GROUND CURRENTS: An important factor in electromagnetic exposure

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INTRODUCTION

Life on this earth has developed and is maintained through the use of both electromagnetic (EM) energies and chemicals. In general, both EM energies and chemicals are required for the continued well being of living organisms. In the modern industrial era we have also experienced negative consequences from the intake of certain undesirable chemicals and exposure to unwanted EM energies. The acceptance and understanding of adverse effects from undesirable chemicals is now quite universal; however, there seems to be a reluctance to accept the possibility of adverse effects from disturbing EM energies.

The stray voltage problem in the dairy industry has been helpful in understanding the relationship between exposure to EM energies and health. The term stray voltage is applied to certain electrical conditions in the housing of confined livestock, and to associated behavior, health, and production effects on dairy animals. Recent investigations also show an association between the presence of stray voltage problems and the health of people who live and work in these livestock facilities. The source of the electricity involved in stray voltage problems is the current entering the earth from the power system and, more recently, from cellular transmitters. These currents in the earth are intentionally present, because of the electrical distribution system's use of the earth as a current-carrying conductor, and also unintentionally present, in the case of electrical problems on farms (Dahlberg and Falk 1995).

The issue of health effects from exposure to EM energies is mired in controversy because of inconsistencies in research data and the inability of present models to explain the empirically observed health effects. From these inconsistencies it is tempting to draw the conclusion that even if a connection may exist between EM energies and certain types of health problems, that connection is weak and probably requires little attention, given the large number of other environmental health risks to which we are exposed. It would be unwise, however, to prematurely minimize the effect of exposure to EM energies. There are a number of factors that may seriously limit the reliability of the existing research: EM energy exposure is very complex and difficult to measure; clearly defined mechanisms are elusive; the electric and magnetic systems of the human body are not well understood; and a control space is in general unavailable. Together these factors make research very difficult and increase the potential for inconsistencies in research results. At the same time, empirical evidence from field investigations continues to show associations between a number of EM parameters and a disturbing number of health effects in humans and animals.

GROUND CURRENTS

All living organisms are exposed to numerous sources of EM energy. The earth-atmosphere system produces electric currents and electric and magnetic fields. The most evident are the magnetic field of the earth and the electric field of the atmosphere. These are continuously present and especially the electric field of the atmosphere is dynamic. There are also pulses of current in the earth from lightning strikes, induced currents from the solar wind, direct currents from galvanic processes in the earth, and currents from movements of the earth's crust. The currents in the earth from these sources are, in general, much smaller than those from technological sources. The exceptions are currents from lightning strikes and occasional direct currents, primarily induced at the geomagnetic poles by a surge of solar, charged particles reaching the earth's atmosphere. The most common term used for these currents is earth currents.

There is also increasing exposure to EM energies from technological sources. Some of these sources are relatively predictable and easily measured, such as 60 Hz magnetic and electric fields from distribution lines and home wiring and appliances. Stray voltage investigators have discovered that a major source of EM energy interacting with the dairy cow is electric current in the floors of barns and in the ground beneath the floors. The levels of these currents are difficult to predict and very difficult to measure accurately. Researchers have come to realize that livestock facilities are not the only place where these currents exist. There is potential for all life to experience an exposure to EM energies from these electric currents in the earth, in addition to those from the more obvious sources mentioned above.

In this paper, electric currents in the earth that emanate from technologically developed systems are called ground currents. Ground currents are a mix of DC and AC, both of which can be continuous and/or pulsed. The present discussion addresses ground currents that arise both from distribution systems of the electrical utilities and from electrical systems of consumers. These currents in the earth are the product of the design of electrical systems and not specifically associated with the use of underground electric cables. It is important to emphasize that in limiting this discussion to ground currents, this paper does not preclude possible effects from other sources of EM energies. Clearly effects are related to the total EM energy exposure.

SOURCES

Farms, businesses, and homes have self-contained, closed electrical systems except for the connection of the electrical utility (primary) neutral to the user's (secondary) neutral. Several electrical problems in the user's electrical systems can lead to aggravating ground currents. Some of these problems are electrical faults, imbalances in the user's electrical system, malfunctioning of motors, and wiring errors. Each of these conditions can cause electricity to be in the secondary grounding system and, therefore, cause electric current to be in the ground. Because the neutral of the secondary system is normally grounded, and frequently grounded through metal water pipes, there is always the possibility of ground currents resulting from the normal use of electricity. Since the user's electrical system is structured to use wires to carry all the current, however, it will produce minimal levels of ground currents. For some applications the neutral and ground wires are totally separated from each other. If the neutral and ground wires are separated, no current reaches the earth from the secondary system unless an electrical fault exists.

Electrical distribution systems serving both urban and rural areas are usually at 7200 V ac and connect the consumer to a substation. The single-phase distribution lines consist of a high voltage wire and a neutral wire; these two wires provide the complete path required in any electrical circuit. These wires may be overhead on poles or buried in the earth. When the distribution system was first conceived, it was totally closed, with no connection to the earth. Early in the expansion of the electrical distribution system in rural America (during the 1930's), the utility industry made a decision to change the originally ungrounded distribution system to a grounded system. This change allowed a portion of the neutral current to return to the substation through the earth. The neutral wire of the distribution system is connected to ground rods and/or other conducting materials in the earth (such as water pipes and systems)
in order to provide a path for the current to be able to get into the earth. Grounding became a common practice in the utilities' distribution and transmission systems.

In addition to causing some of the neutral current of the distribution system to return to the substation through the earth, the grounding of the neutral wire connected everything in and on the earth to the distribution system neutral. During the intervening years since the distribution system was first grounded, demands and loads have grown rapidly, and currents in the wires have increased beyond their designed capacity, resulting in an ever-increasing need for the earth connection. Electric currents flow through wires, objects, and the earth according to their respective conductivities. Today the earth has a higher conductivity than the utility's neutral circuit return wires, and therefore, carries the majority of neutral current returning to the substation (Gonen 1986; Morrison 1963, Hendrickson, Michaud, Bierbaum 1995). Consequently these neutral currents in the earth are the largest contributor to ground currents

In providing electrical energy to the consumer, the utility connects its system to the primary windings of a transformer, and the user's system is connected to the secondary windings of the same transformer. A transformer has the function of isolating electrical systems and increasing or decreasing voltages. In this case, the transformer reduces the 7200 V on the primary system to 120 and 240 V on the secondary system. Both the primary and secondary electrical systems are designed to function without any physical electrical connection between them.

At some point in the expansion of electrical distribution systems, the neutral wires of the primary were connected to the neutral wires of the secondary electrical system. Thus the secondary system was no longer isolated from the primary system. Today this is a common practice throughout the electrical distribution network. The stated reason for this connection is to provide a safer electrical system for both the consumer and the electrical utility personnel. Certainly the potential for electrocution is a significant safety concern to electric utilities. An even more important reason for the interconnection, however, may be to provide additional grounding points for the utility neutral current to enter the earth for its return to the substation. These additional grounds decrease the net resistance of the earth path as compared to the resistance of the neutral wire, and therefore increase the fraction of neutral current in the earth. To solidify the earth connection, and to insure a sufficiently low grounding resistance, the neutral has been connected to water pipes and water systems. Present codes frequently require water pipes to be part of the grounding system, and, therefore to carry electric current, especially from the primary neutral. The user's grounding network has become a fundamental part of the electrical distribution system. The consequence of these practices and code requirements is an increase in current entering the earth where animals live and people live and work. It also increases the connection of all living organisms to the electrical distribution system (Raloff 1993; Burke 1991).

The conductivity of specific earth materials determines the locations and magnitudes of current in the earth. Water saturated soils and bodies of water, such as wetlands, lakes, streams, and rivers, are likely to carry more current than dry soil. Conducting materials buried in or on the earth have the potential of being formidable carriers of electrical current. Natural gas and oil pipelines are good conductors of electricity and are known to carry sizable currents (Lathrop 1978). Ground currents traveling in these pipes also move on and off of them, through the earth, to ground rods and other conductors in the earth. The presence of these 60 Hz currents on pipelines increases the need to apply direct currents to the pipes to prevent corrosion. The consequence of protecting them from corrosion is to increase the quantity of direct current in the ground current mix. Substantial grounding grids are buried in the earth below substations. Electric currents in the ground that emanate from the grounding of the neutrals of the distribution lines and other sources converge on these grounding grids. Consequently greater ground currents are present near substations and in structures in their immediate vicinity. Ground currents also have a greater probability of being present in direct paths between large users of electricity and between these users and the substation. Rural developments increase the number of grounds on the utility neutral, and thus increase the ground currents reaching nearby dairy operations.

DESIGN DECISIONS

A substantial quantity of information has been generated from studies of electrical problems in both urban and rural areas to substantiate the presence of ground currents in structures in and on the earth, and the fact that both humans and animals are exposed to these currents. This exposure of living organisms to ground currents has come about primarily because of engineering design decisions. A number of factors have influenced these design decisions.

One factor is a concern for the dependability of the electrical system. If only one power source were providing the electrical energy for the distribution system, failures in the power source could, of course, disrupt the availability of electricity. Therefore, the majority of electrical utilities in the United States are connected together, allowing power to be transferred among utility systems. interconnecting power sources and individual distribution systems requires careful matching of the phases of the various sources and the users. As individual electrical utilities join together, transferring electricity according to demand and availability, the earth becomes a common reference. As a common reference, the ground, requires that all neutrals be interconnected, thus increasing the potential for ground currents.

Economy of scale has also been applied in the generating of electricity, resulting in larger power plants capable of providing electricity to a larger numbers of users and at a lower cost. There are numerous changes required in the national distribution of electricity in order to utilize the larger power plants. In some cases the larger power plants do not easily change power levels to accommodate changing loads. Additional smaller plants are required in the system to provide for changing demands. In the case of 60 Hz electrical power, storage is not feasible. If the demand for electrical energy falls below the output of power plants, it may be necessary to shunt some electric current into the earth until the output is adjusted to match the demand. Current that is shunted into the earth adds to the ground current.

A second factor is associated with the economics of electrical distribution. According to utility engineers, the resistance of the neutral wire causes significant voltage drops along the lines, requiring frequent voltage adjustments. As the demand for electricity has increased and as the number of users has grown, the distribution lines have been extended to supply the increased number of users. The greater the electrical current on these lines, obviously the greater the loss of electrical energy and the greater the voltage decreases. Experience indicates that using the earth to carry a portion of the current reduces the losses and consequently reduces the need for as many voltage adjustments. Thus the previously ungrounded electrical distribution system has become a multi grounded system which uses the earth to carry a fraction of the neutral current (Mairs 1994).

A third factor influencing design decisions is the expressed requirement for having an electrical distribution system safe from electrocution or other bodily harm. Electric utilities are especially concerned about the potential for electrocution from fallen electric lines and the effects of lightning strikes on electrical distribution systems. With a well-grounded neutral, the current from a fallen line will travel in the earth, causing a circuit breaker to open and disconnecting the high voltage line from its source of current. Since the ultimate destination of the current in a lightning strike is the earth, a well-grounded neutral is most likely to attract the bolt of lightning, and the grounding wires provide the path into the earth. The need to protect people and property is an important issue; of equal importance is the fact that the grounding of the neutral wire changes the role of the high voltage wire. Anyone who is directly or indirectly connected to the earth will certainly be killed if contact is made with the high voltage wire, and a continuous electric field is established between the earth and the high voltage line. Therefore, the present multi grounded distribution system requires that everyone must avoid any contact with the high voltage wire, and all living things are constantly exposed to this electric field. In contrast, a totally ungrounded system has the advantage that a person could stand on the ground and touch either the neutral or the high voltage wire (but not both) and not be electrocuted, and the electric fields are more confined the region of the two wires. For the previously ungrounded system, lightning arrestors were used to alleviate the destruction of electrical equipment in a lightning strike. The lightning arrestor connected the electrical distribution lines to the ground if a lightning strike should occur, and shunted the current to the earth to prevent damage.

GROUND CURRENT INTERACTIONS

The grounding practice in the utility industry forces all living organisms to be continuously in physical contact with the electrical distribution system. The extensive grounding of the neutral in the distribution system also forces electrical currents to be present to a greater or lesser degree in all materials making up the environment of living organisms. Of course the living organisms, since they are themselves conductors of electricity and in contact with materials carrying electric currents, are basically plugged into the electrical circuitry of the distribution system.

The use of water pipes and other conductors in the earth to carry the neutral current of distribution systems has the effect of decreasing the current in the neutral wire. In addition, when unshielded distribution wires are buried in the earth, the neutral slowly corrodes, also increasing the amount of the neutral current in the earth. If the neutral and the high voltage wires carry the same current, the magnetic fields in the vicinity of the lines are relatively small, because the magnetic fields of the two lines nearly cancel each other. When the current in one wire is much less than in the other, the magnetic field is only partially canceled. This condition greatly increases the magnetic field in the area of distribution lines and enhances the range of these fields. In homes and businesses there is also an increase in the 60 Hz magnetic fields from the ground currents in water pipes and other conducting material. This condition is very effectively presented in a paper prepared for Austin, Texas {Preston, 1989)

Alternating current in the ground sets up alternating electric and magnetic fields.

These electric fields give rise to electrical potentials that can induce currents in living organisms in contact with the ground. Alternating magnetic fields, by their very nature, also produce currents in conducting materials. Electric currents in living organisms, regardless of the mechanism that may produce them, are indistinguishable from one another. The currents simply access the body differently. In addition to the possibility of inducing an electric current in the body of living organisms, the electric and magnetic fields may independently or synergistically interact with parts of the body. Complicating the understanding of the interaction of these ground currents with living organisms is the effect of earth materials on the 60 Hz current entering the earth. The non-linear characteristics of the earth distort the 60 Hz sine wave, even affecting the natural processes that produce direct current in the earth. Thus ground currents from the power system are transformed
into some combination of 60 Hz, harmonics, and direct currents.

An assumption has been made, in the design of the electrical distribution system, that the grounding of the system creates a constant electrical potential on the earth's surface. This is called an equipotential plane in the dairy industry. Using that assumption, all living organisms are living on an equipotential plane, connected to the neutral of the electric distribution system. To justify this ground connection, it is also assumed that an equipotential plane is an electrically safe place to be. The stray voltage problems in the dairy industry, however, have shown that when the neutral of the distribution system is connected to the earth, the earth is neither a plane of constant electrical potential nor an electrically safe place. Livestock producers are especially aware that lightning or a fault in a distribution line can kill animals if they happen to be in the path of the electric current in the ground. Dairy operators are frequently required by state codes to construct equipotential planes in their barns as a means of avoiding electric shocks for the cows. Unfortunately the equipotential plane is a good conductor which attracts a greater percentage of the ground currents, causes the cows to be exposed to greater continuous currents, and frequently increases stray voltage effects (Dahlberg and Falk 1995).

Surveys and farm evaluations and investigations have provided a significant body of information concerning the effects of ground currents (Hartsell, Dahlberg, Lusty, and Scott 1994; Dahlberg and Falk 1995; Marks, Ratke and English 1995; Kelly 1998). As mentioned previously, the main documentation of electrical effects in dairy barns historically involves ground faults. When electric current enters the earth from a high voltage wire, the event is called a ground fault. The high voltage wire can be from either the primary or the secondary system. Usually discussions of ground faults center on problems in the secondary system. Well-known effects from ground faults include behavioral, health, and production problems for confined livestock, such as dairy animals, and both human and animal electrocution (Dahlberg and Falk 1995).

On dairy farms, current in the ground is associated with behavioral, health and production effects in cows. It is very important to carry this association to the next step, which is the determination of how these currents interact with the cow to produce the physical effects. The presence of ground currents implies long-term, continuous exposure to low-level electrical currents. Worldwide research and investigations of both animal and human health problems in dairy barns have demonstrated that small continuous currents (as low as a fraction of a microamp) can affect well being. Bjorn Nordenstrom, among others, has suggested models that portray the bodies of living organisms as having electric circuits with small currents actually controlling life (Nordenstrom 1983). Appropriate electric currents of small magnitudes within the circuits of the body are vital to good health. The bodies of living organisms generate these currents and naturally provide the magnitudes that afford good health.

Using Nordenstroms models, one can imagine that exposure to an electric and magnetic environment could affect the currents in the circuits of the body, either positively or negatively. The medical community has utilized this positive potential in a number of ways. Negative changes caused by these currents, however, would require the body to correct the change. Such an event could be classified as a stress on the body. It would be logical to conclude that exposure to certain electrical conditions can be equivalent to initiating a stress. If the currents in the floor of the barn set up an electric and magnetic environment that causes inappropriate currents in the body of the cow or the human, the experienced effects would likely be similar to those caused by other stresses. Unfortunately, the research community has been reluctant to investigate this source of stress on animals and humans. The traditional research model continues to assume that negative health effects are possible only in the presence of physical shock.

CONCLUSIONS

The health of the environment is a determining factor in the health of all life within that environment. Under some circumstances, human ingenuity in the treatment of illnesses can delay and reasonably mitigate the effects of an unhealthy environment. Under other conditions or over time, however, the effects of an unhealthy environment may slowly or rapidly wear on the health of life in that environment. A world population of approximately 6 billion people, with no new frontiers, is extremely vulnerable to unhealthy changes in the environment. This world condition is a compelling reason for seriously monitoring changes in the environment and constantly assessing the effects of those changes.

An important environmental change, and one that has escalated since its inception over a century ago, is the addition of EM energies to the environment. The extensive use of the earth to carry electric current is the most dramatic and least understood of these additions. Even though the earth has been used for all these years as a sink for electrical current, little is known about the paths of these currents or the effects of the currents on either the animate or inanimate world. In fact, shock-effect models still dominate the regulatory agencies' concept of how

EM energies interact with life. Even in decisions regarding research directions, these inadequate models are still applied. Research from around the world has shown the need to recognize new models that are consistent with the electrical nature of living organisms and the complexity of our environment. Stray voltage research and the ground current connection have provided valuable insights into the relationship between exposure to EM energies and effects in humans and animals.

For 50 years professionals in the dairy industry have known that electric current in the earth from a ground fault, occurring on or off a dairy farm, can seriously affect the health and production of dairy cows. Today we live with an electrical distribution system that has been designed to put electric current into the ground. The design of the electrical distribution system has created a perpetual ground fault capable of impacting all life. Perhaps it is time that we heed the warning cries of dairy operators.

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