Stray voltage history and current situation for Wisconsin

Stray voltage[1] concerns surfaced in Wisconsin in the late 1970's. There was no formal way for either government or private industry to deal with the concern at that time with any sort of systematic method. A montage of interested farmers, power company personnel and government workers tried to ascertain the basic facts of the stray voltage phenomena, but as this was a relatively new concept there was not much success. There unfortunately was much misinformation about the subject and little formal research was reaching the public in simple and understandable language thereby promoting a very chaotic situation. Some early proponents of one particular view or another who had little or no formal training in the electrical sciences distributed information as well as solutions that have not proven a benefit to any farm operator in controlling stray voltage. In 1981, the governor of Wisconsin created a committee to look into all areas of stray voltage. It included people from the Department of Agriculture Trade and Consumer Protection (DATCP), the Public Service Commission of Wisconsin (PSCW), electric utilities, electric cooperatives, the University of Wisconsin (UW) and farm equipment companies. The group created three publications, including a stray voltage checklist for farm

[1] Stray voltage is defined by the Public Service Commission of Wisconsin (PSCW) as a natural phenomenon that can be found at low levels between two contact points in any animal confinement area where electricity is grounded. Electrical systems - including farm systems and utility distribution systems- must be grounded to the earth by code to ensure continuous safety and reliability. Inevitably, some current flows through the earth at each point where the electrical system is grounded and a small voltage develops. This voltage is called neutral-to-earth voltage (NEV). When a portion of this NEV is measured between two objects that may be simultaneously contacted by an animal, it is frequently called stray voltage. It is the "level of concern" defined as follows that dictates the significance of the voltage at cow contact. In Wisconsin, the "level of concern" is derived from the 1996 PSC docket 05-EI-115. In that docket, the "level of concern" is defined as 2 milliamps, AC, rms (root mean square), steady-state or 1 volt, AC, rms, steady-state across a 500-ohm resistor in the cow contact area. The Institute of Electrical and Electronics Engineers (IEEE) defines "steady-state" as "the value of a current or voltage after all transients have decayed to a negligible value." The State of Wisconsin deems that this level of voltage/current is an amount of electricity where some form of mitigative action is taken on the farmer's behalf, although only some small percentage of cows may actually perceive its presence. The "level of concern" is not a damage level. Instead, it is a very conservative, pre-injury level, below the point where moderate avoidance behavior is likely to occur and well below where a cow's behavior or milk production would be harmed. The "level of concern" is further broken down into two parts. The first part is a 1-milliamp contribution from the utility, at which level mitigative action must be taken by that utility to reduce its contribution to below the 1-milliamp level. The second part is a 1-milliamp contribution from the farm system, at which level mitigative action should be taken by the farmer.

use. By 1985, the PSC had received over 100 complaints about stray voltage on dairy farms. PSC staff investigated these complaints, but found that more state resources would be needed to meet the increasing public demand in this area. Each of the five major investor-owned utilities in this state, as well as a few electric cooperatives, had started some form of stray voltage investigation team on their own, but the efforts lacked coordination and uniformity.

In December of 1986, the Secretary of DATCP convened a voluntary Stray Voltage Task Force, consisting of legislators, the PSCW, and Department of Industry, Labor and Human Relations (DILHR – now the Department of Commerce – COMM) staff, farmers, veterinarians, utility personnel, agricultural educators, and dairy equipment professionals. During 1987 this task force oversaw development of the first volunteer Stray Voltage Assessment Team (SVAT). The team consisted of an electrician, a veterinarian, two electrical engineers, a milking-equipment professional and a dairy farmer. Together they produced the Stray Voltage Analysis Team (SVAT) 'Nine-Farm Study' report in November of that year. Condensing six months of on-farm visits, the report was able to quantify the basic procedures needed to investigate and mitigate most 60 Hertz, steady-state stray voltage in Wisconsin. The report provided ten general overall recommendations, seven recommendations to the utilities, ten recommendations to the farmer, and two recommendations to researchers. They also suggested fourteen questions that researchers should attempt to answer in the future. Much of this research has been successfully performed since that time, by the UW as well as other educational institutions across the US and Canada. Most of the basic stray voltage investigation procedures used, not only by the PSCW's Rural Electric Power Services (REPS) team, but also by the utilities, were developed and refined during this period.

In August of 1987, the PSCW opened its basic stray voltage docket, 05-EI-106, to gather information about stray voltage to be used in its formal rulings. After much public testamony at formal hearings, an order was issued in 1989 that became the basis for the existing stray voltage program. It included the following twelve points (paraphrased for brevity):

1) The level of concern is define as one mA of steady-state, AC current in the cow contact area.
2) There is a need for the standardization of stray voltage testing.
3) The testing uses defined cow contact areas, the 500-Ohm resistor and high input impedance recording meters.
4) Specific tests outlined for on-farm and off-farm contributions.
5) Goal: prevention is better than mitigation.
6) Utility rules for isolation defined.
7) Comments on other mitigation methods: EGS systems and the equi-potential plane.
8) Information and customer complaint procedures outlined.
9) Information on and for REA electric cooperatives is given.
10) Establishment of specific SVAT responsibilities.
11) Non-jurisdictional commission recommendations.
12) Commission will track on-going research.

This order was further clarified with an amendment in August of 1989 and a supplement in July of 1990. With the basic procedures of stray voltage investigative techniques in hand, the PSCW co-opted the SVAT structure for its own team (consisting of a master electrician, an engineer, a veterinarian and a farm ombudsman) and set out to examine farms that sent in formal

applications for stray voltage investigations. To date, over 490 applications have been processed at the W, resulting in over 300 actual on-farm investigations by the team. Less than half of the farms were found to have traditional steady-state stray voltage. The PSCW received input about investigating the effects of any non-traditional stray voltage and responded by opening docket 05-EI-108 in April of 1990. The resultant order of that docket, issued in June of 1995, called for more research into the areas of DC currents, earth currents, transient effects, and both electric and magnetic fields. It also called for an investigation into the extent of concerns dairy farmers had that were not previously addressed. These dealt with herd health and production. A steering committee was formed to guide this effort. In the last few years, the mission of the REPS team has shifted focus to one of regulatory oversight and training more than hands-on investigations. All the investor-owned utilities, most cooperative utilities and some municipal utilities have well-trained stray voltage investigators who perform on-farm investigations on a regular basis for their farm customers. The REPS team has subsequently developed more guidelines for investigation, technical papers and training materials.

To further serve the farmers, utilities and the citizens of Wisconsin, the PSCW opened another stray voltage docket (05-EI-115) in January of 1996 to bring the latest results of research into stray voltage issues to the public forum. This was especially crucial, since the United States Department of Agriculture (USDA) had released its famous Redbook (publication 696) in December of 1991 --- after the 05–EI-106 docket orders had been issued. This book, titled "Effects of Electrical Voltage/Current on Farm Animals" was created as a compilation of research results from many famous dairy scientists nation-wide. It reinforced the order points of the previous PSCW dockets and led the PSCW to conclude that the "level of concern" should include equal parts of liability from on- and off-farm sources of stray voltage. The new "level of

concern" is now 2 mA in the cow contact area, one from the on-farm neutral and one from the off-farm neutral system. Again, if the contribution is over 1 mA from an off-farm source, the utility responsible must act to reduce that contribution to less than 1 mA. It must offer neutral isolation for a maximum of 90 days until the reduction is accomplished. This docket also outlined the rules of how farmers could request utility isolation even though the utility did not contribute more than 1 mA in the cow contact area. This policy is known as "isolation on demand" (IOD). Since the farm operator is the cost causer, he must bear the cost of such an installation. The initial cost generally is about $750 - $1000 with an on-going $35 per month maintenance fee. The docket also emphasized the need for 24-hour minimum data acquisition of at least four points of the farm electrical system: the primary neutral to reference voltage, the secondary neutral to reference voltage, the difference between these two voltages, and the cow contact voltage. A new testing protocol, known as the Phase II Testing Protocol, was developed. This consisted of the following specific farm-site tests: primary neutral profile, load box test, secondary neutral voltage drop test, signature test, and the 24 hour monitor test.

In December of 1998, a stray voltage summit conference was held in central Wisconsin to take stock of the current situation and see what more could be done to help dairy farmers. In response, a Chairman's (Assembly Ag. Committee Chairman, Al Ott) Roundtable session was held in August of 1999 to summarize the summit's findings and propose a new structure for an advisory committee to DATCP. The result of the roundtable was the creation of the Wisconsin State Assembly Agriculture Committee chairman's newly formed Rural Energy Management Council (REMC), a purely advisory arm of the DATCP. The council has a number of members from many disciplines. Currently eighteen members representing a diverse group are appointed by the DATCP board representing researchers, DATCP REPS, PSC REPS, COMM, educational

institutions, utilities, dairy producers, farm professionals, farm equipment manufacturers, farm organizations, the media, and the legislature. The REMC meets quarterly and has prepared several reports to DATCP and the legislature. The REMC has a number of standing committees to address many of the rural energy concerns voiced at the summit and roundtable. It has held many public input sessions to continue to give the farm community voice in rural energy issues. From its inception, REPS staff was assigned to the REMC. REPS program personnel chair and are members of committees to help farmers manage electric power and electric technology, to assist producers in on-farm energy efficiency and conservation and promote safe efficient and cost effective energy usage in Wisconsin rural communities.

REPS members are represented on the following Standing Committees:

- Education - to disseminate results of research & known facts, solicit input for research topics, media contacts, outreach, and a newsletter.
- Energy Conservation – new technology and technique application, education, financial incentives, new partnerships
- Other Electrical Phenomena – to deal with electrical and energy issues that fall outside of the PSCW's strict definition of stray voltage.
- Professional Services (Wiring/Safety) – need for electrical inspection, certification of electricians, improvement of on-farm wiring, professional liability and farm consumer protection
- Research and Technology – existing research data, ongoing research activity, new research proposals, funding options, new concepts/theories.
- Stray Voltage – classical SV detection, mitigation, education

- Utilities – new practices/procedures, education, conservation, financial incentives/farmstead rewiring grant programs

In 1994, the Minnesota Public Utilities Commission (MPUC) assembled a team of science advisors from around the United States who polled farmers in Minnesota and Wisconsin about stray voltage issues, conducted on-farm research, and contracted with researchers at the UW for more testing at levels of voltage below the "level of concern." The UW research showed no adverse effects to herd health at these low levels. In their final report of July 31, 1998, the MPUC science advisors determined several things. The poll of dairy farmers indicated that stray voltage concerns generally ranked very low (19^{th} in a list of 26) as perceived causes of animal health and production problems. While about 60 percent of responding farms had been tested for stray voltage, 87 percent of those farmers felt that they have had any concerns about stray voltage resolved to their satisfaction. The results of the on-farm research concluded that there was no detrimental effect on herd health and production from DC currents, electric fields, magnetic fields or earth currents. In their final report, the Minnesota science advisors concluded: "We have found no credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters, such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds." More importantly, they attested to the fact that most farm wiring was sorely in need of repair and upgrade.

Recently, another research project has been funded by the state of Wisconsin with direction from the REMC to expand upon the ground current portion of the Minnesota study. In this study, a novel measurement technique, known as the magneto-telluric method, is used. This involves setting up an instrumentation package at several sites around the farm to measure x and y components of the electric field on the plane of the earth's surface and an x, y and z axis

measurement of the magnetic fields. Simultaneously, similar measurements are recorded at a very remote site some 20 to 30 miles away via the use of time reference data from GPS satellites. Because man-made electrical currents in the earth are local contributors to earth currents and natural currents, such as those from the magnetosphere interacting with the solar wind and distant thunderstorms, are more universal, they can be separated using this time-based technique. Initial results on the frequency range from 1 to 1,000 Hz show that the earth currents in the vicinity of an electrically active farm are about 10 - 100 times higher than in a very remote area, well away from local power sources. They mostly contain 60 Hz energy with some small contributions of odd harmonics 10 to 100 times less than the fundamental frequency. The absolute levels on the farm, however, are extremely low - peaking at about 10 milliVolts per meter, open circuit. Using Ohm's Law with a measured value of earth resistivity, the current in the earth was calculated and ranged from one eighth to 10,000 microamps per square meter or up to 1 microamp per square centimeter. A one centimeter square conductor size is equivalent to about a 4/0 copper wire which can safely carry 535 Amperes. The normal current in the earth is therefore about 2 billion times smaller than the maximum safe capacity of an equivalent size copper wire. These are extremely small currents, very hard to measure accurately with most normal instrumentation and are 50,000 times less than the PSCW "level of concern" current. The subsequent parts of the research will expose cows to continuous levels of similar electric signals found from the initial part of the study for long periods and then determine if any changes are seen in their gene expression through a work up of their blood chemistry.

Members of the PSCW REPS team have published ten research papers for the American Society of Agricultural Engineers (ASAE) to date.

943065 (June 1994)
"Distinguishing Stray Voltage Contributions From 'On-Farm' and 'Off-Farm' Sources"
Mark Cook, Daniel Dasho, William K Dick, Doug Reinemann, David Winter

943601 (December 1994)
"Effects of Source Resistance on Cow Contact Voltage Measurements" (17 pages)
Mark Cook, Dan Dasho, Richard Reines, William Dick, D. Reinemann, John Ryder, David Winter

943602 (December 1994)
"Characteristics of Cow Contact Voltage Transients" (28 pages)
Mark Cook, Daniel Dasho, Richard Reines, Doug Reinemann

953623 (June 1995)
"Electrical Service to Agricultural Buildings: Four-Wire and Three-Wire Systems" (9 pages)
Mark Cook, Dan Dasho, Doug Reinemann, LaVerne Stetson

953625 (June 1995)
"Stray Voltage: The Wisconsin Experience" (20 pages)
Dan Dasho, Mark Cook, Richard Reines, Doug Reinemann

963071 (July 1996)
"Magnetic Field Measurements on Wisconsin Dairy Farms"……
Dan Dasho, Mark A Cook, Richard Reines, Doug Reinemann

963072 (July 1996)
"Relationships Between Secondary Neutral and Cow Contact Voltages"
Mark A. Cook, Daniel M. Dasho, Richard Reines, Doug Reinemann

963075 (July 1996)
"Stray Voltage Training Model"
Roger Kasper, Daniel M. Dasho, Mark A. Cook, Jerry Martens, John Patoch, Doug Reinemann

983004 (July 1998)
"Putting Stray Voltage in Perspective: The Wisconsin Experience Revisited
Mark A. Cook, Daniel M. Dasho, Richard S. Reines, Doug Reinemann

993150 (July 1999)
Steady State Stray Voltage Analysis on Wisconsin Dairy Farms: The Phase II Protocol
Richard S. Reines and Mark A. Cook

These papers form an important backbone to the protocols developed by the PSCW over the last thirteen years. They deal with issues such as distinguishing on-farm and off-farm sources, cow contact resistance effects, cow contact voltage transients, 3- and 4- wire systems, magnetic field measurements, the relationship of secondary neutral to cow contact voltages, the

Phase-II testing protocol and statistics that describe the magnitude and correlation of various parameters dealing with stray voltage. REPS members have also helped create, in conjunction with people from Minnesota, a physical stray voltage farm model with inputs and measuring points that simulates most electrical conditions observed on actual dairy farms.

A three course progressive series of stray voltage education is offered through the extension service of the UW College of Agriculture and Life Sciences (CALS). The first is a one-day introductory course, aimed at veterinarians, agricultural media specialists, farmers and other farm professionals, describing general topics about the whole subject of stray voltage to foster an atmosphere of mutual understanding of the exact terms and issues involved. The second is a two-day intermediate course, aimed at utility stray voltage investigative personnel, electricians and others who want to know additional in-depth information. It focuses on a more comprehensive knowledge of stray voltage matters, specifically the mechanics of a Phase II investigation. The capstone third course is a two-day advanced course that provides a follow up on the information from the intermediate course and provides for comprehensive analytical interpretation of stray voltage data and investigative techniques as well as offering hands-on problem solving experiences. Many students have provided feedback that they found these courses very informative and enlightening.

The REPS has developed and maintained and extensive database on all aspects of stray voltage in addition to a glossary of SV terms. The utility database maintained by the PSCW has useful information on the condition and history of the investor-owned utility rural distribution system in Wisconsin. For instance, from 1989 to 2002, the neutral conductor resistance per mile in rural areas has decreased 20%. A decrease in the resistance means that larger conductors are being installed or used as replacements for older lines during a rural rebuild process. As a direct

result of the REPS program, more than 1500 miles of rural line are replaced each year. From 1993 to 2002, the number of neutral grounds per mile in rural areas has increased 36 percent. This makes the distribution system more resistant to outages from lightning strikes and safer for the public from accidental line-to-ground faults. From 1990 to 2002 the voltage on the neutral ground rods in rural areas has decreased 65 percent down to an average of less than ½ volt today. The primary neutral voltage at the farm from 1988 to 2002 has decreased 68 percent and is less than 1 volt today. Wisconsin electric utilities have spent over $950,000,000 in the last 20 years to upgrade their rural distribution systems as well as detect and mitigate stray voltage. They are currently underwriting the cost of the development and implementation of an 18-hour technical college course on farm rewiring methods for rural electricians. Wisconsin utilities each have a farm rewiring incentive program of grants and low interest loans for their dairy customers to rewire their farms to increase safety, increase energy efficiency and decrease the levels of stray voltage. The utility funded farm rewiring programs have spent $4,000,000 so far. The participants include Xcel Energy, Alliant Energy WE Energies, Wisconsin Public Service Corporation, municipal and cooperative utilities. Utilities are also carrying on a program to identify and remove bad split-bolt neutral connections on all rural lines.

On-farm data from this database is also very informative. Farms are increasing in size as a general observation. Transformer sizes are up 46 percent from 1989 to 2002. Herd sizes are up 90 percent from 1993 to 2002. Milk production has increased 54 percent from 1992 to 2002. Today, 20 percent of farms are served with 3-phase power, an increase of 200 percent from 1988/9 to 2001/2. The number of farms found isolated is down 95 percent from 1989 to 2002. Only about 2 percent of all farms tested last year were isolated upon arrival. The number of equipotential planes found on farms has increased from 1992/3 to 2001/2 by 29 percent. In that

same period, the number of 4-wire secondary wiring systems found has increased by 194 percent. The measured cow contact current has decreased from 1988 to 2002 by 77 percent. It is averaging about ½ milliamp today. During the period from 1993 to 2000, the secondary neutral voltage had increased by 6.7 percent, in the last two years it has decreased 25 percent to less than 1 volt. This is due to the utility rewiring programs that address old and inadequate farm wiring. Today, stray voltage investigators can expect to find 2 mA or less on 91.8 percent of all farms investigated. About 2.7 percent of all investigations will yield values of cow contact current at or higher than 4 mA.

The REPS program continues to provided technical expertise in stray voltage for research, universities, national SV symposia, agricultural equipment manufacturers, SV detection and monitoring equipment manufacturers, veterinarians and other farm trade professionals, investor-owned, municipal, and cooperative utilities in Wisconsin, as well as those in other states and countries, the media, consultants, legislators and other government agencies, as well as in farm expansion planning and construction. REPS acts as liaison and educator during public agricultural events such as utility farm shows, dairy expositions, farm progress days, county fairs, and twilight meetings as well as acting as a mediation and technical expert testimony resource to assist in the resolution of SV concerns. The REPS also provides consultation and rural on-site investigations, evaluations and mitigation assistance to provide the rural community with farm wiring upgrade information as well as herd health advice.

REPS staff fields several hundred calls each month and averages more than 55 hours per seven day week. They have conducted more than 1121 field investigations and nearly 500 training programs while traveling further than one million miles in Wisconsin. GREAT PROGRAM!