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PUTTING STRAY VOLTAGE IN PERSPECTIVE: THE WISCONSIN EXPERIENCE REVISITED

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Summary: Data from more than 2900 stray voltage investigations performed in Wisconsin by Investor Owned Utilities (IOU) and the Stray voltage Analysis Team (SVAT) are reported. Data includes electrical characteristics of both the distribution and on-farm wiring systems as well as rolling herd average milk production (RHA) and bulk tank average somatic cell counts (SCC). More than 85% of the first investigations reported maximum primary and secondary neutral-to-earth voltages less than 2 volts rms. More than 90 percent of investigations reported maximum cow contact voltages less than 1 volt rms. The distribution of variables measured by the SVAT and IOU investigators compared well, indicating that consistent testing methods are being used.

The correlation found between electrical parameters are as expected from electrical theory. However, specific measurement of each parameter is required because predictive ability is low. Indicators such as ground per mile, primary neutral or secondary neutral-to-earth voltages are not good predictors of cow contact voltage. This is probably due to the prevalence of on farm sources, which can either add or subtract from primary sources. It is thus imperative to properly identify the voltage sources and their interaction before implementing mitigative action.

There was no meaningful correlation between primary neutral-to-earth voltage, secondary neutral-to-earth voltage, cow contact voltage, or ground rod current and either RHA or SCC ($r < .02$). The correlation between the monthly average Somatic Cell Counts reported stray voltage investigators and by the USDA for all farms in the Midwest ($r = 0.58$) was an order of magnitude higher than for any electrical parameter. Inappropriate conclusions about changes in SCC and milk production can be drawn if these seasonal trends are not taken into account.

Keywords: stray voltage, field measurements

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THE WISCONSIN EXPERIENCE REVISITED

INTRODUCTION

The Wisconsin Stray Voltage Analysis Team (SVAT) is jointly administered by the Public Service Commission of Wisconsin (PSCW) and the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP). The SVAT consists of an electrical engineer, a master electrician and a veterinarian. The SVAT has been collecting data from 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 PSCW since 1988. This data has been presented in and earlier publication (Dasho et al, 1995). This paper presents data collected since that publication.

The SVAT data includes information from applications for on-farm investigations, and actual on-site investigations. Not all applications result in a full investigation, therefore some entries contain only the data sent by the applicant, or information from a partial investigation. To date, 346 applications have been received by the SVAT of which 222 or 64% have resulted in some form of investigation. This represents farms which receive their power from 147 (43%) cooperative, 174 (50%) investor-owned and 24 (7%) municipal utilities.

Data from Wisconsin's 5 largest investor-owned utilities (IOU's) from first-time farm investigations is submitted semiannually to form a separate utility database. The IOU farm-customer representatives are usually trained stray voltage specialists at the technician or engineer level. The form of the data collected by the utilities was standardized beginning in 1993 to correspond with the data collected by the SVAT. While each database is similar since 1993, the SVAT database includes data from municipal and cooperative electric power companies as well as from the IOU's. Unique to the SVAT portion of the database is information about the primary power delivery system, and specific concerns of the applicant. There are more than 2,900 first-time farm investigations reported between 1993 and 1997 in the utility database, representing about 12% of all Wisconsin dairy farms.

The utility investigators measure and re port characteristics of the distribution system serving the farm including:

- Primary phase voltage,
- Material and size of the phase and neutral conductors,
- Number of ground rods per mile near the farm,
- kVA rating of the primary transformer,
- Circuit miles from the farm to the nearest distribution substation, and
- Location relative to the end of a branch line.

Characteristics of the farm are reported including:

- Herd size in number of milking cows,
- Type of herd data recording system (e.g. DHIA or other),
- Rolling Average milk production (RHA) and bulk tank average Somatic Cell Count (SCC) from the most recent test information,
- Type of milking facility, and
- Type of stray voltage mitigation devices installed and recommended.

Electrical measurements on the farm including:

The maximum steady state value of the cow contact voltage found at the worst-case cow contact location. The cow contact current is measured as the current flowing through a 500-ohm shunt resistor connected across cow contact points.

The source resistance of the cow contact measurement point,

Maximum steady state value of the primary neutral-to-earth voltage, and

Maximum steady state value of the secondary neutral-to-earth voltage

Additional data collected by the SVAT includes:

Data from a profile of the distribution system near the farm reporting ground rod current, ground rod resistance and primary neutral-to-earth voltages,

Major herd health and production concerns of the applicant

Whom the applicant had previously contacted

It should be noted that this is not a random sample of Wisconsin farms. Investigations done by the utilities were usually done at request of farm customers. The investigations done by the SVAT were done only after a utility investigation had been done and the farm customer was still concerned.

The PSCW reviewed its stray voltage rules in 1997. The PSCW has defined as a standardized measurement of stray voltage, the voltage measured across a 500 ohm (nominal) resistance connected between two cow contact points. The 'level of concern' has been defined as 1 volt of cow contact voltage measured in this manner (or 2 milliamps of cow contact current). This is a combined contribution from both on-farm and off-farm sources. The utility contribution may be no more than ½ of this total. A cow contact measurement location has been 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 cow contact voltages as well as primary and secondary neutral voltages have been well defined by the PSCW. 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.

UPDATING THE WISCONSIN EXPERIENCE

Distributions of the major electrical and dairy performance measurements are presented in Figures 1-11. The median values reported by the SVAT and IOU investigators are as follows:

	Median (SVAT)	Median (IOU)
Distance to substation (miles)	5.0	5.0
Grounds per Mile	10	10
Primary Neutral-to-earth Voltage	1.10	0.90
Secondary Neutral-to-earth Voltage	1.07	0.95
Cow Contact Voltage	0.30	0.24
Herd Size	53	52
RHA milk production (lbs./cow/year)	17,000	18,000
Somatic Cell count	421,000	300,000

More than 90 percent of farms served by IOUs are within 10 circuit miles of a substation. More than 95% of farms exceed the minimum number of grounds per mile required on the distribution system for IOUs in Wisconsin. The difference between the SVAT and IOU ground rod distributions is that SVAT data contains investigations from Rural Electric Cooperatives and municipally owned utilities. The predominant distribution voltage is 7200 volts with only 3 farms served by a 2400-volt distribution system and about 20 percent served by 14,400-volt distribution. The predominant transformer size reported is 25 kVA. More than 85% of the first investigations reported maximum primary and secondary neutral voltages less than 2 volts rms. More than 90 percent of investigations reported maximum cow contact voltages less than 1 volt rms.

A summary of the current flowing to ground on primary ground rods from 175 SVAT investigations is shown in Figure 8. This data consists of readings of current taken from all distribution line ground rods for a distance of 1.5 miles centered about the farm being investigated. The mean and median values of current are 41 and 19 milliamps respectively. The mean and median primary ground resistance was 78 and 32 ohms. This compares with a study reported by Gustafson, Green, and Brennan (1987) in which the mean resistance was reported as 119 ohms for 42 readings.

The correlation coefficient was calculated between all variables in the IOU database for more that 2900 investigations performed from 1993 to 1997. A weak correlation was found between primary neutral and secondary neutral-to-earth voltages ($r = 0.65$) transformer size and herd size ($r = 0.52$), secondary neutral and cow contact voltage($r = 0.51$) primary neutral and cow contact voltage ($r = 0.39$), herd size and RHA ($r = 0.27$), and RHA and SCC ($r = -0.23$). There was no meaningful correlation between primary neutral-to-earth voltage, secondary neutral-to-earth voltage, cow contact voltage, or ground rod current and either RHA or SCC ($r < .02$). These distributions and correlations are comparable to data previously reported by Dasho, et al. (1995).

The correlation between electrical parameters are as expected from electrical theory. However, as indicated in Dasho et al, (1995), specific measurement of each parameter is required because predictive ability is very low. Gross indicators such as ground per mile, primary or secondary NEV are not good predictors of cow contact voltage. This is probably due to the prevalence of on farm sources, which can either add or subtract from primary sources. It is thus imperative to properly identify the voltage sources and their interaction before recommending a mitigative action. Further detail on the relationship between secondary neutral-to-earth and cow contact voltage is given by Cook et al, (1996).

Dasho et al, (1995) reported no meaningful correlation between cow contact voltage and either RHA or SCC. The greater number of data points in the current database produced similar results. The monthly average somatic cell count recorded by utility investigators was compared with data recorded by the USDA for the federal order region 68 (Upper Midwest) and region 30 (Chicago). These data are presented in Figure 12. The seasonal nature of somatic cell count is apparent, with the yearly maximum occurring during the summer months. The correlation between monthly average SCC reported by utility stray voltage investigators and by the USDA was $r = 0.59$ for region 68 and $r = 0.58$ for region 30. This correlation was thus an order of magnitude higher than for any electrical parameter. Inappropriate conclusions about changes in SCC and milk production can be drawn if these seasonal trends are not taken into account.

STRAY VOLTAGE MITIGATION AND WIRING METHODS

Some common stray voltage mitigation methods reported from over 2,900 farm investigations done by utility investigators from 1993 – 1997 are summarized below. The mitigation and wiring methods found at the time of the first investigation done on that farm by a utility investigator were reported as follows:

As-found On-Farm Mitigation and Wiring Methods	% of Farms
Equipotential Plane	12.4
4-Wire System	6.9
Isolation Device	0.4
Active voltage suppression device	0.4

An equipotential plane was reported on about 12% of farms. A 4-wire system was found on about 7% of farms. A 4-wire system has been required for separating ground and neutral interconnections in branch circuits in Wisconsin since the early 1960's (Cook et al, 1995). Other mitigation methods were found on less than 1% of farms.

The on-farm mitigation methods or improvements to the farm wiring system recommended by the utility investigator after the investigation was completed were reported as follows:

On-Farm Mitigation Recommended by Utility Investigator	% of Farms
Improve Grounding	26.7
Increase size of Secondary Neutral Conductor	22.6
Balance 120 V loads	15.2
Install 4-Wire System	7.0
Install Equipotential Plane	3.8
Install Active voltage suppression Device	0.3
Install On-Farm Isolation Device	0.2

The most common mitigation methods recommended by utility investigators were improved grounding (27%), increase size of secondary neutral conductor (23%), and balance 120 V loads (15%). A 4-wire system was recommended on 7% of farms and an equipotential plane on 4% of farms. Other mitigation methods were recommended on less than 1% of farms.

The off-farm mitigation methods implemented by the utility were reported as follows:

Off-Farm Mitigation Methods Implemented	% of Farms
Improve Grounding	16.1
Increase size of Primary Neutral Conductor	13.9
Install Neutral Isolator	7.2
Rebuild Distribution Line	4.4
Install Underground Primary Conductor	1.6
Balance Primary Loads	1.0

The most common off-farm mitigation methods implemented by utilities were improved grounding of the distribution system (16%), and increased size of the primary neutral conductor (14%). Neutral isolators were installed on 7% of farms; the distribution line was rebuilt on 4%

of farms, underground service conductors installed on 2% of farms and the primary load balanced on 1% of farms.

The on-farm and off-farm mitigation methods that had been implemented by the applicants to SVAT were reported as follows:

Methods Implemented	# of RESPONSES	% YES
Add Grounding	211	77
Rewire Barn	186	62
Add Bonding	181	43
Add Isolation Device	163	41
Add Equipotential Plane	163	30
Change Work Routines	151	27
Add Active Voltage Suppression Device	150	17

Note that the applicants to the SVAT had already had one or more stray voltage investigations performed by the utility or other investigator and many had implemented mitigation methods. The most common methods reported are improved grounding (77%), rewiring the barn (62%), adding bonding (43%) installing an isolation device (41%), and installing an equipotential plane (30%).

The applicant to the SVAT reported that they had previously contacted the following types of individuals in regard to their stray voltage concern:

Applicant Contacted	Responses	% Yes
Utility	252	96
Veterinarian	213	84
Electrician	225	80
Equipment Dealer	214	73
Feed Dealer	189	59
Consultant	188	59
Phone Company	173	35

The main concerns indicated by applicants to the SVAT were as follows:

Concern	Responses	%Yes
Increased SCC	284	87
Reduced Milk Production	279	78
Foot/Leg Problems	284	77
Uneven Milkout	285	76
Nervous Cows	284	75
Increased Mastitis	284	72
Poor Milk Let Down	285	70
Small/Weak Calves	284	52
Water Intake	285	50
Feed Intake	285	46
Other	283	26

SUMMARY

Data from more than 2900 stray voltage investigations performed in Wisconsin by Investor Owned Utilities (IOU) and the Stray voltage Analysis Team (SVAT) are reported. Data includes electrical characteristics of both the distribution and on-farm wiring systems as well as rolling herd average milk production (RHA) and bulk tank average somatic cell counts (SCC). More than 85% of the first investigations reported maximum primary and secondary neutral-to-earth voltages less than 2 volts rms. More than 90 percent of investigations reported maximum cow contact voltages less than 1 volt rms. The distribution of variables measured by the SVAT and IOU investigators compared well, indicating that consistent testing methods are being used.

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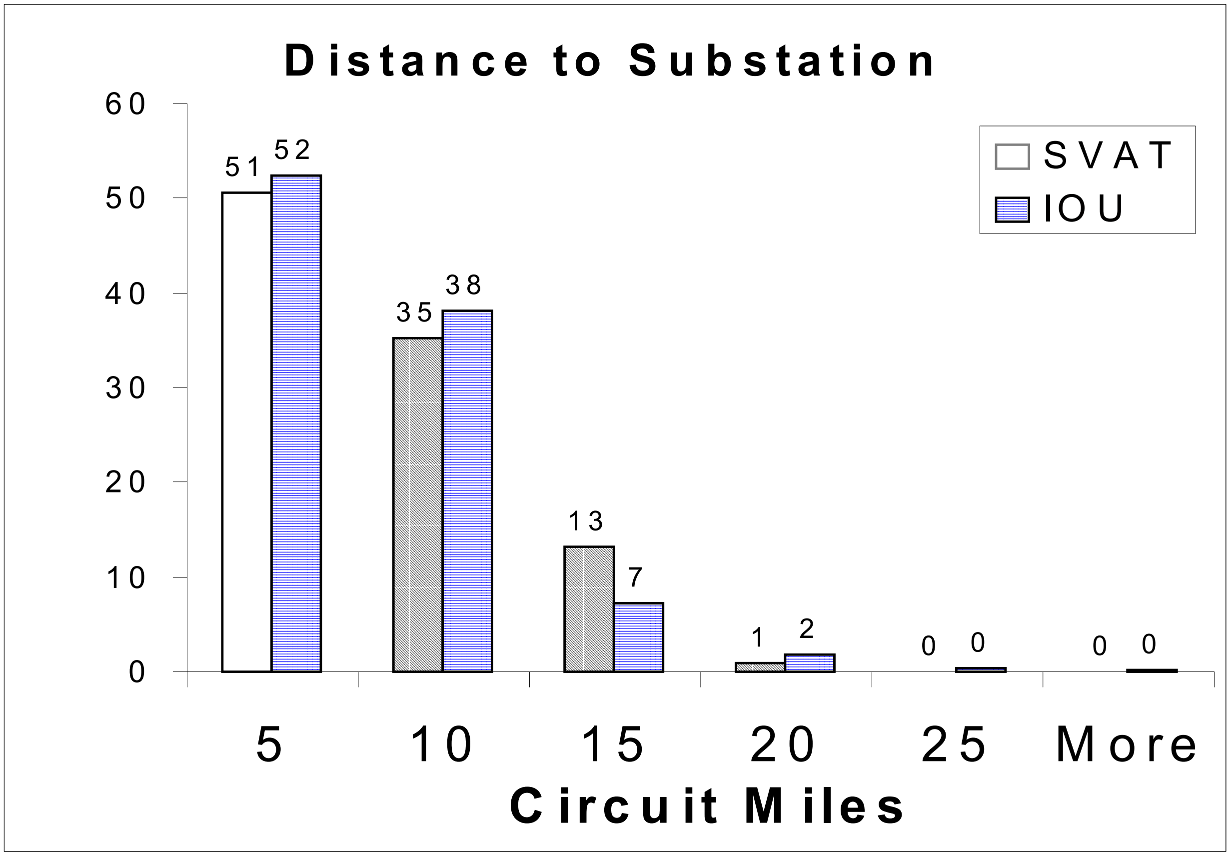
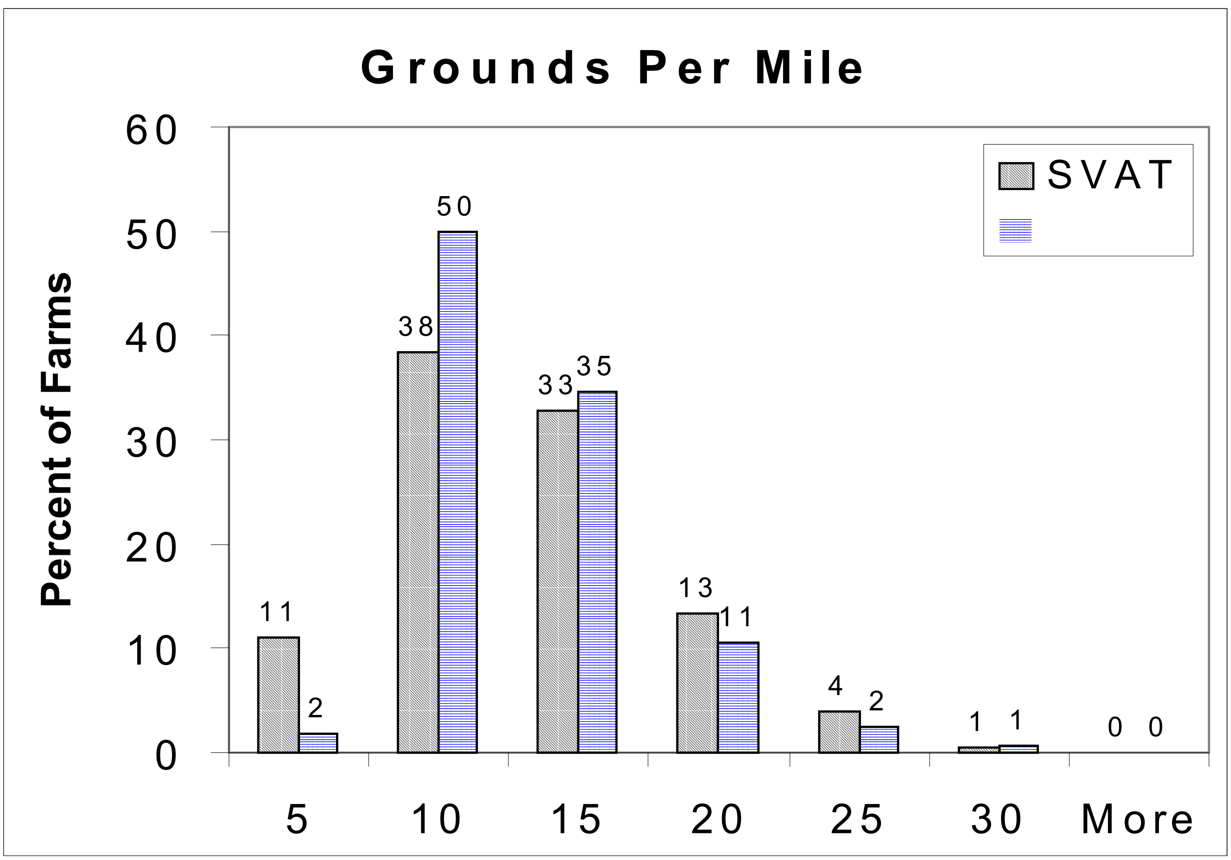
Figures 1 and 2.





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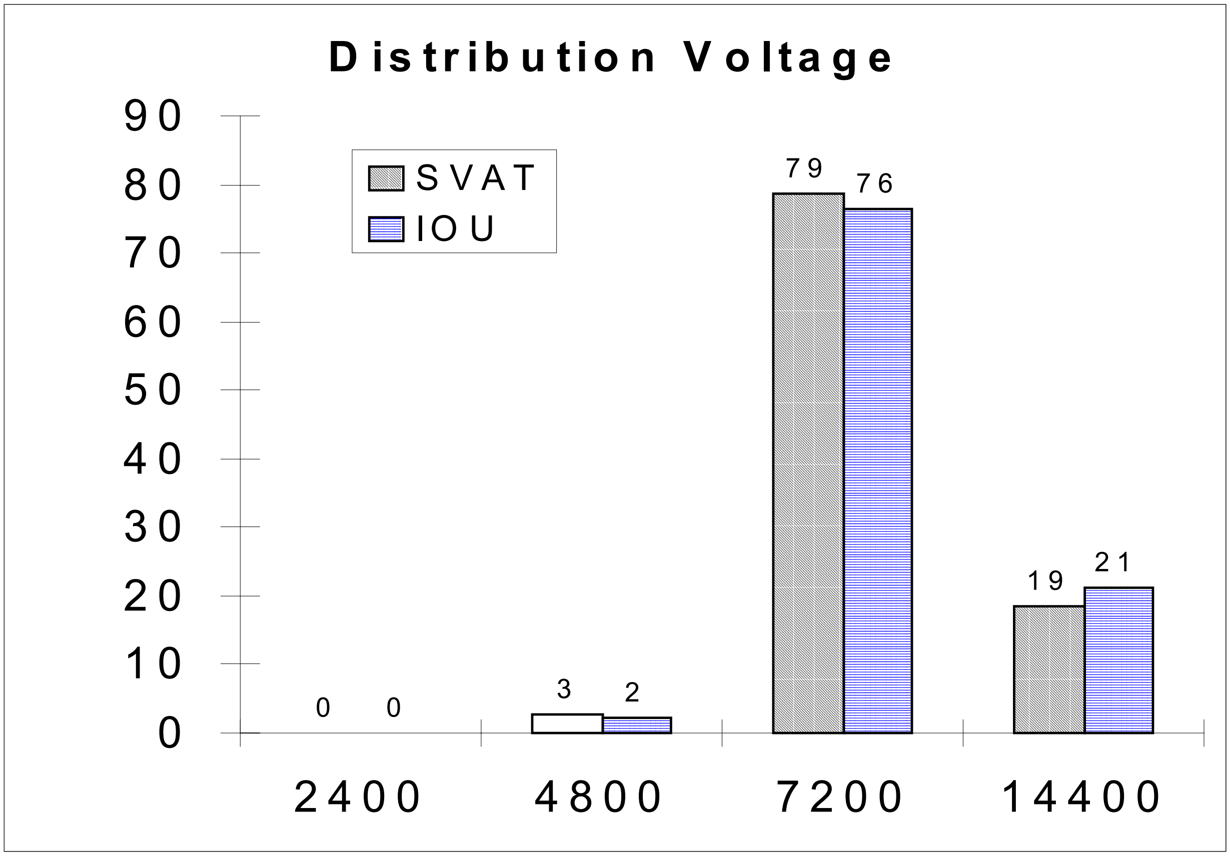

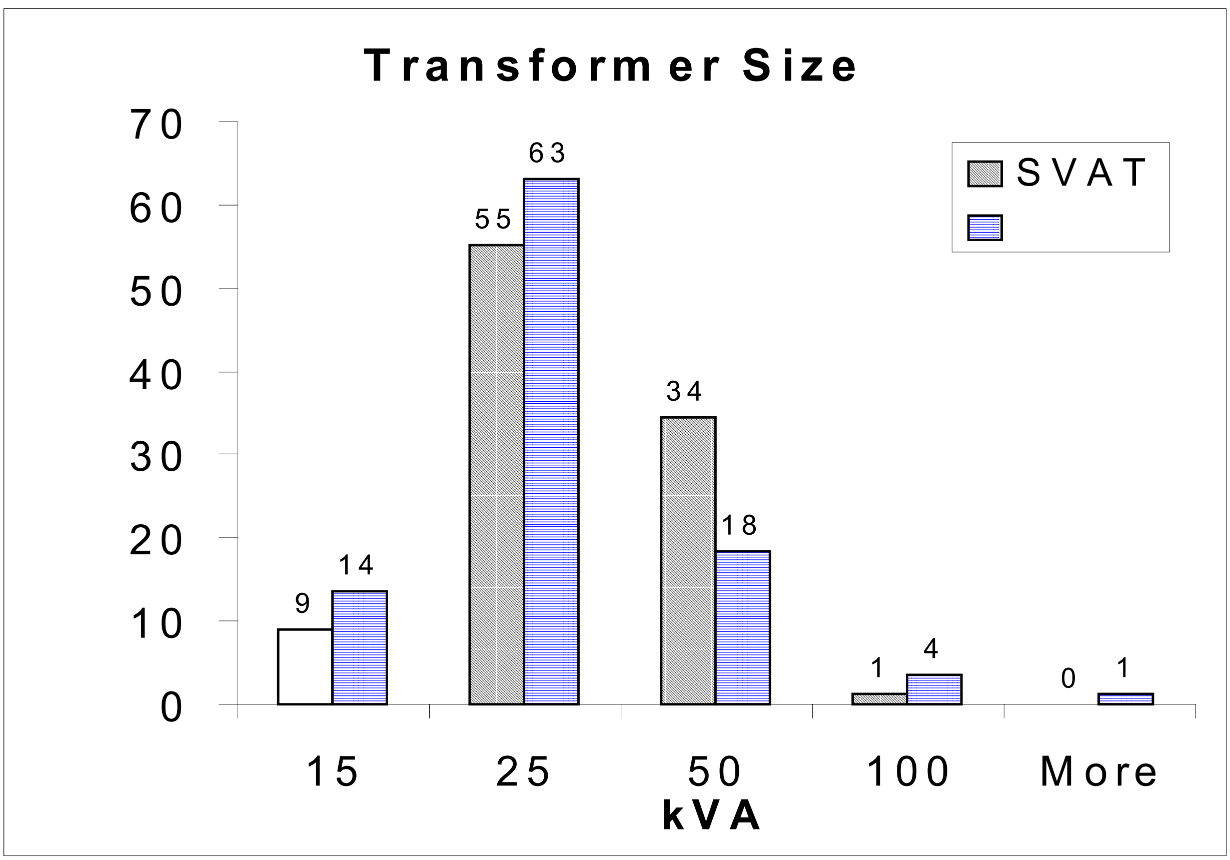

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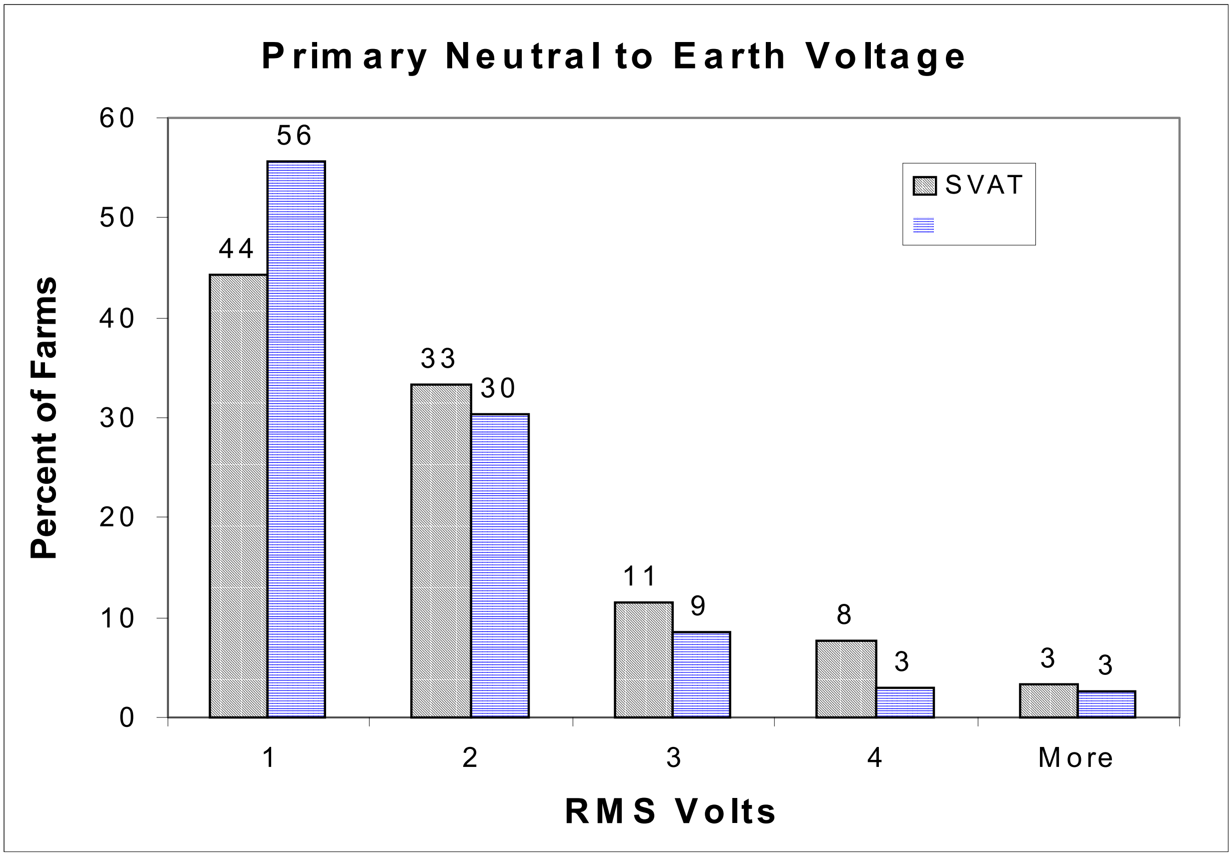
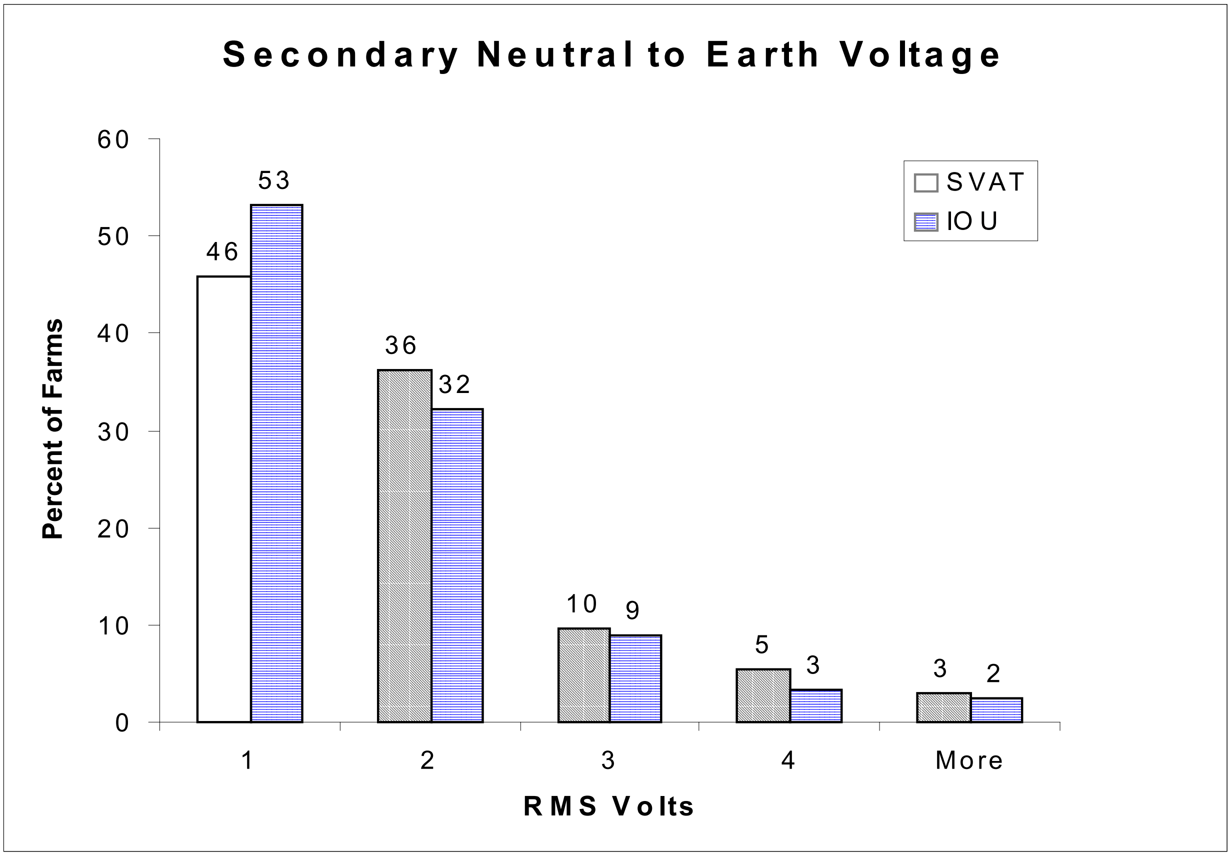
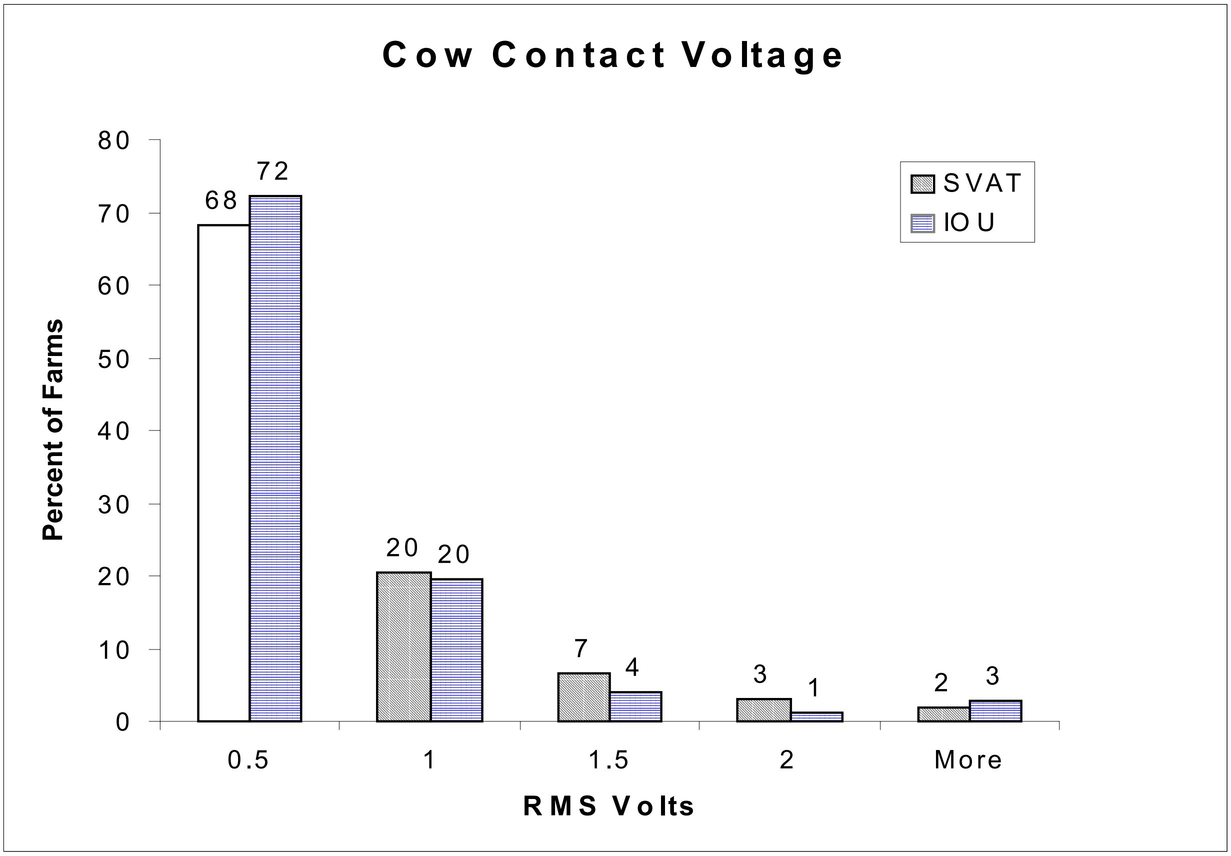
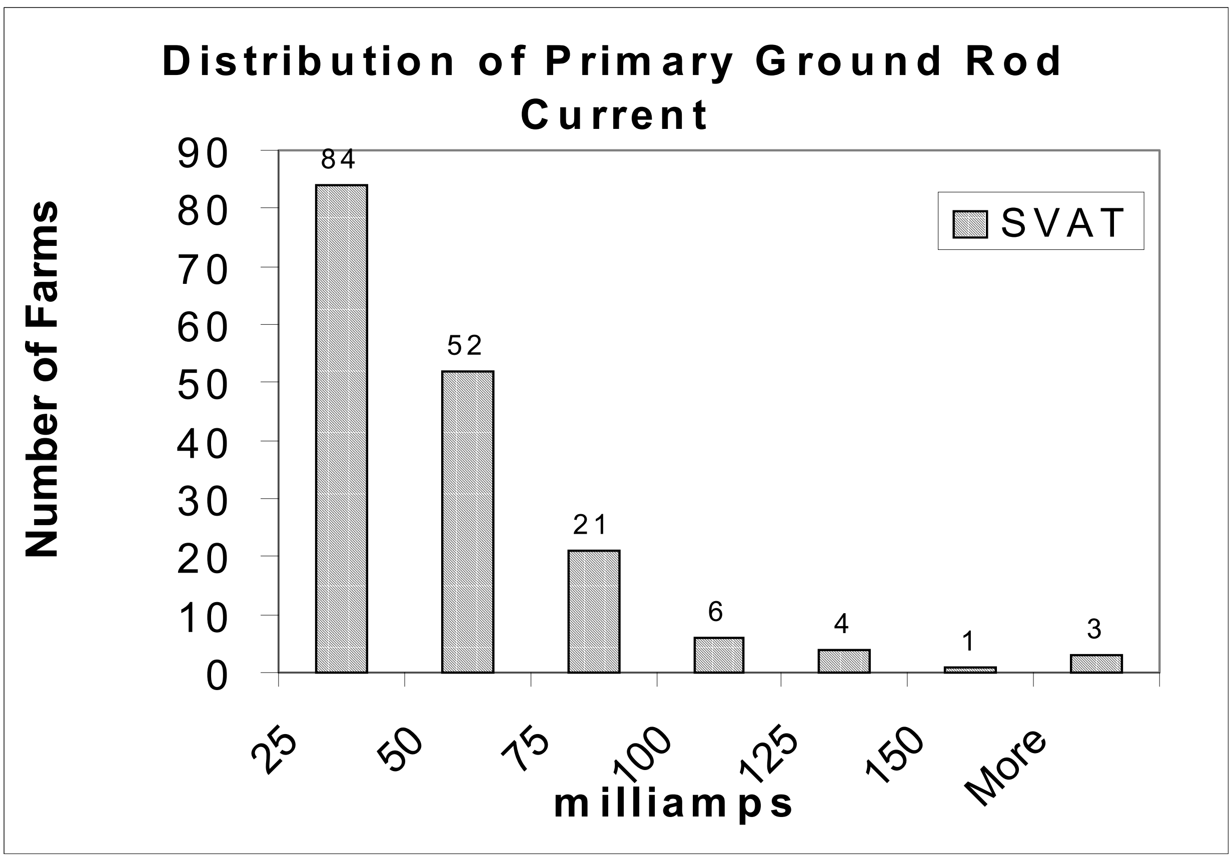


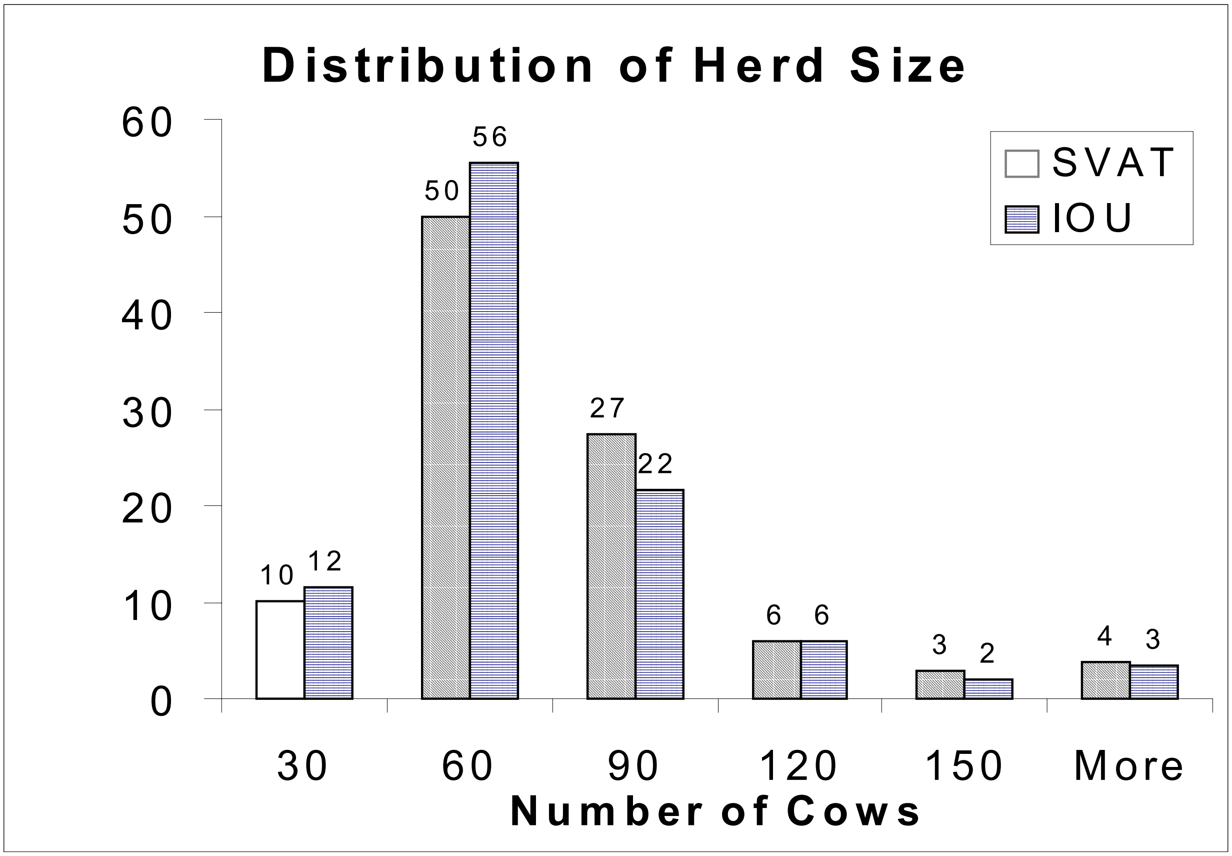


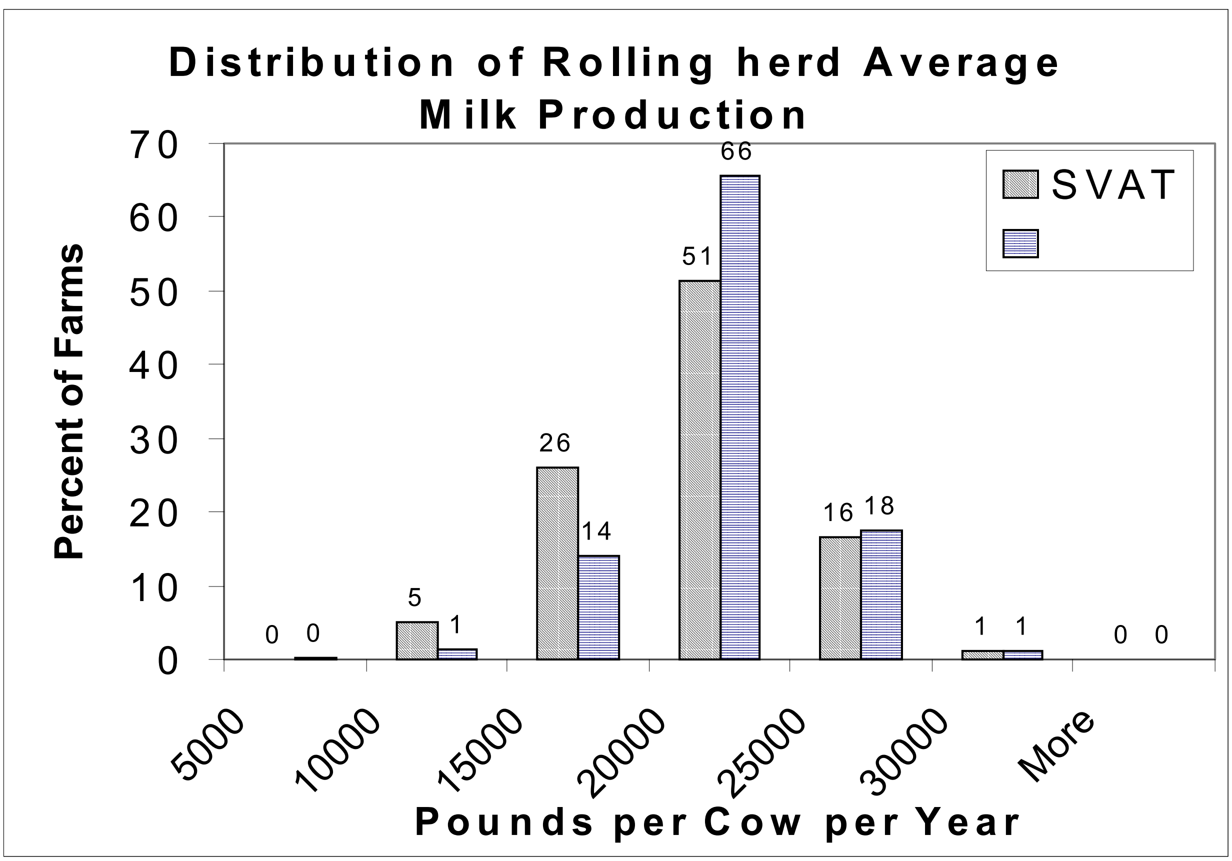
Figures 7 and 8.





Figures 9 and 10.





Figures 11 and 12.