In 1941, Howard S. Warren completed work on the manuscript "How The *Code* Came." This material was turned over to then president, Alvah Small, Underwriters Laboratories, to be made available to anyone should it serve a useful purpose. Alvah Small was chairman of the NFPA Electrical Committee from 1925 to 1950. This tome on the history of the *Code* was dedicated to Alvah for his work as chairman in keeping the *Code* abreast of developments in the electrical industry and always in the public interest. Warren represented the telephone group on the Electrical Committee from 1907 until 1939. Warren was preceded by C.J.H. Woodbury and followed by A.H. Schirmer, L.S. Inskip and L.H. Sessler.

Appendix A

The subject of grounding has always been confusing to many, and as such, precipitates much interest wherever sessions are held on *Code* discussions. Grounding has always had its controversial aspects. Part of this stems from the fact that the early sponsors of the *Code*, the Underwriters' National Electric Association, represented the insurance interests and the grounding of electrical circuits had much to offer for personnel safety, but little fire safety for the building could be obtained.

Many of the associations' names have changed today. The Underwriters National Electric Association was later to become the National Board of Fire Underwriters. The National Conference on Standard Electrical Rules was later to become the *National Electrical Code* Committee. AIEE was later to become the Institute of Electrical and Electronics Engineers (IEEE). The National Electric Light Association was later to become the Electric Light and Power Group.

The applications of grounding and the details of accomplishing it are many. The grounding section of the 1940 *Code* (Article 250) occupies over 18 pages. Curiously enough, grounding has always had a controversial aspect.

In the first (1897) *National Electrical Code*, as in the previous "Rules and Requirements" issued by the Underwriters' National Electric Association, the only mandatory grounding requirement was that for lightning arresters or protectors. There couldn't be much argument about that, since from its very nature a protector or lightning arrester must be provided with a path to earth.

In the July 1, 1894, issue of "Rules for Safe Wiring," there were included directions for installing communication circuit protectors, which covered the following: (l) the location of protector; (2) type of wiring to be used from the last outside support to the protector; (3) conditions which grounding conductor must comply with and (4) means for connecting grounding conductor to earth.

These provisions were carried over into the first (1897) edition of the *National Electrical Code*. In addition, the frames of generators and motors were required to be grounded when, and only when, it was impracticable to insulate them.

The fireworks began about three years later, when the question of grounding secondary distribution circuits was precipitated.

Circuit Grounding

Consider for a moment what the grounding of a secondary circuit involves. Take the simple case of a two-wire, 120-volt circuit fed by a transformer. The transformer keeps the difference of potential between the two wires of the circuit at 120 volts, but, in the absence of grounding, the potential of the circuit with respect to earth is indefinite. If there is no foreign electrical influence, the average potential of the two conductors will hover around zero or earth potential, but if one of the conductors becomes crossed with a foreign wire of high potential to earth, it will immediately become charged to the same high potential (assuming that no breakdown of insulation occurs). This brings about a hazardous state of affairs, for if a person in contact with earth or with any grounded metal should touch the charged conductor, he would be liable to receive a dangerous shock. Such hazardous condition might be produced by an accidental cross with a foreign wire or by breakdown of insulation of the transformer in such way as to impress potential from the primary circuit upon a secondary circuit conductor.

As a safeguard against such hazard, it was proposed that secondary circuits be grounded, i.e., that one conductor, in case of a two-wire circuit, or the neutral conductor, in case of a three-wire circuit, be connected to earth, thus assuring that no conductor of such grounded secondary circuit could have a potential to earth greater than the normal circuit voltage.

Such grounding seemed all right for cases where the normal secondary voltage was not in itself hazardous, but as grounding increases the liability of shocks at normal circuit voltage, it did not look so good for circuits of more than about 150 volts. For example, a 220/440-volt secondary, if grounded, would increase the chance of a 220-volt shock, which of itself would involve a serious hazard. On the other hand, the grounding would protect against the probably much higher voltages due to accidental crosses with foreign wires or to transformer breakdowns. So, in this case, it was a question of balancing the increase in hazard from 220-volt shocks against the decrease in hazard from shocks at higher voltages. The 220/440-volt secondary circuit was a borderline case; some experts favored grounding while others opposed it.

As this was a technical electrical question, the Underwriters, who at this period were in control of *Code* revisions, wisely declined to put a mandatory circuit-grounding rule into the *Code* until the electrical people could agree on what the rule should be, all the more so as such a rule was considered to be more concerned with life hazard than with fire hazard. Differences of opinion on the part of electrical experts as to the circuit voltage below which grounding ought to be made mandatory produced a stalemate that persisted for several years.

Discussions of electrical circuit grounding go back to the beginnings of the ac distribution system. In England, as well as in this country, such grounding (our British cousins call it *earthing*) was proposed. Thus Killingsworth Hedges said, in 1889:[1]

"One precaution is to earth the secondary circuit. Another is to connect one or both leads to a safety appliance which would automatically divert any excess current to earth and at the same time shut off the supply." Professor Elihu Thomson, in 1890, suggested grounding the transformer secondary winding or surrounding it with a grounded sheath. As alternatives, he suggested cutting off the secondary by automatic means or grounding it automatically by film cutouts when excessive voltage appeared. The placing of a grounded metal sheath between the primary and secondary windings of a transformer was called by the English, "Kent's sheath," although the idea had its origin in America. Thomson regarded this device as very effective for securing a safety grounding connection for the secondary circuit when there was a leak from the primary. Discussing this matter at an NELA convention, he said:

"In the ac system with low voltage secondary, good workmanship is all that is necessary to abolish risks if we leave out the high voltage primary which must be thoroughly insulated. Even some static capacity, which may give severe if not fatal shock, is to be looked out for. The writer early recognized this danger and felt it must be provided against. Hence came the expedients of grounding the secondary or surrounding it with a grounded sheath or cutting off the secondary absolutely by automatic means."

But the grounding of secondary circuits had plenty of opposition in the early days. Woodbury, in giving his suggestions about methods for reducing the electrical fire hazard, considered "it undesirable to permanently ground one wire of the secondary circuit."[3]

On March 10, 1892, the New York Board of Fire Underwriters issued a pamphlet report on "Grounding of Electric Wires," prepared by its Committee on Police and Origin of Fires. At a special meeting of the board, held on that date, it was voted that this report be printed and circulated to the members, together with certain parts of a report by Professor Henry Morton, and a reply thereto by the Edison Electric Illuminating Company of New York.

The Electrical World Announced

"The New York Board of Fire Underwriters has condemned the practice of grounding the neutral as dangerous and orders it to be stopped.

"There can be no doubt that the practice of grounding the neutral is not as safe as a completely insulated system. To change it now, however, may require much work and, therefore, may interfere somewhat with the lighting. It is a case in which prevention would have been better than cure."

The following resolutions were also adopted by the board and circulated as aforesaid:

"RESOLVED, that the Committee on Police and Origin of Fires be and they are hereby directed to require all electric companies furnishing current for power and lights (to parties that have received certificates of approval of electric equipments from this Board), to make regular weekly reports of the tests of their currents, as called for in the requirements of this Board, and in the event of failure on the part of the Electric Companies so to do, then the Superintendent of the Survey Department is hereby directed to decline to grant certificates, or make inspections of equipments supplied with current by said delinquent companies, and further.

"RESOLVED, that said Committee give notice to all Electric Companies receiving certificates from this Board that the intentional grounding of any portion of the equipment is a violation of the rules of this Board and such a practice must be discontinued.

"This Board will refuse certificates of approval to all companies who do not comply with this rule, and further

"RESOLVED that the committee require of Electric Companies that all grounds now existing on electric circuits shall be removed on or before October 1st, 1892."

These resolutions were promulgated over the name of William Del. Boughton, chairman of the board.

The extracts from Professor Morton's report on fire hazards from grounding of electric wires, particularly the neutral wire in the Edison system, included the following: "The grounding of the middle wire, in my opinion, decidedly increases the fire risk, for the following reasons:

"First. If all the wires are insulated, then two ground contacts must occur in order that fire should be produced by the contact of a conductor with the gas, water or steam pipe, or other conducting substance connected with the ground. If, on the other hand, the middle wire is "grounded," then every gas, water or steam pipe becomes in fact a 'live wire,' contact with which results in a current, only limited in amount by the capacity of the conductors (including fusible catches and the like) between the point of contact and the general network of supply wires.

"Second. It renders entirely impossible any testing by which from time to time the insulation of the systems can be watched and measured.

"As a result when a ground occurs, unless it attracts attention in its own neighborhood or is enormous in amount, it can go on indefinitely without being discovered, while it may be doing mischief all the time, whereas with an insulated system, a ground will instantly show itself by the proper instruments at the central station or elsewhere, and at the same time will be harmless until another ground, on the wire of opposite polarity, is developed.

"If the middle wire of the Edison system is grounded the entire system is then in such connection with the earth that the contact of either positive or negative conductors with water, gas or steam pipe, or iron parts of a building or other conductor, will establish a connection through which a large current will flow."

Commenting on the foregoing, R. R. Bowker, first vice president of the Edison Electric Illuminating Company of New York, said:[4]

"In view of the fact that many of the questions at issue are comparatively new to members of your board, we have thought it best to make a general explanation of the nature of the three-wire system, and of the practice involved in 'grounding the neutral,' as is done in the accompanying statement, which while it does not take up the leading questions of the report in regular order, does, it will be found from the references, present a direct and sufficient answer to each of these questions. The careful and specific attention of each member of your Board is requested for this statement, as the question involved is one of such large and increasing importance.

"We would emphasize to you that our street system is in no sense dependent on the practice of grounding the neutral and that contrary to the inference of Professor Morton's report, no copper or other element of cost is saved with that practice in view; the motive of the practice is not commercial but precautionary. We remind you that the practice is in vogue in other cities with the approval of Underwriters. We would also beg to correct the misapprehension that there is any grounding of the neutral wire in houses, or any decrease of insulating precautions because of that practice.

"We ask your Board for such modifications of your rules as will recognize the features of the three-wire system and provide for the practice thus adopted. We beg herewith, however, to say that should the Board, in full view of the protest of this company, decide to take the responsibility, with the insuring community and before the public, of directing this company to discontinue the practice, the superintendents of the company will have instructions to prepare to disconnect the neutral grounds at the junction boxes throughout this city, which would require, however, considerable time, and would not, we believe, produce the result desired of giving opportunities for insulating tests on lines of laboratory practice and of special circuit systems. We would, moreover, enter definite protest against the overruling of this company by your board in a question of practice which we believe can best be determined by working electrical engineers familiar with the needs and conditions of actual station practice."

A statement submitted to the New York Board of Fire Underwriters by the Edison Electric Illuminating Company contained the following:

"In the Edison 3-wire system, two dynamos are coupled together both in series by a short copper conductor connecting the negative side of one with the positive side of the other. If each is running at 100 volts the product of the two thus in series is at 200 volts. The positive conductor runs from the outer side of one dynamo; the difference of potential between the positive and negative wire is therefore 200 volts. The middle or neutral wire runs out from the short connecting link between the two dynamos and like the positive and negative wire, is absolutely continuous from the dynamo in the station to the extreme point of every house installation. Incandescent lamps are placed 'in multiple' between the neutral wire and the positive conductor and between the neutral wire and the negative conductor. In each house and throughout the system lamps are 'balanced' as evenly as possible between the two sides of the system - that is, when a hundred lamps are placed in a house, it is the endeavor to put fifty of these on the positive side and fifty on the negative side of the system, so placed that the actual burning is about the same on either side. When one thousand lamps are burning on the positive side and one thousand lamps on the negative side of the system, the neutral wire brings back no current whatever to the dynamo at the station. The current at 200 volts flows through the lamp between the positive conductor and the neutral wire, giving this 100 volts, and thence through the lamp between the middle wire and the negative conductor giving that the other 100 volts, and the return is all on the negative side. If five of these lamps are taken out or turned off on the positive side, the neutral wire would become a positive conductor to the extent of the current for these five lamps, or if five lamps were taken out or turned off on the negative side, the neutral wire would become a negative conductor to the extent of the current for those five lamps.

"On the New York system the neutral is grounded at the junction boxes in the streets, and not at the stations; on the Brooklyn system the grounding is at the station. Authorities differ as to which is the better course to obtain the advantages of grounding the neutral. In New York the neutral is grounded at about 250 junction boxes, something less than 1/3 of the number of junction boxes on the whole system, at a distance from the station varying from 1/4 to 1-1/2 miles. The neutral is grounded, as it were, on the other side of the junction box from the station, so that if in any possible event the current should flow through the ground it would seek the shortest course to the nearest junction box grounded and thence through the regular neutral wire to the station. That the ground is practically not used as the neutral conductor is sufficiently evidenced by the fact that no electrolysis has yet been discovered by our electricians at the points where the neutral wire is grounded, as would certainly be the case were the ground connection used to any extent.

"The neutral wire is not in any case grounded within house installations or in any way in connection with houses.

"It should be clearly recognized moreover that it is not practicable on any large system of electrical conductors, whether overhead or underground, especially so large as is required for the city of New York, that absolute insulation, such as is possible in laboratory tests, can be obtained or maintained. There is no known material which is an absolute insulator and even electrical appliances and adjoining woodwork are themselves conductors to an infinitesimal degree. In any known system of considerable aggregate length, while no single part can be definitely criticized, the mean level of insulation of the system is necessarily brought into comparatively close association with the ground by numerous small leaks, each of individual importance but all together making a considerable aggregate.

"I desire to make perfectly clear that if any given system could be made and kept absolutely free from leakage and best electrical authorities, including Edison himself, would agree that the balance of advantage would be found in keeping the system in that condition and not in grounding the neutral. But the difference between laboratory tests and actual working conditions is such as to make their practical conclusions almost contradictory and we have the authority of Edison's chief electrician for the assertion that 'in endeavoring to attain the perfection of safety' the report 'advocates a course of procedure which would introduce greater risk and defeat its own purpose.'

"It would seem scarcely necessary after these remarks to reply more specifically to Professor Morton's position that there should be no difference between the rules made to apply to the two-wire and three-wire systems and no reason to alter previous rules of the Board to recognize or apply to the present situation. If Rule 40, which has often been quoted in this connection, is understood by your board to apply to the grounded neutral of the Edison three-wire system, it should certainly be modified. As a matter of fact, having been adopted before the three-wire system came into operation, this company asserts that it does not so apply and in this respect no alteration would then be needed.

"It is the general opinion of the Edison interest that, while absolute insulation, if it can be had and where it can be had, is preferable, the advantages of grounding the neutral under certain conditions and particularly on large systems, are such as to make that practice in those cases the best working method particularly as a precaution against fire risk."

Discussion at National Conference

At the meeting of the National Conference on Standard Electrical Rules in March 1896, Professor Kennelly suggested a rule requiring "that the secondary coil of a converter should be grounded at its center." This led to the following discussion:

James I. Ayer:

"Relative to the question 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, so that in 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. There is no doubt about the advisability of getting some sort of transformer protection, especially on the primary lines where 2000 volts and upwards are transformed directly to the house service low potential.

"In a discussion of this question some time last spring, Professor Puffer recommended the same thing. I suggested carrying out a practice which I adopted years ago in a good many cases of using a magnetic cutout. This magnetic cutout was made with two solenoids, each of which have one connection to one of the secondary lines, one on one side and one on the other, the other terminal being connected to ground. These solenoids are of very high resistance so that the leakage of a 50-volt current amounts to 8 watts and for 110 volts to about 11 watts. This gives absolute protection. Any rise of pressure on the secondary mains above 500 volts would operate the circuit breaker. It is very positive. It rather straddles the question of grounding secondaries or grounding house mains by grounding them through a fixed high resistance ground connection. It gives an absolute, positive-acting device, not necessarily one that burns up transformers. In fact, it leaves the transformers to take care of itself but cuts out the primary from the secondary main.

"This is a matter to which I have given a great deal of thought. I found in the early days of the use of transformers the necessity of some such protection where there are many of them connected with the line. Thunderstorms would readily break them down and create punctures which would give a connection from one side of the transformer to one side of the secondary circuit. The lights would burn and things continue on apparently all right. Transformers do break down with the high potential being used and I believe the right thing to recommend, and in time to demand, is the proper protection for isolated transformers, to give you protection between the secondary and primary, but the question of grounding secondary mains and low resistances IS a very serious one and should receive a very full discussion before action is taken."

Professor Kennelly:

"I think the matter is so important that it is worth while to give it a few moments. I should be sorry to advocate anything which would unduly harass the manufacturers, but I believe that I make this suggested recommendation in the interests of the manufacturers just as much as in the interests of the parties who receive lighting from electric systems.

"If we exclude lightning, there can be no objection to grounding the secondary because it is obvious that the system should be capable of standing the working pressure. Then no one can fairly object to grounding the center of the secondary on the score of danger of puncture because, if the transformers are going to be so weakly insulated that grounding the secondary is going to injure them, those transformers had better be replaced. It may not be necessary, however, to actually ground the secondaries. A simple protective device that will ground the secondary if a cross develops would be preferable, and if Mr. Ayer's device is simple and practical, its adoption would seem worthy of consideration. A cross between the primary and coils of a transformer is, we know, of very rare occurrence, yet we all know that no one would be justified in permitting a person standing, say on a cellar floor, to handle the socket of a lamp if the operation involved making contact with one of the secondary conductors, unless the transformer had just been tested free from leakage or cross. If, however, the secondary coil of the transformer were grounded permanently, or protected in an equivalent degree there would be no such danger from accidental contact."

Mr. Ayer:

"In considering this question of the protection of the transformers, the practical conditions to be met with have got to be well understood. You take the case of distribution with the overhead system, where there are any material number of transformers in a network covering a large area, there is no such thing as getting an insulated circuit. You have got a grounded circuit, always.

"There has been a great deal of discussion especially among the Edison Companies and Underwriters, as to the wisdom of grounding the third wire of the Edison system. That has been a very fruitful topic of discussion. I think it is useless to try to enumerate the details or discuss the pros and cons of this here.

"In a resume of the English rules, you see that they contemplate at all times an automatic device in the secondary circuit, or in the primary wire, if not in the secondary, which will automatically cut off the primary current from the transformer or the secondary from the house. That is the English practice. They call for some intervening device which shall open the secondary circuit in the event of the primary forming a connection with high tension. It is a simple thing to make. I have one in my residence today and have had for five years, which has been in service all the time. The thing is operated with a leakage of 500 volts from the primary line to the secondary. It introduces a high resistance ground on the secondary and a leakage on the secondary of about 8 watts. I believe the solution of the problem of the protection of the secondary coil is the introduction of this intermediate automatic device. Devices have been made in England operated by clock work, fuses, etc., but not similar to this to my knowledge."

The protective device for secondary circuits, which Ayer thus commended, did not meet with much favor and the solution of the problem was long delayed; indeed, it has not been solved even yet in all its aspects.

The Underwriters were slow to reverse their stand against allowing any permanent grounds on electric circuits.

The electric companies, on the other hand, were generally in favor of grounding the neutral wire. W.L.R. Emmet of the General Electric Company said, in 1899:

"The permanent grounding of transformer secondaries is prohibited by the fire underwriters' rules, which pro prohibition is generally respected throughout the country, so that most secondary circuits are entirely unprotected."[5]

AIEE Talks it Over

In 1899, Dr. Cary T. Hutchinson presented an AIEE paper on the protection of secondary circuits, in the course of which he heartily endorsed the practice of grounding and reproved the Underwriters for their stand against it saying,[6]

"The need of some effective method for protecting secondary circuits is well recognized yet there is at present probably no device for the purpose that is thoroughly trustworthy and efficient in all circumstances. The means that have been employed for this object may be classified under three general heads: (l) Devices intended to ground, short-circuit or open-circuit the secondary circuit when subjected to abnormal difference of potential; (2) grounded metallic shields imposed between the primary and secondary coils of the transformer; (3) permanent grounding of the secondary system.

"The third method, grounding the secondary permanently, is the only sure way to prevent the potential above earth of the secondary system rising above the voltage of the circuit.

"The grounding of the secondary circuit thus absolutely insures the safety of the circuit as regards abnormal pressure.

"It would seem that a remedy as simple as this, one generally applicable, would have been applied in all cases but the fact is that it has attained a limited use only. 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 current brings about an increased liability to fire, because the full voltage of the circuit continually acts upon the insulation of the circuit, instead of one-half of this voltage as in an insulated system, and because one accidental ground on the insulated side may cause a fire.

"The Association of Edison Illuminating Companies has had a committee on grounding the neutral since 1890. The recommendations of this committee being based on extensive experience are entitled to great weight. Their recommendation of uniformity being the greatest safety was assured by the practice of grounding the neutral. This is the practice of nearly all the large Edison Companies as is well known. In some cases the companies have been forced to this position because they were not able to free the neutral from ground. In other cases they have deliberately adopted this as the best remedy for many troubles due to operation dangers from fire and to abnormal pressures.

"It is notorious fact that the systems in nearly all of the large cities, particularly the Edison system, are grounded. The neutrals in most cases are permanently grounded at the junction boxes. It is equally well known that in several of the large ac distributing systems the neutral wires are grounded. The authorities of the Board of Underwriters certainly should, and probably do know, these facts. To keep rules in print prohibiting such practices under the circumstances must weaken their authority and lessen the respect for all their rules.

"I therefore offer the following resolutions:

"RESOLVED that the AIEE favors a rule permitting the grounding of one wire of every low potential consumption system, and

"RESOLVED that the committee of the AIEE 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 the permanent grounding of one wire of such systems under suitable restrictions."

Hutchinson's resolution was passed, after discussion, some of which is noted below: Professor Elihu Thomson: "I endorse everything that is said and I hope some action will be taken by a body so influential as this, toward getting some such thing adopted."

C. M. Goddard:

"I should like to second the resolution and for several reasons; 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. I am not convinced of that fact but because we are delighted to have the institute take up any subject in relation to our rules and try to help us arrive at a right solution.

"I think it very probable that this grounding of the secondary may be the best solution but the Underwriters are always conservative in such matters.

"We would be delighted to have you help us in making our rules. We modified this rule last year at the request of the Institute and we will certainly modify it further if you will only come to us and show us that you are right, for we have a great deal of respect for the opinions of the Institute."

Professor W. E. Goldsborough:

"I hardly feel like saying anything in opposition but I am very much interested in the subject and all my experience has tended to lead me to feel it is not best to ground the secondary."

Professor W. L. Puffer:

"I would carry grounding to such an extent that I would compel the absolute grounding immediately at the point of entrance in buildings of every system (except series arcs which ought not to be allowed in buildings) and including such things as water pipes and gas pipes."

While the consensus of this discussion was decidedly in favor of grounding the secondaries, there was some adverse opinion and the Underwriters seem to have continued other opposition to the practice, although the *Code*, i.e., the 1897 and 1899 editions, did not specifically prohibit it.

Father Defers to Mother

The Electrical World and Engineer, reporting the December, 1900, meeting of the Electrical Committee, said:[7]

"The motion to change the limit of low tension circuits from 300 to 550 volts was carried at the first session. A long discussion took place on the advisability of grounding one of the wires in low tension circuits in which numerous authorities were quoted and prominent electrical engineers spoke in its favor. The resolution was finally adopted to allow the grounding of one wire in every low potential circuit but making it optional with the installing engineer."

In accordance with this decision, the 1901 edition contained the following section:

"13A. 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.

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. 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."

Thus, by making the practice permissive, the Underwriters began a strategic retreat from their early position against the grounding of electrical circuits.

At the Electrical Committee meeting in December, 1901, the following proposal was considered:

"A letter was also referred for conference with the AIEE Committee, asking for modification of the rules with regard to grounding low potential circuits so that the ground might be on one side of the circuit instead of at the neutral point of the transformer.'[8]

The Underwriters held to their position that the grounding of secondaries was a question for the electrical people to decide. A special subcommittee on the subject reported to the Electrical Committee meeting of December 9, 1902:[9]

"It was also agreed that Rule 13A-b should be amended to read as follows:

"(b) Transformer secondaries of distributing systems should preferably be grounded and when grounded the following rules must be applied:

"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, the maximum difference of potential from the grounded point of the secondary circuit to any other point there of must not exceed 250 volts.

"3. To be identical with the present clause marked (2)." Here was a proposal to go further and take a position favoring circuit grounding. The meeting declined to either approve or reject this recommendation but voted to submit it to the Board of Directors of the AIEE and to the Underwriters' National Electric Association.

This recommendation to change the permissive "may be grounded" to "should preferably be grounded," was evidently accepted by the AIEE, for the rule in the 1903 *Code* was substantially the same as the subcommittee had recommended, namely:

"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."

This rule in the 1903 *Code* represented quite a step away from the old position prohibiting circuit grounding, but still it was unsatisfactory in that it left the question open as to whether secondaries should be grounded or not. There was a substantial body of opinion in favor of making the grounding mandatory under certain conditions, but there were differences of opinion as to what the conditions were which warranted making grounding mandatory. It was generally agreed that where the voltage between conductor and ground did not exceed 150 volts, safety was promoted by grounding, but where the voltage was from 150 volts to 250 volts, the advantage of grounding was in a doubtful region. For voltages to ground over 250, the consensus of expert opinion was against grounding.

At the Electrical Committee meeting on December 2-3, 1903, a suggestion that the grounding of secondary neutrals be made compulsory was referred to a committee of three to be appointed by the chair, to report back.

More Discussion

At an AIEE meeting on December 19, 1903, H. G. Stott took up the discussion, saying:

"Some years ago a committee of the Institute met with the Board of Fire Underwriters and a rule was passed making it permissible to ground the neutral at the central point of the transformer or at one side of the transformer. The grounding of any part of the secondary network, especially the neutral point, is the best form of protection obtainable because in case of a cross with an electric light wire carrying perhaps 8,000 volts, the pressure of the wire is immediately reduced to the pressure of the circuit as the carrying capacity of the secondary network is greatly in excess of the amount of current passing through the average arc light circuit."

Discussion of this question continued. It was one of the subjects considered at the meeting of the National Conference on April 21, 1905. On that occasion, Dr. F. A. C. Perrine (formerly Professor of Electrical Engineering at Stanford University) stressed—perhaps overstressed—the opposing effects of grounding on the fire and life hazards, saying:

"For example, we have heard a good deal of the rules for grounding secondaries. We know the Underwriters have admitted that, at the request of the electrical interests, in spite of the fact that if anything it increases the fire hazard, decreases the life hazard. Now there is a condition in which the Underwriters have acceded to the request of the electrical interests but it is a condition in which the fire hazard risk is distinctly opposed to the life hazard risk."

Benallack confirmed the influence exerted on the Underwriters by the electrical people:[10]

"Other speakers had called attention to the importance of grounding secondary circuits as a good way, and in fact the only way, of making these circuits safe from the leakage of currents from the primary circuits. The Underwriters had been slow to permit this at first and it was largely due to the central station men who appreciated the danger that the practice was permitted and finally positively recommended by the Underwriters."[11]

At the National meeting on December 4, 1905, the subject of grounding secondaries was discussed further. H.C. Wirt remarked:

"The most important rule here is the rule on grounding of the secondary to make it compulsory." After discussion, the following resolutions were adopted:

"RESOLVED, that it is the sense of this Conference that the grounding of low tension secondary ac systems be strongly recommended in all cases wherever reliable grounding connections can be secured.

"RESOLVED, that in cases of three-wire systems with grounded neutral, solid connections without fuse be permitted on the neutral wire.

"RESOLVED, that it is the sense of this Conference that the grounding of secondary ac systems inside of buildings to water pipes, provided such connection is made at the nearest point to cellar wall on water pipes and outside of meter, is not only safe but places no additional burden or menace on such water pipes."

Woodbury referred to this meeting in his Annual Report for 1905, to H. V. Hayes:

"At the second meeting of the Conference on December 4, results of importance to the electrical interests were adopted in regard to grounding of secondaries on ac systems and also the resolution that grounding did not furnish any hazard or menace to water pipes to which they were attached. Although these results were filed by others yet I was concerned in their operation, particularly in relation to the last clause, on account of difficulties which some of the operating companies had experienced through claims of town officials for reimbursement for damage to water mains by lightning, alleging that the grounding of telephone lines to water pipes was the cause."

However, the Electrical Committee at its December 1905, meeting did not adopt the National Conference resolutions, as no formal endorsement of them by the AIEE or NELA had been received. The grounding of low-potential circuits was discussed but no changes in the rule were made and the matter was referred back to the subcommittee for further consideration. Nor was any such endorsement, or any further recommendation as to the grounding rule, received from the electrical people in 1906. Accordingly, in the 1907 edition, rule 13A remained practically unchanged from the previous edition. The year 1908, however, saw some progress toward a mandatory grounding rule for the *Code*. At the Electrical Committee meeting on March 25, the Committee on Rule 13A reported:

"The sense of the meeting was that, when suitable rules are prepared, the grounding of secondary systems shall be made mandatory."

At the meeting of the National Conference on March 27, 1908, C.M. Goddard made these remarks: "The Underwriters have all along felt that it (grounding) was a rule which did not very seriously affect the fire hazard but I think the more it has been looked into, that the Underwriters have perhaps decided that there are certain fire hazards guarded against by the grounding although, of course, we all know that it is principally for guarding against life hazard."

"It is apparent that when the rule has been whipped into shape so that it will be satisfactory to all, it shall be made mandatory by the Underwriters instead of being simply permissive.

"Now the Underwriters want to be very sure that it is the desire of the electrical interests as a whole, both central station men and the engineering branch, also the municipal departments. We want to be very sure that we are not making the rule mandatory against their wishes, I should think the Underwriters would be perfectly satisfied to leave the rule as it stands."

It was voted to be the sense of the meeting that the grounding rule be made mandatory; also that instructions be given for making the grounds.

At the 17th annual meeting of the Electrical Committee, held in New York on March 24 and 25, 1909, the Committee on Rule 13A reported:[12]

"Your committee appointed to consider changes in grounding rule, and question as to whether it should be made mandatory, begs to report as follows:

"First—As we are asked only to make this rule mandatory up to and including 150 volts for alternating current secondary circuits, and to prohibit grounding of such circuits carrying in excess of 150 volts, it is evident that this suggestion cannot be based on the question of fire hazard because the fire hazard must certainly be as great from an ungrounded circuit in excess of 150 volts as from such circuit carrying not over 150 volts.

"Second—Your committee believes that the Underwriters have no right to enforce a rule which they cannot defend on the ground that it is adopted for the purpose of lessening the fire hazard.

"Third—Your committee believes that the Underwriters should use all of their moral influence in supporting any rule which may seem advisable in order to lessen the life hazard.

"Your committee would, therefore, recommend no change in the present rule but suggest that the rule, if made mandatory, might be followed in the rules of the National Board of Fire Underwriters for the government of insurance inspectors by a note saying, that in order to lessen the life hazard, compliance with the rule is recommended, but as the rule is not adopted for the purpose of lessening the fire hazard, no penalty could be enforced by the Underwriters for failure to observe its provisions.

"Your committee regrets that they have received no information as to the position of the American Institute of Electrical Engineers or the Associated Edison Illuminating Companies in regard to the subject."[13]

This report was adopted by the meeting and the grounding section was again left unchanged in the 1909 *Code*.

In its annual report for 1909, the Board of Directors of AIEE included this passage:[14]

"The Code Committee has held several meetings, the most important matter considered being in connection with Rule 13A of the Board of Fire Underwriters. This rule deals with the grounding of secondary circuits. The committee agreed that the rules should be made mandatory up to and including 150 volts between any wire and ground, and optional up to, and including, 250 volts between any wire and ground. This resolution was handed to the president of the National Conference on Standard Electrical Rules. Final action on the resolution was deferred pending an arrangement for a meeting of the *Code* Committee with a committee of the National Board of Fire Underwriters."[15]

So, in the 1911 *Code* the grounding rule, which in revision became Rule 15, was kept about as it had been, to wit:

"15. Grounding Low Potential Circuits

"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 transformers or on the individual service as provided in sections c to g, and when transformers feed systems with a neutral wire, the neutral wire must also be grounded at least every 500 feet."

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

But the time was now approaching when the grounding of low-tension secondaries was to be made mandatory.

In its report for 1911, the Board of Directors of the AIEE included the following passage:[16]

"The Code Committee through its chairman, represented the institute at the annual meeting of the National Board of Fire Underwriters held at New York on March 20-21, 1911. The only matter of interest to the institute taken up at this meeting was the grounding of secondaries and the work of the institute's representative resulted in the passing of a resolution by the underwriters conference enforcing the practice of the grounding of secondaries and recommending that municipalities and lighting companies make such a rule mandatory with the further resolution that the institute use its efforts to bring about an agreement with the NELA in the matter of grounding secondaries up to 250 volts instead of at 150 volts, the present adopted standard of the Association."[17]

In March 1911, the Electrical Committee held its first meeting as the adopted child of the National Fire Protection Association. The following is an extract from a report of that meeting:[18]

"The following resolution, presented by the Committee on Rule 13A, was adopted:

"WHEREAS—The grounding of secondary alternating-current circuits having a normal difference of potential of not over 150 volts does effectually eliminate the life hazard of such circuits due to their accidental contact with circuits of a dangerous potential without introducing any hazard due to grounding, and

"WHEREAS—There is a difference of opinion as to whether the grounding of such circuits having a normal difference of potential of over 150 volts introduces hazards due to such grounding, and

"WHEREAS—Such grounding does not increase but rather tends to decrease, the fire hazard, therefore be it

"RESOLVED—That municipal departments are urged to make the grounding of secondary circuits up to 150 volts mandatory as a necessary safeguard to life; and

"RESOLVED—That Underwriters Inspection Departments be urged to recommend at all times such grounding as a proper and desirable precaution which introduces no fire hazard, and

"RESOLVED—That the National Electric Light Association be urged to see that all of its member companies be brought to realize the necessity of such grounding for the protection of their customers, and

"RESOLVED—That departments in charge of water works be urged to allow the attaching of such ground wires to their piping system in the full confidence that the integrity of such piping systems will in no way be affected, whatever may be the normal voltage, and

"RESOLVED—That all concerned give careful thought to other methods of obtaining satisfactory grounds wherever metallic water pipes are not available, to the end that this most necessary precaution of grounded secondary circuits may be available in all localities and under all conditions, and

"RESOLVED—That the American Institute of Electrical Engineers be urged to use its best endeavors to harmonize the present difference of opinion as to the limit of voltage at which grounding ceases to be desirable by determining a limit which shall meet with general approval."[19]

During the year following, the American Institute of Electrical Engineers joined with other prominent national electrical societies in a final effort to secure a mandatory requirement for the grounding of low-potential secondary circuits. The AIEE Board of Directors' report for 1912, contained this passage:

"The Code Committee held a meeting on March 12, 1912, with representatives of the National Electric Light Association, Association of Edison Illuminating Companies, the National Inspectors Association, and concurred in a joint recommendation to the NFPA in regard to the grounding of secondaries."

With this substantial backing, the Electrical Committee was encouraged to approve, at its meeting on March 26 and 27, 1913, the report of its Committee on Rule 15, which made "the grounding of transformer secondary circuits obligatory."

Circuit Grounding Made Compulsory

So, at last, in the 1913 *Code*, a mandatory grounding rule was included, reading as follows:

"15. Grounding Low-Potential Circuits

"Alternating-Current Secondary Systems b. Transformer secondaries of distributing systems (except when supplied from private industrial power or lighting plants when 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. In either case 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 must be grounded.

3. The ground connection must be at the transformers or on the individual service as provided in sections c to g, and when transformers feed systems with a neutral wire, the neutral wire must also be grounded at least every 500 feet."

This rule has not been changed much, in substance, since that time. The main difference is that in the 1940 *Code*, grounding for voltages from 150 to 300 is recommended, instead of being merely permitted. This change first appeared in the 1923 edition.

Specifications to Assure Safety

Certain conclusions can thus be established to assist in writing specifications to cover Service and Equipment Grounding to assure safety in installations. They are as follows:

1. All ungrounded systems should have a ground detector and proper maintenance applied to avoid, as far as practicable, the occurrence of grounds on opposite phases at the same time. If proper maintenance cannot be assured for an ungrounded system then a grounded system should be installed.

2. The use of grounding electrodes at a transformer bank and at the building service provide by themselves virtually no protection in the event of a ground fault, as far as overcurrent protection is concerned. However, the lowest practical resistance for such grounds is desirable to serve the second purpose of holding the equipment as near to ground potential as possible.

3. The service ground and the equipment ground must have their common point of connection within the service equipment enclosure. If the service

equipment is in the switchboard, then the common point must be within the switchboard section which houses the service equipment. A common grounding conductor to the grounding electrode must be run from that common point of connection.

4. When a transformer bank is grounded, that is, when a service is run to a building from a system which has any point grounded, the grounded conductor must be run to the service equipment whether that grounded conductor is to be used for voltage requirements or not, and that grounded conductor must be connected to the equipment grounding conductor within the service equipment enclosure.

5. When a fault occurs on any grounded system we must not assume it began as a short circuit. (phase/ to/phase fault) until we have clearly indisputable evidence to the contrary, if we are to analyze the fault correctly. It is almost self-evident, when the overcurrent devices do not operate promptly that the trouble was owing to a ground fault.

Unless *effective grounding* is followed and carefully observed, we cannot expect a ground fault to clear unless the circuit is manually opened or the ground fault continues and develops into a phase-to-phase fault. The latter condition may require many minutes during which time the equipment grounding conductor will develop a potential to ground, which may become high enough to be dangerous. Further, we may have a disastrous fire loss. Some method of automatically clearing a ground fault in limited time is highly desirable.

Engineering specifications must be carefully written to cover service and equipment grounding and not left to chance interpretation of how to accomplish safety. It is not an uncommon practice for specifications to read: "Ground in accordance with the provisions of Article 250 of the *National Electrical Code*." The engineer is not assuming his full responsibility for the safety of the installation when he writes such specifications. It is the engineer's responsibility to outline in his specifications how the job should be installed to fully comply with all three of the objectives of "effective grounding" and not leave it to chance, as is now often the case.

Ufer Ground

H.G. Ufer, in an IEEE Conference Paper, CP-61-978, describes an installation of made ground electrodes on 24 buildings in 1942, in Arizona, to meet a 5-ohm maximum value. The resistance values were checked bimonthly over an 18-year period, during which time no servicing was required.

In 1960, the maximum reading was 4.8 ohms and the minimum 2.1 ohms. The average value of the 24 installations was 3.57 ohms.

The installations used 13 mm ($^1/_2$-in.) steel reinforcing rods set in a concrete footing. They were at two locations in Arizona. The first was near Tucson, Arizona, which is normally hot and dry during most of the year and has an average annual rainfall of 10.91 inches. The soil is sand and gravel. The second location was near Flagstaff, Arizona, where the soil is clay, shale gumbo, and loam with small area stratas of soft limestone. The made electrodes were used, as no water piping system was available.

As a result of these installations and the 18-year test period, Mr. Ufer suggested that a 4 AWG or larger copper wire be embedded in the concrete footing of a building and that test data be compiled further to verify the effectiveness. Based on this data, CMP-5 accepted a concrete-encased electrode commonly referred to as an *Ufer Ground*. The concrete-encased electrode shall consist of at least 6.0 m (20 ft) of bare copper not smaller than 4 AWG encased in 50 mm (2 in.) of concrete near the bottom of the footing or foundation.

1 "The Fire Risks of Electric Lighting" by Killingsworth Hedges, *Electrical World*, October 6, 1889.

2 "Safety and Safety Devices in Electrical Installations" by Professor Elihu Thomson, Electrical World, Feb. 22, 1890.

3 Address at Cornell University by C. J. H. Woodbury, Electrical Engineer, November 18, 1891.

4 *Electrical World*, March 26, 1892.

5 "Means of Attaining Safety in Electrical Distribution" by W. L. R. Emmet, *Electrical Review*, June 7, 1899.

6 "The Protection of Secondary Circuits from Fire Risk" by Dr. Cary T. Hutchinson, *Trans. AIEE*, Vol. XVI, 1899.

7 *Electrical World and Engineer*, December 15, 1900.

8 *Electrical World and Engineer*, December 14, 1901.

9 *National Electrical Contractor*, January 1903.

10 "The Electrical Fire Hazard" by William T. Bennallack, Journal Western Society of Engineers, Chicago IL., March 10, 1905.

11 *National Electrical Contractor*, January 1906.

12 *National Electrical Contractor*, April 1909.

13 *National Electrical Contractor*, April 1909.

14 Trans. AIEE 1909, Part 2, p. 1513.

15 "The Fire Risks of Electric Lighting" by Killingsworth Hedges, *Electrical World*, October 6, 1889.

16 Trans. AIEE, 1911, Part 3, P. 2591.

17 "The Protection of Secondary Circuits from Fire Risk" by Dr. Cary T. Hutchinson, *Trans. AIEE*, Vol. XVI, 1899.

18 *National Electrical Contractor*, April 1911.

19 *National Electrical Contractor*, January 1903.