The Hazardous Multigrounded Neutral Distribution System

And Dangerous Stray Currents

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Abstract – The multigrounded neutral system is the predominant electrical distribution system used in the United States. It permits an uncontrolled amount of electric current to flow over the earth unrestrained, posing the potential of harm to the public and to animals causing electric shocks and is presumed responsible for undetected electrocutions. To compound the problem of uncontrolled current over the earth, utility practices places harmful current from lightning strokes directly into customers homes.

As today's electrical loads continue to escalate, more current is forced into and over the earth. The question electrical engineers and the public must answer is what is the acceptable safe level, if any, of the passage of uncontrolled flow of electrical current over the earth and into our homes, office buildings and industrial facilities.

The decisions to "save money" by the adoption of the multigrounded neutral electrical distribution system outweighed the public's safety are disclosed in this paper and the electrical distributions systems that are safe are presented.

The history of the development of the multigrounded neutral distribution system is covered. Examples of the dangers associated with the multigrounded neutral distribution system and the ungrounded distribution system are disclosed. The methods of converting these dangerous and hazardous distribution systems into safer systems are presented.

Index Terms – Circuit, ground, grounding, earth, multigrounded neutral distribution system, neutral

Definition of Terms:

The definitions are predominately those used in the United States unless otherwise noted.

Circuit: Webster's Dictionary definition, "A path or route, the complete traversal of, which without local change of direction, requires returning to the starting point. **b.** The act of following such a path or route. [1] **3.** *Electronics* (IEEE Definition): **a**. A closed path, followed or capable of being followed by an electric current." The beginning can be arbitrarily selected.

A conductor or system of conductors through which an electric current is intended to flow [1]

Earth: A conducting body of varying resistances, often used in place of a conductor. Earth is commonly used as a reference point for building and structure wiring systems. The term is used interchangeable with the term "ground".

Earthing: A connection to earth.

Electric Shock: Stimulation of the nerves and possible convulsive contraction of the muscle caused by the passage of an electric current through the human or the animal body. May or may not result in electrocution.

Electrocution: To kill with electricity.

Fault current: (general) A current that flows from one conductor to ground or to another conductor owing to an abnormal connection (including an arc) between the two. A fault current flowing to ground may be called a ground fault current [2].

Ground: A conducting connection, whether intentional or unintentional or accidental, by which an electric circuit or equipment is connected to the earth or to some conducting body of relative large extent that serves in place of the earth [3]. (Also, see Grounding)

Ground current: Current that flows through the ground, earth, equipment ground conductors, etc.

Ground electrode: A conductor buried in the earth and used for collecting ground current from or dissipating ground current into the earth.

Ground fault: See *Ground fault current* below.

Ground fault current: The ground current resulting from any phase-conductor-to-earth fault.

Ground fault current (Normal): The flow of ground fault current should be brief, until the protective device opens. This brief flow of current is considered normal.

Ground fault current (Abnormal): The ground fault current, which is continuous, resulting from any phase conductor coming into contact with a grounded conductor or grounded equipment or to earth, or as the result of a neutral-to-ground fault, is objectionable and the fault should be removed, corrected or repaired as soon as possible.

Ground return circuit: "A circuit in which the earth or an equivalent conducting body is utilized to complete the circuit and allow the current circulation from or to its current source." [3] Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or unintentional or accidental [4].

Grounded Conductor: "A conductor that is intentionally grounded, either solidly or through a noninterrupting current-limiting device. [1]

A (current carrying) conductor that is intentionally grounded. This can be the neutral or one of the phase conductors in a Corner-of-the-Delta Grounding system [5].

Grounded: Connected to or in contact with earth or connected to some extended conductive body that serves instead of the earth. [1]

The NEC definition is: "Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazards to connected equipment or to persons."

Grounded, solidly: Electrical Systems. Connected directly through an adequate ground connection in which no impedance has been intentionally inserted [4].

Grounded system: A system of conductors in which at least one conductor or point is intentionally grounded, either solidly or through a noninterrupting current-limiting device. [1]

Grounding: "A permanent and continuous conductive path to the earth with sufficient ampacity to carry any fault current liable to be imposed on it, and of a sufficiently low impedance to limit the voltage rise above ground and to facilitate the operation of the protective devices in the circuit." (Note: Can be thought of as being associated with the "green" wire when associated with the NEC.)

Grounding conductor: A conductor that is used to connect the equipment or the wiring system with a grounding electrode or electrodes. [1]

Normally a non-current conductor used to connect electrical equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes. Part of the equipment grounding system.

Grounding electrode: A buried metal water-piping system, or metal object or device buried in, or driven into the ground so as to make intimate contact. The grounding conductor is connected to the grounding electrode. This is usually the reference connection point for a grounded wiring system [5].

Multigrounded/multiple grounded system: A system of conductors in which a neutral conductor is intentionally grounded solidly at specified intervals. A multigrounded or multiple grounded system may or may not be effectively grounded. *See:* effectively grounded. [1]

Neutral: (IEEE Definitions) (1) (rotating machinery) The point along an insulated winding where the voltage is the instantaneous average of the line terminal voltages during normal operation.

Neutral conductor: A system conductor other than a phase conductor that provides a return path for current to the source. Not all systems have a neutral conductor. An example is an ungrounded delta system containing only three energized phase conductors.

Neutral Point: (IEEE Definitions) (2) (A) (power and distribution transformers) The common point of a Y connection in a polyphase system. (B) (power and distribution transformers) The point of a symmetrical system which is normally at zero voltage.

Stray current: The uncontrolled flow of continuous electric current over and through the earth.

Stray voltage: An incorrect term associated with the measurement of the voltage developed from the flow of stray current.

System, electrical: The portion of the electrical conductors, constituting a voltage level, which exists between transformers, and if the last transformer, generating the lowest system voltage, the conductors extending from the transformer to the load.

Zipse' Law: "In order to have and maintain a safe electrical installation: All continuous flowing current shall be contained within an insulated conductor or if a bare conductor, the conductor shall be installed on insulators, insulated from earth, except at one place within the system and only one place can the neutral be connected to earth."

I. INTRODUCTION

There is no difference between the fundamentals in low voltage and high voltage as Ohms Law, Kirchhoff's Laws, etc. apply equally to each.

Examples of the protective grounding used in low voltage, 600-volt and below, applications will be described and used to explain the hazards involved with the present day multigrounded neutral distribution system, used in the United States. This will allow the reader to see the parallels between the safe low voltage distribution system and the dangerous medium voltage multigrounded neutral distribution system.

There will be references to animals in this paper. Cows and pigs are much more sensitive to electricity than humans. If animals are dying because of stray current and they are as in one case at the rate of five cows per day for over a year until it was discovered that the reason was stray current, how much increase in electrical load will it take until the human animal is affected? This could happen in the work place or in the home. Reports are constantly being received by the author about showers, swimming pools [5] [6], and hot tubs shocking persons.

The term ground will be interchanged with earth in the hope that in the future the United States will adopt the European terminology as the term earth is much more descriptive and it will be one more step in harmonizing and unification of terms.

II. HISTORY

When Thomas Alva Edison started his electric illuminating company and began the electrical distribution system, he used only one insulated (from earth) conductor and the earth for the return conductor. He filed his patent application on February 5, 1880. This uncontrolled flow of electric current over the earth resulted in shocking horses and his employees as they dug along side of the underground distribution system. Horse pulled traction companies' employees working on the tracks received electric shocks, especially when separating the track joints.

This prompted Edison to devise the three-wire distribution system, similar to what we use today in our homes. However, Edison insulated all three conductors. This allowed Edison to know exactly where all the current was at all times. In his "SPECIFICATION forming part 0f Letters Patent No. 389,280, dated August 30, 1887" he states on page 2, "the conductors of which are well insulated from each other and from the earth." Edison goes on to give several reasons for not using the earth for a return conductor.

Likewise, when the Underground Railway was being developed in London, they also elected to eliminate any stray current by using a four (4)-rail track system, two rails for supporting and guiding the coaches, one supply rail and the return conductor rail. The latter two rails were insulated from earth.

Major debate raged over whether an electrical system should be connected to earth – ground. Like Edison's electrical systems, which originally were not connected to earth, the ungrounded electrical system flourished until approximately 1913. In 1913, the National Fire Protection Association's (NFPA) National Electrical Code (NEC) made mandatory the connection to earth of any electrical system of 150 volts or less as measured to earth. However, when more than one connection to earth exists on the same electrical system, current can flow uncontrolled over the earth, metallic piping, equipment and through the earth causing problems with personnel safety, electrical equipment, etc., [6], [7].

Over time the utilities in the United States have failed to learn from Edison, as today the utilities use the earth for a partial ground return path permitting the uncontrolled flow of parallel current over not only the earth but over the adjacent underground metallic piping and other conducting materials resulting in damaging the health of dairy cows, reducing their milk output and harming humans and other animals. [6][7][8][9]

III. THE PROBLEM

In low voltage applications, 600-volts and under for safety purposes the NFPA's NEC requires in residential, commercial and industrial facilities, starting approximately in the early 1950s, a third wire, the equipment grounding conductor. In some cases, the metallic conduit is used for the "equipment grounding conductor" However the equipment grounding conductor should be installed in each and every circuit. This wire was added to electrical appliances such as electric drills, heaters, washing machines, etc. The equipment grounding conductor is connected to the neutral at just one point within the house, at the service entrance panel. The equipment grounding conductor is connected to earth. However, as will be discussed later, the neutral is also connected to earth a second time at the transformer, which results in a parallel circuit. The green color or bare conductor can be connected both intentionally and unintentionally to earth at many places, which is the object of the equipment grounding conductor.

The function of the equipment-grounding conductor, the green or bare conductor is **not** to carry any continuous flowing electric current. The key word here is "continuous." The only time the equipment grounding conductor and or earth carries any electric current is when an electrical fault occurs and then the object of the equipment grounding conductor is fulfilled by allowing the fault current to flow back to the source with very little resistance or impedance in the circuit. This allows the protective device, such as a fuse or circuit breaker to operate and turn off the electricity thus ending quickly the hazardous electrical fault condition.

For over 50 years, the 3-wire concept has been used to insure electrical safety in 600 volts and below electrical circuits, which are used in homes, commercial and industrial establishments:

- Phase conductor (usually black colored) carrying electric current to the load or appliance
- Neutral conductor (usually white colored) carrying all the return electric current
- In addition, the equipment grounding conductor (usually green in color) and/or earth only carrying electric current when an electrical phase-to-ground fault occurs which will insure adequate flow of fault current to operate the protective device such as to blow the fuse or open the circuit breaker.

This concept of restricting electrical current flow over the equipment grounding conductor and/or earth to only momentary fault current is valid for all electric circuits of any voltage when safety is a major concern. This is true whether low voltage or high voltage, whether residential, commercial or industrial wiring or electrical distribution wiring.

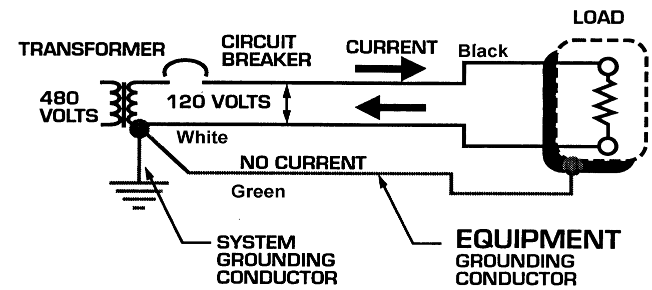

Figure 1 Circuit diagram showing the black phase conductor carrying current, the white neutral conductor carrying return current and the equipment grounding conductor carrying no continuous current.

The majority of the electrical utilities in the United States have elected to save costs of electrical distribution installations by combining two conductor functions into one conductor.

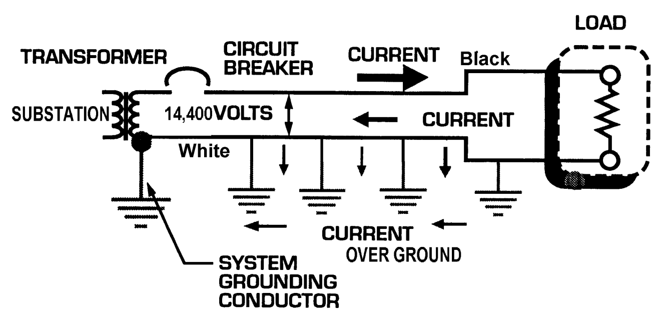

Figure 2. Diagram showing the electrical substation with a transformer, protective device, the circuit breaker, the two electrical distribution conductors, the multiple connections of the neutral to earth and the flow of uncontrolled electric current over the earth.

By combining the white wire, the neutral return current conductor carrying continuous electric current with the non-continuous current carrying equipment grounding conductor the utilities have saved billions and billions of dollars over 50 or more years as will be shown later.

The problem is that the utilities have used the earth as a partial return for the neutral current allowing the neutral current to continuously flow uncontrolled over the earth, as will be shown, which has caused irreparable and irreversible harm to dairy herds and pig farms and has caused electric shocks to humans and most likely may have resulted in electrocutions.

IV. IS IT “STRAY VOLTAGE” OR “STRAY CURRENT”?

Before one can fully comprehend the magnitude of the problem one has to understand the difference between “Stray Voltage” and “Stray Current” and determine which is the correct term. When voltage is measured, the measurement is between two points.

Remember Ohm’s Law which states in order to have a voltage we must have a current flowing through a resistance; Voltage = Current times Resistance. Thus, it is very easy to measure voltage as compared to measuring current. In order to measure current one method is to place a sensing coil around the conductor or if possible the animal.

The question that begs an answer is which is the determining factor, voltage or current. In order to answer that question we need to look at the human animal sensitivity to voltage and current.

A. Human Sensitivity to Electricity

It has been reported by Edward Owen, a student of Professor Charles F. Dalziel, University of California that Professor Dalziel “required” his students to participate in experiments to measure the human animal’s response to voltage and current by placing their feet into a bucket of salt water and holding onto a conductor. Professor Dalziel then applied varying amounts of current and measured their response. As recalled by the author from presentations by Professor William B. Kouwenhoven, Electrical Engineering, Johns Hopkins University, he used fresh cadavers to measure electric current necessary to revive the heart in order to develop the defibrillator. These experiments and others produced Table 1.

It has been shown that it takes approximately 35 volts across dry skin to force electricity into the human body. Less voltage or electrical pressure is required for a woman’s dry skin.

As shown in the Table 1, for a 60 Hertz alternating current (ac) at 0.4 milliamps (mA) or 0.0004 Amps (A) a male will feel a slight sensation on the hand. For a woman it only takes 0.3 mA. A painful shock requires 9 mA for a man and for a woman 6 mA. One must note these low values.

Time plays a function in the equation of electrical current and injury. The longer a person is subjected to an electrical current flow through the body, the more likely an injury will occur.

“The most damaging path for electrical current is through the chest cavity. In short, any prolonged exposure to 60 Hz current of 20 mA or more may be fatal. Fatal ventricular fibrillation of the heart (stopping of rhythmic pumping action) can be initiated by a current flow of as little as several milliamperes. These injuries can cause fatalities resulting from either direct paralysis of the respiratory system, failure of the rhythmic heart pumping action, or immediate heart stoppage.” [7]

It is clear that it is the current that causes a reaction in humans, not the voltage. The voltage is the driving force and there is a threshold below, which there is an inability to drive any current through the human body.

Comparison of the human animal with the cow animal shows many similar conditions. Both are mammals with a blood system and both have an electrical communication system, nerves.

Professor Dalziel in 1946 states, “Perhaps the most serious misconception concerns the effects of voltage versus the effects of current. Current and *not* voltage is the proper criterion of shock intensity.” [10] It is a shame the U.S. Department of Agriculture, the American Society of Agriculture Engineers and others who coined and use the term “stray voltage” in the 1970s failed to do adequate research on the subject.

B. Measuring Electric Potential, Voltage

Electric current flowing into the earth from a ground rod at a pole will flow into the earth in all directions. The value of current, in amperes, can be different for various directions. The resistivity of the soil is not uniform. This is explained in the IEEE Technical Paper titled: “Analysis of Grounding Systems in Soils with Hemispherical Layering” [11]. The paper discusses grounding systems located inside or near hemispherical soil heterogeneities.

The amount of current flowing into the earth will depend upon the resistance of the earth. Voltage measurements for an individual ground electrode at an electric pole are not taken uniformly around the pole, but usually only one voltage measurement is taken for each pole in an arbitrary direction and at an arbitrary distance.

Supposedly, **the object of taking a voltage measurement is to determine if any adverse effects exists due to a stray voltage being present. As has been shown it is current that is responsible for adverse reactions of humans and animals, not voltage.**

It is usual for utility personnel to make stray voltage measurements with one reference lead connected to the ground rod or the down ground conductor while the other reference lead, a probe is forced into the soil some distance from the pole. As is shown in Figure 3, where the second reference probe is placed will determine the voltage drop across the earth. The voltage drop will be a function of the current flow between the ground rod and the reference probe times the resistance of the soil between the two points, the rod and the probe.

As is shown in the Figure 3, depending where the rod is placed could determine the voltage. What if there were additional current flows from an adjacent pole flowing in or across the same reference distance, rod to point A. The value of voltage would not be an indication of current flow from the rod at the pole under investigation into the earth.

With only a voltage measurement being made the value of such information is useless and usually a waste of time and energy. However, this is the standard used to determine if a problem exists.

	Direct Current		Alternating Current 60 Hz		Alternating Current 10kHz	
	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1.	0.6	0.4	0.3	7	5
Perception “let go” threshold median	6.2	3.5	1.1	0.7	12	8
Shock – not painful and NO loss of muscular	9.	6.	1.8	1.2	17	11
Painful shock – muscular control loss	62.	41.	9.	6.	55	37
Painful and severe shock breathing difficult	90.	60.	23.	15.	94	63

Table 1. Sensitivity of Humans to Electric Current in Milliamperes

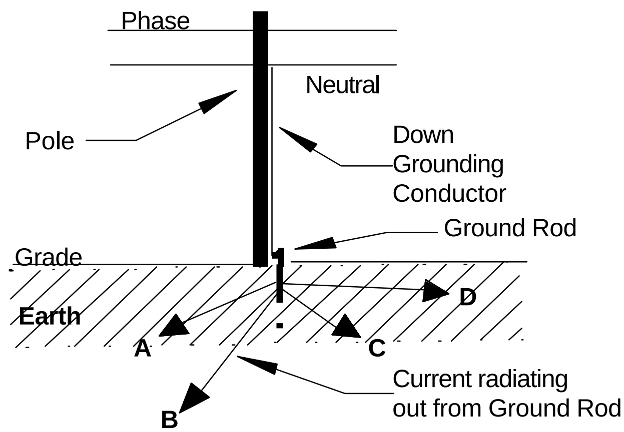

Figure 3. Current emanating from the ground rod - magnitude as a function of earth resistance and electrical load.

Ohm’s Law has three unknowns, Voltage, Current and Resistance. Algebra shows that in order to solve any equation one must know or have values for one less unknown than the total number of unknowns. With Ohm’s Law there are three unknowns, thus to solve Ohm’s Law one must have values for any two items; voltage and current, current and resistance or voltage and resistance. Measuring just the voltage basically does not show anything except the value of voltage between those two points. That is all; nothing else can be stated about a voltage measurement between two points if only the voltage was measured.

Making a voltage measurement only gives the value of voltage across that one spot. The one voltage measurement does not tell you the value of current or resistance of the circuit under investigation. Voltage decreases as resistance is encountered. However, current remains constant throughout the circuit.

No matter where one measures the current in the circuit shown in Figure 1, the current will remain the same. **The current will not change depending on where one measures the current in the circuit. This concept is critical in dealing with stray current, not the magnitude of voltage once the voltage threshold is sufficient to breakdown the barrier to current flow is exceeded.**

V. HISTORY OF ELECTRICAL DISTRIBUTION AND EARTH RETURN

In order to fully comprehend the detrimental effects of allowing the earth to continuously conduct electric current it is imperative that one understands the history and how the utilities elected to use an unsafe electrical distribution method. It was shown that **earth return had been tried in the early days of electrical distribution and found to be too hazardous and harmful to not only the human population but also to animals.**

A. Experience of Thomas A. Edison and Earth Return of Electrical Current

Thomas Alvin Edison patented the first electrical distribution system. The patent was filed on February 5, 1880 in the United States and given the number 2,282. It was titled, “System of Electrical Distribution”.

Edison tried several approaches to distributing electricity. Tom Shaughnessy, PowerCET Corporation writes, “Early on, Edison implemented a floating approach for his DC systems after several events demonstrated the adverse effects of stray DC currents flowing throughout buildings and neighborhoods. Once, a horse was shocked when it walked on "electrified soil" near Edison's Pearl Street generating station and laborers working on his underground distribution system believed there was a "devil in the wire."‘ As a result of some of these problems, Edison apparently adopted a three wire system which did not rely upon earth return.” [12]

With seven years of experience, Edison in August 30, 1887 in his Specifications forming part of Letters Patent No. 389,280 on page 2, line 34, states:

“All of such conductors from the generators at the station to the lamps are made in pairs--one for the outgoing current and the other for the returning current of electricity, the circuits throughout the system being complete or round metallic circuits, **the conductors of which are well insulated from each other and from the earth**. (Emphasis by the Author) The use of the earth for one half of the circuit would largely increase the difficulties arising from the grounding of the conductors or the crossing of the conductors among themselves or with the conductors of other circuits to such an extent that a system so constructed would be impracticable.”

Edison recognized the hazards involved in using the earth as a return path. “The Edison Three-wire System” is described in the Instruction book No. 8148, published by the General Electric Company in Dec. 19, 1900 and consists of a three wire grounded mid-point at one location only, which supplies phase to phase voltage of 220 and 110 volts for lighting. This is the basis of the electrical distribution in homes today. (See figure 5.)

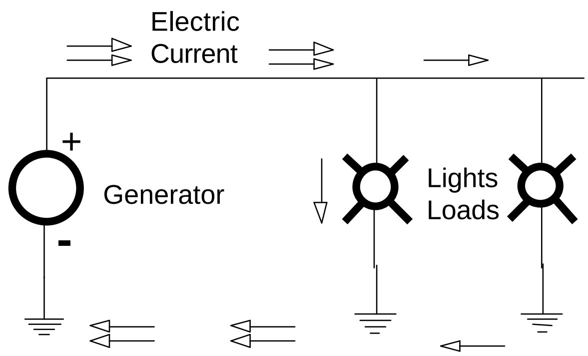

Figure 4. Direct Current Electrical System with the Earth Used as Current Return Path

With a balanced electrical load, that is loads “A” equal to loads “B” the current in the neutral will cancel and the neutral will not carry any current. The maximum amount of current the neutral will carry will be if the load is connected to one generator only, and only that load, is turned on.

However, an important concept can be learned from figure 5. Figure 5 shows the “A” and “B” loads opposite each other, which conveniently cancels the neutral current. Let us assume that the loads are not opposite each other as is shown in Figure 5 and that the “A” loads are extended beyond the end of the “B” loads as would occur in an extension of a single phase circuit.

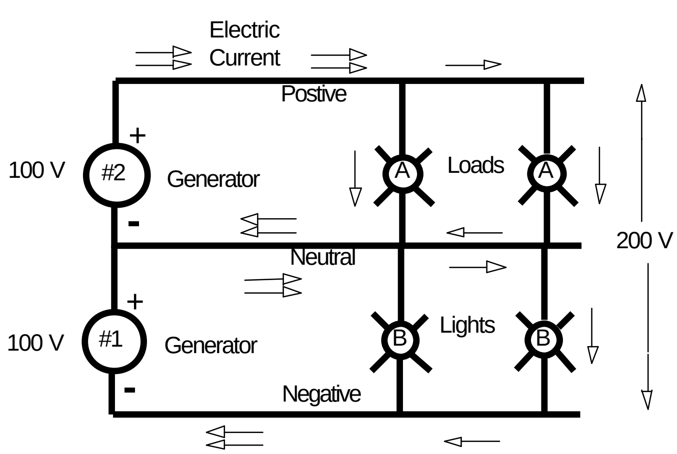

Figure 5. 3-Wire Direct Current Electrical System Conductor Used as Current Return Path

In the above case, the neutral would be carrying neutral return current over part of the circuit. If one were to measure the current on each conductor at the source, it would be a balanced load. However, out on the system the load would not be balanced. We will need this concept later. It is also important to recognize that so far we are dealing with all the current being contained within a conductor insulated from earth.

B. Alternating Current Grounding Practices

The Westinghouse-Tesla system of alternating currents was not always solidly grounded (earthed). The practices of grounding were first introduced for AC systems in 1885 by Elihu Thomson. One must note that today European and Latin American countries may ground (earth) only at the power source.

Mr. H. H. Dewey states that from the beginning of power transmission in 1888 or 1890 to 1910 or 1912 that there was no general practice as regards the question of operating electrical systems either with grounded neutral or with the neutral isolated.

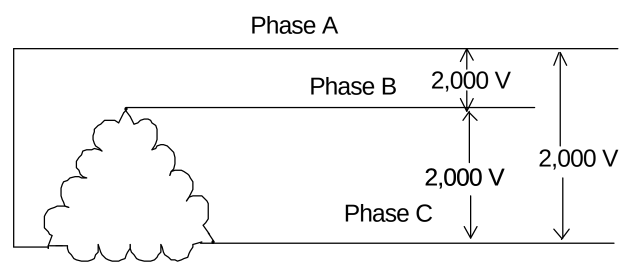

Figure 6. Electrical System Secondary Source Connected in Delta Ungrounded – Not Connected to Earth

> “ . . . there was no decided difference in the results of operating either with the neutral grounded or ungrounded.. As they (the electrical systems) grew in extent, voltage surges began to make themselves felt over wide areas, resulting in breakdown of insulation at various points. In seeking a remedy, many engineers grounded the neutral of their generators or transformers.” [13]

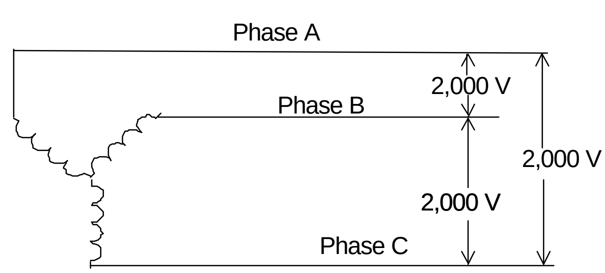

Figure 7. Electrical System Secondary Source Connected in Wye Ungrounded – Not Connected to Earth

The lack of sufficient insulation to withstand the voltage surges resulted in grounding the electrical system at the generator or at the transformers. If more than one transformer were connected to the system for transmission purposes, sometimes each transformer was grounded.

Any arcing fault on an ungrounded delta connected electrical system will result in the electrical system voltage rising to two, three or to as high as six times the normal voltage from conductor to earth, culminating in insulation failure [4]. Dewey goes on to write, "The evidence was not conclusive at that time and perhaps is not conclusive today (1923) but there are certain fundamental principles that seem

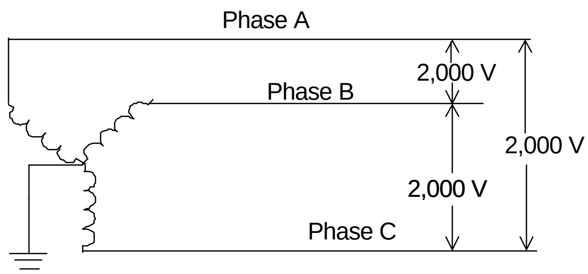

Figure 8. Electrical System Secondary Source Connected in Wye Grounded – Connected to Earth at One Location Only – Uni-Grounded

to be reasonable definite and most of them tend to show important advantages in favor of the grounded neutral system."

C. Utilizing the Neutral

In a wye transformer connection the middle point, the neutral point, can be connected to earth as is shown in Figure 8 without using the neutral for any electrical loads. Figure 9 shows the neutral also connected to earth, but the neutral conductor is extended along with the phase conductors. The configuration shown in figure 9 allows electrical loads, transformers to be placed between any of the three phase conductors, phase-to-phase and/or phase-to-neutral.

This connection, phase to neutral will force electric current to flow over the neutral back to the transformer. So far, this electrical connection is acceptable, as long as the neutral is insulated or treated as being potentially energized, but modifications will be made in the future that will negate safety for the public and animals.

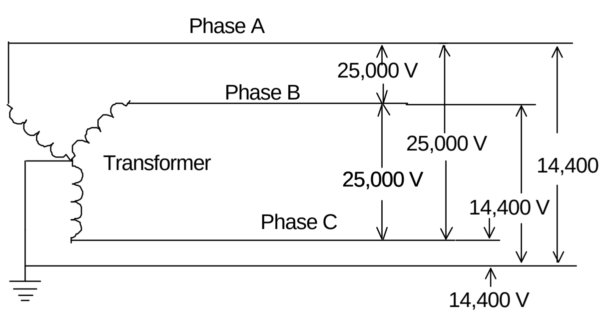

Figure 9. Electrical System Secondary Source Connected in Wye with Neutral Conductor Grounded and a Grounded Conductor Carried with Phase Conductors – Connected to Earth at One Location Only – Uni-grounded

In 1914 J. P. Jollyman, et al., writes about the Pacific Gas and Electric Company's practices which include the utilization of the neutral in distribution systems. Transformers are wound for only 57.7 percent of the insulation voltage requirements for a full voltage, phase-to-phase transformer. This amounts to a substantial savings. In addition, there is only one phase bushing on the transformers. This is additional savings over the costs of fully rated two bushing transformer and full transformer insulation rating. The savings in costs equate to additional profits.

The authors continue to cite additional savings in construction of the distribution line. The pin type insulator, the insulator screwed onto a wooden pin mounted in a cross arm, was the only type that was available in 1904. Savings were generated by applying only 57.7 percent of the voltage rating to the insulator. Instead of having an ungrounded electrical system with 25,000 volts between phases and earth, they now had, with a grounded neutral, only 14,400 volts to earth from any phase. There was still between phases 25,000 volts, but the pin insulator only was stressed to 14,400 volts.

This appears to be a sensible move, but this electrical configuration led later to other problems. Increasing the insulation rating would have been one of the correct methods to resolve the problem along with other solutions that will be discussed later.

D. Wisconsin Rural Electrification

One of the conditions for harmful stray continuous electric current flow is the electrical load. **As the electrical load increases the detrimental effects, also increase.** In order to show why dairy farmers are the first to encounter the stray current problem and are now coming to the forefront of the stray voltage (incorrect term) or stray current problem, we will need to go back and look at the growth of both the rural electrical industry and the dairy industry.

Today the problem manifests itself in the dairy and pig industry since they are very sensitive to stray current as compared to humans but as the load increases and maintenance decreases, tomorrow it will be humans. Unfortunately, it appears that tomorrow is now making itself known with the multitude of electric shocks in showers, hot tubs and swimming pools.

Mr. Post, an early AIEE member [14] writes about the eastern and southeastern 11 counties served by Milwaukee Electric Railway & Light Company where there were 21,000 farms. On January 1, 1926 there were only 2,740 farms receiving electric service, 13 percent of the total. The object of the utility was to discourage the use of motors and to encourage the use of lights and electric ranges. Operation of motors was prohibited from sundown to 11 p.m.

Note that in Figure 10, in 1926 there are two phase conductors supplying the two bushing transformer. The secondary neutral is connected to earth at a remote distance from the pole where the lightning arrester is connected to earth. This Wisconsin utility started out wiring transformer and secondary electrical systems correctly in 1926.

"Up to 1923 only about 120,000 of the 6,250,000 farms in the United States had been wired to use electricity." By 1930 according to a radio speech made by the General Electric Company's President over radio station WGY , " . . shows that only about one-tenth of the farms are connected to public service electric lines and in the second place, that only a small part of the power used on any farm is electric power."

This low usage of electricity continued until late 1930s. There was an increase in the number of farms connected to

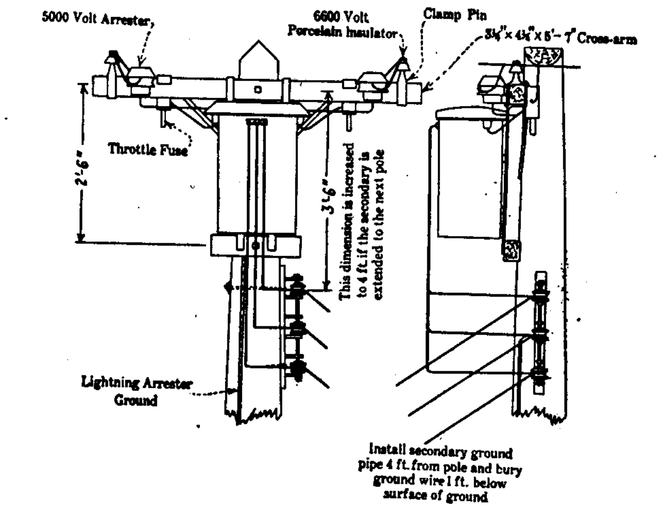

Figure 10. Pole Mounted 2-bushing Transformer with Lightning Arrester Separately Connected to Earth with No Primary Connection to Secondary Conductors, circa 1926.

the electrical distribution systems, however there were few electric motors used on the farms. The motors that were used were for water supplies and cream separators. [15]

VI. USING OTHERS PROPERTY WITHOUT COMPENSATION

A. Lightning Arrester Primary to Secondary Wiring Connection

In Chicago in 1932, the transformers were failing. By this time, the NEC was requiring grounding of the neutral in the electric service to homes. The earthing connection was made to the metallic water lines.

The Utilities Research Commission of Chicago and the Engineering Experimental Station at the University of Purdue conducted an investigation of surge protection of distribution circuits as to why transformers were failing. Test involved the interconnection of the primary lightning arrester ground and the grounded neutral of the secondary main circuit.

The conclusions reached were, "Measurements of the voltage between primary phase c lead and secondary neutral have shown that the *interconnection of the secondary neutral with the lightning arrester ground is, in general, beneficial to the transformer.* In particular, with a low resistance secondary neutral ground and a high resistance lightning arrester ground, the interconnection reduced the above voltage by 30 to 50 per cent." [16]

Instead of lowering the lightning arrester's resistance to earth by installing additional ground rods or other methods, at additional costs to the utilities, the utilities elected to save the additional cost by using the customers' connections to earth. This practice placed the industrial facility, the homeowners and the farmers in danger from excessive lightning current flow over the neutral conductor and the ground conductor in their facilities and the potential of high voltages during the lightning arresters' operations.

This connection permitted the hazardous electrical current from the operation of the lightning arrester to flow into the customers' homes, into the homeowner's ground rod, through the metallic water piping without their knowledge or consent which benefited the utility without proper approval or compensation of the owner of the secondary wiring system.

B. Primary Neutral to Secondary Neutral Connection

The extension of this invasion of the customers' wiring systems was when the utilities connected the primary neutral to the secondary neutral at the transformer and allowed primary neutral current to flow unimpeded into and over the customers' homes, into the homeowner's ground rod, through the metallic water piping into their showers, hot tubs and bathtubs and into the industrial facility without the owners' knowledge or consent. To comprehend this situation we need to start with what is a transformer.

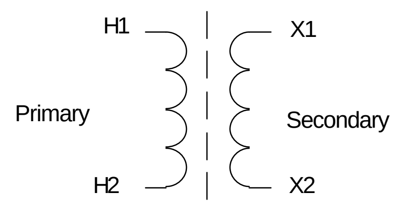

Figure 11. Transformer Electrically Isolated

Figure 11 shows what is considered by the majority of electrical engineers as a standard electrical transformer connection or wiring. Note that on the left side is the primary winding with two terminals, H1 and H2. For the purposes of this report, only a step down transformer will be discussed.

The lower voltage windings are referred to as the secondary. In the case at hand, a primary voltage of 14,400 volts is applied to the primary winding and the secondary voltage for sake of discussion will be 120 volts. Note that Figure 11 shows a dividing dashed line separating the primary windings from the secondary windings.

There are no solid electrical connections between the primary windings and the secondary windings. The vast

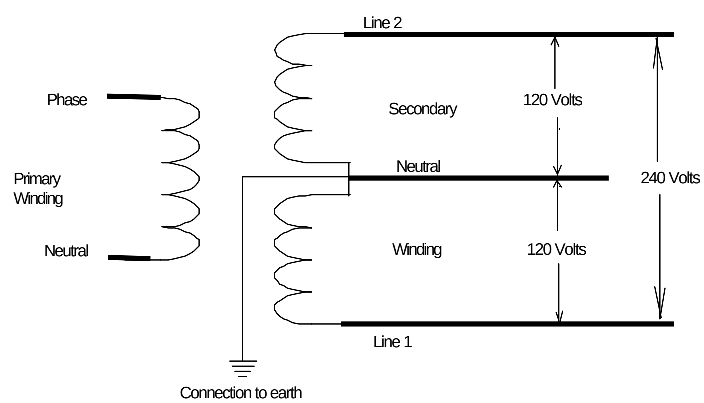

Figure 12. Phase to Neutral Primary Connection with Secondary winding Center Tapped – Primary and Secondary Electrically Isolated

majorities of electrical engineers are aware of and consider this the correct wiring for a transformer configuration.

A poll of electrical engineers NOT associated with utilities were asked if Figure 12 was the electrical wiring diagram for the transformer located on the pole outside their home, or the wiring diagram for the pad mounted transformer located on the ground near their home or if they had an underground electric transformer vault, the correct representation for the transformer?

Eighty-five percent of the electrical engineers working in industrial and commercial facilities, answered yes. The correct answer is Figure 13 with the solid electrical connection from the primary neutral to the secondary neutral. Such a connection is unthinkable and unheard of in the industrial, commercial and residential electrical engineering fields. Only electrical engineers working in the utility distribution area are aware of such a non-standard transformer connection and the disastrous results of allowing hazardous, stray electrical current to flow continuously uncontrolled over the earth, metallic piping, building steel, into industrial, commercial facilities, homes and farms.

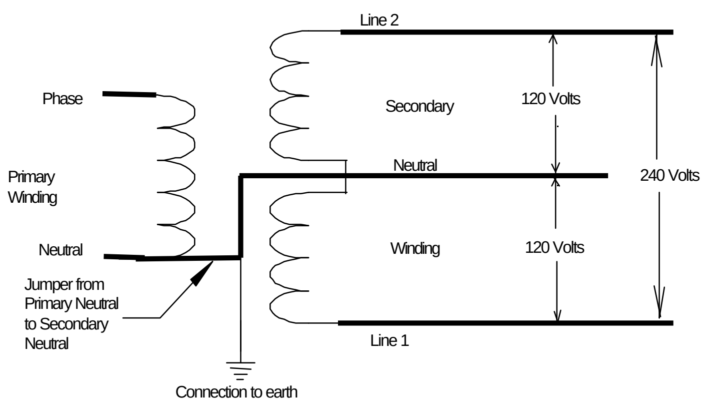

Figure 13. Phase to Neutral Primary Connection with Secondary winding Center Tapped and the Primary Neutral Solidly Connected to the Secondary Neutral.

This is verified by the Institute of Electrical and Electronic Engineers' Standard 141, titled, "IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants" and IEEE Standard 241, titled, "Recommended Practice for Electric Power Systems in Commercial Buildings" [17].

Why should one industry, the utility industry, be allowed to use transformers with such a non-standard transformer connection considered unsafe and/or unknown of by the vast majority of electrical engineers just because it saves money?

VII. UNDERSTANDING THE CONTINUOUS FLOW STRAY CURRENT

To completely understand the flow of stray current a person needs to 1) understand the definition of stray current and 2) realize how the current flows over the primary to secondary neutral connection and into industrial and commercial facilities, residences or farms and 3) the multigrounded neutral distribution system with uncontrolled flow of continuous electric current over the earth and into and through industrial and commercial facilities, residences or farms.

A. Stray Current

It has been shown previously that it is the current that is dangerous to the human animal and to the animal kingdom. Voltage is only the pressure that pushes the current. Voltage does not burn the body. It is the current that burns the body, sets the heart into fibrillation, halting the pumping action of the heart, resulting in death of both.

As long as we know that the mighty Mississippi River is contained within its banks, everyone is comfortable, satisfied and content. Likewise, the flow of all electric current must be contained within an insulated conductor just like the banks of the Mississippi. When the mighty Mississippi overflows its banks there is a problem and we become concerned. Just because we cannot see the flow of electric current over the earth is no reason that we should not be concerned when the electric current over flows its "banks".

Any continuous flow of electric current and the key word is continuous flow, must be contained within a conductor insulated from earth and not permitted to flow uncontrolled over and through the earth, metallic water pipes, building steel, etc.

When an electric fault occurs it is normal and acceptable for the fault current to flow over the ground path, whether that be a green or bare ground conductor or the earth, only for so long as it takes to open the circuit protective device (circuit breaker, fuse, recloser or other device). If the wiring system has been correctly installed, that period of time is very short; normally less than a second before the protective device, opens and halts the flow of fault current.

Thus we can now **define "stray current" as the continuous flow of any current, other than momentary fault current, over the earth, metallic piping, building steel, into houses and farms, etc. which is thus objectionable and undesirable to the continued good health of humans and animals.**

B. Parallel Current Paths

A lineman was asked to place an ammeter on the primary phase conductor of the conductor shown in Figure 13. He yelled down the reading, "42 amps". "Would you read the neutral conductor current please?" he was asked. "22 amps" he called down. "What happened to the other 20 amperes?" "Oh! That is normal" he replied. This exchange actually took place. [18]

Let us look closely at Figure 12, the primary winding of the transformer. The current enters the conductor on the conductor labeled "phase". Now the current flows just like water in a coil of hose, around and comes out the end marked "Neutral". All of the electric current that went into the transformer on the primary phase conductor, all of it came out on the primary neutral terminal of the transformer. See Figure 12.

The same is not true of the Figure 13. The current coming out of the transformer at the primary neutral terminal now has two paths that the "return current" can take. Some of the current will flow back on the neutral primary conductor and some will flow onto the neutral connection to earth on the secondary side of the transformer. In the example above with the lineman, 20 amperes flowed out the connections to earth and was uncontrolled and flowed continuously over the earth, through metallic pipelines, into industrial facilities' metallic piping, building steel, commercial buildings' steel and metallic piping, residences, metallic piping and over the earth, etc resulting in hazardous conditions to humans and animals.

One of the methods used to "eliminate" "stray voltage" is to increase the size of the neutral conductor in utilities distribution circuits. It is assumed by some that increasing the neutral size will "prevent" current from flowing over the earth since the larger neutral has less resistance.

Confusion may also exist over harmonics and their associated problems. One low voltage distribution system solution for 3rd harmonics is to increase the neutral. Harmonics are not applicable in this discussion of stray current. The following will clarify the fallacy of increasing the neutral size.

Using Figure 14, let us assume that leaving the transformer at the neutral is 10 amperes of electrical current. There is a path using the neutral conductor, path A to B and another path A to C through the earth to another earth connection D to B. Since the resistance through the conductor path is 1 Ohm and equal to the resistance through the earth, 1 Ohm also, the current will divide equally. There will be 5 amperes through each path. This is based on Ohm's Law.

If we keep the resistance of the conductor constant, path A to B and change the resistance of the path A, C, D to B through the earth the current flow through the earth values will change. Using Figure 15, we will keep the resistance of the conductor from A to B constant at 1 Ohm. The resistance through the earth, "Z" will change. This change will affect the amount of current through both the paths A to B through the conductor and the path through the earth, A to C to D to B.

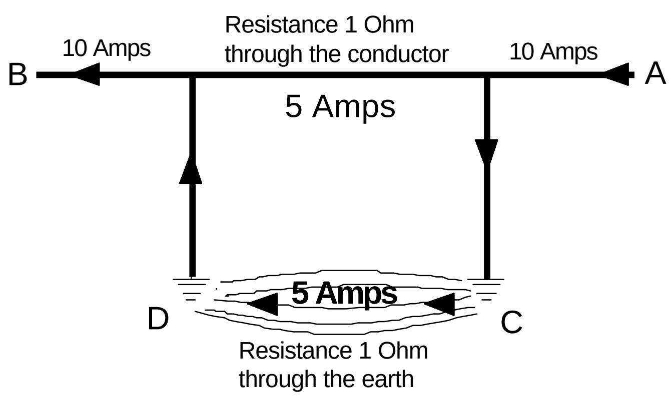

Figure 14. Parallel Path Through A Conductor And Flow Of Current Through The Earth with Fixed Resistance Values

The point that Table 2 and Figure 15 make is no matter what the ratio of resistance of path A to B if it is kept at a low value as compared to path A, C, D, B which is increasing, there will be some amount of current through the earth. Another way of saying it is no matter how great the differences in the resistance of two parallel paths, there will always be some value of electric current flowing through both parallel paths. Just because the earth may have a high resistance does not mean that there will be no current flow over and through the earth.

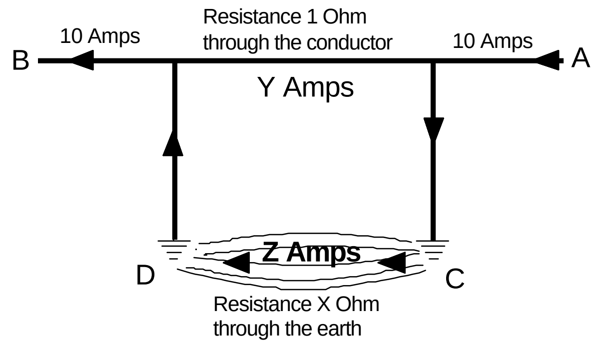

Figure 15. Parallel Path Through A Conductor And Flow Of Current Through The Earth with Variable Resistance Values

Resistance X Ohms	Current through Conductor Path A to B	Current through the Earth Path A, C, D, B
1 Ω	5.00 A	5.000 A
10 Ω	9.09 A	0.910 A
100 Ω	9.90 A	0.100 A
1000 Ω	9.99 A	0.010 A

Table 2. Current through a Parallel Path Using Figure 15.

Just to put into perspective for a male 1.1 mA is the level of perception "let go" threshold median.

When there exists more than one electrical connection to earth, no matter what the resistance of the earth is, there will always be some amount of hazardous electric current flowing continuously over and through the earth uncontrolled. Referring to Table 1, it can be seen that any current exceeding 9 milliamperes (0.009 A) can be hazardous to humans.

VIII. DANGEROUS PRACTICE OF COMBINING THE EQUIPMENT GROUNDING CONDUCTOR AND THE NEUTRAL CONDUCTOR INTO ONE CONDUCTOR SERVING TWO FUNCTIONS

The next step in the evolution of electrical distribution would have been Figure 16. Figure 16 shows a substation symbolized by the secondary wye transformer configuration with the neutral connected to earth. In addition to having the neutral connected to earth the neutral is carried on the poles along with the three phase conductors.

Somewhere along the distribution line, the three phases are dropped in favor of just one phase conductor. This is changing from three-phase distribution to single-phase distribution circuit. A typical load is shown in the form of a transformer connected from a phase conductor to the neutral conductor.

In figure 16, the current flow is shown originating at the substation transformer starting at the neutral connection in the center of the wye, labeled "N". The current flow continues to

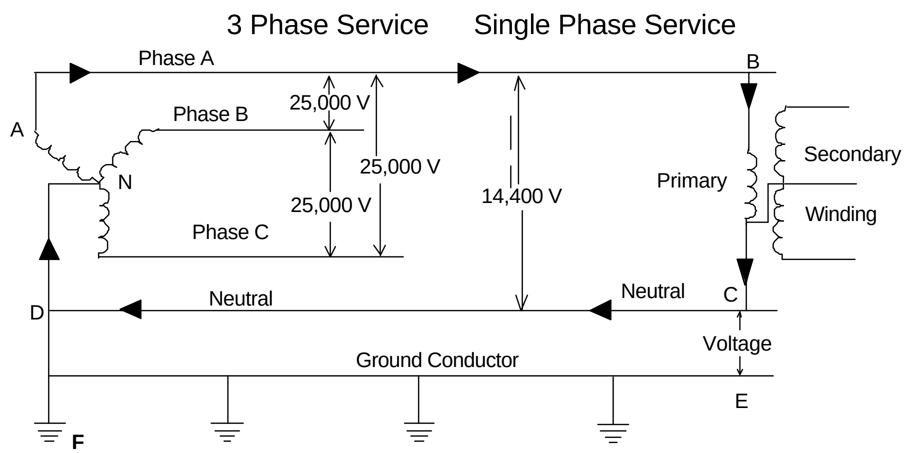

Figure 16. Wye Connected Electrical System Grounded at the source, Uni-Grounded With Transformer Connection To Earth At Only One Location With Both A Neutral And Ground Conductor Carried With The Phase Conductors With Phase-To-Neutral Loads (Which Generate A Hazardous Neutral Voltage –To–Earth, Point C to E) And A Ground Conductor

point A to point B through the transformer to point C onto the neutral and continuing on the neutral to point D and back to the beginning point, the center of the substation transformer N.

The neutral conductor has resistance. With current flowing through the neutral conductor, which has resistance, a voltage will be developed between point "C" and point "D". The voltage on the neutral at point "C" to earth point "E" can be high enough, depending on resistance and amount of current, to cause harm to a person, especially a lineman. Even though this wiring configuration contains all the continuous current flow within a conductor insulated from earth, there is a problem with a voltage build up from the neutral to earth along the length of the neutral conductor especially if it is on a pole and bare.

Since there is a voltage developed between the neutral conductor and the ground conductor, the neutral conductor should be treated as an energized conductor and installed on insulators, which add additional costs to the electrical distribution system and result in additional costs for the utilities. This type of electrical system allows the use of the less costly phase-to-neutral transformer.

Figure 16 is referred to as a 5-wire electrical distribution system consisting of one, two or three phase conductors, an insulated (from earth) neutral and an "equipment grounding conductor". This is exactly like what has been used in low voltage electrical distribution system in industrial and commercial facilities since approximately the 1950s.

Again, costs were the determining factor in resolving the problem with the difference in voltage between the neutral and the earth. Instead of installing, the neutral insulated from earth and treating the neutral as an energized conductor, the utilities took the least costly way and multigrounded the neutral thus reducing the build up of harmful potential to the linemen to less than approximately 25 volts at the mid-location between grounding points.

IX. MULTIGROUNDED NEUTRAL

The least costly solution to the problem with a voltage build up between the neutral and the ground conductor as shown in Figure 16 was to combine the function of the neutral and the ground conductors into one conductor. This combination of the neutral conductor and the ground conductor is called "multigrounded neutral".

When a fault of a primary conductor to earth occurred it was necessary to have low impedance paths back to the substation transformer in order that sufficient electrical current would flow to operate the protective device, the fuse, circuit breaker or recloser. In order to insure a low resistance, impedance path back to the source it was necessary to earth the multigrounded neutral conductor just like when there were two separate conductors, the neutral and the ground as shown in Figure 16.

Figure 17 shows the multigrounded neutral system. In Figure 16 all the current is contained within an insulated conductor; See path "N" to "A" to "B" through the service transformer to "C" to "D" and back to the starting point "N". With a multigrounded neutral distribution system it is necessary to have an electrical connection to earth at least 4 times per mile to keep the voltage on the multigrounded neutral from exceeding approximately 25 volts making it safe for the linemen should they come into contact with the neutral and the earth. See NESC Rule 096 C in the section on the National Electrical Safety Code.

With the multigrounded neutral conductor connected to earth at least 4 times per mile and at each transformer and lightning arrester there are now multiple paths over and through the earth that the hazardous electric current can flow over continuously, uncontrolled. The solid arrows in Figure 17 indicate this hazardous current flow. This flow of hazardous electric current, which is shown with the solid arrows, is created as primary current only. Additional primary current may be produced by unbalanced electrical loads.

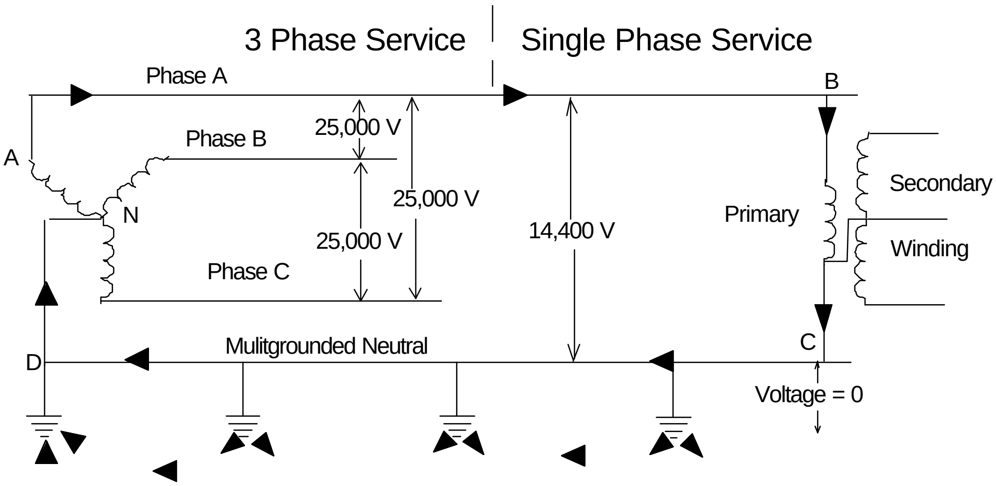

Figure 17. Wye connected at the source primary electrical system multigrounded neutral showing the continuous current flow through the earth when utilizing phase-to-neutral loads

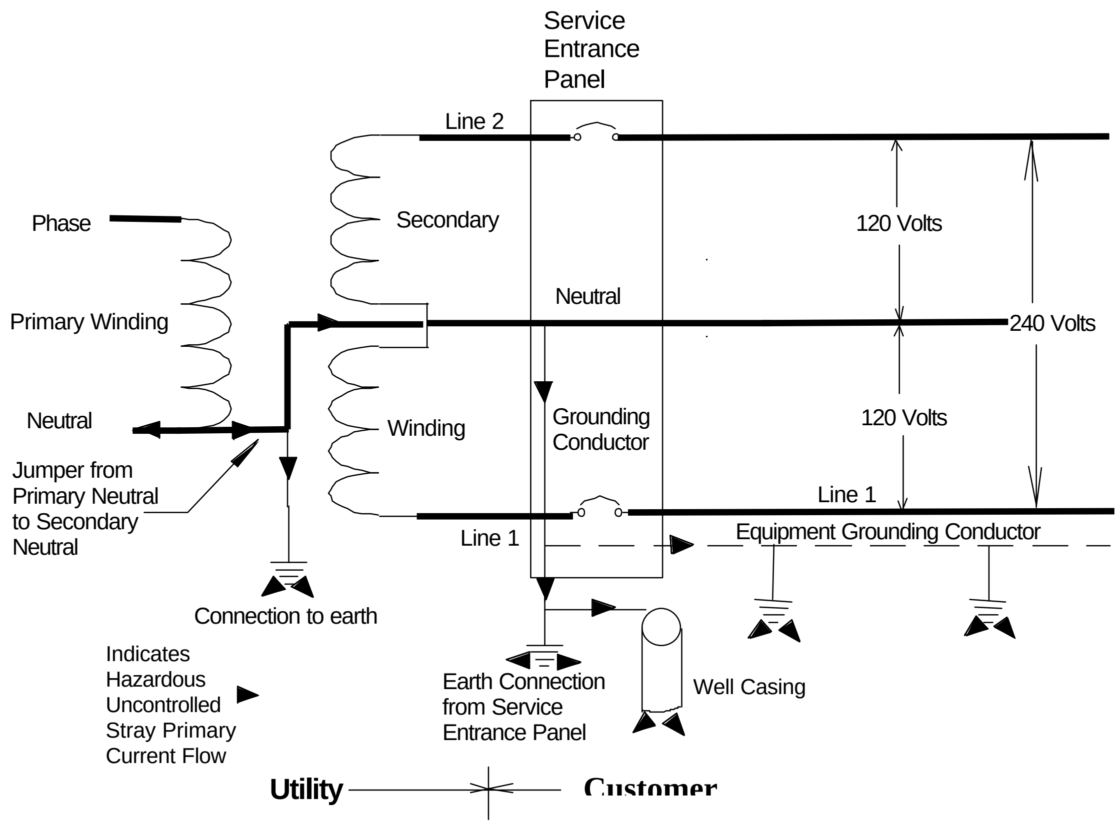

Figure 18. Wiring diagram showing the hazardous uncontrolled stray primary current flow over the customer's property.

A.   Hazardous Electrical Current Flow

Figure 17 shows just part of the primary current flow into the earth. The path that this current flow takes through the earth cannot be determined. We cannot put an isotope on each electron and trace its path as it flows uncontrolled through the earth.

Public Service Commissions and Utilities are obligated to provide adequate electrical service without any adverse effects. It is irresponsible to permit stray uncontrolled electric current to flow into and over private property. This act is hidden from view, as the public is very unaware of what is being done by the utilities. It is not advertised on TV nor is information included in the bill sent to the utility customers.

B. Primary Neutral Current Entering through the Service Transformer (S)

As was explained previously in the section titled, "Lightning Arrester Primary to Secondary Wiring Connection" in 1932, The Utilities Research Commission of Chicago and the Engineering Experimental Station at the University of Purdue conducted an investigation of surge protection of distribution circuits. The conclusions reached were, "Measurements of the voltage between primary phase c lead and secondary neutral have shown that the *interconnection of the secondary neutral with the lightning arrester ground is, in general, beneficial to the transformer."*

This connection and the adverse effects are shown in Figure 18. The primary current leaves the transformer winding and has a fork in the path. One path is back to the substation over the multigrounded neutral conductor. In many cases, the neutral conductor is of a smaller size than the phase conductor supplying the current and the multigrounded neutral conductor has many high resistance twist connections which increases the impedance of the line forcing more and more current into the earth uncontrolled.

In addition, the neutral current can now flow over the jumper between the primary neutral conductor and the secondary neutral conductor as is shown in Figure 18. The NESC requires the transformer's neutral to be connected to earth at the transformer. This is the first connection to earth in Figure 18. Just because the NESC has a Rule that requires something to be accomplished does not make it safe or correct as will be covered later. In fact, a judge made such a ruling in a case.

The distribution line and the product, electrical energy, are inseparable and thus, become one. A Court has concluded that electricity is a product by holding as follows: "It is no answer for a company engaged in the public sale of such a highly destructive agency as electricity to say that precautionary measures which may have been adequate to meet the test of due care 50 years ago when the lines were installed, must be regarded as sufficient in modern industrial society."[1]

The National Electrical Code (NEC) requires the neutral in the service disconnect and overcurrent panelboard to be connected to the earth also. Now the secondary neutral is connected to earth a second time. A parallel connection of the neutral to earth now exists permitting hazardous electric current to flow continuously uncontrolled over the earth.

The equipment-grounding conductor has to be connected to everything that is metal and contains an electric conductor as per the NEC. The well casing offers another path to earth, the third parallel path contributing to the flow of hazardous uncontrolled electric current over the earth.

The discussion thus far has been about the hazardous stray continuous flowing primary neutral current from the electrical system owned and operated by the utility. This hazardous stray primary neutral current flowing continuously over the earth is the major contributor to the flow of uncontrolled stray current.

In addition to the primary electrical stray current, there are additional stray current sources flowing from the secondary side of the service transformer.

C. Fee for Using the Utilities Poles by Other Utilities

The communication and cable companies when mounting their conductors on utility companies' electric power poles compensate the utility company for their use.

Assume that Mr. Utility Customer wanted to communicate with his brother's house located on an adjacent street by utilizing an electronic communication device and the existing power conductors of surreptitiously. There would be no interference with the normal electric power distribution system. Such action would no doubt be considered by the utility company as utilization of their electric lines without adequately compensating. Alternatively, consider a person hanging his own conductors on the utility company's poles, the utility company would want compensation for the use of their poles.

The original wiring installed in and on Mr. Customer's property after the electric service meter was paid for and owned by Mr. Customer. That wiring consists of the neutral conductor being connected per the National Electrical Code to a driven ground rod supplied and owned by Mr. Customer. The internal electrical wiring on Mr. Customer's property has the neutral connected to the metallic water piping system and is owned by Mr. Customer.

The utility has usurped Mr. Customer's internal wiring system for the enhancement of their electrical system in order to reduce the utility's costs for the benefit of the transformer. The National Electrical Code (NEC) requires the neutral in the service disconnect and overcurrent panelboard to be connected to the earth through the grounding conductor. Now there is a second connection to earth. A parallel connection of the neutral to earth now exists permitting current to flow continuously uncontrolled over the earth.

The equipment-grounding conductor has to be connected to everything that is metal and contains an electric conductor as per the NEC. The well casing offers another path to earth.

The discussion thus far has been about the stray continuous flowing primary neutral current from the electrical distribution system. This stray primary neutral current flowing continuously over the earth is the major contributor. There are additional stray current flows from the secondary side of the service transformer.

D. Total Primary and Secondary Hazardous Uncontrolled Continuous Stray Current Flows

Figure 19 shows the magnitude of the points where the hazardous uncontrolled continuous flow of primary and secondary current can originate. The single phase-to-neutral transformer electrical circuit originates at the "N" in the center of the transformer winding. The current flows to point "A" to point "B" and through the primary winding of the service transformer.

As the current exits the transformer winding there is a fork in the circuit and one branch continues to "C to "D" and back to the beginning. However, the other path is the primary neutral to secondary neutral, point "K". From point, "K" the

[1] Black v. Public Service Electric & Gas Co.

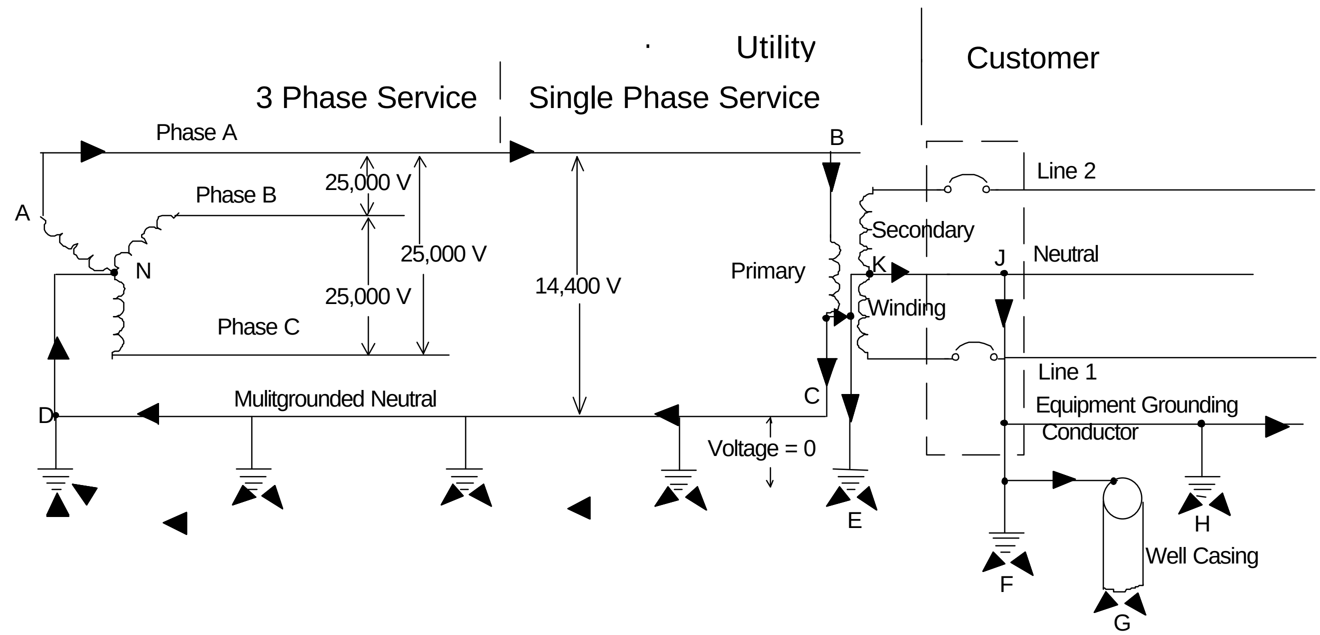

Figure 19. Wye Connected Electrical System Multigrounded Neutral with Primary Neutral to Secondary Neutral Electrical Service Connection Showing the Hazardous Stray Uncontrolled Primary Current Flow.

current can flow to the ground rod at the base of the pole, point "E" and into the earth, uncontrolled.

The other path is to point "J" down to another junction point where the stray current can flow into the earth at point "F" or into the earth at the well casing, point "G". There is another branch allowing the stray current to flow onto the "equipment grounding conductor and into the earth at every point where the equipment grounding conductor touches earth.

Figure 19 also shows the secondary electrical system where the primary and secondary continuous flowing stray uncontrolled current entered the earth at points E, F, G and H, but not limited to these points.

X. A RECOMMENDED SAFE METHOD FOR ELECTRICAL DISTRIBUTION

Figure 20 shows the source transformer at the substation as a wye connected transformer, uni-grounded. The phase conductors are insulated from earth just as the present day phase conductors are. The ground conductor is earthed at multiple places. This multiple earthing of the ground conductor allows any fault current that enters the earth, should a phase conductor fall to earth, to flow over the lower impedance path of the ground conductor and over the earth back to the neutral point of the transformer. This improves the safety of the electrical distribution system.

The load transformers are electrically connected phase-to-phase not in the present method of phase-to-neutral. This requires a two bushing transformer and fully rated insulation in the transformer.

The lightning arresters are connected to the grounding conductor, which has a low impedance connection to earth because of the four connections to earth plus the connection at each transformer can and lightning arrestor.

To accomplish this improved electrical distribution system requires the installation of another insulated phase conductor, which should have been installed in the beginning. The present "multigrounded neutral" conductor becomes the ground conductor.

Since the lightning arrester now has a low impedance earth connection due to the multiple earthing connections of the ground conductor, it is no longer necessary to use the earthing systems of the customers to obtain a low impedance connection to earth for the lightning arrestor successful operation. With the now required two bushing, full phase-to-phase voltage across the service transformer there will be no primary neutral current or primary neutral terminal on the service transformer.

Since there is no primary neutral the non-standard, transformer electrical connection of the primary neutral to secondary neutral cannot be made. Thus, the flow of primary current into the secondary side and into the customer's property will not exist. With this electrical distribution system, that does not have any primary neutral connections to earth, the customer will no longer have hazardous stray continuous electrical current from the primary distribution system flowing over his property or nearby earth.

XI. TRANSFORMER CONNECTED 3 PHASE, 5-WIRE GROUNDED WYE WITH LOADS PHASE-TO-PHASE OR PHASE-TO-NEUTRAL CONNECTIONS

Figure 16 shows an alternate method that is also safe for the public and animals. It is known as the 5-wire system. This system has been shown to reduce stray currents. [19]

This second type of system that is safer than a multigrounded neutral distribution system is a 3 phase, 5-wire grounded wye with all loads either phase-to-phase or phase-

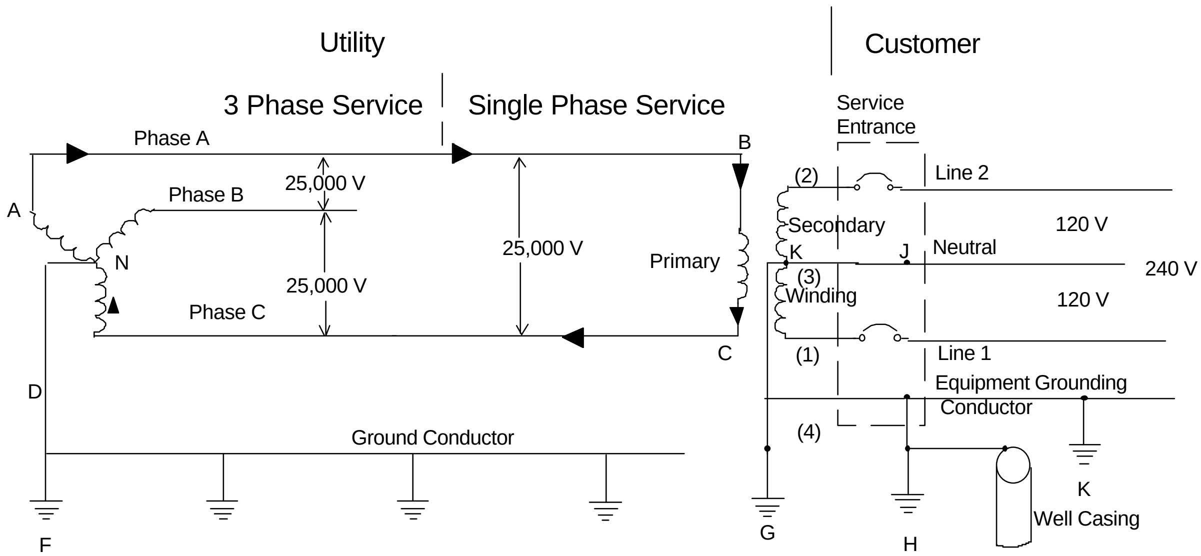

Figure 20. 4-Wire, Wye Connected Electrical System Grounded at the Substation Only and at the Service Transformer Secondary Side Only with Complete Electrical Isolation from Earth and All Continuous Electric Current Contained in Conductors Insulated from Earth.

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to-neutral connections. The fourth conductor is a neutral insulated from earth. This type of electrical distribution has been in existence within industrial and commercial facilities for over 50 years. In the case of utilities, the neutral is treated as an energized conductor

This electrical configuration is considered one of the most desirable and safest type of electrical distribution systems for the simple reasons that whenever a phase comes into contact with the earth or the ground conductor, the fifth wire, the ground conductor, which is connected to earth at frequent intervals and is directly connected back to the transformer allows the placement of protective devices that can detect low levels of fault current to trip immediately.

Depending on the configuration of the circuit the fault current detection could be as low as approximately 25 to 50 amperes or lower and can be made to open the circuit removing the voltage from the circuit as compared to the 100, 150, 200 amperes or more current required to operate the protective device.

The utilities saved billion and billion of dollars over the years by utilizing the multigrounded neutral distribution system. The cost to fix or solve the problem is much less since the transformers can be re-used. The cost to add a single bare neutral is all that is required. The existing multigrounded neutral conductor would be converted to the ground conductor and the required NESC four ground rods per mile already exist. The costs to correctly wire the circuit or circuits system wide would be minimal, considering only one additional conductor would have been required. It has been estimated that the costs would be approximately $ 10 000.00 per mile and could be accomplished in the same fashion that the three wire receptacle was phased in – over a period of years.

It is reported by Mr. Lawrence C. Neubauer, Master Electrician who has tested many dairy farms in California that the utilities in the dairy areas of California do not use multigrounded neutral distribution system. There are no reports of stray current from the primary system.

There are no prohibitions in the NESC against such an electrical installation. Electric Power Research Institute (EPRI), an organization of the electric utilities, conducted extensive testing of the 5-wire electrical distribution system. The experimental facilities of the utilities have installed and tested such a safe electrical distribution system in New York State and have made the report available to their EPRI members.

B. Make the Secondary Service Conductors Safe

Initially, if utility companies had used four (4) service drop conductors, Figure 20, conductors (1), (2), (3) and (4), the secondary neutral earthed at the transformer as it should be, and the secondary neutral an insulated conductor, this would have resulted in a very safe electrical service drop without any continuously flowing stray electric current over the earth.

By bringing the insulated phase and insulated neutral conductors plus the equipment-grounding conductor to the customer there will be no need to re-earth the neutral in the service disconnect and overcurrent panelboard. The re-earthing of the neutral a second time in the service panel results, as has been shown, in parallel continuous stray electrical current paths.

XII. ARGUMENTS TO CONFUSE

There will be presented arguments that will try to show the system as shown in Figure 20 cannot work because of various excuses. One such argument will state lightning strikes will destroy the transformer unless the transformer is connected to the secondary circuit. Or that the primary neutral must be connected to the secondary neutral in order to "stabilize the system". This is pure poppycock, a new technical term.

In the intervening years since 1932, the utility industry has forgotten the reason for the resultant connecting of the primary neutral to the secondary neutral. The intermediate step was the adoption of the multigrounded neutral distribution system, which connected the lightning down connection to earth to and through the multigrounded neutral conductor, which was connected to earth multiple times, and the multigrounded neutral conductor was connected to the secondary neutral since it was "*beneficial to the transformer*". In the industrial world of electrical distribution, Figure 20 is the method used to install electrical distribution systems every day for over 50 years or more.

It will be granted that transformers were not as well constructed in the 1920s as they are today. Failures were common due in some part to poor lightning arrester design and insulation methods as cited above. Transformers today rarely fail and when they do the fail, the mode of failure is not one where the primary voltage is applied to the secondary winding causing the users to have high voltage on their electrical circuits.

In fact, in a recent Virginia Division of Energy Regulation, State Corporate Commission action concerning VEPCO where VEPCO dropped a 25,000-volt line onto a 12,470-volt distribution line the voltage at the service entrance was calculated to have risen only to 334 volts maximum. The point is even with the primary connected to the secondary there was still a voltage rise at the customer services. Not everyone suffered electrical damage even after this happened four times. There were no transformer failures reported.

Like many things in the past, the utilities were aware of the cost savings and may not initially been aware of the safety concerns. It can be argued that once a practice is begun, it is often difficult to undo what has been done. However, it can and has been undone.

Proof that this non-multigrounded neutral electrical distribution system functioning safely can be found in California's Public Utilities Commission's General Orders – 95.

A. California's Public Utilities Commission's General Orders – 95

On January 19, 1994 the California's Public Utilities Commission in their General Orders – 95 generated a resolution SU-25 resulting in Rule 33.2.

33.2 Ground or Earth as a Conductor

Ground or earth shall not be used as a normal return or circuit conductor. In direct current supply systems or in single phase or polyphase supply systems, a neutral or any other conductor shall be used under normal use as a return or circuit conductor; however, the grounding of the neutral or any other conductor is not permitted as a normal return or circuit conductor. The neutral or any other conductor is permitted to be grounded only for the purposes of stabilization and protection.

In California, there is another term "messenger" that is used that has a different meaning and application elsewhere in the rest of the utility companies. California applies the term messenger correctly.

21.11 Messenger

means stranded wires in a group and which generally is not a part of the conducting system, its primary function being to support wires or cables of the conducting system; sometimes called "suspension strand".

The messenger has been corrupted into serving as not only a messenger, but as a combined neutral and ground conductor as will be discussed in detail later.

B. Transformers – Two Bushing Type – Two Phase Conductors

Two bushing transformers are required in California. Two bushing phase-to-phase transformers have full voltage

Figure 21. Left – Single Bushing Transformer With Ground Strap Connecting Secondary Neutral To Metal Can Of Transformer (Shown just above the "10"), Which Is the Primary Connection. Right – Two Bushing Transformer.

insulation rating where as a phase-to-neutral transformer has only 58 percent insulating rating, resulting in a savings in material cost in insulation and bushings.

A two bushing transformer eliminates any neutral current, thus there are no hazardous uncontrolled stray continuous flowing current over the multigrounded neutral conductor to earth since there is no need for any multigrounded neutral conductors

XIII. CONFLICT BETWEEN NATIONAL ELECTRICAL SAFETY CODE AND THE NATIONAL ELECTRICAL CODE

The National Electrical Safety Code Rules govern the electrical installation up to the service point, which include the service transformer. The service point is usually the electric meter or the line of demarcation between the utility and the customer.

"NESC Rule 011.Scope

B. The NESC covers utility facilities and functions up to the service point.

NOTE: The National Electrical Code. (NEC.), NFPA 70-1999 covers utilization wiring requirements beyond the service point."

There is lack of trust between the two code making bodies, the NESC and the NEC. Both bodies want the neutral to be connected to earth, ground. The most logical place to make this electrical connection to earth is at the transformer. The IEEE industrial and commercial electrical engineers state this in the IEEE Standard 141 [17].

The NEC fearing the utility companies will not ground the neutral at the transformer and the utilities supplying only a 3-wire service using the messenger for triple duty, requires the neutral to be grounded a second time at the service disconnect and overcurrent panelboard. This second grounding of the neutral on the secondary side of the transformer results in a parallel path condition and the problem of hazardous stray secondary neutral currents.

In addition, the utilities insist saving money by combining the neutral conductor with the ground conductor and the messenger support wire; three functions into one conductor.

It would be acceptable to combine the ground conductor and the messenger, but not include the neutral conductor. The neutral conductor must be insulated like the phase conductors, from earth except at the transformer. In the service disconnect and overcurrent panelboard the neutral is connected again to the earth using the grounding conductor. See Figure 22.

A. Joint NESC and NEC Meeting Rejected

To resolve the conflict between the NESC and the NEC over the neutral being grounded by both code-making bodies at different locations a letter was sent to the Chair of both organizations requesting a joint meeting. This suggestion was based on the joint meeting of the NEC with the Canadian Electrical Making Code body to have uniform adoption by both codes of the European method of hazardous location installation, the IEC's Zones method. Both bodies rejected the suggestion for the NEC and the NESC meeting.

The members to the National Electrical Safety Code making body have their way paid by their utility employers. This is a clear conflict of interest. When one considers that utility employees have lived with the errors that were made in the distant past it should be no surprise to a person that utility employees would hesitate to try and change something management would be opposed to if it would cost additional funds.

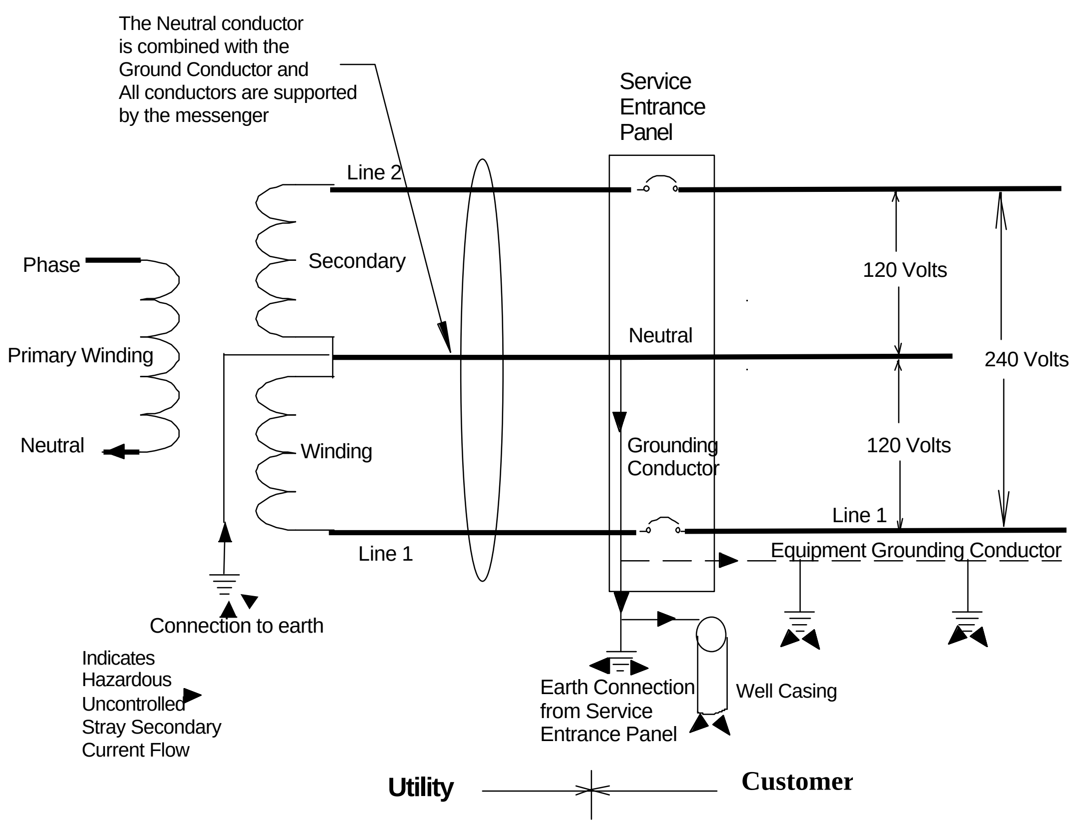

Figure 22. Conflict between the NESC and the NEC over the Grounding of the Neutral.

B. Proposals to the NESC to Fix the Service Drop Conductors Rejected

Contributing to the conflict is the fact that the conductors that run from the utilities' pole to the house consists of only two-phases, also known as hot or energized conductors and a messenger to support the two-phase conductors.

A neutral must be delivered to the house. The utilities have saved millions and millions of dollars by combining the neutral with the messenger when the neutral should be, for safety purposes, an insulated conductor.

In addition, the grounding of the transformer generates an equipment-grounding conductor that must also be carried into the house. In summary, the utilities should have supplied the following conductors in the service to any residence:

- Insulated either two or three phase conductors. (Line 1 and Line 2 in Figure 22.)
- Insulated neutral.
- A bare wire connected to the grounding conductor at the transformer and used as a messenger to support the above-insulated conductors.

Figure 23 shows the correct number of conductors installed between the transformer and the home. A proposal was submitted to both code making bodies, NEC and the NESC that would permit the correct number of service drop conductors if the homeowner paid the difference. In other words, there would be no additional cost to the utility, for the correct installation of service conductors that would prevent the flow of continuous electric current over the earth and/or home. This proposal was soundly rejected by the NESC, receiving only one vote, that of this writer.

No doubt, it was surmised that if such an admittance of incorrect electrical installation were acknowledged by the adoption of such a Rule change, the utilities would be inundated with legal action by homeowners. No such legal action to this writer's knowledge has occurred in California.

C. Proposals to the NEC to Fix the Service Drop Conductors Rejected

Proposals and comments have been made to the National Fire Protection Association's National Electrical Code Making Panel to change the service entrance conductors as described above. The proposals and comments were soundly rejected by the NEC with the excuse that it is the domain of the NESC.

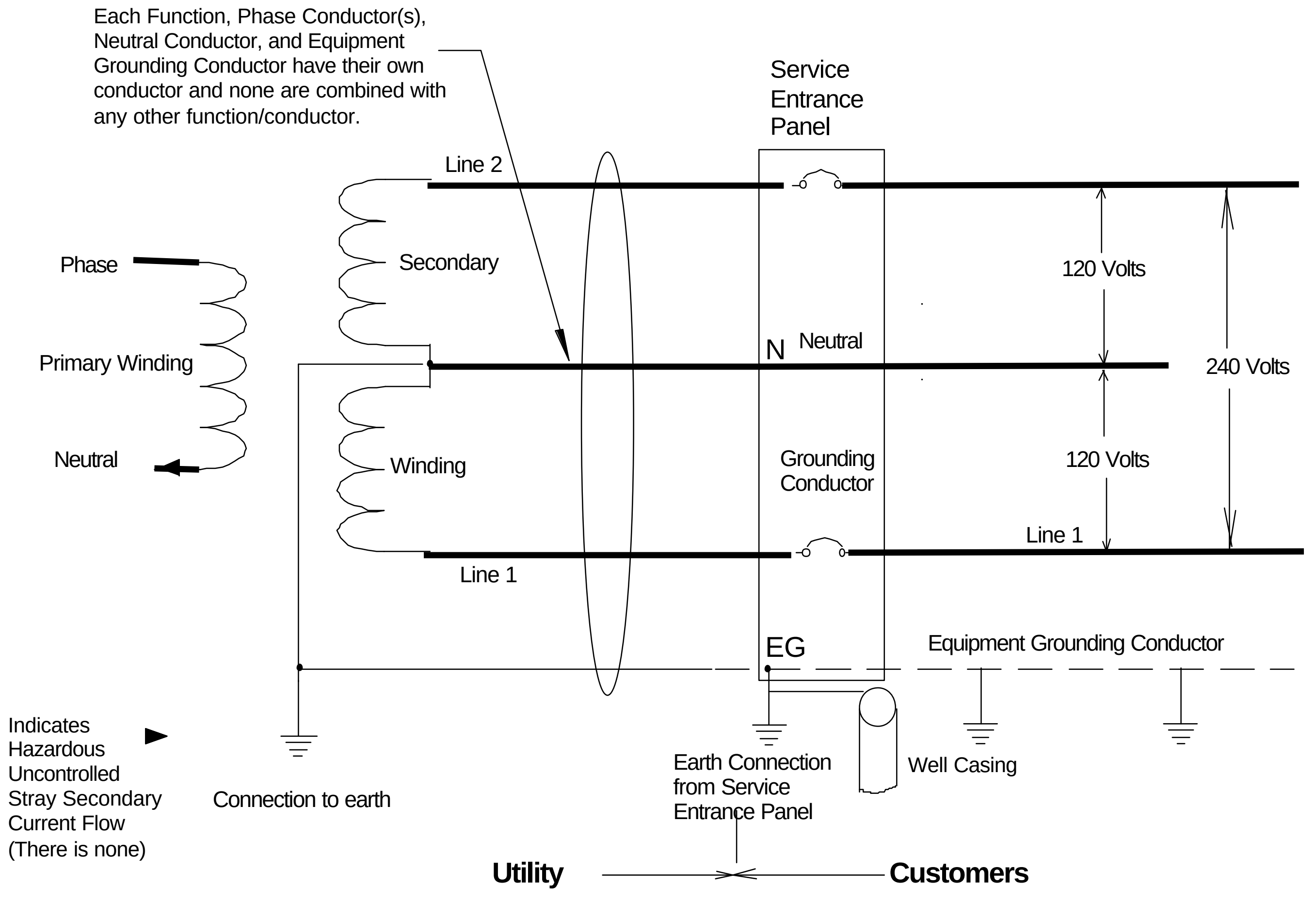

Figure 23. The Correct Number of Conductors for the Utilities Service Entrance

However, the NEC does require and has specifications for the conductors that connect with the utility's service drop conductors. Each, the NESC and the NEC say that they would consider making the change if the other code making body would do so first. Yet, both bodies refuse to meet in a joint meeting to iron out the conflicts.

D. Proposals to the NEC to Prevent adoption of Multigrounded Neutral Rejected

Before the NEC's 2002 code edition, Section 250.184 read as follows:

Section 250-184. Solidly Grounded Neutral Systems

(a) Neutral Conductor. The minimum insulation level for neutral conductors of solidly grounded systems shall be 600 volts.

Exception No. 1: Bare copper conductors shall be permitted to be used for the neutral of service entrances and the neutral of direct-buried portions of feeders

Exception No. 2: Bare conductors shall be permitted for the neutral of overhead portions installed outdoors.

FPN: See Section 225-4 for conductor covering where within 10 ft (3.05 m) of any building or other structure.

(b) Multiple Grounding. The neutral of a solidly grounded neutral system shall be permitted to be grounded at more than one point for the following:

1. Services
2. Direct-buried portions of feeders employing a bare copper neutral
3. Overhead portion installed outdoors

(c) Neutral Grounding Conductor. The neutral grounding conductor shall be permitted to be a bare conductor if isolated from phase conductors and protected from physical damage.

During the NEC 2002, cycle there was proposed expansion of NEC Section 250.184.

(D) Multigrounded Neutral Conductor. Where a multigrounded neutral system is used, the following shall apply:

(1) The multigrounded neutral conductor shall be of sufficient ampacity for the load imposed on the conductor but not less than 331/3 percent of the ampacity of the phase conductors.

Exception: In industrial and commercial premises under engineering supervision, it shall be permissible to size the ampacity of the neutral conductor to not less than 20 percent of the ampacity of the phase conductor.

(2) The multigrounded neutral conductor shall be grounded at each transformer and at other additional locations by connection to a made or existing electrode.

(3) At least one grounding electrode shall be installed and connected to the multigrounded neutral circuit conductor every 400 m (1300 ft).

(4) The maximum distance between any two adjacent electrodes shall not be more than 400 m (1300 ft).

(5) In a multigrounded shielded cable system, the shielding shall be grounded at each cable joint that is exposed to personnel contact.

This writer made a presentation to the NEC Making Panel # 5 at the beginning of the 2002 cycle proposal stage explaining the fallacies of such action. Since a subcommittee made the proposal and the proposal was taken from the NESC, it is believed the committee's proposal was received with validity where as an individual opposing the NESC was not.

In addition, one must realize that the NEC Making Panel # 5 is extremely slow in making correct decisions. This was evident in the adoption of the same four wire as described above for electric ranges and dryers. Beginning in 1944 because of the war effort electric ranges and dryers were allowed to combine the neutral and the equipment grounding conductors to save copper "for the duration". There was never a definition of the term, "for the duration" and the duration lasted 50 years.

In 1950s, the NEC adopted the safety policy of the three-wire grounding system prevalent in homes, commercial and industrial facilities. House trailers were wired using the incorrect method of combining the equipment-grounding conductor with the neutral. This action resulted in many electrical deaths and electrical shocks when someone touched the metal sides of the trailer and was standing on wet ground.

The NEC Making Panel handling Articles 550 and 551, trailers and mobile homes about 1968 made mandatory wiring that had insulated phase conductors (2) and a separate insulated neutral conductor and a bare or insulated equipment-grounding conductor. This separation of the neutral and the equipment-grounding conductor eliminated electrocutions and electrical shocks from the metal siding of trailers and mobile homes of persons standing on wet earth or in water and touching the metallic siding.

The very next NEC cycle, 3 years later, the panel responsible for marinas made the very same change. However, NEC Making Panel # 5 resisted making the same change for electric ranges and dryers for over 21 years. The author was told that NEC Panel # 5 had not heard of anyone being electrocuted thus there was no need to make any change in the wiring for ranges and dryers and continued to allow the combining of the neutral and the equipment grounding conductors. However, persons were receiving electric shocks from electric dryers. Finally, after over 21 years, in 1996, NEC Making Pane # 5 made the change and now the NEC requires that all new electric ranges and dryers be wired with insulated phase conductors (2), a separate insulated neutral conductor and an equipment-grounding conductor. Safety at last prevails with trailer homes, marinas, ranges and dryers. However, the service conductors still pose a problem.

There are several points to be made from the above discussion.

The logical progression from trailers to marinas to ranges and dryers has been accomplished. The next step is the service entrance conductors.

The majorities of the members of the National Electrical Safety Code Making Panels are employed by or sell services to the utilities, and thus are reluctant to make code changes that will cost their employers or clients' additional funds.

The majorities of the members of the National Electrical Safety Code Making Panels have probably been employed only by utilities and thus are very comfortable with the existing multigrounded neutral electrical distribution system since it is the only electrical distribution system with which they have worked and with which they are familiar.

XIV. LEGISLATION AND REGULATION

It is interesting to note the courts thinking on code and legislature enactments. Wisconsin legislation states:

"Sec. 288C. **Compliance With Legislation or Regulation.**

"Compliance with a legislative enactment or an administrative regulation does not prevent a finding of negligence where a reasonable man would take additional precautions." [2]

A New Jersey court has stated:

"An uninsulated high voltage power line carrying a deadly current must be considered one of the most dangerous contrivances known to man. In the pursuit of its business, by installing and maintaining such a line, a utility company must use care commensurate with the risk of harm, i.e. a high degree of care, to others who in the course of their ordinary and lawful activities might suffer injury, death or damage therefrom. In the utilization of such deadly wires along, adjacent to, across or over public highways, streets or ways, or private property, the (utility) company must be aware not only of the killing quality of its high-voltage lines, but also need to adjust the degree of care exercised in its control and maintenance of such wires." [3]

It was not until the period of 1942 to 1950 that the ability to determine the amount of current humans are sensitive to began. Excluding the EKG studies, which began about 1921, it was in the 1950 to 1974 period that the amount of electric current controlling the heart became known. These studies resulted in the defibrillator being developed.

Unfortunately, the use of the earth as a partial return path was permitted in the April 15, 1927 Edition of the National Electrical Safety Code although the wording is vague.

NESC Rule 012 C General Rules - 1927

C. For all particulars not specified in these rules, construction and maintenance should be done in accordance with accepted good practice for the given local conditions known at the time by those responsible for the construction or maintenance of the communication or supply lines and equipment.

"NEC Rule 215 C Use of Ground as Part of Circuit - 1927

In urban districts, supply circuits shall not be designed to use the ground normally as the sole conductor for any part of the circuit.

Recommendation. --- It is recommended that such use be avoided in rural districts."

"NESC Rule 215. C. Use of Ground as Part of Circuit - 1927

"The use of the ground for the return portion of telegraph circuits and other communications and signaling circuits has long been customary and is for many purposes satisfactory, . . . For supply purposes a similar arrangement has been sometimes used, but it has objections from both the service and the accident standpoints, and its use is considered undesirable."

At that time, the NESC also lacked the understanding of hazardous levels of current as is evident from the following:

"(c) Current in grounding conductor. - Where multiple grounds are used there is a possibility of circulating currents between the different ground connections, arising from unbalanced loads, improper connection of grounding wires, and for other reasons. It is advisable to ascertain the amount of this current flow when the grounds are made in order to make certain that it is not great enough to be objectionable. A fraction of an ampere, or even several amperes on circuits of large capacity, may not be a serious matter, but cases can easily arise where the flow would be sufficient to be disturbing to the service."

As we see from above the amount of electric current to cause harm to humans and animals is extremely small, not "even several amperes on circuits of large capacity". We know today that that statement is false. Nevertheless, the warning was there.

A. Failure of the National Electrical Safety Code to Protect the Public

The National Electrical Safety Code states in the beginning of the Code the purpose.

NESC Rule 010.Purpose - 1997

"The purpose of these rules is the practical safeguarding of persons during the installation, operation or maintenance of electric supply and communication lines and associated equipment.

"These rules contain the basic provisions that are considered necessary for the safety of employees and the public under the specified conditions."

B. Removal of or Disconnection of Grounding Down Connections

In order to protect from the objectionable hazardous stray continuous flow of electrical current the NESC allows removal of or disconnection of grounds.

"**NESC Rule 092 - 1997**

"D. Current in Grounding Conductor

"Ground connection points shall be so arranged that under normal circumstances there will be no objectionable flow of current over the grounding conductor. If an objectionable flow of current occurs over a grounding conductor due to the use of multi-grounds, one or more of the following should be used:

1. Abandon one or more grounds.
2. Change location of grounds.
3. Interrupt the continuity of the conductor between ground connections.

"Subject to the approval of the administrative authority, take other effective means to limit the current. The system ground of the source transformer shall not be removed. The temporary currents set up under abnormal conditions while the grounding conductors are per-forming their intended protective functions are not considered objectionable. The conductor shall have the capability of conducting anticipated fault current without thermal overloading or excessive voltage buildup."

Thus, it is acceptable to remove the parallel connections once it has been shown that irreparable damage has been inflected.

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[2] Kemp v. Wisconsin Electric Power Co., 44 Wis.2d 571, 579 (1969), quoting Restatement, 2 Torts 2d, p. 39.

[3] Black v. Public Service Electric & Gas Co.

Section 250-6(b) and (c), NEC – 1999, also states:

"(b) Alterations to Stop Objectionable Current. If the use of multiple grounding connections results in an objectionable flow of current, one or more of the following alterations shall be permitted to be made, provided that the requirements of Section 250-2(d) are met.

"Discontinue one or more but not all of such grounding connections.

"Change the locations of the grounding connections.

"Interrupt the continuity of the conductor or conductive path interconnecting the grounding connections.

"Take other suitable remedial action satisfactory to the authority having jurisdiction.

(c) Temporary Currents Not Classified as Objectionable Currents. Temporary currents resulting from accidental conditions, such as ground-fault currents, that occur only while the grounding conductors are performing their intended protective functions shall not be classified as objectionable current for the purposes specified in (a) and (b)."

The currents that are continuously flowing currents over the earth, <u>are</u> objectionable. On the other hand, non-objectionable currents are those that flow over the earth momentarily until a protective device such as a fuse, circuit breaker or recloser operates to stop the current flow.

XV. UNGROUNDED ELECTRICAL DISTRIBUTION SYSTEMS

Another very dangerous to the public and to utility linemen is the ungrounded electrical distribution system. With only the capacitance connection to earth there is less likelihood that the normal ungrounded electrical distribution system will operate the protective devices at a low value of current, when a person comes into contact with the energized lines.

An example is a case where a 12 year old boy riding his bicycle on the payment after a storm when an energized conductor snapped and wrapped around his neck. He laid on the ground with the energized conductor around his neck smoking while his parents watched helplessly for between 20 and 45 minutes. The utility linemen had to cut the line before it was safe to attend to his lifeless body. [20]

Another case involved a lineman who was accustomed to multigrounded neutral distribution system and during storm duty was sent to another utility where the distribution system was ungrounded. He fuzzed the line and getting no response somehow touched the line and was electrocuted.

XVI. GFCI – PROTECTION AGAINST ON SITE STRAY CURRENT

The GFCI contains two electronic circuits. One circuit measures the amount of current flowing on the phase conductor and the amount of current on the neutral conductor. If the amount differs by 0.005 to 0.006 amperes, the GFCI trips, stopping the flow of current. It is assumed the unaccounted for current could be flowing through a person and thus protection from electrical injury is provided.

The second circuit in a GFCI detects when a neutral to ground fault occurs. The designers of the GFCI with pressure from Europe where whole house ground fault detection is required installed in 1986 the second neutral fault detection circuit.

Since any current flowing over the earth would be objectionable, unwanted and harmful the GFCI trips and opens the electrical circuit stopping the flow of harmful neutral current over the earth. A proposal has been submitted to the 2005 NEC to have dairy and pig farms install GFCIs on all 120-volt circuits.

XVII. CONCLUSIONS

It appears that whenever the utilities were faced with the choice of public safety or saving costs they chose saving costs over the safety of the public with respect to the multigrounded neutral distribution system and the modifications that were made that were *"beneficial to the transformer"*.

In order to have an electrical distribution system that is safe from the great and continuous risks of harm from stray current flowing uncontrolled over the earth in unrestrained amounts the following must be accomplished:

i. The multigrounded neutral distribution system must be eliminated and replaced by the 4-wire, see figure 20 with phase-to-phase loads or the 5-wire, see figure 16 with either phase-to-phase or phase-to-neutral loads type distribution system, which will eliminate using the earth for a return current path and will contain all the return current on an insulated conductor as specified by Zipse's Law.
ii. The hazardous connection of the primary neutral to the secondary neutral is no longer needed to allow previously poorly earthed lightning arrestors to function since the ground conductor is earthed at four times per mile providing adequate earth connection for the lightning arrestors.
iii. No longer will the messenger be allowed to functioning as a messenger, a neutral and a ground conductor. The service drop conductors will consist of one, two or three phase conductors, an insulated neutral, and the messenger that can also serve as the earthing conductor only.
iv. No longer will the neutral be connected to the earth at the service disconnect and overcurrent panelboard. With a separate insulated neutral, which will be connected to earth at the transformer and a ground conductor from the transformer coming into the service disconnect and overcurrent panelboard at the residence, it will not be required to connect the neutral to the earth again at the service disconnect and overcurrent panelboard.
v. Consideration should be given to the installation of GFCIs on all 120-volt circuits that could become or could develop a neutral-to-ground fault.

If the public wants to be able to enter a swimming pool or a hot tub or to take a shower without the fear of receiving an unwanted electric shock or to be a victim of an electrocution, then the public must rise up in letter writing to their Public Service Commissions and their legislators both local and federal and demand an electrical distribution system free from to flow of uncontrolled hazardous stray current.

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VITA

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He is a registered Professional Engineer. He represents the IEEE on the National Electrical Code Making Panel #14, Hazardous Locations as well as the Lightning Standard NFPA 780 and is a member of the International Association of Electrical Inspectors. He serves on the National Electrical Safety Code Grounding Subcommittee.

He has served on many IEEE committees, participated in the color books (IEEE Recommended Practice), and standards groups, including the Standards Board and the Standards Board's Review Committee. He is a member of the IEEE COMAR, Committee On Man And Radiation and Standards Correlating Committee #28, Non-Ionization Radiation. Mr. Zipse received the Standards Medallion for his work in and promoting standards.

He has published countless technical papers on such diverse and controversial subjects as Unity Plus Motors, Computers, Neutral to Ground Faults, NEC Wire Tables, Health Effects of Electrical and Magnetic Fields, Measuring Electrical and Magnetic Fields, Lightning Protection Systems: Advantages and Disadvantages, the NESC and the NEC: Are Dangerous to Your Health? Electrical Shock Hazard Due To Stray Current and has participated on National Electrical Code panels and in teaching the Code.

For the last ten years, he has been President of Zipse Electrical Engineering, Inc., an electrical forensic engineering consulting firm. For the past seven years, he has been primarily involved as a forensic engineer and expert witness in cases resulting from electrical accidents and electrocutions and for the last two years he has been involved in legal cases concerning stray current and dairy cows.