Ground Currents

An Important Factor in Electromagnetic Exposure

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Introduction

Life on this earth has developed and is maintained through the utilization of both chemical and electromagnetic(EM) energies. In general, both chemicals and EM energies are required for the continued well being of living organisms. In the modem industrial era we have also learned that the consequences of the intake of certain undesirable chemicals and exposure to unwanted EM energies can have a negative impact on this well being. The acceptance and understanding of adverse effects from undesirable chemicals is quite universal, whereas in the Western world, especially in the United States, there has been a reluctance to accept or try to understand the possibility of adverse effects from disturbing EM energies. The stray voltage problem in the dairy industry has opened the door to a realization of effects on behavior, health, and production of dairy cows and on the health of people when they are exposed to EM energies arising from the power system and, more recently, from cellular transmitters. Stray voltage problems can be caused by electric currents in the earth and EM energy fields. The currents in the earth are advertently present, because of the electrical distribution system's use of the earth as a current-carrying conductor, and also inadvertently present, because of electrical problems on the farm.

Health effects from exposure to electromagnetic (EM) energies become quagmired in debates over inconsistencies in research data and the inability of present models to explain the empirically observed cancer connection. From these inconsistencies it is tempting to draw the conclusion that even if a connection may exist between EM energies and certain types of cancer, that connection is weak and probably requires little attention considering the large number of other environmental health risks. Another more persuasive conclusion would be that the approach to understanding EM effects has thus far been too narrowly focused. The effects examined must extend beyond cancer. 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

In the dairy industry an impasse exists between observation and laboratory research. In laboratory research the cause of animal effects is assumed to be intermittent electric shock, with no consideration given to causes from chronic exposure to a number of types of EM energies, especially from electric currents in the earth. In addition laboratory research has based its search for effects on the behavior of the dairy cows and has assumed that without behavioral effects, there can be no health and production effects. Within this model human health effects are considered impossible. Through observation and qualitative research Dahlberg and Falk have shown that the causes are not only from low energy electrical shock, but also from a continuous exposure to low level electric currents and fields. They also discovered that these currents and fields are able to produce a number of behavior, health and production effects in dairy animals as well as human health effects (Falk and Dahlberg 1993, Dahlberg and Falk 1995). This difference in the conclusions from laboratory research and those from observation and qualitative research calls for a new research effort - a quantitative research effort that addresses the findings frown observation and qualitative research-

Stray Voltage

For a period of over 50 years the dairy industry has been aware of the need to maintain a trouble free electrical system in the environment of the dairy farms. Dairy cows are known to experience a set of behavioral, health and production effects when an electrical problem exists proximate to dairy farms in which electricity is short circuited into the earth. Farm experience identifies the effects as a general attack on the well being of the cows. Veterinarians experienced with electrical effects describe them as an apparent destruction of the cows' immune system. Farmers, dairy equipment suppliers, power suppliers, agricultural extension specialists, veterinarians, feed suppliers, and electricians all attest to the effects associated with electrical exposure from ground faults. In addition, more recent research associates the

effects in dairy herds with the grounding of the electric utility neutral on the farm (Hartsell, Dahlberg, Lusty, Scott 1994, Dahlberg and Falk 1995). The general name given to this problem is stray voltage. The results of stray voltage research may offer some guidance in the overall understanding of ground currents and their potential for affecting animals and people. Frequently the dairy cow has been described as the "canary in the coal mine". Since many other spaces, including schools, factories, shopping centers, etc. have similar physical characteristics to the dairy barn, the application of the findings from stray voltage research may extend far beyond the dairy barn.

The traditional theory emanating from the stray voltage research rests on the assumption that a cow will be affected when experiencing an electric current as it makes contact with a conducting part of the barn. This theory assumes that the animal receives a low voltage shock, and only when contacting a conducting material in the barn. The results of research based on this theory have shown no statistically significant health and production effects from shocking the cows intermittently with electric currents below 6 milliamperes. These research results precipitated the deduction that the health and production problems are the ramification of the methods used by the dairy operators to manage the behavioral problems (Lefcourt 1991). Unfortunately this deduction was accepted without any research to determine the management procedures used by dairy operators under stray voltage conditions. The traditional theory is not consistent with the dairy operators' observations, nor does it take into account possible effects from continuous exposure of cattle to lower levels of currents and other electric, magnetic and EM fields in the barn. In addition, it is important to keep in mind that during approximately 95 percent of the time the cows are in the barns, they are in contact only with the floor (Dahlberg and Falk 1995).

Whether associated with dairy cows or humans, a gulf exists between the observations of dairy farmers, the field experience of those investigating the problems, and the traditional concept of stray voltage. Even though field experiences abound relating electrical exposure to human health effects and behavioral, health, and production effects in livestock, the results of research associated only with effects from electrical shock have dominated the interpretation of how electricity may or may not affect cows and people in the dairy barn setting. There has been an effort to restrict the use of the term stray voltage to this traditional concept of electrical shock. Contradictory reports continue to appear, however, resulting in a serious conflict between observation and theory (Dahlberg 1986,1991, Marks, Ratke, English 1995).

Since the term stray voltage has become so closely associated with electrical shock and effects from shock, it might be preferable to consider a new term, electromagnetic ecology, that would take into account all EM energy parameters and all potential effects on both animals and people. Shock would be one aspect of electromagnetic ecology. The term stray voltage, however, has been used for so many years that the term persists, although it is often redefined to include all aspects of the problem. For example Michigan's Attorney General has defined stray voltage as "any electrical energy (whether alternating current, direct current, transients, harmonics or other spikes, etc.), regardless of strength, that is flowing outside the circuit's designed path, be it from the electric utility's transmission or distribution lines and facilities, or the telephone, cable or gas utilities' designed systems" *(Kelley* 1998). For this reason, the term is used in this paper as defined by the Michigan's Attorney General with the additional implication of effects on livestock and humans. Whatever the choice may be for a term, it is most important to recognize that the cause of the problem has not changed; it is our understanding of the problem that is evolving.

Experience in problem solving encourages that a "systems" methodology be used as a first approach for a problem as complex as the effects of EM energy on living organisms. A good example of the systems methodology is that used in the NASA organization as they worked on the challenge of landing people on the moon. The information provided subsequently is based on this research methodology.

Observations of the actions and responses of cows in the dairy barns suggest that cows sense some adverse stimulus that seems to be continually present in the barn. Frequently the cows also respond to random events that appear to be present only for relatively short periods of time and then disappear. These effects can be observed even in stalls where the only cow contacts are the hooves of the cows as they stand on the floor of the barn. Many of the effects are associated with chronic health issues. Usually the effects include a sudden onset of a number of bacterial diseases as well as a gradual deterioration of the muscle and skeletal

structure of the body. In severe cases cows suddenly fall to the floor of the barn and in some cases die immediately. The overall well being of the animals tends to degenerate in direct relationship to time spent in the barn. Housing the cows in elevated facilities that are electrically isolated from the earth significantly improves both the production and health of the dairy animals (Dahlberg and Falk 1995).

Dahlberg and Falk conducted surveys assessing the perceptions of dairy farmers who experience stray voltage problems. The results of these surveys reveal a strong correlation among effects in cattle behavior, health, and production; human health effects; the malfunctioning of electrical equipment; and a rapid deterioration of metals in contact with the earth. If there is a stray voltage problem on the dairy farm causing problems for cattle, there are likely to be commensurate health problems for the dairy operators and unusual effects in electrical equipment used on the farm (Dahlberg and Falk 1993). Using PROBIT as the analytical tool, Dahlberg and Falk also found a suggestion of a double track connecting human health directly to the electrical exposure and indirectly through stress brought about by the livestock problems. Significant correlation was found between human and animal symptoms and proximity to transmission lines. However there was also a weaker correlation between human and animal symptoms and proximity to a natural gas or oil pipeline. Stray voltage problems can also exist at long distances from either electrical transmission or pipelines. It seems appropriate to assume that transmission lines and pipe lines are sources of EM energy, but certainly are not the only sources associated with the assessed symptoms. These surveys also show that the mitigation methods developed as solutions to the problem have typically only served as Band-Aids with short term benefits. Mitigation procedures help some dairy operations while for others the problems are made worse. These studies suggest that the traditional assumptions about the sources of EM energy and their effects require alteration (Dahlberg and Falk, 1993).

Ground Currents

All living organisms are exposed to numerous sources of EM energy. Some of these sources are obvious, such as 60 Hz magnetic fields and shock currents between contact points in the barn, and their interactions with living organisms can more easily be determined. In stray voltage investigations a major source of EM energy interacting with the dairy cow is electric current in the floor of the barn and in the ground beneath the floor. Whether by shock or through continuous electrical exposure, earth pathways are the means by which a most intrusive EM energy reaches cows in the dairy barn and, as a matter of fact, also reaches all other living organisms. In this paper, this source of EM energy is called **ground currents.** Ground currents can be either DC or AC and either continuous or intermittent. Their sources can be either natural or man-made, a product of the way electricity is generated and distributed for use in our society. The present discussion is limited to ground currents that arise from the farm electrical system and from the electrical utility distribution system.

The farm has a self-contained, closed electrical system except for the connection of the electrical utility (primary) neutral to the farm (secondary) neutral. Several electrical problems on the farm could lead to significant ground currents, such as electrical faults, imbalances in the farm electrical system, motor problems, or wiring errors. Each of these conditions can cause electricity to be in the farm grounding system and, therefore, cause electric current to be in the ground. Because the neutral of the secondary system is normally grounded, there is always the possibility of ground currents resulting from the normal use of electricity. Since the farm electrical system is structured to use wires to carry the current, the ground currents from this source are minimized.

The electrical distribution system serving the rural areas is usually at 7200 V ac and basically connects the consumer to a substation. The single phase distribution lines consist of a high voltage wire and a neutral wire. The 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, 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 throughout the system in order to provide a path for the current to be able to get into the earth. Grounding became a common practice in both the utilities' distribution and transmission systems. The grounding of the neutral wire

caused the earth to become a path for electric current on the neutral side of the distribution system and also connected everything in and on the earth to the distribution system neutral. Since the original grounding of the distribution system, demands and loads have grown rapidly, and voltage levels have increased beyond their designed energy carrying 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 going back to the substation (Gonen 1986; Morrison 1963, Hendrickson, Michaud, Bierbaurn 1995).

In providing electrical energy to the consumer, the utility connects its system to the primary windings of a transformer, and the farm electrical 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 may be to provide additional grounding points for the utility neutral current to enter the earth for its return to the substation. To solidify the earth connection for insuring adequate grounding the neutral has been grounded to water pipes and water systems. This present code requirement forces water pipes to become a current carrying conductor, especially for the primary 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, and accounts for the electrical utilities' distribution system being a primary source of ground currents.

Through the evolution of the electrical distribution system, the earth has become a major current carrying conductor in that system. Because of the potential impact of that large quantity of current in the earth, it is important to investigate the factors that have influenced the changes in the original system.

One factor in the proliferation of power plants is a concern for dependability. 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. Economy of scale has also been applied in the electrical generating industry, resulting in larger power plants capable of providing electricity to a larger numbers of users. 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. Interconnecting power sources and individual distribution systems require careful matching of the phases of the various sources and the users. As individual electrical utilities joined together, transferring electricity according to demand and the availability of electrical power, the earth became the common reference for the entire system and the neutrals were interconnected. Interconnection of the electric utilities certainly increased the reliability and dependability for the user and also possibly decreased the cost.

A second reason for the utilization of the earth to carry current is economic. 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 reduces the losses and consequently reduces the need for as many voltage adjustments. Thus the previously ungrounded electrical distribution system became a multi grounded system which uses the earth to carry the neutral current (Mairs 1994). Ground rods were added for the users and the power system. The neutral wire in the entire system was wired to the earth through the ground rods and other connections in the earth. This connection has produced an electrical distribution system which uses the earth in parallel with the neutral wire as the return path for the electric current.

A third reason that has been expressed for this change is safety from electrocution or other bodily harm caused by contact with electric lines. For the previously ungrounded system lightning arrestors were used to alleviate the destruction of electrical equipment, which could occur if lightning were to strike the lines. The lightning arrestor connected the electrical distribution lines to ground and shunted the current to the earth, avoiding damage from the lightning strikes. In contrast to the present multi grounded system, 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.

The present multi grounded system has the disturbing effect of placing every living organism in contact with one terminal (the neutral wire) of the entire electrical distribution system of the North American continent. As human beings, we literally stand on one terminal of the electrical system with no way of escaping that state. The consequences of this continual contact are numerous. An assumption has been made that the multi grounded system places living organisms on an equipotential plane, the earth connected to the neutral of the system. An additional assumption follows, that an equipotential plane is an electrically safe place to be. The stray voltage problems in the dairy industry have shown that neither of these assumptions holds. The currents in the earth produce voltage differences, and alternating currents have many interactions. Electric utilities' warnings for people to keep all materials away from the electric distribution lines are a continual reminder of the dangers in contacting the high voltage wires. Of course the reason is that we are in constant contact with the neutral wire. Consequently if we make contact with a high voltage wire the entire voltage is across our bodies. This condition makes the present multi grounded electrical system far more dangerous than the former ungrounded one.

The fact that living organisms are in continuous contact with the electrical distribution system forces a continuous electrical exposure. Contact with the neutral of the distribution system also forces electrical currents to be present to a greater or lesser degree in all materials making up the environment of all living organisms. Of course the living organisms, since they are themselves conductors of electricity and in contact with materials carrying electric currents, are plugged into the electrical circuitry of the distribution system.

Alternating currents move in non-conducting paths by means of capacitive and inductive coupling. Associated with the 60 Hz alternating current are 60 Hz alternating electric, magnetic and electromagnetic fields. Electric currents can be induced in living organisms inductively by the 60 Hz magnetic fields associated with the electric currents in transmission lines, distribution lines and in any other carrier of electric current. Electric currents can also be induced into living organisms capacitively by electric fields associated with all sources of electric charge. Electric currents produced in living organisms by each of these mechanisms are indistinguishable from one another. The currents simply access the body differently. In addition to possibly inducing an electric current in the body of living organisms, the magnetic, electric and electromagnetic fields may independently or synergistically interact with them.

Ground Currents and Stray Voltage

Surveys and farm evaluations and investigations have provided a significant body of information concerning the effects of ground currents. As mentioned previously, the historic documentation of electrical effects in dairy barns involved ground faults. When electric current inadvertently enters the earth from a high voltage wire, the event is called a ground fault. The high voltage wire can either be from the primary or secondary system. Usually discussions of ground faults center on problems in the secondary system. Well-known effects from ground faults include the behavioral, health, and production problems for confined livestock, such as dairy animals, and human electrocution. In the investigation of stray voltage problems, a number of verifiable observations have been made.

1. Changes in the electrical distribution system affect the stray voltage problem: Adding substations or changes in the areas serviced by particular substations frequently correlate with increases and/or decreases in stray voltage problems. Adding electrical services on a distribution line, especially to large users of electrical energy, increases stray voltage problems in the area of the additions. Electric utility personnel increase the number of grounds or replace damaged grounds on the distribution lines in order to decrease the primary neutral to earth voltages. Invariably when the net ground resistance for the system is decreased, problems on the dairy farms increase. In areas where unshielded, buried distribution lines are used, there tends to be a greater probability for stray voltage problems. Research has shown that within a few years after installation the neutrals become seriously corroded, requiring more of the neutral current to travel in the earth. The addition of new transmission lines is always associated with increases in problems proximate to these lines. Many dairy farmers and equipment suppliers documented significant increases in behavior, health, and production problems and human health problems after the activation of two different DC transmission lines in Minnesota. Both of these continuously employ some ground return and at times total ground control.

2. Certain physical characteristics correlate with more severe stray voltage problems: Either surface water, such as wetlands, lakes, streams or rivers, or shallow ground water is nearby. Farms either near the end of a distribution line or near a substation frequently experience the worst problems. One would expect that the greater the water concentration, the greater the electric current in the area. Measurements have shown that more electric current is transferred between neutral grounding wires and the earth at the ends of distribution lines and near substations. In locations where there are vacation cabins around lakes, dairy operators experience significantly greater stray voltage problems on weekends and vacation holidays. Frequently soil moisture is an important factor. Most often wet conditions are associated with more severe problems and dry with less severe. On occasion the opposite occurs.

3. Electrical use affects stray voltage problems. Increases in stray voltage problems are correlated with increases in electrical use in regions around dairy farms. For example, when the grain dryers are operating at harvest time, dairy operators encounter increases in behavior, health, and production problems of the dairy cows.

4. Attempts to mitigate stray voltage have produced mixed results: Behavior, health, and production problems in dairy herds are so common internationally that not only is every effort made by the dairy operator to prevent the problems, but numerous mitigation concepts have been developed to ameliorate the problems. Some of these are separating the primary and secondary neutrals, installing isolation transformers, separating the grounds and neutral on the farm, changing the grounding on the farm, equipotential plane, electronic grounding system, moving the utility transformer ground further from the farm, disconnecting primary grounding wires, placing electric current trap in the path of the current in the earth, a ring of interconnected ground rods surrounding the farm, and cattle housing that is electrically isolated from the earth. Except for the equipotential plane and the electronic grounding system, all of these mitigation concepts have developed, primarily, to reduce the exposure of the cattle to ground currents. Those that have been most successful have done the best job of reducing the amount of current reaching the cows through the ground. Since these are for mitigation, none are able to solve the basic problem and eliminate the effects.

5. General observations: Cutting off the electric power to the farm does not consistently reduce the measurable electricity in the barn to which the cows could be exposed. On some farms the magnitudes decrease and on others they increase. There are many sources for electricity capable of reaching the dairy cows when they are housed in the barn. When all electrical equipment and the total electrical system on the farm is functioning appropriately, electricity capable of reaching the cows is in direct relation to the current accessing the earth by means of the neutral wire. This amount of electricity is in direct proportion to the unbalanced 110 VAC loads on the farm. When there is no electrical use on the farm, no electric current reaches the cows by means of the farm system. Electrical current is also capable of reaching the cows from the electric utility system. Various conductors connected to the neutral side of the utility system are also connected to the farm neutral. A major connection is the common utility-farm neutral at the transformer. A fraction of the neutral current in the utility system, usually estimated at 40 percent, flows in the farm

neutral. With no wire connection, the electricity reaches the cows by means of earth pathways. The electricity in the earth caused by the general use of the earth to carry current in the electrical distribution system is literally reaching all living organisms, whether in the dairy barn or in other work or living spaces. This is another of many means by which living organisms are exposed to EM energy. In the dairy barn the ground connection may be a major source. Measurements of the electrical environment of the cows indicate the presence of both alternating currents and direct currents emanating from the earth (Dahlberg and Falk 1995).

Conclusions

The health of the environment is a determining factor in the health of all life in that environment. Under some circumstances human ingenuity in 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 population of well over 5 billion people in a world with no new frontiers is extremely vulnerable to unhealthy changes in the environment. This world condition is a compelling reason for seriously monitoring the changes in the environment and constantly assessing the effects of those changes. An important change, which has escalated since its inception over a century ago, is the addition of EM energy to the environment. An especially important aspect of this change is the extensive use of the earth to carry electric current. After nearly a century of the use of the earth to carry current, little is known about the paths of these currents or the effects of these currents on either the animate or inanimate world. In fact, archaic models still dominate the regulatory agencies' concept of how EM energies interact with life. Even in decisions regarding research directions, these outmoded models are still applied. Stray voltage research and the ground current connection have provided valuable insights for connecting exposure to EM energies associated, primarily, with electric currents in the earth to human and animal health and behavior. There is a clear need to test new models that are consistent with the electrical nature of living organisms and the complexity of our environment.