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STRAY VOLTAGE: THE WISCONSIN EXPERIENCE

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Summary:

This paper presents data from more than 1000 stray voltage investigations conducted in Wisconsin by the Wisconsin Public Service Commissions Stray Voltage Analysis Team and investor owned utilities.

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INTRODUCTION

The Wisconsin Stray Voltage Analysis Team (SVAT) has been collecting data from its on-farm stray voltage investigations since its beginning in 1989. The major investor owned utilities in Wisconsin have also recorded information from their stray voltage investigations at the request of the Public Service Commission of Wisconsin (PSCW) since 1988. The scope of the data collected by the utilities was enlarged beginning in 1993 to correspond with the data collected by the SVAT. Unique to the SVAT portion of the database is information about the primary power delivery system, EMF measurements and specific farmer complaints.

It should be noted that this is not a random sample of Wisconsin farms. The investigations done by the utilities were usually done at the request farm customers who were concerned about potential stray voltage problems. The investigations done by the SVAT were done only after a utility investigation had been done and the farm customer was still concerned about potential stray voltage problems. Because this is not a random sample, no conclusions can be drawn about the applicability of this data to the entire population of farms in Wisconsin.

For each investigation, data was recorded about the characteristics of the distribution system serving the farm including:

- Circuit miles from the farm to the nearest distribution substation,
- Number of ground rods per mile near the farm,
- Material and size of the primary neutral conductor,
- Primary phase voltage,
- KVA rating of the primary transformer;

Characteristics of the farm including:

- herd size in number of milking cows,
- rolling herd average milk production (RHA) from the most recent test information
- Bulk tank average Somatic Cell Count from the most recent test;

and electrical measurements relating to the level of animal contact voltage present on the farm:

- Maximum cow contact current reading,
- Maximum value of the primary neutral to earth voltage, and
- Maximum value of the secondary neutral to earth voltage.

Stray voltage, in the PSCW docket 05-EI-106, has been defined as a measurement of 1 milliamp of steady state current flowing in a cow contact area (0.5 V potential across a nominal 500 ohm resistance simulating a cow). This is further defined as a "level of concern," at which action should be taken to reduce cow contact current to below 1 milliamp. The cow contact area is defined as any area where a cow could simultaneously contact two conducting surfaces having a difference in electrical potential. The test methods used to measure primary, secondary and cow contact voltages are well defined by the PSCW and the SVAT. Utility investigators have been made aware of these standardized procedures through various educational efforts conducted by the SVAT and the University of Wisconsin beginning in 1989.

In some instances, a spot check was performed on the farm, and the entire data set was not complete for that investigation. Linear Regression analysis was performed to determine correlation between variables. Only complete data sets for a farm investigation were used to avoid potential influence on cross correlations.

THE TYPICAL FARM

Figure 1 presents the data on a "typical" farm with and without stray voltage. Figure 1 presents the average, standard deviation, sample size and range. The data represents all farms investigated by SVAT and the reporting utilities. The "typical" farm with no stray voltage, below the PSCW "level of concern" present (cow contact measurement from 1 microamp to .99 milliamp) has an average herd size a herd of 62 cows with an average rolling herd average production of 17,714 pounds and a somatic cell count of 367,000. The average measurement of cow contact current is 0.32 milliamp. The primary profile of the utility's distribution system near the farm has a ground rod resistance of 73 ohms, a ground rod current of 33 milliamps. On the farm itself, the average primary neutral to reference (PNREF) reading is .88 volts while the average secondary neutral to reference (SNREF) reading is .85 volts. The main complaints registered by the farmer in his application for a formal stray voltage investigation, in decreasing order of frequency, are an increased somatic cell count, uneven milkout, nervous cows, reduced milk production and milk letdown problems. The average magnetic field (EMF) reading in the barn is .69 milligauss.

For farms with stray voltage present, above the "level of concern," (cow contact current above 1 milliamp), the average herd is 54 cows with an average rolling herd average production of 17,278 pounds and a somatic cell count of 428,000. The average cow contact current is 2.04 milliamp, with a median of 1.45 milliamp. The primary profile has an average ground rod resistance of 102 ohms, a rod current of 40 milliamps. On the farm, the PNREF is 1.82 volts while the SNREF is 1.92 volts. The main farmer complaints, in order of decreasing frequency, are increased somatic cell count, reduced milk production, nervous cows, uneven milkout and increased clinical mastitis. The average EMF reading in the barn is .61 milligauss.

COW CONTACT CURRENT VERSUS DISTANCE TO SUBSTATION

Figure 2 contrasts the magnitude of maximum cow contact current (milliamps) with the circuit miles from the farm to the substation which feeds power to the farm. The data consists of 1090 points ranging from .3 miles to 43 miles from farm to substation. The cow contact current varies from 1 microamp to 19 milliamps. The correlation coefficient (r square) was .00031 and with a p value for the significance of the correlation was .85 indicating no correlation between the parameters. There have been concerns raised over the years that location on the distribution line, i.e., an end of line customer, was related to the probability that the customer had stray voltage. This data shows that there is no significant relationship between cow contact current and distance from the substation.

COW CONTACT CURRENT VERSUS GROUNDS PER MILE

Figure 3 contrasts the magnitude of the cow contact current with the number of ground rods per mile from the farm toward the substation. The number of grounds per mile is related to the effective resistance to ground of the primary distribution system. The number of ground rods varies from a minimum of 3 to a maximum of 23. The number of data points shown is 1090. The correlation coefficient (r square) was .0032 and with a p value of .06 indicating no correlation between the parameters. However, this approaches significance at the 95% level and the trend agrees with circuit theory, the more grounds per mile the lower the resistance, hence the lower the primary neutral voltage, given similar loads. The fact that the correlation explains less than 1% of the variation indicates that there are other factors of far greater importance influencing cow contact currents.

COW CONTACT CURRENT VERSUS PRIMARY NEUTRAL CONDUCTOR SIZE

The data of Figure 4 compares the nominal resistance, in the first mile, of the primary neutral conductor with the magnitude of the average cow contact current. This nominal resistance (in ohms per mile) is determined by both the wire gauge and the material from which the conductor is made. The correlation coefficient (r square) was .0124 and with a p value of .0002 indicating a significant correlation between the parameters at the 95% level, but a very low correlation coefficient. The primary neutral conductor size explains only 1% of the variation in cow contact currents. The graph is based on 1089 data points.

COW CONTACT CURRENT VERSUS PRIMARY LINE VOLTAGE MAGNITUDE

Figure 5 compares the average cow contact current with the magnitude of the primary distribution line voltage. There are 1089 points of data represented in the graph. The data shows a trend indicating that higher primary line voltages produce lower cow contact current measurements. The correlation coefficient (r square) was .0047 and with a p value of .024, again indicating a significant correlation between the parameters at the 95% level, but a very low correlation coefficient.

COW CONTACT CURRENT VERSUS PRIMARY TRANSFORMER KVA RATING

Figure 6 contrasts average cow contact current and the KVA rating of the primary to secondary transformer. As a general rule the larger the herd size the larger the transformer rating will be to supply power to the farm. The data consists of 854 points with transformer sizes ranging from 10 kVA to 75 kVA. The average cow contact current varies from .74 milliamps to 1.37 milliamps. The correlation coefficient (r square) was .0013 and with a p value of .30 indicating no significance. As the graph illustrates, no clear trend is apparent.

COW CONTACT CURRENT VERSUS PRIMARY NEUTRAL TO REFERENCE VOLTAGE

The dependence of cow contact current to the primary neutral to reference voltage (PNREF) is illustrated in figure 7. Note that there are many points clustered in a narrow range of from .25 to 2 volts. The correlation coefficient (r square) was .19 and with a p value of less than .001 indicating, significance. There is correlation, as expected from circuit theory, between the primary neutral to reference voltage and the cow contact current. The regression equation is cow contact current (CCA) = 0.155 + 0.568*PNVREF. The data is based on 1088 points.

COW CONTACT CURRENT VERSUS SECONDARY NEUTRAL TO REFERENCE VOLTAGE

The data of figure 8 shows the relationship between cow contact current and the farm's secondary neutral to reference voltage (SNREF). The graph appears very similar to the previous one for primary neutral to reference voltage. It is based on 1088 points. The average cow contact current is 0.76 milliamps. The correlation coefficient (r square) was .25 and with a p value of less than .001 indicating, significance. There is similarly correlation between the SNREF and the cow contact current. The regression equation is cow contact current (CCA) = 0.09 + 0.62*PNVREF. The data is based on 1088 points.

STRAY VOLTAGE SOURCE VERSUS POWER PROVIDER

Figure 9 is based strictly on the investigations done by the SVAT. This graph compares the various power suppliers, Municipal Utilities, Investor owned and Electric Cooperatives, and the sources of stray voltage more than 1 milliamp. There are only two sources of stray voltage. Either it is due to the power suppliers' system, or it is the result of on-farm (secondary) conditions. It can be due to the combination of these two sources. Of the cases where the contribution from the primary distribution system to cow contact current was more than 1 milliamp, 69% were served by an Electric Cooperative and 23% were served by an investor owned utility. In those cases where the contribution from on-farm sources was greater than 1 milliamp, 62% were associated with investor owned utilities (IOUs) and 31% were associated with Electric Cooperatives. In those cases where the stray voltage exceeded 1 milliamp and a combination of the two sources was identified, 69% were served by electric cooperatives and 25% were served by investor owned utilities. In those cases where cow contact current was less than 1 milliamp, 40% were served by electric cooperatives and 57% were served by IOUs.

Figure 10 provides more detail on the cow contact current levels, the sources of the current, and the power providers. As an example, for cow contact currents greater than 1 milliamp, and the source being the primary neutral, the average of cow contact currents for IOUs is 1.9 with a standard deviation of .77, with 6 cases ranging from 1 to 3 milliamps.

HERD SIZE VERSUS COW CONTACT CURRENT

Figure 11 compares the size of the herds in the sample to milliamps in the cow contact. Most of the data is clustered between herd sizes less than 100 cows and currents less than 2 milliamps. The correlation coefficient (r square) was .008 and with a p value of .004 indicating significance. While there may be a slight trend in the data, it does not explain a meaningful percentage of the variations.

ROLLING HERD MILK PRODUCTION VERSUS COW CONTACT CURRENT

The data shown in figure 12 contrasts a farm's rolling herd average milk production and its measured cow contact current. The correlation coefficient (r square) was .0047 which indicates very little correlation and a p value of .0361 indicating significance. The number of data points was 929. The results were reevaluated removing the lower 15% and the top 5% of the data points. The correlation coefficient was .0013 and the p value was .333 indicating no significance. The number of data points was 743. By analyzing a subset of the data base the results shifted from significant to not significant. The possible correlation is, in any case, weak with 99.5 % of the variation in RHA explained by other factors.

SOMATIC CELL COUNT VERSUS COW CONTACT CURRENT

The data shown in figure 13 contrasts by the bulk tank average somatic cell count with cow contact current. The correlation coefficient (r square) was .003 which indicates very little correlation and a p value of .09 indicating no significance. The number of data points was 929. The results were reevaluated removing the lower 15% and the top 5% of the data points. Using this subset of data changed the correlation coefficient to .0073, no correlation, and the p value became .02 indicating significance. The number of data points was 744. By using a subset of the data base the results shifted from not significant to significant, the opposite as the rolling herd average. The correlation is, in any case very weak with 99.3% of the variations explained by other factors.

CONCLUSIONS

More than 90% of by the farms in this data set had cow contact currents less than 2 mA and more than 70% had less than 1 mA. The low cow contact voltages are likely attributable to efforts by utilities in response to by the PSCW regulatory and educational efforts.

Correlation was found between primary neutral voltage, secondary neutral voltage and cow contact current, as expected. There was no meaningful correlation between cow contact currents and either production or somatic cell count.

The distribution of variables measured by the SVAT and IOU investigators compared well illustrating that consistent testing methods are being used. One goal of the PSCW was to develop and encourage consistent test procedures across the state.

The data show that cow contact current is dependant on many physical factors stemming from both by the on-farm and off-farm electrical power systems. Specific measurement of cow contact current on each farm is required to determine the potential impact on cows on that farm. Because of the wide variation in the data, gross indicators, such as grounds per mile, secondary and primary neutral to reference voltages, etc., are not good predictors of cow contact currents.

There are many confounding factors that may outweigh the impacts of stray voltage which makes it difficult to draw conclusions from field studies about its effects on production and animal health. The implications for future research are that groupings of farms based on certain non-electrical parameters are important in attempting to draw correlations between cow contact currents and production and health variables.