, stating that your Board has passed a resolution requesting persons interested in Electric Lighting to furnish any facts to the Board bearing upon the subject of danger of fire from electric wires, I beg to say that the system of Electric Lighting of the Edison Electric Light Company is absolutely free from any possible danger from fire, even in connection with the most inflamable material; and that it is the intention of the Edison Company, before actually furnishing light, to the public, to invite your Board to give a most critical test of the absolute safety of the system, by the aid of such experts as you may select. From the outset I have had especially in view this subject of protection from fire, and I have succeeded in perfecting a system, which, in that respect is not only safer than Gas, but is, as I will show to your Board, absolutely secure under all and every condition.

Very respectfully
Your obedient servant,

Thomas A Edison

Figure 2-1
Letter from Thomas Edison to the New York Board of Fire Underwriters, 1881.

Courtesy of New York Board of Fire Underwriters.

The Electrical Committee of the Underwriters National Electric Association, in existence from 1892 to 1912, initially consolidated the previous codes and was the originator of the *NEC*. The name *Underwriters National Electric Association* appears on the title page of the *NEC*, along with *National Board of Fire Underwriters*, through the 1911 edition. Summary reports of a few paragraphs from the Underwriters National Electric Association containing very little detail appear in the annual *Proceedings of the National Board of Fire Underwriters.*

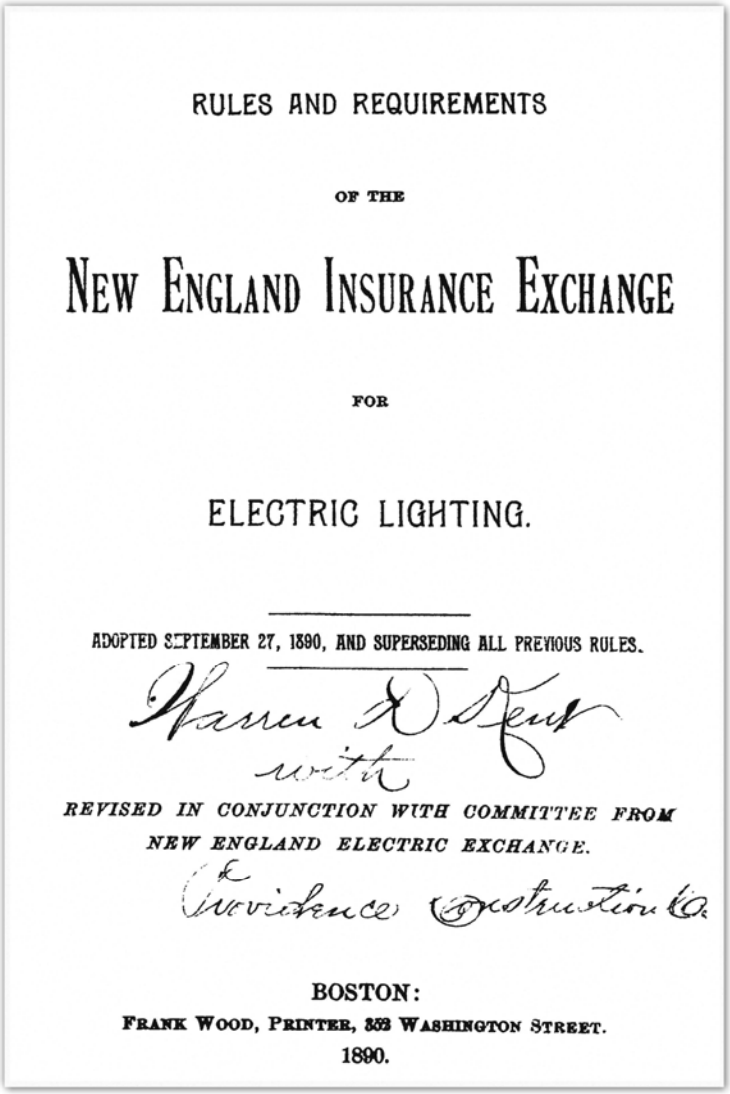
In 1896 the National Fire Protection Association (NFPA) was organized. The NFPA Electrical Committee was formed in 1910 and took over the work of both the National Conference on Standard Electrical Rules and the Electrical Committee of the Underwriters National Electric Association in 1911. Subsequently, the Underwriters National Electric Association disbanded, since formulating the *NEC* was their only function. The 1911 annual report of the NFPA was the first to include reports of its Electrical Committee. From 1913 on, the NFPA's name was on the title page of the *NEC* along with that of the National Board of Fire Underwriters.

Revisions of the *NEC* were made periodically. A 1912 discussion of the Code reported: "Revised editions of the Code have been appearing every two years in about the month of December, since the first issue in 1897. The revisions are made by an electrical committee of the National Fire Protection Association, after being chosen from a large number which are usually read and discussed at a biennial open meeting held in New York City. This usually takes place in March and is largely attended by interested electrical men of all kinds. This committee is responsible for the technical composition of the Code. The revisions are slowly and cautiously made" [14].

2.3 Pre-1901 Codes

An example of an early electrical code preceding the *NEC* is the *Rules and Requirements of the New England Insurance Exchange for Electric Lighting. Adopted September 27, 1890 and Superseding All Previous Rules. Revised in Conjunction With Committee From New England Electric Exchange* (Figure 2-2). In Section 27, under the heading "Low Potential (350 volts or less) Incandescent General Rules," this code states that **"the entire installation must test free from grounds"** [15]. This statement indicates that grounded low-voltage distribution was prohibited by code in 1890, but it does not explicitly rule out grounding at the transformer neutral.

The first (1897) edition of the *NEC* did not prohibit grounded low-voltage circuits at the transformer, but did seem to presume that low-voltage circuits were not grounded [12]. Under "Class E. Miscellaneous," Section 56, "Insulation Resistance," states: **"The wiring in any building must test free from grounds**, i.e. the complete installation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following . . . ." The section continues with a list of resistance values for circuits of different current ratings.



RULES AND REQUIREMENTS

OF THE

NEW ENGLAND INSURANCE EXCHANGE

FOR

ELECTRIC LIGHTING.

ADOPTED SEPTEMBER 27, 1890, AND SUPERSEDING ALL PREVIOUS RULES.

Warren D Kent

with

REVISED IN CONJUNCTION WITH COMMITTEE FROM
NEW ENGLAND ELECTRIC EXCHANGE.

Providence Construction Co.

BOSTON:
FRANK WOOD, PRINTER, 353 WASHINGTON STREET.
1890.

Figure 2-2
Cover of 1890 New England Insurance Exchange Code [15].

The 1899 *NEC* was issued under the auspices of the National Board of Fire Underwriters [16]. Under "General Suggestions," this code states "In all electric work conductors, however well insulated, should always be treated as bare, to the end that under no conditions, existing or likely to exist, can a grounding or short circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum." Under Section 7, "Testing of Insulation Resistance," Section 7.a. states: "All circuits must be provided with reliable ground detectors. Detectors which indicate continuously, and give an instant and permanent indication of a ground are preferable. Ground wires from detectors must not be attached to gas-pipes within the building." Section 26, "Fixtures," contains a provision (26.e.) that building wiring "must be tested for 'contacts' between conductors and fixture, for 'short circuits' and for ground connections before it is connected to its supply conductors." Like the 1897 code, the 1899 code does not explicitly prohibit grounded low-voltage circuits at the transformer, but appears to presume that low-voltage circuits are not grounded. Supporting this presumption is the change in wording in Section 7.a. that was made in the 1901 edition [1].

That the code at this time was understood to forbid grounding is illustrated by a quote in an 1899 American Institute of Electrical Engineers (AIEE) paper [17]: "The reason for this state of affairs is the refusal of the Board of Fire Underwriters to authorize the practice of grounding any part of a circuit carrying current. The underwriters take the position that to ground one side of a circuit brings about an increased liability to fire . . . ." The discussion to this paper by Mr. C. M. Goddard contains the statement: "Not, however, because the underwriters are fully convinced as yet, that one of their rules, almost as unchangeable as the laws of the Medes and Persians, that no circuit should be permanently grounded, has been wrong all the time . . . ." Since Mr. Goddard was involved in formulating the code, his assertion that it forbade secondary grounding should be taken as a definitive statement that prior to 1901 the *NEC* forbade grounded circuits.

2.4 1901 Permissive Provision

In 1901, following the 1899 resolution by the AIEE, a considerable revision of the *NEC* was made [1]. The revised code included a new Section 13 A, "Grounding Low-Potential Circuits." In connection with this revision, the wording in Section 7.a. was revised to read: "All circuits except such as are permanently grounded in accordance with No. 13 A must be provided with reliable ground detectors . . . ."

The preamble to Section 13 A. states: "The grounding of low-potential circuits under the following regulations is only allowed when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire." This provision means that grounding is intended to provide a safety function only, and not a deliberate current path.

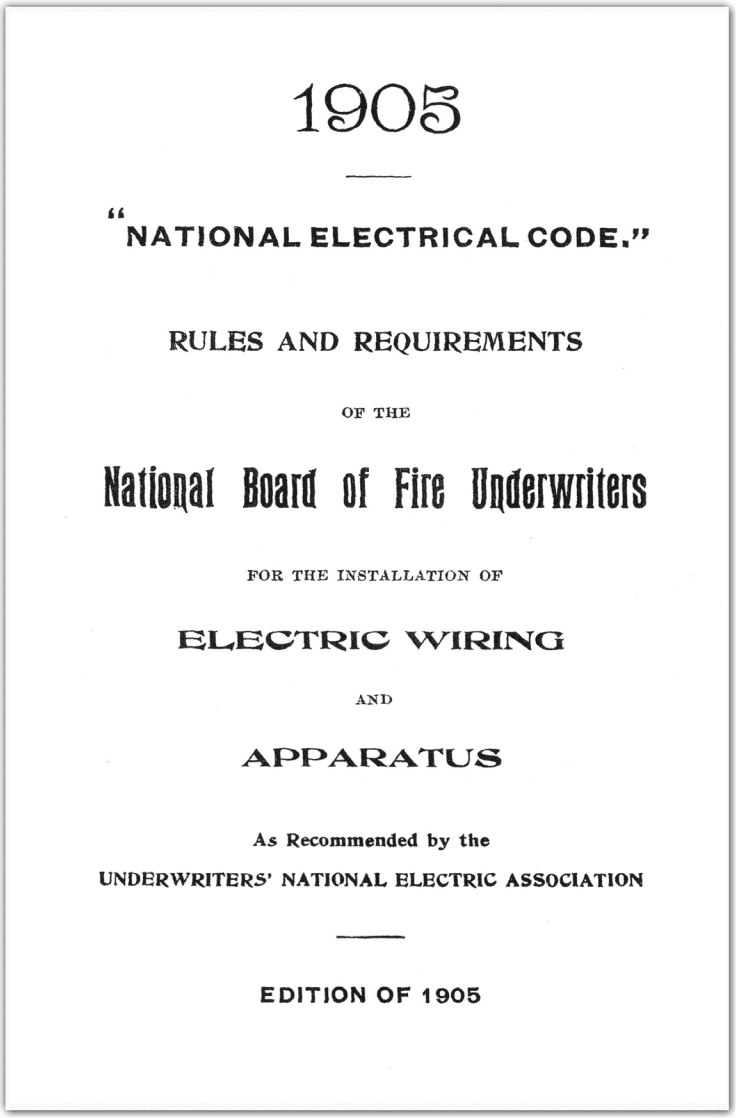
Under "Alternating-Current Secondary Systems," Section 13.A.b. reads: **"The neutral point of transformers or the neutral wire of distributing systems may be grounded**, and when grounded the following rules must be complied with: 1. Transformers feeding 2-wire systems must be grounded at the center of the secondary coils as provided in Sections d, e, f and g. 2. Transformers feeding systems with a neutral wire must have the neutral wire grounded as provided in Sections d, e, f and g at the transformer and at least every 250 feet for overhead systems and every 500 feet for underground systems. **Inspection Departments having jurisdiction may *require* grounding if they deem it necessary."**

The 1901 *NEC* is thus the first to explicitly permit grounding of low-voltage circuits.

2.5 Refinements 1903–1911

The permissive wording on grounding included in the 1901 *NEC* was maintained—with a few refinements—in editions published from 1903 through 1911. In 1903 Section 13A.*b*. was changed to read: **"Transformer secondaries of distributing systems should preferably be grounded . . ."** [18]. This statement represents a shift from merely allowing secondaries to be grounded to recommending that they be grounded. Figures 2-3 and 2-4 show the cover and the page containing Section 13 A. from the 1905 edition of the *NEC*.

The 1901 *NEC* required that a two-wire system be grounded at the center of the transformer coil [1]. In 1903 this requirement was changed to allow grounding one side of a two-wire system if no neutral point is available "provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts" [2]. Generally the neutral point or wire is to be grounded.



1905

"NATIONAL ELECTRICAL CODE."

RULES AND REQUIREMENTS

OF THE

National Board of Fire Underwriters

FOR THE INSTALLATION OF

ELECTRIC WIRING

AND

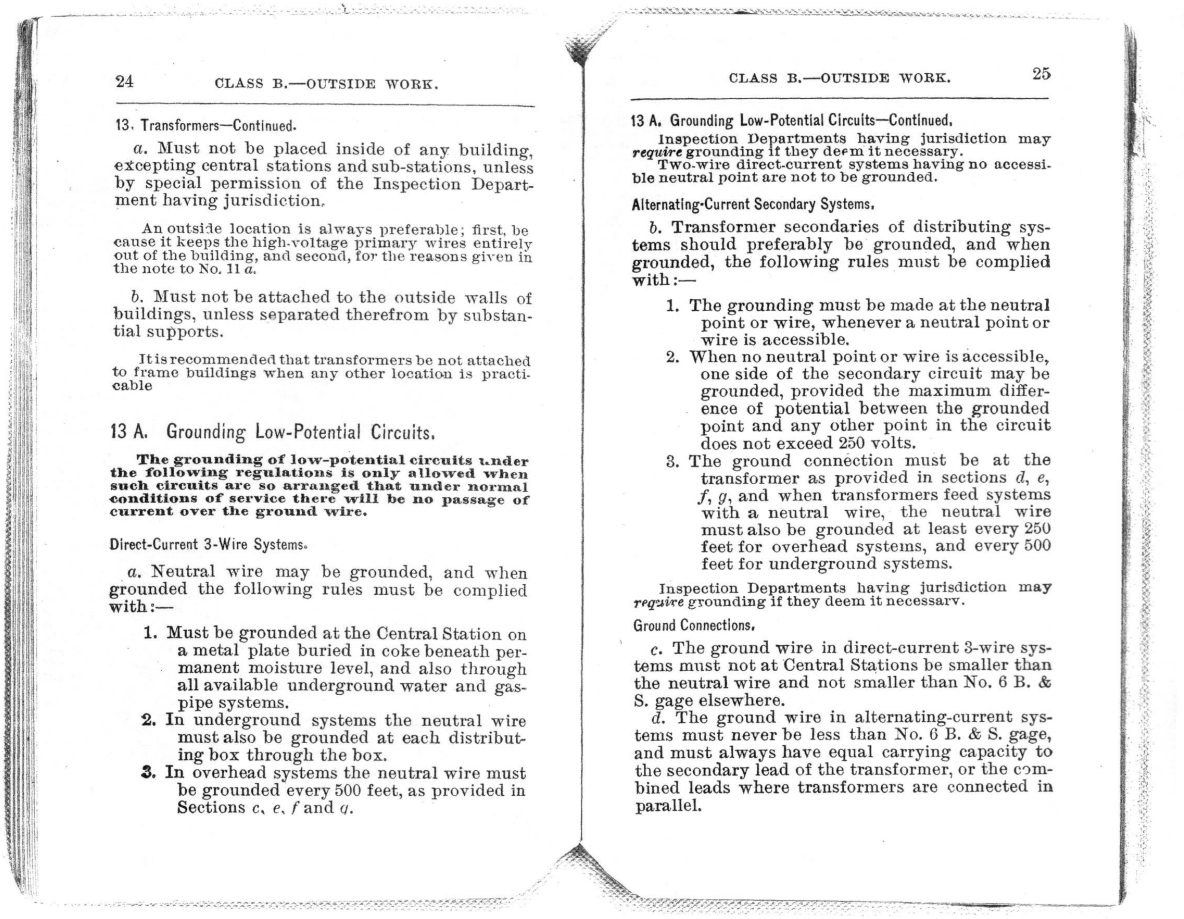
APPARATUS

As Recommended by the

UNDERWRITERS' NATIONAL ELECTRIC ASSOCIATION

EDITION OF 1905

Figure 2-3
Cover of 1905 Edition of the *National Electrical Code* [18].



24 CLASS B.—OUTSIDE WORK.

13. Transformers—Continued.

a. Must not be placed inside of any building, excepting central stations and sub-stations, unless by special permission of the Inspection Department having jurisdiction.

An outside location is always preferable; first, because it keeps the high-voltage primary wires entirely out of the building, and second, for the reasons given in the note to No. 11 *a*.

b. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

It is recommended that transformers be not attached to frame buildings when any other location is practicable

13 A. Grounding Low-Potential Circuits.

The grounding of low-potential circuits under the following regulations is only allowed when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

Direct-Current 3-Wire Systems.

a. Neutral wire may be grounded, and when grounded the following rules must be complied with:—

1. Must be grounded at the Central Station on a metal plate buried in coke beneath permanent moisture level, and also through all available underground water and gas-pipe systems.
2. In underground systems the neutral wire must also be grounded at each distributing box through the box.
3. In overhead systems the neutral wire must be grounded every 500 feet, as provided in Sections *c*, *e*, *f* and *g*.

CLASS B.—OUTSIDE WORK. 25

13 A. Grounding Low-Potential Circuits—Continued.

Inspection Departments having jurisdiction may *require* grounding if they deem it necessary.

Two-wire direct-current systems having no accessible neutral point are not to be grounded.

Alternating-Current Secondary Systems.

b. Transformer secondaries of distributing systems should preferably be grounded, and when grounded, the following rules must be complied with:—

1. The grounding must be made at the neutral point or wire, whenever a neutral point or wire is accessible.
2. When no neutral point or wire is accessible, one side of the secondary circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts.
3. The ground connection must be at the transformer as provided in sections *d*, *e*, *f*, *g*, and when transformers feed systems with a neutral wire, the neutral wire must also be grounded at least every 250 feet for overhead systems, and every 500 feet for underground systems.

Inspection Departments having jurisdiction may *require* grounding if they deem it necessary.

Ground Connections.

c. The ground wire in direct-current 3-wire systems must not at Central Stations be smaller than the neutral wire and not smaller than No. 6 B. & S. gage elsewhere.

d. The ground wire in alternating-current systems must never be less than No. 6 B. & S. gage, and must always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are connected in parallel.

Figure 2-4
Section 13 of the 1905 Edition of the *National Electrical Code* [18].

Another statement appears under Section 13. "Transformers": "Where transformers are to be connected to high-voltage circuits, it is necessary in many cases, for best protection to life and property, that the secondary system be permanently grounded, and provision should be made for it when the transformers are built." In other words, this is a recommendation that even if it is decided not to ground the secondary, transformers should be constructed so as to allow grounding in the future. This statement is a further recommendation that secondary grounding be applied, even though strictly speaking the code leaves it optional.

Section 13A.*b*.3. was changed in 1907 to read: **"The ground connection must be at the transformer or on the individual service as provided . . ."** [19]. This wording clarifies grounding at building services, as previously provided in Section 13.A.g.

In 1911 "Grounding Low Potential Circuits" was moved to Section 15 with only minor changes [20]. The interval for grounding the neutral wire was changed to every 500 feet instead of every 250 feet for overhead systems (for underground systems, the interval remained every 500 feet). Some wording was also changed in the subsection on ground connections; for example, the minimum size for a ground wire was changed from Number 4 to Number 6.

In addition to the *NEC* grounding recommendations, a resolution was passed at the March 22, 1911 meeting of the Underwriters National Electric Association in New York City "urging municipal departments to make the grounding of secondary circuits up to 150 volts mandatory; urging the underwriter's inspectors to recommend such grounding at all times; urging the National Electric Light Association to impress upon its member companies the necessity for such grounding; urging the departments in charge of water works to permit the attachment of ground wires to their piping systems; urging all concerned to give careful consideration to their methods of obtaining satisfactory grounding where water pipes are not available; and urging the American Institute of Electrical Engineers to use its efforts to harmonize the present difference of opinion as to the limiting voltage at which grounding ceases to be desirable and to determine the proper limit" [21].

2.6 1913 Mandatory Provision

The Electrical Committee Report to the 1913 annual meeting of the National Fire Protection Association [22] states: "You may also be interested to learn that this committee has **now made a change in the Code, which will make the grounding of low potential systems obligatory, when the maximum difference of potential between the grounded point and any other point on the circuit does not exceed 150 volts**. While this is a somewhat radical departure, the committee believes that it is fully justified by the reduction of the hazard to life, which this will undoubtedly produce" [10].

The section on grounding low-potential circuits was moved to Section 15 in the 1913 *NEC* [2]. Section 15.b. for alternating-current secondary systems in the 1913 code reads: "Transformer secondaries of distributing systems (except where supplied from private industrial power or lighting plants where the primary voltage does not exceed 550 volts) **must be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 150 volts and may be grounded when the maximum difference of potential between the grounded point and any other point in the circuit exceeds 150 volts . . . ."**

The 1913 *NEC* code explicitly refers to grounding of low-voltage "secondary systems" for the first time and makes such grounding mandatory. The reference to mandatory grounding in the Electrical Committee's report to the NFPA indicates that the Committee regarded the change to mandatory grounding as a fundamental one.

2.7 Refinements 1915–1925

Prior to 1918 the section on grounding of low-potential circuits was included in the overall section "Outside Work." In 1918 the bulk of the discussion on grounding was moved to "Inside Work" [7]. Section 15, "Grounding Low-Potential Circuits," was included under "Outside Work," and Section 15A, "Method of Grounding, when Protective Grounding is Required," was under "Inside Work."

Section 15.b. of the 1918 *NEC* states: "All secondary distribution systems (except circuits entirely unexposed to leakage or induction through overhead construction from overhead circuits above 550 volts or through transformers or other devices) must be grounded, provided

the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 150 volts, and may be grounded when the potential exceeds 150 volts." While this statement may seem to imply that there are exceptions to grounding secondary systems, grounding is required when a low-voltage system is supplied from a higher voltage through a transformer.

Section 15A.d. of the 1918 *NEC* discusses the point of attachment for grounds on alternating-current systems. It states: "The ground connection for alternating current systems must be made at the building service or near the transformer (or transformers) whether by direct ground connection, through water piping system or artificial ground, or by the use of a system ground wire to which are connected the grounded conductors of many secondary mains and which itself is effectually grounded at intervals that will fulfill, for any secondary utilizing the system ground wire, the resistance and current-carrying requirements for Ground Conductors section k and Ground Connection Section t." The section further prohibits fuses that could interrupt the ground connections, and grounds within buildings except for the ground at the building service. Section 15A.d. seems to imply that if the transformer is grounded, additional grounding at the service entrance is not necessary.

In the 1920 code, Section 15A.d. starts out: "The ground connection for alternating current systems must be made at each service or near the transformer . . . ." Although the wording in this version was changed from "the building service" to "each service," the "or" preceding "near the transformer" was retained.

In 1923 a major reorganization of the *NEC* resulted in the collection of grounding requirements in "Article 9. Grounding" [8]. Section 902.c. of Article 9 reads: "Alternating current systems shall be grounded as provided in this article, if the maximum difference of potential between the grounded point and any other point on the circuit does not exceed 150 volts. Electric furnace circuits need not be grounded. It is recommended that such systems also be grounded as provided herein, if the difference of potential exceeds 150 volts but does not exceed 300 volts." Section 902.d. reads: "The connection with the ground on alternating current systems shall be made at each service entrance before being connected to the line; provided, however, that by permission of the inspection department the connection may be made on or near the transformer, or transformers, or by connection to a system ground wire." The thrust of this revision is to **require grounding at each individual service** unless the local inspector allows either grounding at or near the transformer or connection to a ground wire.

Section 902.f. of the 1923 *NEC* requires that if a lighting circuit is taken from one phase of a two- or three-phase service, one side of the lighting circuit is to be grounded. The wording of this section was revised in 1925, but the essential provisions remain the same [23].

2.8 1965 Provision for Multiple Grounding

Until 1965 the standard procedure for grounding residential service entrances was to ground to water pipes where they enter the building [24]. In 1965 a refinement was added to the *NEC* to require additional residential service-entrance grounding: "A new addition to the 1965 Code is that an interior metallic cold-water piping system shall always be bonded to one or more grounding electrodes. Note that the electrical wiring system should be adequately grounded without depending on the outside piping system. This means that supplementing the water-pipe system with made electrodes is advised. Additional safety may be gained by bonding the electrode to the gas, sewer, and hot-water piping, and to metallic air ducts within the building" [25].

While details have changed, since 1965 the essence of the requirements of *NEC* Section 250 H, "Grounding Electrode System," has been to bond together the following to form the residential grounding electrode system:

- Metal underground pipe if in direct contact with earth for 10 feet or more and electrically continuous (not relying on water meters), but including metal well casing effectively bonded to the pipe. "A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Section 250-81 or in Section 250-83" [26].
- Metal frame of the building.
- Concrete-encased electrode.
- Ground ring encircling the building or structure.

Where none of these electrodes are available, one of the following may be used:

- Metal underground gas-piping system if permitted by the gas supplier and the local authority having jurisdiction.
- Other local metal underground systems or structures such as underground tanks.
- Rod and pipe electrodes.
- Plate electrodes.

For residences these requirements work out to grounding to the water pipes plus an 8-foot ground rod, if the ground rod has a resistance to ground of less than 25 ohms. If the ground-rod resistance is greater than 25 ohms, a second 8-foot rod is to be driven at least 6 feet from the first rod. Many electricians dispense with the resistance test and routinely connect to a water pipe in addition to installing 2 ground rods. A wiring manual from 1981 warns: "There is little doubt that this concept of grounding electrode systems gives rise to many interpretations of the Code. The electrician must check with his local code authority to determine the local interpretation" [27].

2.9 Provisions Relating to Water Pipes

The first (1897) edition of the *NEC* contains, under "Class E. Miscellaneous," Section 57, "Protection Against Foreign Currents," which covers the protection of telephone, telegraph, and similar circuits from electric light and power wires [12]. With regard to the grounding of protector devices, Section 57.b.5. states: "The ground wire shall be attached to a water pipe, if possible, otherwise may be attached to a gas pipe. [Subsequent codes restricted grounding to gas pipes to special circumstances.] The ground wire shall be carried to, and attached to, the pipe outside of the first joint or coupling inside the foundation walls, and the connection shall be made by soldering, if possible. In the absence of other good ground, the ground shall be made by means of a metallic plate or a bunch of wires buried in a permanently moist earth." The existence of this provision indicates that water pipes were considered an acceptable ground from the beginning of the *NEC*.

As previously mentioned, the 1901 *NEC* was the first to contain a section explicitly permitting the grounding of low-voltage circuits [1]. Sections 13.A.c., d., e., f. and g. discuss the types of ground connections that are required, including the minimum allowed size of wires used for grounding. Section 13.A.f. discusses ground connections for central stations, transformer substations, and banks of transformers. Section 13.A.g. provides: **"For individual transformers and building services the ground connection may be made as in Section f, or may be made to water or other piping systems running into the buildings.** This connection may be made by carrying the ground wire into the cellar and connecting *on the street side* of meters, main cocks, etc., but connection must never be made to any lead pipes which form part of gas services." Section 13.A.g. goes on to prescribe how the ground connections are physically to be made to the pipes. Thus, the 1901 *NEC*, the first code to provide for grounding of transformers and building services, also provides that these ground connections may be made to building water pipes.

When grounding of secondary systems became mandatory in 1913, the provision for grounding to water pipes was maintained as written in Section 13 g. of the 1901 code, with the one change that the words "or other" were eliminated, making water pipes the only type of piping system entering a building acceptable [2]. This change was presumably made to eliminate grounding to gas pipes.

Section 15.f. of the 1913 code contains the following words: "Companies and Departments in charge of water works are urged to allow the attaching of ground wires to their piping systems in the full confidence that the integrity of such piping systems will not in any way be affected whatever may be the normal voltage" [2]. The fact that the committee felt it necessary to insert this sentence in the *NEC* indicates a degree of reluctance on the part of water authorities to allow grounding to their pipes. This same sentence is included in the 1915 code [30].

The discussion on ground connections was greatly expanded in the 1918 *NEC* [7]. Section 15A.o. states: "The ground connection must be permanent and effective and be made as indicated below, **but always to water piping system if available. The protective grounding of electrical circuits and equipment to water piping systems, in accordance with these rules, should always be permitted,** since such grounding offers the most efficient protection to life and property and is not injurious to the piping systems." Section 15.a.q. states: "Ground connections to metallic piping system must be made on the street side of water meters, but connections may be made immediately inside building walls to secure accessibility for inspection

and test . . . .” Section 15.a.q. goes on for considerable length about grounding to water pipes, allowing grounding inside a building if the run would otherwise be too long and if care is taken to ensure that the piping is electrically continuous. Gas piping “must be avoided wherever practical.” Gas pipes “should not be used” for grounding unless water piping is not available, and then only for grounding of “equipment, metal raceways, etc.” The continued reference to permission of grounding of water pipes indicates there was still hesitation on the part of water authorities in 1918.

The 1923 reorganization of the *NEC* moved connections to water pipes to Section 906, which states in 906.b.: “Elsewhere than at supply stations, the grounding conductor shall be connected to at least one such piping system, if available” [8]. 906.c. requires the point of connection to the piping system to be on the street side of water meters, except for grounds for equipment, conduit, etc.

A diagram from a 1924 wiring book [28] of grounding of the neutral at the service entrance to a water pipe is shown in Figure 2-5. In Figure 2-6, a diagram from a 1931 wiring book [29] shows an enclosed grounding-service switch with a ground to the water pipe.

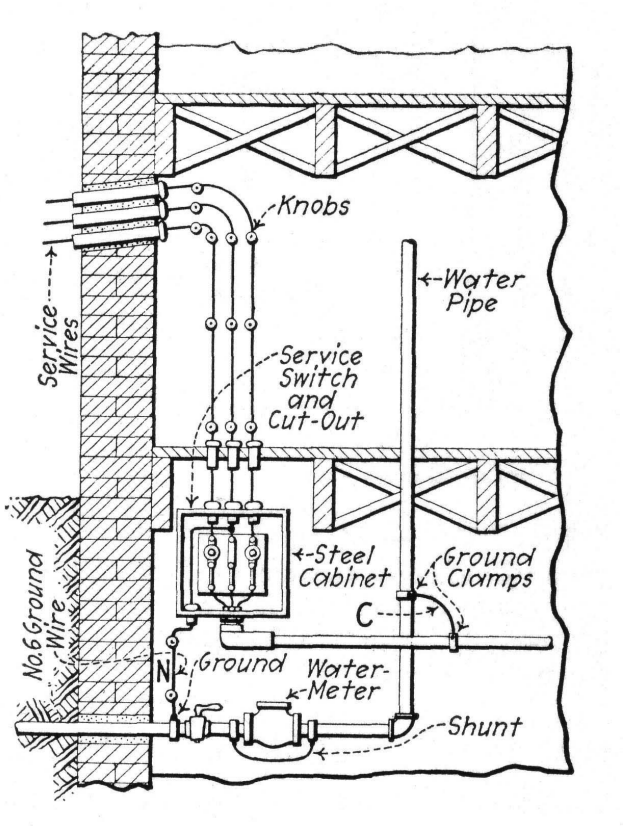


Figure 2-5
Figure from 1924 Wiring Book Showing Grounding of Neutral at the Service Entrance to a Water Pipe [28].

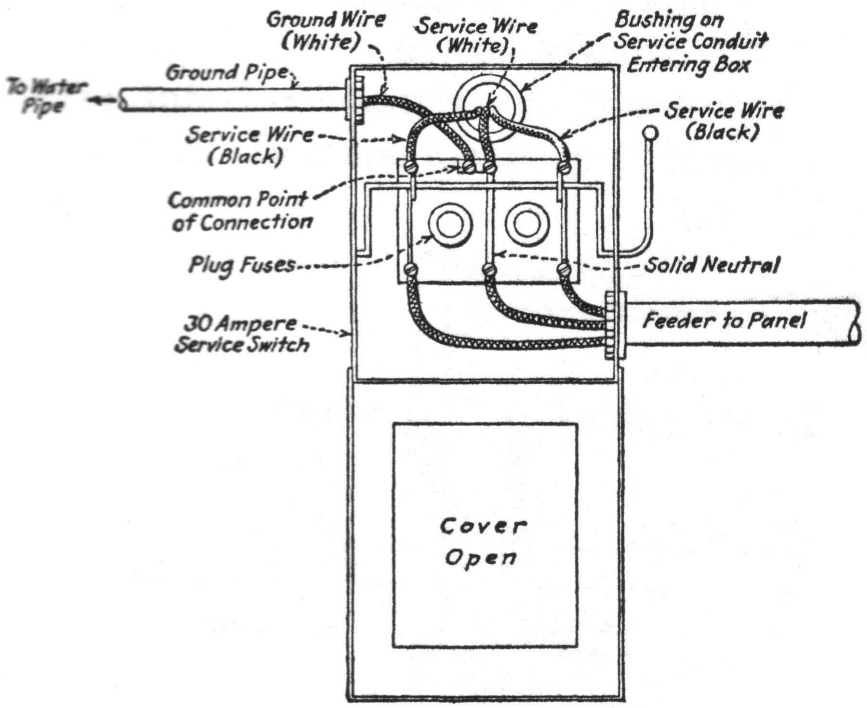


Figure 2-6
Figure from 1931 Wiring Book Showing Enclosed Grounding-Service Switch with Ground to Water Pipe [29].

2.10 Note on Voltages

Household wiring of approximately 110 volts for electric lighting was established early in connection with the design of incandescent lamps. Edison developed the "Edison Three-Wire" system at the beginning of the central-station power industry to effectively allow transmission of power at double this voltage and half the current, with one-quarter of the losses for the same wire size. In the Edison Three-Wire system, there is a grounded neutral as well as two 110-volt wires with opposite polarity, so that the voltage between the two live conductors is 220 volts. This system is still used in residential wiring, where lighting and most branch circuits operate at 120 volts, but 240 volts are available for larger appliances such as stoves and clothes dryers. Note that the specified voltages are nominal ones, in that actual measured voltage in a house may vary a few percent above or below nominal. Depending on the time period, the nominal voltage may be identified as 110/220, 115/230, 120/240, or occasionally some other value. It is not uncommon even today to refer to electric wiring as 110, 115, or 120 volts (or, for stoves, 220, 230, or 240 volts.)

Electrical literature in the early 1900s uniformly assumed that voltage in the 110-volt range was safe, though without a detailed theoretical or experimental basis for this opinion. In order to cover a possible range of service voltages, a maximum voltage of 150 volts between a live conductor and ground was specified, as opposed to some merely nominal value. For example, the 1913 code clearly states: "When the maximum difference of potential between the grounded point and any other point on the circuit does not exceed 150 volts" [2].

Occasionally some other voltage has appeared in the code. The 1903 code did not specify voltage for a normal three-wire service, where the voltage to ground would be less than 150 volts [31]. Two-wire services were also widely used. In homes, 110-volt nominal two-wire services were used, while higher voltage two-wire services primarily served nonresidential purposes. According to the 1903 code, two-wire services could also be grounded on one side, if the voltage to ground did not exceed 250 volts. This provision covered 220-volt two-wire services for commercial customers. Later codes specified the 150-volt maximum-to-ground value for three-wire services. The code published in 1923 continued the 150-volt-to-ground value, but allowed grounding of electric furnace circuits up to 300 volts to ground [8]. Some discussions at the time encouraged mandatory grounding of all circuits up to 300 volts to ground to ensure safety. (See Section 7.5 for additional information.)

While nomenclature varied, the essence of the provisions was related to grounding of the typical residential circuit supplying lighting and small amounts of power.

3
DISCUSSION IN WIRING BOOKS

From the earliest days of the electrical industry, books have been published to guide electricians in the installation of electrical wiring and systems. An early volume published in 1896 was *The National Electrical Code. An Analysis and Explanation of the Underwriter's Electrical Code, Intelligible to Non-Experts* [32]. The authors of this book claimed it was based on the 1895 code. The book includes a discussion of revisions of a code edition dated January 1, 1896, before the first meeting of the committee to develop standard electrical rules. The code as cited in this book is similar to the one adopted later in 1897 and contains the same provision that the wiring in any building must test free from grounds, along with specification of minimum levels of resistance to ground. The book elaborates on the allowed resistances to ground but does not explicitly discuss grounded versus ungrounded systems.

Standard Wiring for Electric Light and Power [33], published in 1904, was based on the 1903 *NEC*. The discussion on grounding is basically a paraphrase of the code provisions. A 1921 revision updated the book to reflect the code in effect at that time [34].

A more complete discussion is given in another 1904 book published by the Associated Factory Mutual Fire Insurance Companies [35]. The chapter "Rules in Brief" includes the following: "Where transformers are to be connected to high voltage circuits, the Inspection Department should always be consulted before work is begun or the apparatus is purchased, as it is necessary in many cases, for best protection to life and property, that the secondary system be permanently grounded, and this cannot be done unless provision is made for it when the transformers are built." This statement is a clear endorsement of grounding of secondary circuits.

The Factory Mutual book elaborates its reasons for supporting grounding on page 53: "If the primary and secondary coils of a transformer come into contact electrically, the high-voltage primary current may flow to the secondary system. If this should happen, the life of any one handling any part of the secondary system would be endangered, and fires would probably be started by arcs caused by breaking down of the insulation of the wires or fittings on the secondary system. If, however, the secondary coil is grounded, a breakdown in the transformer cannot cause a dangerous difference of potential between the secondary system and the ground, and only with certain unusual combinations of contacts between the primary and secondary wires outside of the transformers will this protection fail to prevent the voltage of the secondary system from being raised above its normal limit. In order to secure the full benefit of the ground connection, reliable primary fuses of proper carrying capacity must be provided. The *middle* of the secondary coil is the proper point to ground, as there is then only half the normal secondary voltage between either side and the ground, thus reducing the liability of a breakdown of insulation and also materially lessening the danger of fire if a breakdown does occur. There is an objection to grounding the secondary on the other hand, for when this is done, the first breakdown of insulation may mean a short-circuit and a possible fire. With a system free

from grounds, a breakdown must exist on each side of the system to cause a short-circuit, and with proper ground detectors, the first can generally be discovered and remedied before the second occurs. Grounding is therefore a choice of evils, but in many cases it is believed to be a lesser one than to risk getting the primary current on the secondary system. This is especially true where the primary voltage is high, say 3500 or over. For this reason it is advised that all transformers be so designed and connected that the middle point of the secondary coil can be reached if, at any future time, it should be desired to ground it. After the transformer secondary has been properly grounded a test should be made, especially if the transformer is some distance from the building supplied, in order to determine if the protection expected from the ground connection at the transformer is really effective inside the building in question, and if not the connection should be extended to accomplish the desired result. Cases have been known where the effectiveness of a ground connection has been limited to a comparatively small area, due to the exact conditions of the earth in the neighborhood of the ground plate and between it and the point where the protection due to the grounding was desired. The entire ground connection should be carefully examined at least once a year."

A third book published in 1904, *Modern Electrical Construction* [36], also presents the argument for grounding: "It quite frequently happens that the insulation between the two windings breaks down and thus the high pressure is accidentally brought into buildings. Under such circumstances should any one touch any live part of the installation while touching also grounded parts of the building death would very likely result. Also, should there be a weak spot in the insulation, it is quite likely the high pressure would pierce it at that point with a possible result of a fire. Many deaths and fires have been caused in this way. If such lines are connected to ground the chances for harm are very much lessened, for the current will never take the path of high resistance through a man's body, while a direct path through a low resistance wire is open to it. It must not be supposed that 'grounding' one side of an electric light system is not often followed by serious consequences, for under such circumstances a ground coming on any other part of the system will cause a short circuit at once. The grounding in these cases is to be looked upon as the lesser of two evils rather than as an advantage. With alternating currents, the chances of possible damage from grounding are much less than with direct currents, because each transformer with its small group of lamps is a system by itself and not affected by grounds on other transformers. Thus, a 5,000 light alternating current installation would consist of from 25 to 50 separate systems, each independent of defects on the rest, while in a continuous current installation, a ground on the most remote branch circuit would in conjunction with a ground on the opposite pole of any other part of the system form a short circuit. In connection with 3-wire systems, grounding of the neutral wire can do little harm, because ordinarily the neutral wire seldom carries much current, and that current is apt to vary in direction so that the electrolytic effect will be on the whole quite negligible. There is, of course, the hazard brought about by the fact that a ground coming on one of the outside wires will immediately form a short-circuit in connection with the ground on the neutral. In connection with 3-wire systems, however, it is of the greatest importance that the neutral wire remain intact, and it being thoroughly grounded at all available outside places will help to keep it so."

The 1912 book *Questions and Answers on the National Electrical Code* [37] is of interest because it reflects the time when secondary grounding was about to become mandatory. In a section entitled "Life Hazard" on page 5, the book states: "Failure of a lighting company to ground secondaries will soon become an invitation for litigation. Fortunately, progressive practice is ahead of discussion and many secondaries are now grounded throughout the

United States, especially in centers. The highest conservative opinion obtainable is found in the official expression of the American Institute of Electrical Engineers, which has declared in favor of grounding up to 250 volts as being good engineering practice and highly desirable."

Terrell Croft's *Wiring for Light and Power*, which includes an extensive section (Article 9) on grounding, was published in 1924 [38]. By that time the *NEC* required secondary circuits to be grounded. In his book, Croft included an extended discussion of the reasoning for and against grounding (to be presented in subsequent sections of this report).

The practice of secondary grounding soon became so common that the controversy could be dismissed with the statement: "In the interior wiring system, the neutral conductor is permanently grounded to a water pipe at the service entrance" [39].

4
ARGUMENTS IN FAVOR OF SECONDARY GROUNDING

The predominant argument in favor of grounding low-voltage systems relates to overvoltages elevating the secondary to primary voltage levels owing to either the crossing of primary and secondary wires or insulation failure in the supply transformer. This argument pervades the literature from the 1890s to 1924. Leakage or induction from high-voltage to low-voltage wires was also considered possible. The quality of transformer insulation at the time, together with prevalent construction practices, made this a not uncommon occurrence [40].

Diagram A in Figure 4-1 shows a cross between a primary and a secondary wire without secondary grounding. The voltage to ground on the secondary wire assumes the level of the primary voltage. For a 7600-volt primary, the household wiring attains a voltage of 7600 volts—probably sufficient to damage insulation and endanger anyone touching anything connected to the household wiring. If, on the other hand, the secondary neutral is grounded, as in Figure 4-1, diagram B, there is a direct connection to ground through the transformer secondary winding. While the actual voltage would depend on such things as ground resistance and transformer saturation, the effect in a grounded system would be a relatively minor rise in voltage.

As previously mentioned, primary voltage on the secondary is life-threatening. Contact between primary and secondary wires is also a fire hazard because the elevated voltage can break down building wiring insulation. Both accidents and fires were commonly reported in the early years of electricity as a result of crossed wires or other causes of excessive voltage on building wiring.

Grounding the secondary limits the amount of voltage rise possible between earth or grounded metallic objects and a live wire, thus limiting the voltage a person may contact [41]. Contact with 115 volts was considered safe in the early 1900s, so grounding was considered to ensure safety. Likewise, because grounding limits the possibility of insulation breakdown in buildings due to overvoltage, it was promoted as a means for reducing the large number of fires attributed to electrical causes.

The Association of Edison Illuminating Companies instituted a Committee on Grounding the Neutral in 1890 [42]. The Committee's recommendation at that time was that "the greatest safety was assured by the practice of grounding the neutral." This conclusion was based on reduced fire risk "in face of the fact that the underwriters have uniformly refused to countenance the practice." Grounding the neutral was in fact the practice of the large Edison companies in the 1890s [43].

Another argument in favor of grounding was that if the secondary is grounded and there is a problem, the problem is readily apparent.

Legal arguments were also cited to emphasize that grounding would reduce lawsuit [44] and insurance claims [45, 46].

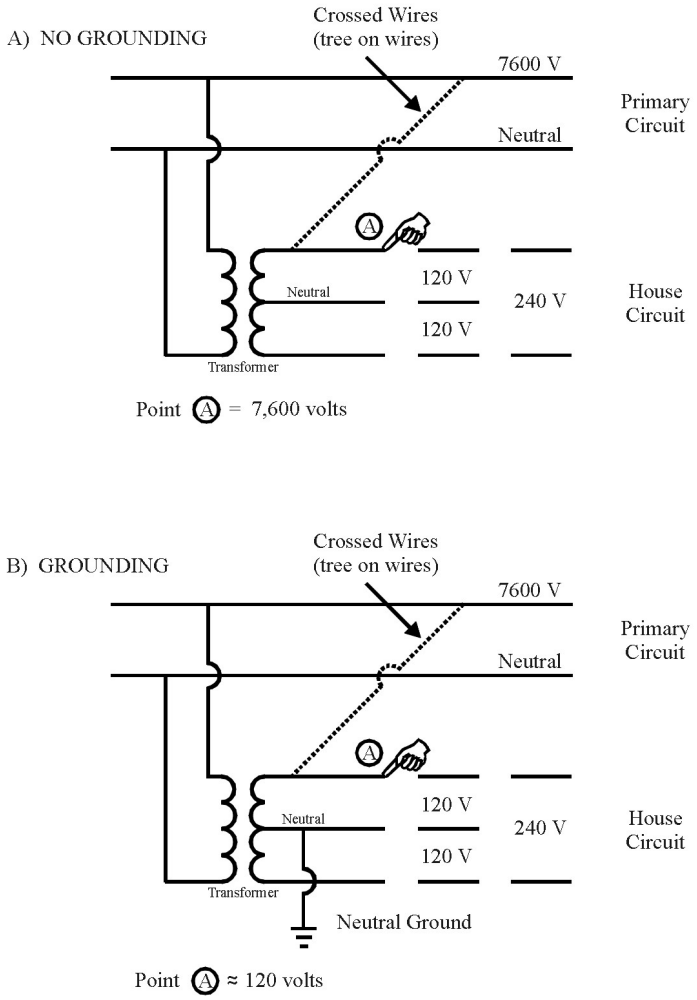


Figure 4-1
Diagram Illustrating Crossed Primary and Secondary.

5
ARGUMENTS AGAINST SECONDARY GROUNDING

5.1 Electrical Arguments

Three main arguments were put forth from the electrical standpoint against grounding of the neutral:

1. In principle, an ungrounded circuit can continue to operate properly in the presence of a single accidental ground, while a single accidental ground necessarily causes an interruption of service in a grounded circuit.
2. Secondary grounding may increase fire hazard, because a single ground results in a short circuit in a grounded system. Fault current due to a single ground on a grounded system was an issue especially because of primitive and unreliable fuses in the earlier years. This was especially true before 1904, when a supplement on fuses was added to the *NEC* [47]. Owing to the unreliability of fuses prior to that time, the fire hazard argument carried considerable weight. At the start of the 1900s there was also a fire-related concern that the full voltage of the circuit would continually act on the insulation in a grounded system, as opposed to one-half of the voltage in an ungrounded system. However, this latter point was contradicted by the requirements for insulation even at that time.
3. Some claims were made that grounding increased the risk of shocks, possibly because it was thought that touching an ungrounded wire was safe at any voltage. (See the discussion on capacitance in Section 6.2.)

As noted above, fire hazard was cited in arguments both for and against secondary grounding. Part of the issue was the reliability of fuses: those who believed in fuses tended to support grounding, while those who mistrusted fuses tended to oppose grounding. A similar issue involved insulation, with some arguing for grounding based on insulation breakdown under secondary voltage (115 or 230 volts, depending on line-to-neutral or line-to-line) and some arguing against grounding based on insulation strength. Of the two issues, the problem of fuses was the more technically valid since fuses were still in an initial state of development before 1904, while insulation strong enough to withstand 115 volts would not have been safe under any condition if it could not also withstand 230 volts continuously.

There were several other electrical arguments against grounding of the neutral. Some relate to primitive practice and others to limited understanding, while still others may be considered merely obstructionist [48]:

- Permanently grounding the transformer secondary increases the electrical stress on the transformer insulation, especially between primary and secondary windings. This argument was countered by the observation that a transformer whose insulation could not stand that level of stress should not be in service at all [49]. (See the discussion on Section 7.1 from the first meeting of the National Conference on Standard Electrical Rules.)

- Permanent grounds may increase the difficulty of performing certain electrical tests [38].
- Permanent grounds may increase the expense of installation due to the additional wire required for grounding, the need for additional inspection, and trouble from defective grounds [50].
- Building owners were being asked to protect themselves against carelessness on the part of the electrical company. (See the discussion in Section 7.3 on the 1901 meeting of the New England Water Works Association.)
- Another issue cited was "possible troubles in operation, particularly in regulation and excessive registration on the meters, but no increased risks are foreseen" [51].

An electrical argument was put forth specifically against grounding to water pipes: "But one company out of over one hundred writing considers the water-main ground even to water-service pipes of buildings unfavorably, as making possible current exchange between water mains and secondary grounds at different potentials. [Note that "even to water-service pipes" is stated in distinction to other possible locations for connections to water pipes.] Four operating companies state they have noticed such an exchange. No companies, however, have noted harmful results, some claiming freedom from noticeable direct current on secondaries" [52].

The same reference [52] noted a legal argument against grounding: "The later opposition has come more particularly from those lighting companies which have either suits pending, or the moral necessity for supporting their former defense of such suits."

5.2 Water-Supply Arguments

The primary issue relating to the interaction of water- and electricity-supply systems at the dawn of the twentieth century was electrolytic destruction of water pipes as a result of current from electric street railways [53, 54, 55, 56, 57, 58]. (Figure 5-1 shows some examples of damaged underground piping.) The American Water Works Association (AWWA) had a special committee on electrolysis that reported on legal cases at the association's annual convention. In 1901 the AWWA unanimously adopted a report written by this committee calling for the removal of railway currents from the earth. An editorial in the June 27, 1901 issue of *Engineering News* supported the resolutions adopted by the AWWA by reprinting them with the comment, "It would appear, therefore, that no mistake was made in the action taken by the Association at this time" [59]. The 1903 AWWA convention heard two papers on electrolysis [60].

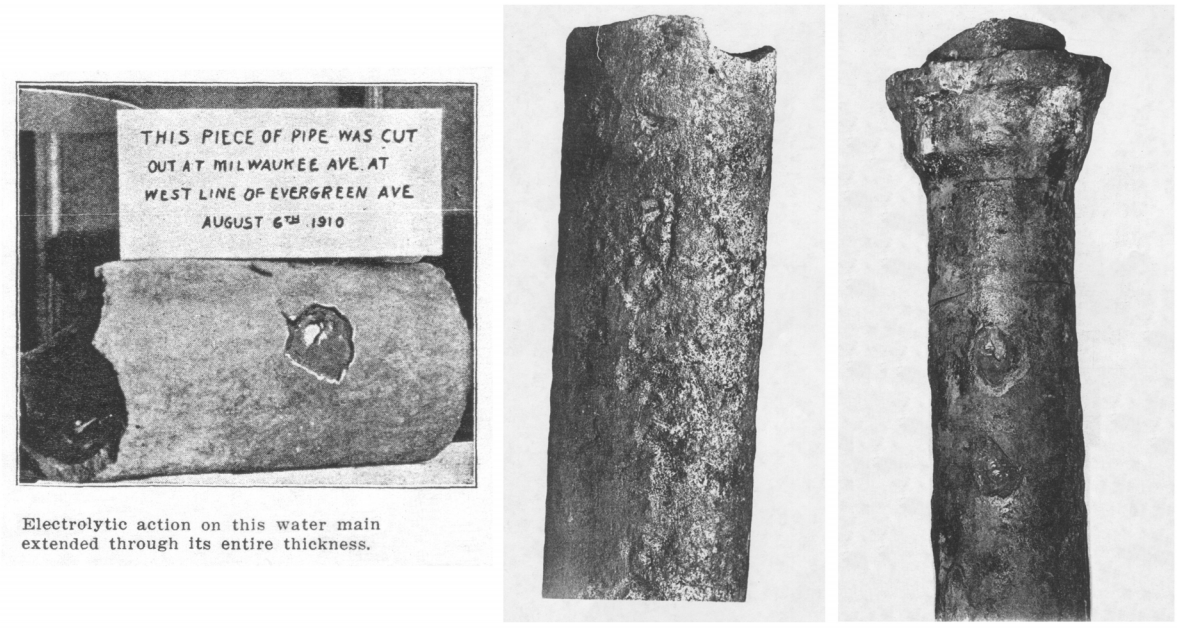


Figure 5-1
Examples of Electrolytic Damage to Underground Piping. Left: Piece of Pipe Damaged by Electrolysis in Chicago [64]. Center: Pipe Damaged by Electrolysis Removed from 339 West Broadway, New York City [65]. Right: Pipe Damaged by Electrolysis Removed from South Ferry, New York City.

Owing to the extent and seriousness of the problem of electrolytic damage to water pipes, the literature on electrolysis from 1901 to 1924 is very extensive. As mentioned above, the main cause of electrolysis was leakage return current from electric street railways. Street railways used 500 to 600 volts of direct current, with return to the powerhouse through the rails. Some of the return current, however, found its way into the earth and returned through underground piping. Electrochemical action where the current joined the pipe resulted in significant corrosion of the pipe metal, which led to frequent failure and leaks. In 1902 the use of alternating current instead of direct current for supply of street railways was seen as a possible solution to the electrolysis problem [61]. The problem was finally addressed by changing the return-current path of the street railways. A 1914 article reported: “The waterworks authorities are coming to realize that grounding is a means of protection to life. Early trouble from electrolysis was usually due to improperly grounded wires of street-railway companies” [62].

Two points regarding the problem of electrochemical corrosion of pipes from street-railway currents were of relevance to the discussions surrounding residential grounding. First and foremost, the corrosion made the water companies reluctant to permit any intentional grounding to their pipes, including residential supply circuits. Second, the recognition that electrolysis was much less of a concern for alternating current than for direct current worked in favor of obtaining approval of grounding alternating-current residential secondary systems to the water system.

That electrolysis was the main issue is indicated by the following quote from a 1939 text on water supply [63]: “Probably the most satisfactory ground is a connection to a water-supply pipe. The practice of so making grounds is widespread and is generally recognized and approved in spite of some objections that electrolysis of the pipes may result. The objection is least valid where alternating current is used.”

The preamble to Section 13A of the 1901 edition and subsequent editions of the *NEC* provided that ground connections were not to carry current during normal operation. This lack of current during normal operation, along with the fact that electrolysis is considerably less with alternating current than with direct current due to the alternating polarity, provided the basis of the electricity industry's counterargument.

Other concerns expressed were "coloring of the water, electrical shock to personnel and others, corrosion of pipes, and tastes added to the water. The remedy is to mitigate the effects rather than to abolish the cause" [66]. The most common concern in turn-of-the-century literature was the safety of plumbers and water-supply workers when they performed tasks such as installing water meters. However, this concern was not usually expressed as an objection to grounding.

Ultimately the practice of grounding gained approval, for in 1911 it was reported "as such grounding of secondaries to water-pipes has the approval of the American Waterworks Association" [67].

6
MISUNDERSTANDINGS AND PRIMITIVE WIRING PRACTICES

6.1 Primitive Wiring Practices and Materials

A large number of fires were caused in the early years of electricity by various primitive wiring practices. One of these practices was the use of "underwriter's wire," which carried a type of insulation so unreliable some wag said it should be called "undertaker's wire." Another practice was installation of wooden cleats to hold electrical wires; the cleats absorbed moisture and thus became conductive. Also, no insulating tubes were used when wires were passed through the walls of buildings; only a piece of soft rubber tubing protected wires passing through brick or plaster walls. Owing to these practices, ground faults were common.

Combination gas and electric lighting fixtures presented a special problem because of the proximity of electric wires to grounded gas pipes. Fuses were also a problem in the early years, because of both unreliable operation and the tendency of people to defeat them to prevent interruptions. There were reports of electrical fires that started because of people tampering with fuses. One magazine reported someone filling the fuse with lead "to do away with the only weak part of the system" [68].

A ground fault on a well-grounded circuit, like a fault between the two wires of a circuit, results in passage of a high fault current that can overheat or melt the wiring and create a significant fire hazard. The purpose of fuses is to protect the wiring by cutting off the fault current in a sufficiently fast time that the wires do not overheat. Fuse design is a matter of coordinating the melting time of the fuse with the heating of the wiring; early primitive fuses were not sufficiently reliable for protecting wiring because of the long time that could elapse before a fault might be cleared. Before 1904, much of the hesitation about secondary grounding had to do with concerns about interrupting fault current on a grounded circuit and fires resulting from long-term passage of fault current. Addition of a supplement on fuses to the *NEC* in 1904 was a major step forward in protection of building wiring from fault currents [47].

Another area related to primitive wiring practices concerned the voltage level a person could safely touch. As previously mentioned, it was widely felt that it was safe to touch a 115-volt circuit, so much discussion automatically assumed that if the voltage could be held to less than 150 volts, safety would be assured.

6.2 Capacitance

Much misconception was prevalent around the turn of the century because of the lack of understanding of capacitance. This problem was addressed by an article on the grounding of high-voltage systems that appeared in *Electrical World* in 1902 [69]. The article states that "the convenience of the practice (grounding) lies in the fact that grounding the zero-point fixes the potential between conductors and ground, and thereby limits it to a known value, for which proper insulation can be provided, and other safeguards be taken; but it is the current opinion that the very fact that the conductor potentials are thereby maintained at a fixed dangerous value above earth potential, is final evidence that the danger to life is increased by the practice."

The misconception the author is addressing relates to the concept that if a person touches an ungrounded system of any voltage, the "potential of the point touched immediately falls to zero"; in other words, it is perfectly safe to touch any wire of an ungrounded system. The author shows the fallacy of this reasoning to be a neglect of capacitance: "Owing to capacity, each conductor is, in effect, grounded through a condenser, and, though the conditions are not exactly the same as when one wire is grounded direct, the results are somewhat similar." He points out that capacitance was accepted as a cause of dangerous shocks that had been received from alternating-current lines.

Following an extended analytical discussion of the physical phenomena involved in grounding, the author concludes: "As a conclusion it may be stated, that the practice of grounding high-potential systems conduces (sic), in most cases, to reliability in operation, and that, with rare and unimportant exceptions, it cannot be objected to on the score of causing increased danger to life and property."

Even down to the present day, neglecting the effect of capacitance has led power engineers to a number of false conclusions. Strictly speaking, there is no such thing as an ungrounded system, because every electrical wire is grounded through capacitance. A person touching a wire of an alternating-current circuit is, at the very least, part of a circuit that is completed through capacitance. In this way it is possible to experience an electrical shock by touching only one wire.

Another misconception relates to ground faults on three-phase systems. If there is no capacitance to ground, the highest voltage possible on an unfaulted phase during a ground fault on a three-phase ungrounded system is phase-to-phase voltage. In other words, the voltage may go to 1.73 times normal during a fault. This level is significant for both insulation design and specification of surge arresters. In fact, when capacitance is taken into account, the voltage can rise to a value greater than 1.73 times normal. This effect has resulted in equipment damage and fires, and has led to the conversion of many ungrounded industrial systems to grounded systems. It is also why the use of ungrounded delta primary feeders is disappearing in favor of multi-grounded neutral primary feeders. Harold Peterson provides a thorough analysis of overvoltages possible on ungrounded systems as a result of capacitance [70].

7
SYNOPSIS OF DISCUSSIONS AT MEETINGS

7.1 First Meeting of the National Conference on Standard Electrical Rules (1896)

At the first meeting of the National Conference on Standard Electrical Rules in 1896, the grounding of secondary circuits occasioned some discussion [11]. The question of whether it was necessary to specify how much resistance should exist between primary and secondary coils was raised, as well as the question of whether there should be any requirements for construction for safety.

The following statement was made specifically concerning grounding: "Relative to suggestion of Mr. Kennelly as to the grounding of the secondary coil of the converter at its center, it seems to me that is putting a severe strain on the insulation. I assume a low resistance ground is meant, something that, in the event of a ground occurring on the line and a breaking down of the insulation of the transformer, the current would pass through so as to destroy the converter and cut out the primary current from the secondary. You put an insulation strain on your transformers that is rather serious; and, taking a good many transformers in the circuit, you get a condition that may make considerable trouble. But there is no doubt about the advisability of getting some sort of transformer protection, especially on the primary lines where two thousand volts and upwards are transformed directly to the house service low-potential."

Mr. Kennelly responded that although he would not like to overburden transformer manufacturers, he thought that transformer manufacturers, as well as users of electricity, would benefit from secondary grounding. He agreed that grounding the secondaries increases insulation stress caused by lightning, but stated that any transformer whose insulation could not stand grounding the secondary should be replaced. He also mentioned the question of the safety of a person touching a low-voltage wire in case of a contact between high- and low-voltage wires, asserting that grounding would protect the person, but adding that some device that could quickly ground would also do so.

A suggestion was made regarding a device using a solenoid to short-circuit the secondary mains in the event that the voltage rose too high. The breakdown of transformer insulation due to lightning or high voltage was given as a common cause of failure, and although the speaker acknowledged that something needed to be done about this, he was unwilling to support secondary grounding.

The code that resulted from this meeting did not include any provision for secondary grounding.

7.2 1899 American Institute of Electrical Engineers Meeting in Boston

At the June 27, 1899 AIEE meeting in Boston, a paper entitled "The Protection of Secondary Circuits From Fire Risks," with a discussion by luminaries such as Elihu Thompson and Charles Steinmetz, was presented by Gary Hutchinson [51]. After discussing the physics of overvoltage problems on secondary circuits, Mr. Hutchinson proposed three possible solutions:

1. "Devices intended to ground, short-circuit or open-circuit the secondary circuit when subjected to an abnormal difference in potential."

2. "Grounded metallic shields interposed between the primary and secondary coils of the transformer."

3. "Permanent grounding of the secondary system."

Mr. Hutchinson rejected the first solution as a temporary makeshift at best, and the second because it provides no protection for crossed wires outside the transformer. Permanent grounding of the secondary system, however, he regarded as "the only sure way to prevent the potential above earth of the secondary system rising above the voltage of the circuit."

A number of other significant points were brought up in the discussion. The following paragraphs summarize the highlights:

Professor Elihu Thompson stated that his home in Lynn, Massachusetts had its secondary grounded on gas and water pipes in 1887. He discussed a film device to ground wires under fault conditions that was disparaged by later speakers as unreliable.

Mr. C. M. Goddard, who was connected with the code committee, stated: "Not, however, because the underwriters are fully convinced as yet, that one of their rules, almost as unchangeable as the laws of the Medes and Persians, that no circuit should be permanently grounded, has been wrong all the time . . . ." He further indicated that grounding of the secondary could turn out to be the best solution as the lesser of two evils, but that the underwriters were a conservative group. His point was that if the secondary was "thoroughly and properly grounded . . . then you know what you have."

Professor Goldsborough thought it best to not ground the secondary, because in his mind it would encourage inferior materials and equipment that would not be subject to rigorous insulation tests. He proposed severe testing of building wiring before allowing it to be connected to the supply.

Steinmetz disagreed with Goldsborough, preferring that grounding be mandatory. After observing that majority opinion seemed to favor grounding to reduce fire risk, he stated: "Regarding danger to life, however, there never has been any doubt, and never can be, that the only absolute and perfect protection against danger to life in case of an accidental contact of the lighting circuit with a high-tension circuit of any description, is a permanent and absolute ground of the low-tension circuit." He went on to say that he did not want to turn on a lamp while standing on the damp floor of his cellar "knowing that the only protection against certain death is the insulation of some unknown type of transformer which hangs somewhere on a pole, exposed to the weather for years."

Dr. Bell pointed out that the problem was not the initial condition of the insulation, but what happened to it over a period of time, and agreed that the only way to ensure safety was to ground the secondaries. He went on to propose grounding of the primary feeders as well. Bell characterized the opponents of grounding as saying "you shan't ground your secondaries because something that we do not understand may possibly cause trouble of a character we cannot predict in some wiring we know nothing about."

Captain William Brophy reviewed some of the background behind the grounding issue, noting the improvements in the previous ten years in insulation and transformers and the role that poor insulation played in the earlier decision not to ground the secondaries. Captain Brophy agreed that now "the time has come when this plan of grounding the secondaries can be adopted."

Professor Puffer, a consultant to the insurance companies, stated: "I want to go on record as stating what I believe to be the truth, that this grounding of the secondary has been held off for two years by the action of gentlemen in connection with the electrical industries. I have attended the annual meetings of the insurance inspectors and I found two years ago, that it seemed as if we could adopt a rule requiring, under suitable conditions, a grounding of the neutral circuit, but it was prevented by the statements and efforts of certain electrical gentlemen who I presume believe what they said."

Professor Puffer discussed the necessity for reliable fuses, adequately sized ground wires, and the possibility that a ground could become a conducting path for other systems, such as electric street railways. Nevertheless, he concluded: "I would carry grounding to such an extent that I would compel the absolute grounding immediately at point of entrance of buildings of every system and including such things as water pipes and gas pipes."

The session concluded by adopting the following resolution:

"Resolved, that the American Institute of Electrical Engineers favors a rule permitting the grounding of one wire of every low potential consumption system.

Resolved, that the Committee of the American Institute of Electrical Engineers on the National Electrical Code is hereby requested to confer with the Electrical Committee of the *Underwriters' National Electric Association* in relation to recommending to the *National Board of Fire Underwriters* the passage of a rule permitting or requiring the permanent grounding of one wire of such systems, under suitable restrictions.

Resolved, that they also confer with the same committee in regard to recommending to the National Board of Fire Underwriters some modification of Rule 39 of the code in relation to the installation of secondary wires when the primary wires carry a current of over 3500 volts potential."

7.3 1909 Meeting of the New England Water Works Association

At the February 9, 1909 meeting of the New England Water Works Association, Mr. F. E. Merrill, Water Commissioner of Somerville, Massachusetts, read and discussed a paper entitled "Grounding Electric Light Wires on Water Pipes" [71]. The commissioner had received a request

in 1902 (following issuance of the 1901 *NEC*) from the local lighting company to ground the secondary connections of its transformers to the water pipes in the city of Somerville. On the advice of an electrician that "because of the uncertainties of the effect of electric currents which might get into the water pipe system, and the difficulty, if any trouble did arise, of establishing the fact that it was caused by the ground wires, and the possibility of attendant complications," permission was not granted at that time. A few years later, after the lighting company had been taken over by another company, the new company attempted to ground its house service wires without first obtaining permission from the water department.

The city then called in a consulting electrical engineer, who prepared a report on the subject. He "regarded the grounding of the secondary wires a necessary safety precaution, the neglect of which almost amounts to criminal negligence, and that the only question involved was the way in which this grounding should be carried out." He concluded, "If proper precautions are taken, this is entirely safe." The engineer's chief concern related to safety while working on the water-service pipe, and that could be dealt with by suitable precautions. After studying the opinion, it was decided to permit grounding "in a manner satisfactory to the water commissioner and the commissioner of electric lines and lights of the city."

Several questions were raised in response to the commissioner's presentation. They include the following:

- The question of compensation for worker deaths due to the grounding system: "In case of the death of an employee of the Somerville Water Department, caused by a stray current on this connection, to whom would the heirs of the man look for damages?" The response was that the heirs would look to the city and the city to the lighting company.
- The matter of whether to ground at the pole or inside the building, especially in outlying areas (in 1909 the provision for grounding at both places had not yet been made, so there was frequently a question of whether to ground at one or the other). A case involving two fatalities was cited, probably involving excessive ground resistance, although that was not stated at the time.
- Resistance in water-pipe joints and meters, and how to test for resistance. The point was brought out that grounding was to be on the street side of the meter and shutoff.
- Why it is necessary to ground at all. It was pointed out that in Worcester there were over 16,000 services, without a single one known to be grounded inside or outside.

Representatives of the Boston Edison Company noted:

- The company decided in 1905 to ground all alternating-current services.
- No damage to water facilities had been reported to date in any of the towns that had grounded electric services.
- Boston Edison obtained permission of the building owner for grounding rather than deal with the water company. In one case they agreed to a save-harmless provision; in another they made payment to the city (with a few implications left unstated).
- Some electrical contractors "took great pleasure in presenting to the minds of the public that the company was asking the customers to protect themselves against carelessness,

or whatever they might choose to call it, on the part of the company." Certain contractors also opposed the idea of grounding "because of the slight additional expense in the cost of wiring."

- It is difficult to obtain a good, reliable ground other than by grounding to water pipes. It is desirable to have multiple ground connections and not rely on a single connection.

A case involving a fault from a street-railway circuit to a telephone cable sheath that burned off a ground connection and started a fire was brought up, along with one concerning electrolysis of water pipes from street-railway circuits.

7.4 1909 Meeting of the International Association of Municipal Electricians

The International Association of Municipal Electricians met in Atlantic City in 1909. The following resolution was adopted at the meeting [72]: "Whereas, One of the purposes of the International Association of Municipal Electricians is the protection of lives and property of the people whom we represent from electrical hazards, and Whereas, Alarming destruction of life and property has resulted from high voltages on alternating current secondary systems by reason of the failure of the insulation between the primary and secondary circuits, and Whereas, The existence of the said high voltages may be prevented by properly grounding the alternating current secondary systems. Now therefore be it Resolved that the International Association of Municipal Electricians, deliberating as an international body, urges and demands the enactment of proper legislation requiring the grounding of all alternating current secondary systems, when by so doing, the voltage between the earth and any part of the said secondary system will not exceed 250 volts, and this body pledges the support and advocacy by its members of all legislative measures to the end."

7.5 1910 and 1911 Meetings of the National Electric Light Association

The Committee on Grounding Secondaries presented a report at the 1910 convention of the National Electric Light Association in St. Louis. Withdrawing its earlier opposition to grounding circuits above 150 volts to ground, the committee decided to leave the matter to the individual companies. It also recommended that the secondary circuits should be grounded, and should have the ground connection "made on the premises of each customer, and preferably to a water pipe" [73]. The following summarizes the discussion of this report [74]:

- *Why to Ground*. The two principal reasons for grounding are "protection afforded human beings from the danger of injury, especially, fatal injury, by electric shock. A secondary benefit is the lessening of the fire hazard when the secondary system is grounded." The discussion states that the Board of Fire Underwriters should make grounding of secondary systems mandatory.
- *When to Ground*. Citing the resolution approved at the 1909 meeting of NELA recommending mandatory grounding of secondary systems up to 150 volts, the discusser supports grounding secondary systems up to 300 volts to ensure human safety. He adds that the Code Committee of the AIEE in 1909 reported to the Board of Directors, which voted in

favor of grounding all circuits up to and including 300 volts; however, because of a later dissent, the recommendation was not presented to the joint meeting of the Underwriters.

- *Where to Ground.* There are only three possible places to ground: the generating station, the transformer, and the customers' premises. The discusser favors multiple grounds, especially stressing the need to ground at the customers' premises.
- *How to Ground*. There are three possible methods of grounding: to an active water-supply system, a buried copper plate, or a driven metal pipe; of these, water pipes are best. Methods need to be addressed where water pipes are not available, especially in areas of high earth resistivity.

The discussion, largely on what voltage circuits should be grounded, continued at the 1911 meeting [75]. It was decided that lighting circuits especially should be grounded, because they were used by the general public and because of the type of wiring and attachments they required. "The Committee hopes to get data on the value of different kinds of ground connections, but is still convinced that metallic pipe grounds are the best and that plates and other ground devices are but makeshifts." Some reluctance on the part of the Fire Underwriters to change the *NEC* stemmed from the argument that the fire risk was not lessened. Some on the underwriter's committee seem to have held that safety was outside the realm of the code.

7.6 1912 Meeting of the American Water Works Association

At the 1912 meeting of the American Water Works Association, Albert Ganz, professor at Stevens Institute in Hoboken, New Jersey, presented a paper on electrolysis [76]. While the paper itself deals with direct-current street railways rather than residential grounding, the discussion of the paper is of interest for the light it sheds on misconceptions prevalent at the time.

An engineer from the water department in East Orange, New Jersey claimed that "during the past two or three years we have been having considerable trouble from alternating currents used for light and power. The neutral wire, even though grounded properly, does not seem to accomplish all that it is supposed to accomplish, due probably to defective work at some unseen point." He cited a case involving destruction of a bronze stopcock, its core "being almost completely melted out." As a result, his city was "seeking to prevent absolutely the grounding of any such current on to our water pipes." He also claimed that there were cases of shocks—some fatal—being received by occupants of houses because of grounded light or power wires.

Professor Ganz responded that the damage to the stopcock was probably caused by electric arcing rather than electrolytic action. He did not believe that electrolytic action from grounding an alternating-current lighting system to water pipes could occur under ordinary conditions. However, he "had no doubt that alternating currents on piping caused by accidental grounds can give considerable trouble from burnouts and from shocks."

It is not clear from the discussion whether fault currents in the New Jersey case were sustained for extended periods, or whether there were high resistance conditions on the ground circuit.

7.7 Other Meetings

The Chicago Electrical Association met on April 3, 1903 to discuss "The Effects Produced by Grounding the Neutral on Alternating Current Systems" [77]. G. M. Eastman, who was in charge of the testing department of Chicago Edison Company, presented a paper that discussed mathematical principles, using examples from the overhead and underground lines of Chicago Edison. The report of the meeting stated: "the conclusion being in every case that arises in practice that the neutral of a four-wire, three-phase, alternating-current system should be grounded" [77]. The discussion supported the practice of neutral grounding, though it was pointed out that "it had actually been proposed to forbid by law the grounding of the neutral in the City of Chicago."

At the Colorado Electric Light, Power, and Railway Association annual convention at Glenwood Springs on September 21–22, 1910, a report on grounding secondaries was presented [78]. The report stated that a number of serious accidents had occurred on secondaries that were not grounded, but none had occurred on grounded circuits and there had been no increase in fires. The Association recommended to its members the grounding of secondary distribution wires wherever a good ground connection was available.

8
EXAMPLES OF ACCIDENTS AND FIRES

In 1903 *Electrical World* presented a fatal accident report as evidence supporting secondary grounding [79]. The report stated: "The importance to electric light and power companies of making use of the recommendations of the national code, which permit the grounding of low-tension circuits, was recently sadly illustrated in a small central station plant in the middle West. In this case it was the chief engineer of the plant who suffered the consequences, but this fact serves only the more to show the importance of safeguarding the low-tension circuits by grounding. Evidently there was a defective transformer, or a cross somewhere in the station between the high-tension and incandescent lighting circuit wires. One of the employees of the station received a severe shock from a droplight. The chief engineer went to disconnect the extension cord, by unscrewing the plug, and was accidentally killed. Shocks had been received from this circuit previously. It is astonishing that men of intelligence should take such risks, as did this engineer, immediately after direct evidence that the circuit was crossed with some high-tension line. Had the incandescent lighting circuit been grounded, this man would have been protected even against his own carelessness. Customers of an electric lighting company are entitled to this protection."

Fire and Water, a weekly magazine, regularly published accounts of electrical fires. Under "Electric Fires During the Past Quarter," the August 2, 1902 issue [80] reported: "In the case of one of these, a limb of a tree, after being burned off by contact with a primary wire, fell and crossed the primary with the secondary, sending high potential current at 2,300 volts into three dwellings, in each of which fires were started." The report went on to state: "Fixture wires grounded on gas pipes, feeder wires grounded under sidewalks and service switches grounded on outside walls formed the commonest cases of the grounding of wires reported." (The phrase "grounding of wires" was used at that time for what today would be called short circuits to ground.)

Crossed primary and secondary wires causing fires were a recurring theme in *Fire and Water* in 1901 (for examples, see the June 8 issue, page 181 [81], and the November 9 issue, page 398 [82]). On June 1 the magazine reported on page 173: "Over half the fires in Dallas, Texas are due to electrical causes" [83]. On June 8, 1901, on page 183, the author of an article presenting a diatribe against electricity in buildings likened electricity to "streams of liquid fire" [84]. Another diatribe against electricity appeared in on page 190 of the June 15 issue [85].

Fire losses caused by electricity were also reported in *The Metal Worker*. On June 15, 1901 [86] the magazine reported: "While 33 were due to defective wiring and general breakdown of insulation, mostly of old work . . . 3 cases are noted where fires were started by 'arcing' between water and gas pipe, caused by the difference of potential between them . . . Nine burn outs and crosses were reported as occurring during wind and sleet storms, thus emphasizing the necessity of placing wires underground." The opinion expressed on placing wires underground demonstrates the prevalence of the problem of crossed primary and secondary wires.

On March 1, 1902 [87] *The Metal Worker* stated: "Many of the recent disastrous fires have, on investigation, been traced to the use of electricity, and the public is not by any means satisfied that the methods of electric illumination and electric motive power have yet been developed to the point of perfection." The magazine then went on to compare the fire safety of electricity and acetylene for lighting.

In 1913 the *Electrical Review and Western Electrician* [88] reported the following table of injuries and fires resulting from high voltages in buildings:

"Deaths in buildings from 2200 volts in five years, United States…….149

Deaths in buildings from 2200 volts in five years, Colorado……..29

Fires in buildings from 2200 volts in five years, United States……..…237

Fires in buildings from 2200 volts in five years, Colorado……..….61

Number of cities from which such deaths were reported……..…49

Number of cities from which such fires were reported……...32"

The number of references to accidents and fires caused by electricity in the early 1900s indicate the severity and widespread nature of the problem and, consequently, the need for changes in electrical practice for safety.

9
GROUNDING IN DIFFERENT PARTS OF THE UNITED STATES

Because organizations such as the National Fire Protection Association and the American Institute of Electrical Engineers were headquartered in the northeastern part of the United States, many of the references to the discussion on grounding come from that part of the country. Grounding practices were similar throughout the country, with local differences, especially where there was difficulty obtaining a satisfactory ground. The practice of grounding, and grounding to water pipes, seem to have been adopted everywhere at about the same time.

A 1910 paper presented at the Minnesota Electrical Association convention [89] reports "the local insurance bureau (Minnesota); . . . University of Minnesota; the St. Paul Gas Light Company; . . . city electrician of Omaha; . . . electrical department of the District of Columbia; electrical inspector . . . in Chicago; . . . commissioner of wires in Boston. Each of these not only advises strongly in favor of grounding the neutral wires of secondary circuits, but also condemns the practice of attempting to ground to anything but underground systems of piping, preferably water pipes. They also unanimously agree that absolutely nothing is to be feared with such an arrangement from electrolysis." The paper reports that the supervisor of the Minneapolis water department supports grounding electrical systems to water pipes, and that the Edison Electric Illuminating Company of Boston has adopted the practice of grounding at each consumer's premises on the water pipes inside the house.

Kansas City was grounding neutrals in 1911 "from a point directly where they enter the customers' homes, through No. 4 copper wires soldered to the house water pipes . . . . Grounds to the water pipe are practically perfect electrically and are quite reliable . . . The local water company has given its tentative permission for the use of its pipes for this purpose . . ." [90].

In the Rocky Mountain region, grounding of secondaries was not considered until 1908 because of high altitudes where lightning troubles were considered to be more severe than elsewhere [91]. The Rocky Mountain Fire Underwriters' association urged investigation and trial of secondary grounding, and one town, Julesburg, undertook the practice. Thirty-four towns were grounding secondaries in 1910; by 1911, 54 out of 103 cities served by electric light companies were grounding, and 14 cities and towns required ground connections by ordinance. In 1912, 55 cities were grounding [92]. Grounds were made to waterworks systems where available. The Central Colorado Power Company "was first to ground all final secondaries, and after two year's such operation it is not experienced a single loss of life or property" [91]. Transformer failures increased in two towns, probably due to a succession of storms of unusual severity. "The grounding in Denver has been followed by less personal injuries, less fires, less transformer losses and quicker detection of line troubles" [91].

Denver Gas & Electric Company started investigating secondary grounding in 1909. The company began grounding its secondaries in 1910, and by fall of that year "the entire system of distribution secondary circuits was grounded" [93]. The company began by grounding the neutral of the secondary "mains" (electrical mains) to the nearest water hydrant, with the consent of the Denver Union Water Company, at spacing of about two blocks. In 1911 grounding was made mandatory for all new electric lighting installations by regulation of the municipal authorities. Conduit systems in buildings were required to be grounded to water pipes.

In 1913 the city of Colorado Springs was preparing an electrical ordinance to provide that all transformer secondaries be grounded within one year for voltages not exceeding 250 volts to ground and to fix the character of grounding to water mains for future electrical service. A similar ordinance became effective at the same time in the town of Greeley [94], while a controversy delayed grounding secondaries in Pueblo. The usual method of driven pipes was opposed as being unreliable in dry soils, and water-main grounds were promoted, as they had been generally adopted in the Rocky Mountain district [95].

The New Jersey Board of Public Utility Commissioners upheld the practice of grounding secondaries in 1912 after a complaint had been filed "alleging that the practice of the Public Service Electric Company in the Hoboken-Jersey City district requiring the grounding of transformer secondaries to interior water pipes was burdensome and unreasonable" [96]. The complaint was based on objections raised by the Hackensack Water Company and the Board of Street and Water Commissioners of Jersey City. The New Jersey Board rules then permitted inside grounding of secondaries to water pipes.

In the State of Washington, the legislature passed a law in 1913 that made grounding of transformer secondaries mandatory in conformance with the 1913 *NEC* [97]. The law required that the ground connection be made to a water pipe or a copper ground plate.

In Texas, grounding to water pipes was found to be the only satisfactory method of grounding by 1913 [98].

The *Electrical Review and Western Electrician* reported in 1914 that "larger cities in which companies are grounding their secondary circuits to water pipes are: Chicago, Baltimore, Brooklyn, New York, Boston and Toronto" [99]. By September of that year, at the final session of the Narragansett Pier convention of the New England Section of the National Electric Light Association, secondary grounding (generally to water pipes) was reported in Cambridge, Massachusetts; Hartford, Connecticut; Providence, Rhode Island; Springfield, Massachusetts; and Woonsocket, Rhode Island [100].

Secondary grounding was practiced in Oklahoma by 1914, although there was difficulty obtaining adequate grounds in the dry soil. "The water mains would, of course, furnish a good ground connection, but these pipes are not always available nor will permission for their use be always be granted by the authorities" [101].

As the practice of grounding spread throughout the United States, it also extended into neighboring Canada. By 1914 the grounding of house services to water pipes was practiced there as well [102].

10
NOTES IN THE ELECTRICAL LITERATURE

In November 1900 The *American Electrician* published "a brief article in which the following advantages of grounding the neutral of large three-wire systems are discussed; it is never possible to get a shock between any wire and the ground of more than 110 volts; the risk of blowing neutral fuses is also reduced, which is shown in diagrams. In small systems, however, which can easily be kept clear of grounds, and where grounds can be promptly located by means of a ground detector, it is not advisable to permanently ground the neutral" [103].

The *Electrical Review and Western Electrician* of April 29, 1911 wrote on "Grounding Secondaries": "The Underwriters National Electric Association has recommended the grounding of secondary circuits up to 150 volts. This action was taken after consultation with and under the advice of leading construction engineers. Many electric light companies now ground their secondaries either to water mains or to home-made grounding devices. Other companies have put the matter off because they have been prohibited from using underground water mains or have been unable to secure reliable grounds at a reasonable cost. **The best ground is a connection to a water system. In some cities, however, this is prohibited because of the fear of electrolysis.** Whenever a transformer breaks down or a circuit is crossed there is only a momentary flow of current to the ground until the fuse or the circuit breaker opens up. This momentary flow is alternating in character and has therefore no electrolytic effect. The water main can therefore be safely used and is recommended whenever it is practical to make the ground connection without undue expense. Wherever water mains are not available, or where a portion of the street, side-walk or basement must be torn up in order to get to water connection, some other method of grounding must be used" [104]. The rest of the article discusses other types of grounds.

A thorough discussion of the status of grounded secondaries is given in a paper presented at the 1912 annual convention of the Western Association of Electrical Inspectors [105]. The paper discusses theoretical considerations and experience of operators; it favors grounding secondaries to water pipes, and cites statistics of accidents and fires to support its case.

Several articles appeared around the turn of the century on thawing frozen water pipes by electricity [106, 107, 108]. The methods for connection of electric current to the water pipes reported in these references probably would not have worked as well if the pipes were connected to the secondary distribution system, as multiple grounds would have provided a parallel path for the current. The fact that nothing is said in these articles about connections between the pipes to the electrical system is a further indication that secondaries were not connected to water pipes where these authors worked.

11
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A
TIME LINE RELATED TO GROUNDING

Time Line for the History of Residential Grounding

1881	Edison displays "jumbo" 50-kilowatt generator in Paris Edison writes to NY Board of Fire Underwriters saying electricity is safe NY Board of Fire Underwriters' and National Association of Fire Engineers' first requirements
1882	Edison's Pearl Street Station in New York City
1884	American Institute of Electrical Engineers (AIEE) founded
1887	Wiring grounded to water pipes in Lynn, Massachusetts
1888	Polyphase motor patented by Tesla
1890	New England Insurance Exchange electrical code Association of Edison Illuminating Companies Committee on Grounding the Neutral
1892	Electrical Committee of Underwriters National Electric Association founded
1894	1890s: Edison Illuminating Companies ground neutrals
1896	First meeting of the National Conference on Standard Electrical Rules National Fire Protection Association organized
1897	First edition of the *National Electrical Code* (*NEC*)
1899	AIEE passes resolution favoring permitting grounding of low-voltage systems
1901	*NEC* makes grounding of secondary circuits permissible
1904	Supplement on fuses added to *NEC*
1909	Denver Gas and Electric investigates grounding secondaries
1910	National Fire Protection Association (NFPA) Electrical Committee organized

1911	NFPA Electrical Committee takes over from National Conference on Standard Electrical Rules
1912	Electrical Committee of Underwriters National Electric Association disbanded New Jersey Board of Public Utility Commissioners upholds grounding secondaries
1913	*NEC* makes grounding of secondary circuits mandatory NFPA name appears on *NEC* State of Washington passes law making grounding of secondaries mandatory
1918	*NEC* explicitly requires grounding at building service or near the transformer
1923	*NEC* requires grounding at each building service entrance (with local exception)

Targets:

Electric and Magnetic Fields Health Assessment

Electromagnetic Compatibility

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Printed on recycled paper in the United States of America

1005490

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