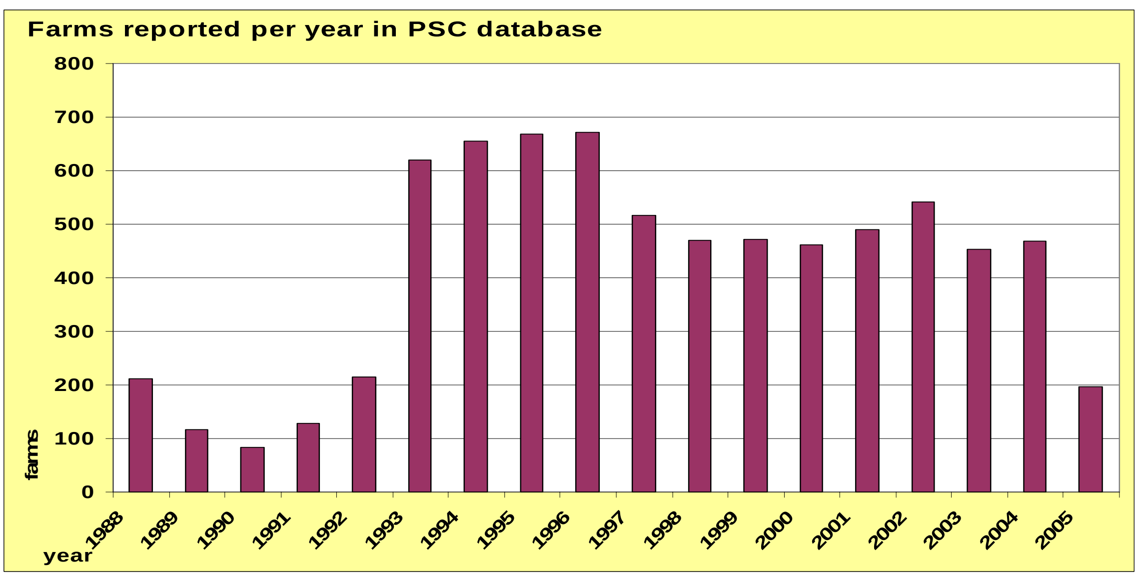
Public Service Commission of Wisconsin

Stray Voltage Phase I and Phase II
Combined Database Summary
January 26, 2006

Since 1988, the Public Service Commission (PSC) has been accepting data filed by the five major investor-owned utilities (IOU's) regarding certain aspects of their stray voltage (SV) Phase I investigations. Recently, the database has been expanded to include extra fields from their Phase II investigations. The Wisconsin Electric Cooperative Association has also been submitting some data on behalf of a number of its members in the last few years. Please refer to the glossary in Appendix A for definitions of various terms and acronyms use in this document. All voltage and current data is express as rms, 60-Hz, AC, steady state.

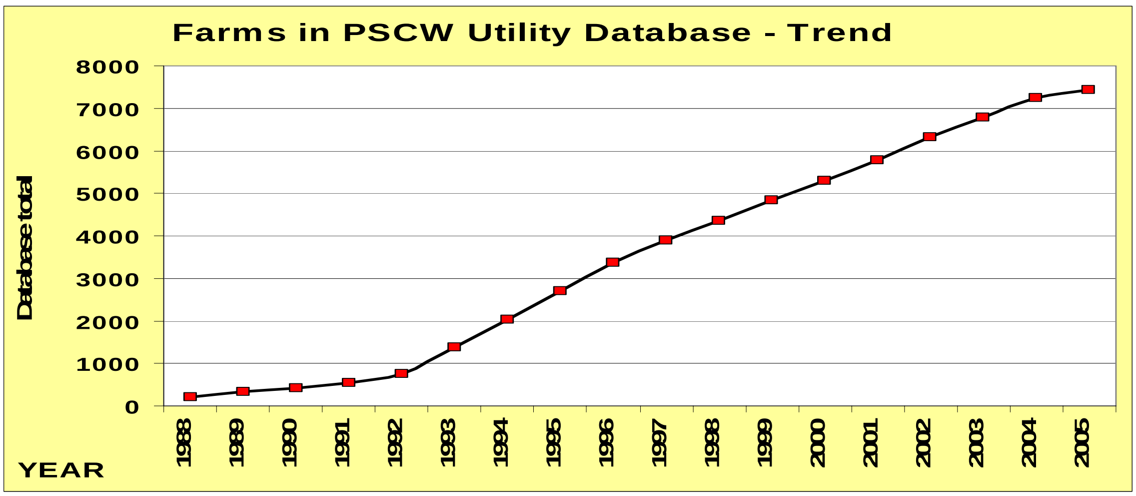
To date, the PSC SV database has entries from 7,441 farms. A separate database of Phase II primary profiles now has data on 12,430 grounded distribution poles. The data from these databases is summarized in this paper. A statistical summary for each parameter is presented along with correlations and contrasts between some of the parameters. All of the submitted data is accepted as it comes in. Some data are suspect as the magnitudes do not seem within a reasonable range, but are included and will appear as statistical outliers. Entries of zero or blank fields are treated the same – as a 'no report' condition.



There were very few submissions to the database in the first five years of record keeping, but the last thirteen years has shown a relatively steady level of submissions. Only half of the 2005 data had been received by the time this report was prepared.

The data can be analyzed and presented using several statistical methods. Each numerical parameter has an overall average along with a 5-number summary that lists the minimum value, the median value, the maximum value along with the first and third quartile values. The distribution of values for each parameter is summarized in a graph or a table that lists the percent of entries that fall within a specific range of values. These statistics provide a standard yardstick against which any subsequent data point collected in the field can be compared to see how it measures up and where it falls within the known range of reported values.

A historic trend of the values versus the year they have been submitted is also presented in graphic form. Lastly, a correlation is usually made with the most important parameter, the average cow contact current, to see if the parameter in question may have any influence on the magnitude of current that can be measured at the animal contact point or itself be influenced by the cow contact current.



The data are divided up into electrical and similar parameters and farm and miscellaneous parameters as follows.

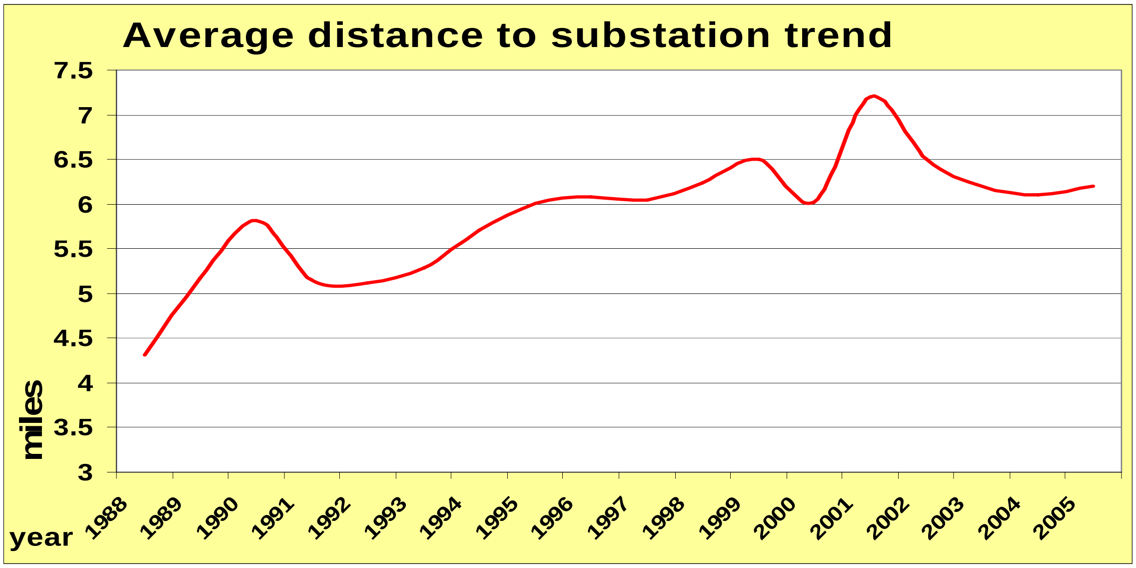
Electric parameters			Farm/misc. parameters
Location within WI	Rshunt	Load box test Rprimary	Fencer status
Distance to substation	Vp Primary neutral-to-reference voltage	Load box test Rfarm	Stanchion/other milking
Grounds per mile	Vs Secondary neutral-to-reference voltage	Load box test K-factor	Pipeline/other delivery
End-of-line status	Vcc Cow contact voltage	Load box test CRR – current return ratio	Electric/pneumatic pulsation
Primary Voltage	Icc Cow contact current	Secondary neutral voltage drop test Vdrop	Herd size
Neutral Conductor Resistance/mile	Vcc source on/off farm status	Primary profile current Ipp	Test program
Transformer kVA rating	As-found mitigation	Primary profile resistance Rpp	Milk production level
Measured Vps drop	Recommended on-farm mitigation	Primary profile voltage Vne	Somatic cell count (SCC) level
Secondary phase arrangement	Recommended off-farm mitigation		
Rsource	Recommended neutral isolation		

ELECTRICAL PARAMETERS

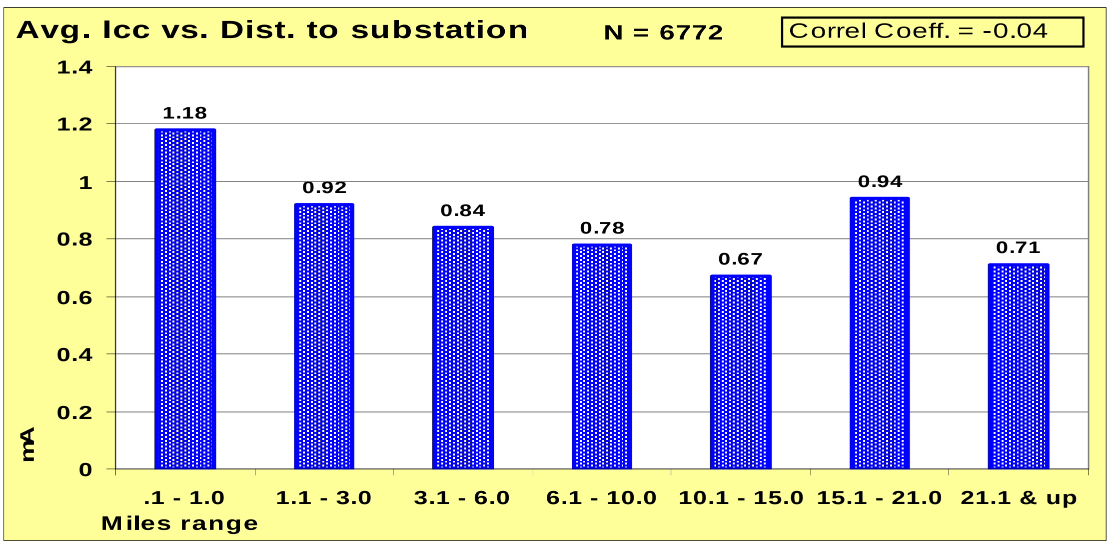
1) Distance to Substation

This parameter is defined as the circuit miles from the farm being investigated to its serving distribution substation.

	7 number summary	UNIT		Distribution Range	% in range
Average	6	mile		0.1 - 1.0	3.3
Minimum	0.1	mile		1.1 - 3.0	20.1
1st quartile	3.5	mile		3.1 - 6.0	39.6
Median	5	mile		6.1 - 10.0	25.5
3rd quartile	7.8	mile		10.1 - 15.0	9.1
Maximum	55	mile		15.1 - 21.0	2.0
Entries, N	7,068			21.1 & up	0.4



The trend indicates that in the early years of the SV program at the PSC, most farms that were investigated by the IOU's were closer to the substation. Recently, there is a trend to investigate farms that are farther away from the substation. From 1988 to 2005, the average distance has increased 44%.



There is a slight visual correlation between cow contact current levels and being too close or too far from the substation. The data is skewed by the fact that early investigations (1988 – 1993) found higher levels of stray voltage than are found today and these farms were close to the substation. The mathematical correlation coefficient indicates a very weak link between distance and cow contact current.

2) Location

One of nine specific areas of the state where the farm is located is submitted as a data point. The areas are named central, east central, north central, northeast, northwest, south central, southeast, southwest and west central. They are determined by a table look-up based on the county in which the farmstead is located. The average cow contact voltage and the average secondary neutral-to-reference voltage for each of the nine locations is shown in the following table.

	Avg Vcc (Volts) vs. location:		
Avg Vcc	0.47	0.28	0.33
points	315(NW)	645(NC)	428(NE)
Avg Vcc	0.38	0.33	0.30
points	362(WC)	824(C)	1,612(EC)
Avg Vcc	0.51	0.48	0.62
points	987(SW)	1,214(SC)	161(SE)
total points	6,548		
	Avg Vs (Volts) vs. location:		
Avg Vs	1.42	1.07	1.19
points	320(NW)	645(NC)	427(NE)
Avg Vs	1.29	1.18	1.03
points	369(WC)	827(C)	1,503(EC)
Avg Vs	1.31	1.28	1.44
points	981(SW)	1,205(SC)	159(SE)
total points	6,436		

We can calculate an average K-factor (defined as Vcc/Vs) for each of the nine locations as follows:

Average K-factor (N = 6,079) in percent from above data Overall average = 29%		
29(NW)	24(NC)	27(NE)
28(WC)	26(C)	27(EC)
32(SW)	33(SC)	37(SE)

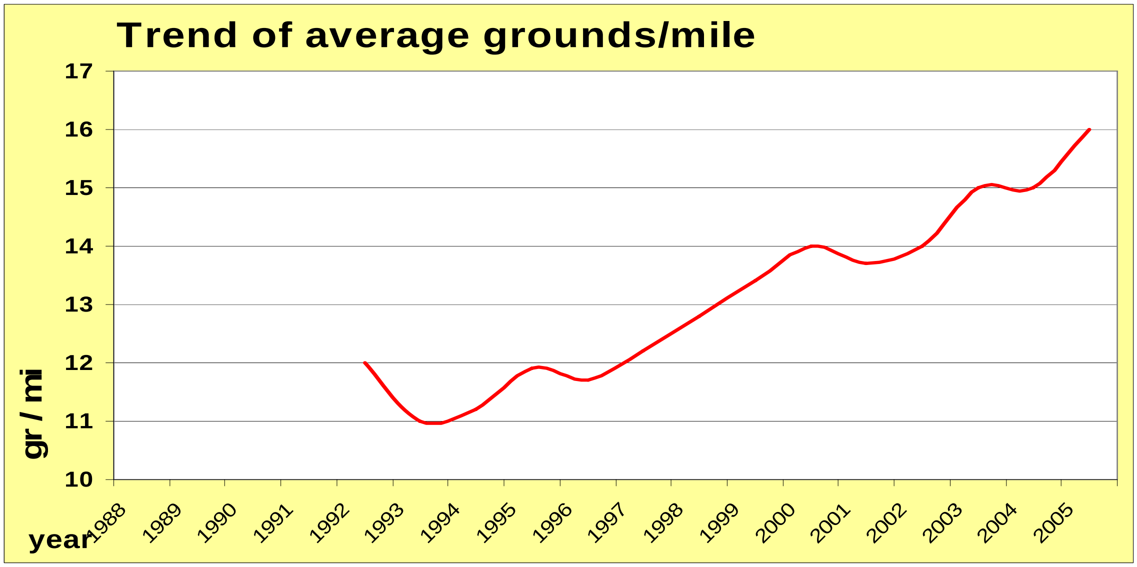
The average K-factor for the state is therefore 29% which agrees well with the typical value of 33.3% predicted by the PSC REPS team.

3) Grounds per mile

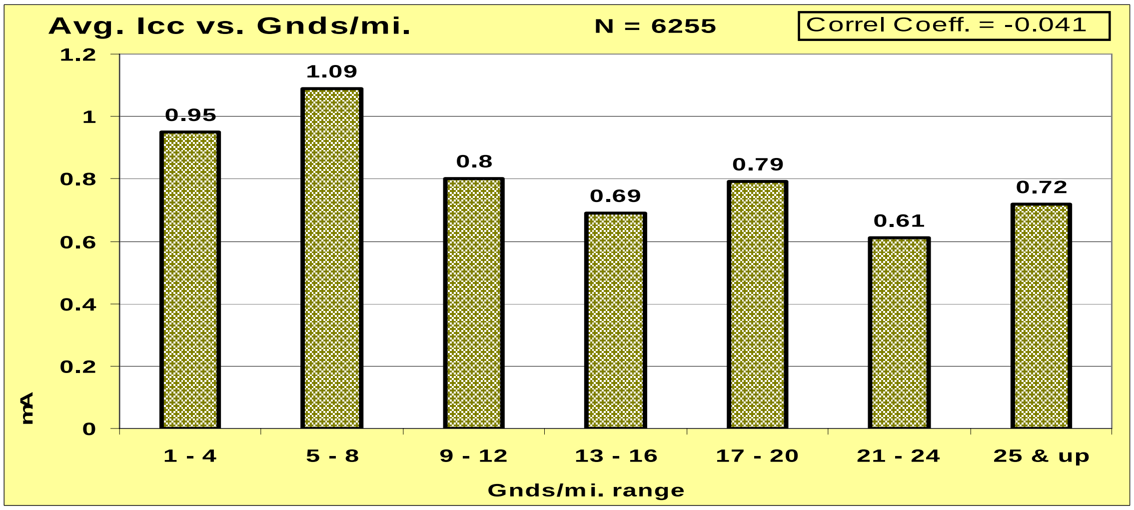
This parameter is defined as the average number of neutral-to-earth grounding electrode connections on the primary distribution system per mile in the area of the farm towards the substation.

	7 number summary	UNIT		Distribution Range	% in range
Average	13	Grnds/mile		1 - 4	0.6
Minimum	1	Grnds/mile		5 - 8	5.0
1st quartile	9	Grnds/mile		9 - 12	53.7
Median	12	Grnds/mile		13 - 16	20.1
3rd quartile	15	Grnds/mile		17 - 20	11.1
Maximum	33	Grnds/mile		21 - 24	6.9
Entries, N	6,418			25 & up	2.6

Wisconsin has always required nine grounds per mile in any continuous one mile section for overhead distribution systems and 4 grounds per mile for underground distribution systems. The measurement is made starting at any point on the line to include at least one mile, if possible, or a prorating thereof. Modified in 1996, PSC ch. 114.096C now requires a connection between the distribution neutral and a grounding electrode at every pole for all new rural overhead construction.



No data for this parameter was submitted before 1992. The trend shows the effect of the 1996 change in code, as there was an overall decrease in the recorded average grounds per mile between 1992 and 1996 of 2.5%. From 1996 to 2005, however, the average has increased 37%.



There is an extremely weak mathematical correlation between the number of grounds per mile in the area of the farm and the maximum average level of cow contact current recorded.

The following table shows that underground (UG) conductors, some of which are open concentric cables with continuous contact with the soil, have that lowest average cow contact current associated with them compared to overhead (OH) conductors. It also demonstrates that copperweld (CW) and small wire gauge conductors are associated with higher average cow contact currents.

	Avg Icc	N
UG conductors - any gauge	0.64	201
OH conductors (non-CW) #4 to 336MCM	0.77	3,852
OH conductors (CW or steel) any gauge	0.98	2,102
OH conductors (non-CW) #6 and smaller	1.19	177

4) End-of-Line (EOL)

A notation is made of the status of the farm as to whether on not it is an end-of-line customer. The first docket for SV before the PSC contained concerns that EOL customers might have more stray voltage due to less or no grounding past the farm. By PSC definition, a customer is considered end-of-line if s/he is the last customer of a radial feeder or is on a tap at least 1/2 mile from a distribution line going in two different directions from the tap.

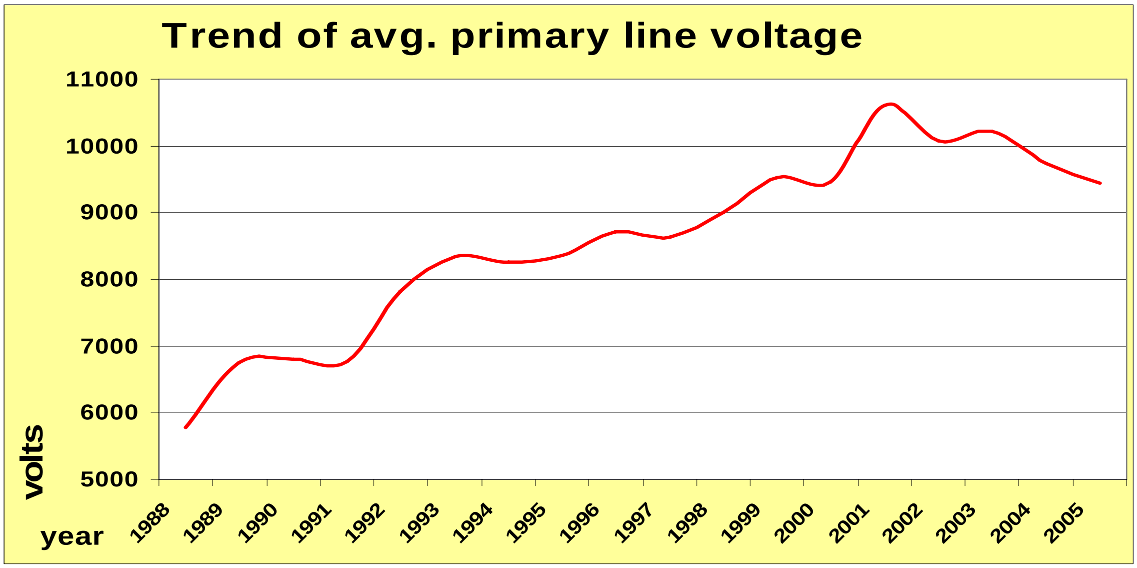
EOL Status?	Avg Icc mA	N =	Avg Grnd/mi	Avg. Dist. to subst.	DHI/ No DHI	Avg. HERD size	Avg. PRIM. VOLT.	Avg. kVA rating	Avg. Neutral Ohm/mi	Avg. Vs Volts	Avg. Rfarm Ohms	Avg. CRR %
No	0.82	5,696	13.1	5.9	63/37	88	8,931	43	1.8	1.1	2.1	76
Yes	0.99	1,385	12.7	6.5	58/42	80	8,581	38	2.1	1.5	2.8	68

There is higher average cow contact current associated with end-of-line farms, but many other parameters suggest that the end-of-line status alone is not the sole factor in the higher average. The farms that are end-of-line also are smaller, have less DHI management systems, are farther from the substation, have fewer grounds per mile in the area, tend to be on lower primary voltage systems, have smaller transformers, have smaller primary neutral conductors associated with them, have higher on-farm neutral voltages, have less on-farm grounding and have less return current on the neutral conductor. These and other confounding factors make much less clear the issue of if end-of-line status alone contributes to higher animal contact current.

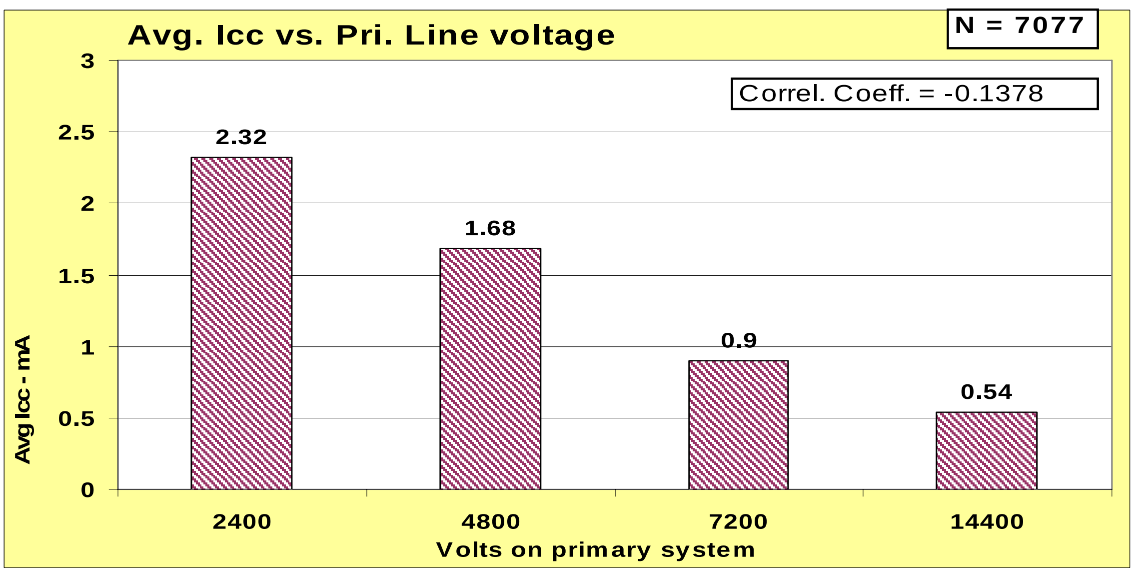
5) Primary Voltage

Distribution systems in Wisconsin are designed to operate on several different system voltages, depending on the design standards of the individual utility that serves the farm. Older systems and those that feed out of small communities are usually lower voltage systems compared to others. The common distribution voltages in Wisconsin are: 2,400, 4,160, 4,800, 5,464, 7,200, 7,960, 8,320, 12,470, 13,800, 14,400, 23,900, and 24,900. Some of these are measured phase-to-phase and some are phase-to-neutral. Only 5.9% of the reported farms are not fed from 7,200-Volt or greater systems. These were usually the farms reported from 1988 to 1992.

	7 number summary	UNIT		Distribution V. range	% in range
Average	8,910	AC Volts		2,400	0.5
Minimum	2,400	AC Volts		P4,800	5.4
1st quartile	7,200	AC Volts		P 7,200	68.1
Median	7,200	AC Volts		P 14,400	26.0
3rd quartile	13,800	AC Volts			
Maximum	24,900	AC Volts			
Entries, N	7,435				



There is an overall trend in Wisconsin to increase rural distribution system voltage levels, but it has flattened out in the past 4 years. On its own initiative, Wisconsin Public Service Corp. began a 7,200-to-14,400 Volt conversion program many years ago. Wis. Electric Co. has been successfully implementing a 15-year rural rebuild (and voltage conversion) program for the past 12 years. Other utilities rebuild to higher system voltages as the needs of each situation dictates.

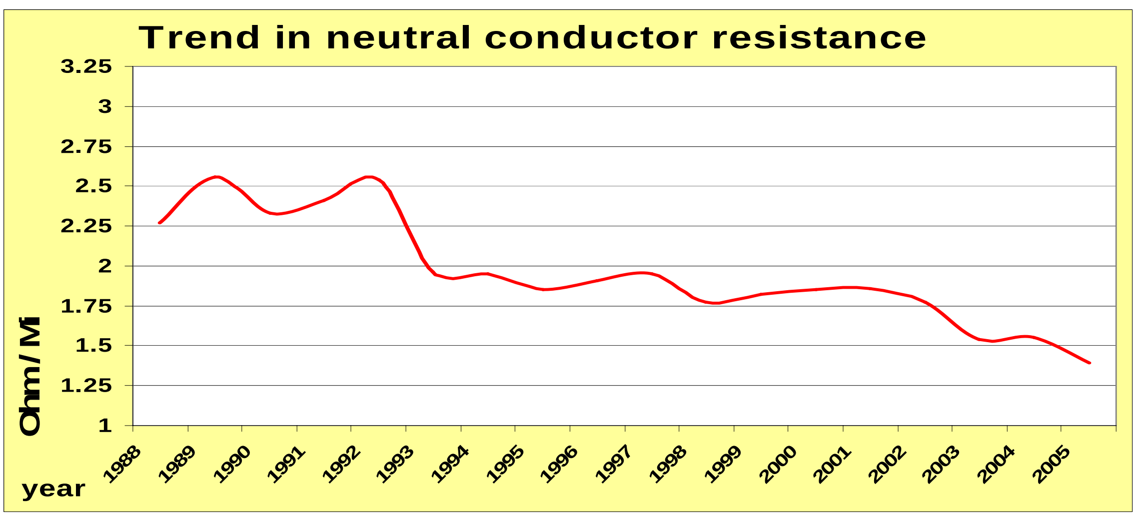


There is a distinct visual correlation to the relationship of primary system voltage level to average cow contact current. The mathematical correlation coefficient is moderate, but remember that the bar for 2,400 Volt only represents 0.5% of the systems and the next bar only 5.4 % of the systems reported.

6) Neutral conductor resistance

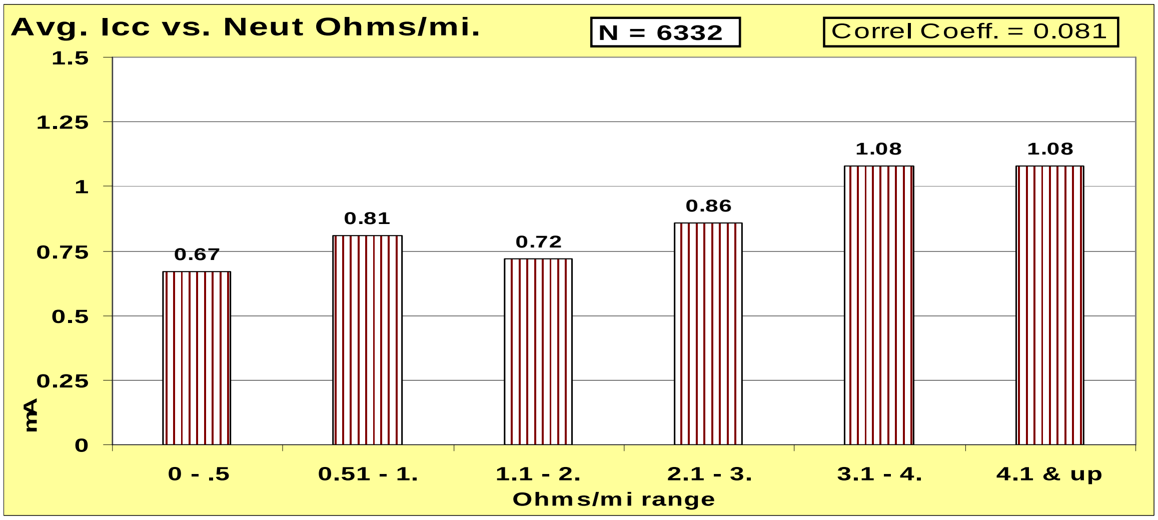
Each utility reports the gauge and material for the majority of spans of primary distribution system neutral conductor feeding the farm's transformer. This is converted to an 'Ohms/mile' resistance from a conversion table at the PSC. Smaller gauge and non-copper conductors have higher resistance per mile, which is a contributor to higher neutral-to-earth voltages for given loads on the primary distribution system.

	7 number summary	UNIT		Distribution range	% in range
Average	1.87	Ohms/mi.		0 - 0.5	3.8
Minimum	0.17	Ohms/mi.		0.51 - 1.0	23.8
1st quartile	0.89	Ohms/mi.		1.1 – 2.0	31.5
Median	1.41	Ohms/mi.		2.1 – 3.0	18.3
3rd quartile	2.27	Ohms/mi.		3.1 – 4.0	22.4
Maximum	18.99	Ohms/mi.		4.1 & up	0.2
Entries, N	6,664				



On average, 77.4% of the neutral conductors have a unit resistance of 3.0 Ohms per mile or less. As rural distribution rebuilds progress in this state, the standard conductor for neutrals has increased in gauge from the previous small conductors to anywhere from a 1/0 ACSR to a 336 MCM ACSR (Aluminum Conductor Steel Reinforced) wire (0.89 to 0.28 Ohms/mi). Since 2000, the PSC has been tracking the prevalence of old copperweld conductor used during World War II as a measure to conserve copper, which was critical for the war effort. There is currently about 25,900 circuit miles of this conductor reported in the state and each year that number is decreasing as it is being replaced with more modern types. The farms investigated early in the program were located on rural distribution systems that had small gauge neutral conductors, typically 6A and 8A copperweld. From 1988 to 2005, the average neutral conductor resistance has decreased 39%.

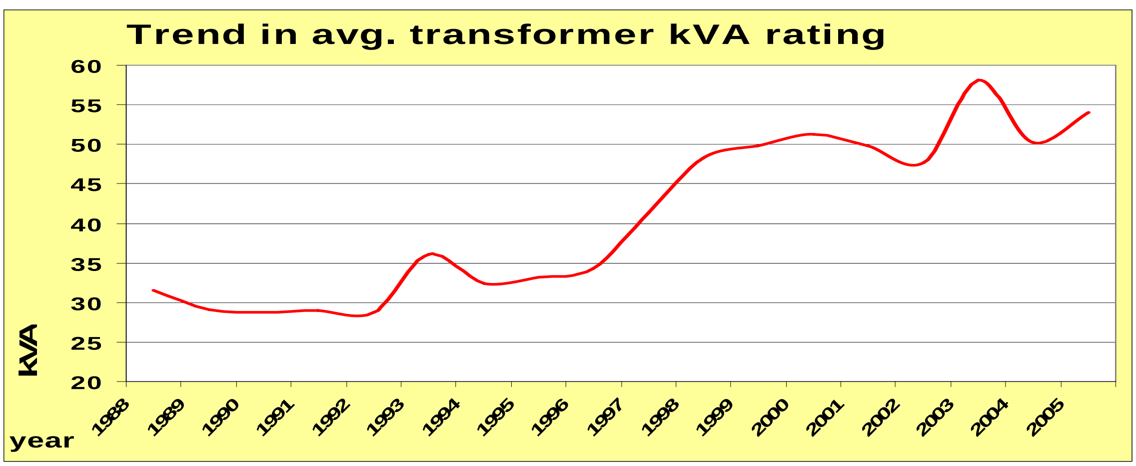
The statistical correlation between neutral conductor resistance and average cow contact current is very weak, but one could speculate that very small gauge resistive distribution neutral wires (above 3 Ohms per mile) can be a contributing factor to elevated neutral-to-earth voltages on the distribution system.



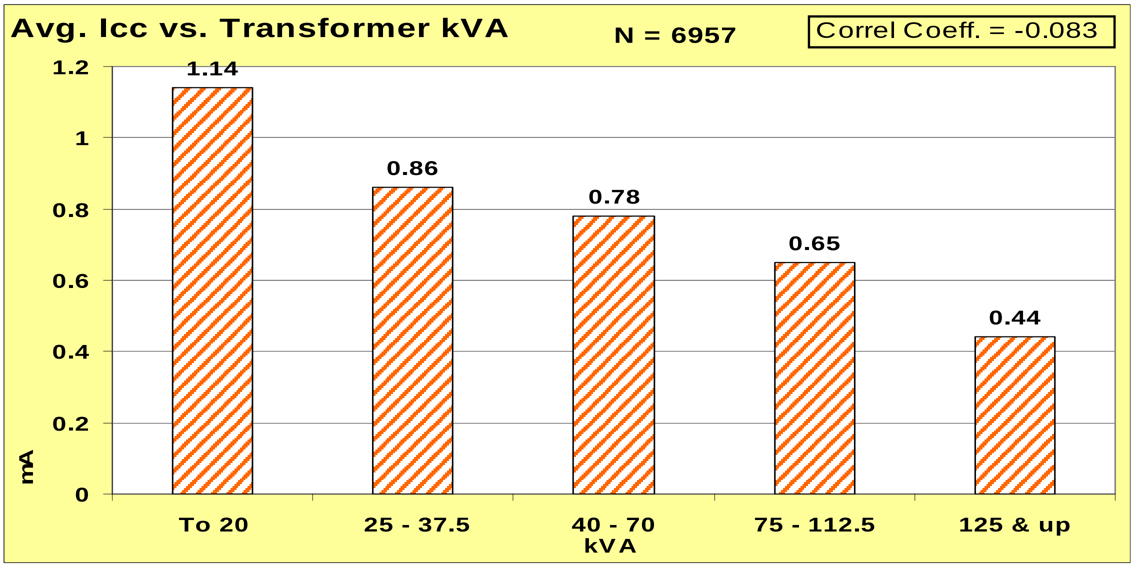
7) Transformer size

This parameter is the kVA (kiloVoltAmp) rating of the transformer or transformers serving the farm. As the farm grows, the transformer that supplies the farm distribution system, usually a 240/120 single phase system, must keep pace with the demand of all the major farm loads and be sized appropriately. The overall average size is between a 37.5 kVA and a 50 kVA and this past year the average was over 50 kVA.

	7 number summary	UNIT		Distribution range	% in range
Average	42.3	kVA		UP TO 20	11.5
Minimum	5	kVA		25 - 30	53.8
1st quartile	25	kVA		37.5 - 50	21.1
Median	25	kVA		75 - 112.5	8.6
3rd quartile	50	kVA		125 & up	5.0
Maximum	500	kVA			
Entries, N	7,300				



The trend clearly shows that the average size of dairy farms in Wisconsin is increasing, as the transformer kVA rating on the farms being investigated is increasing. From 1988 to 2005, the size of the average farm transformer's kVA rating increased 71%.



Although the statistical correlation coefficient between transformer size and average cow contact current is very weak, one could suggest that transformers that are too small for the total farm load may be some kind of contributor to elevated levels of cow contact current, although many other confounding factors are present. This view is skewed by the fact that many larger transformer installations are three-phase systems that contribute very little to average cow contact current levels, as they have no neutral current for balanced three-phase loads. This is borne out by the following table.

Secondary phase arrangement*				
	1	**2**	**3**	**4**
N =	6,117	4	791	88
Avg Icc (mA) =	0.88	0.29	0.60	0.83

* 1 = single-phase, 2 = open Y/open delta, 3 = three-phase and 4 = both single- and three-phase on the same farm.

8) Source resistance, Rs and Shunt resistance, Rsh

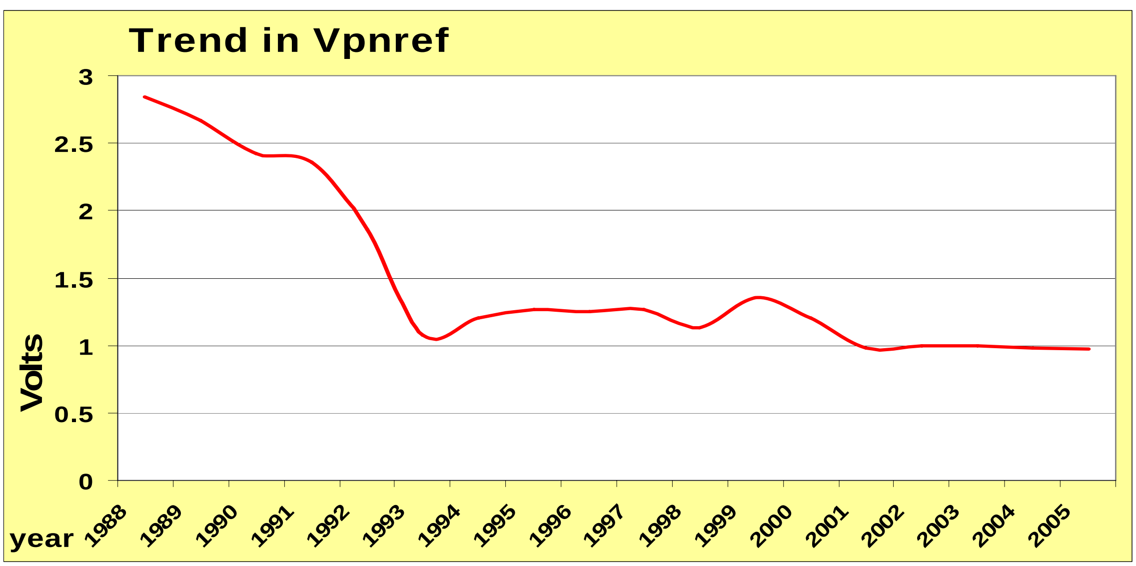
	SHUNT RES.	SOURCE RES.	Distribution Range, Rsource	% in range
Average	505	199.4	UP TO 100	28.1
Minimum	213	1	101-200	40.4
1st quartile	500	95	201-300	15.4
Median	500	148.1	301-400	6.3
3rd quartile	509	235	401-500	6.2
Maximum	663	8,822	501 & up	3.6
Entries, N	7,168	6,406		

The source resistance parameter is a value that has been calculated at the main cow contact location. It is calculated using the open- and closed-circuit voltage reading at the animal contact point. Ideally the value should be less than 500 Ohms, but some physical situations do not allow for lower source resistances. The shunt resistance is typically 500 Ohms in this state per PSC protocol and this nominal value is most often reported. The actual exact value read with an Ohmmeter is occasionally recorded. Source resistance can usually be improved by making better (i.e. lower resistance) connections to either (or both) the muzzle and/or rear hoof contact locations.

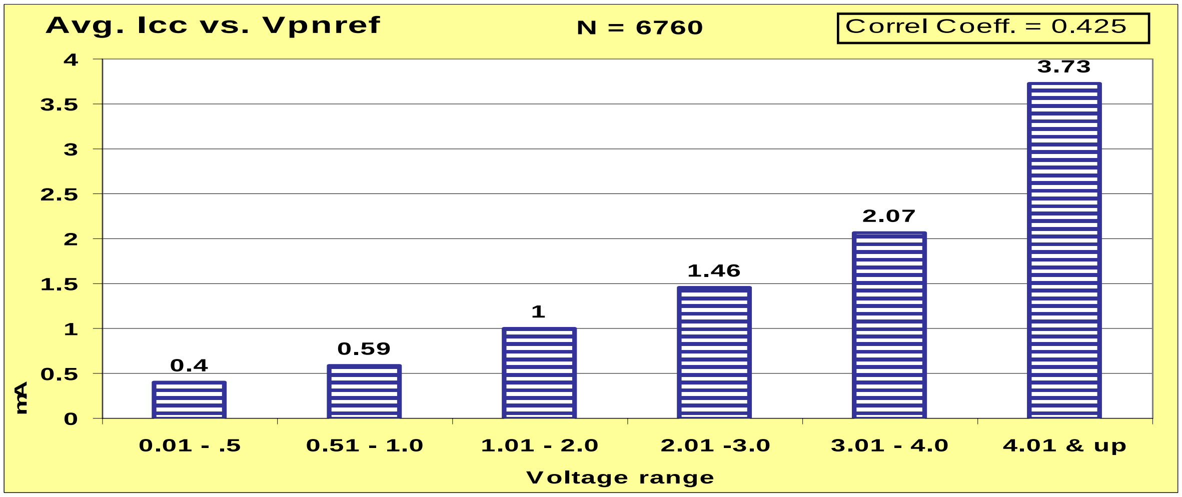
9) Primary neutral-to-earth voltage, Vp

This parameter is measured between the distribution system's neutral grounding conductor at the farm's transformer and a remote reference rod. Primary system neutral voltage can contribute some portion to the cow contact area on non-isolated farms.

	7 number summary	UNIT		Distribution range	% in range
Average	1.24	Volts		0 - 0.5	25.1
Minimum	0.01	Volts		0.51 - 1.0	29.9
1st quartile	0.5	Volts		1.1 – 2.0	30.0
Median	0.92	Volts		2.1 – 3.0	9.0
3rd quartile	1.56	Volts		3.1 – 4.0	3.3
Maximum	30	Volts		4.1 & up	2.7
Entries, N	6,944				



Overall, 94% of the Vp has been at or less than 3.0 Volts. This number is chosen as significant because if the nominal K-factor is 1/3, then one third of 3 Volts is 1 Volt, the PSC "level of concern." The early years of SV investigation revealed that very high neutral-to-earth voltages could be measured on rural distributions systems. No effort had been made up to that time to reduce them because no one measured them before the issue of stray voltage was raised. Distribution system rebuilding and other mitigation efforts of the utilities in Wisconsin have seen this voltage decrease by 66% from 1988 to 2005. It has leveled out at nominally 1 Volt for the last 5 years.

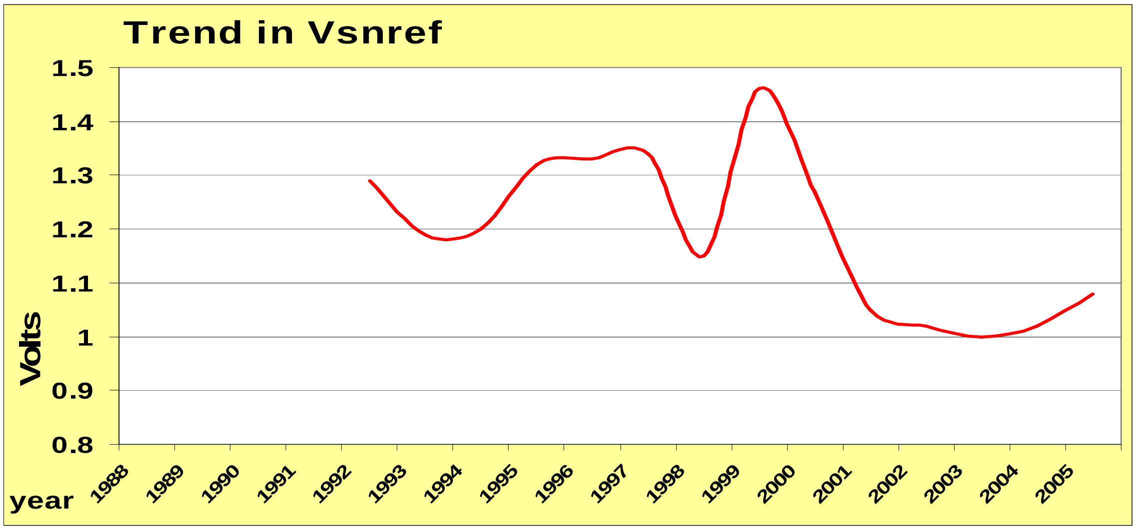


There is a significant statistical correlation between the average primary neutral-to-earth voltage and the average cow contact current. This is consistent with the electrical model that shows that Vp along with Vs, Vps, and Vd are the major contributors to animal contact currents.

10) Secondary neutral-to-earth voltage, Vs

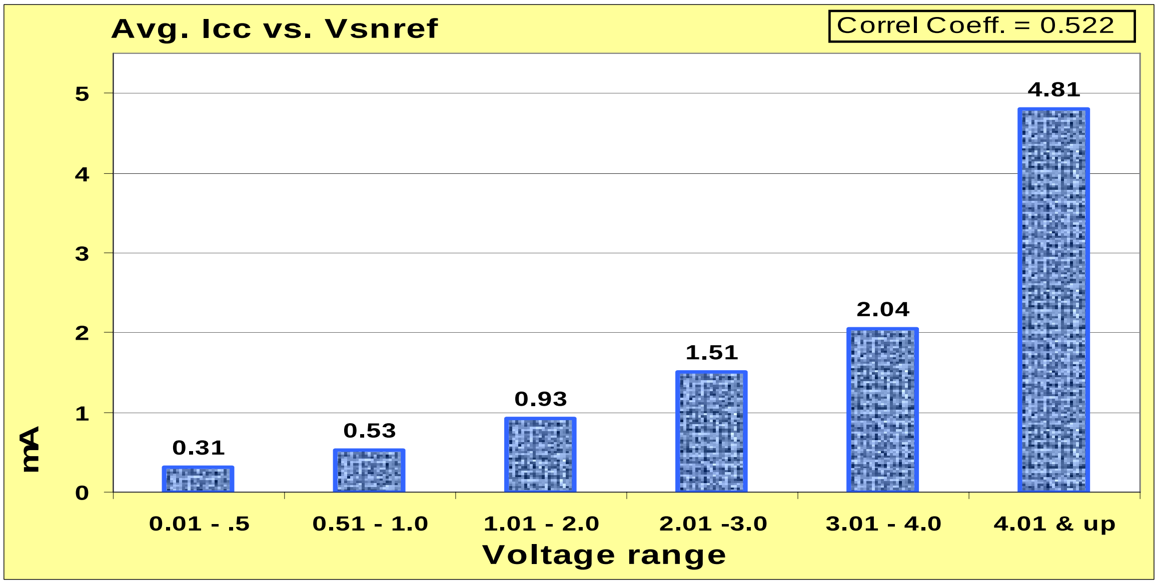
This parameter is measured between the secondary neutral's grounding conductor at the farm's main service entrance panel and a remote reference rod. It is one of the voltages that the secondary system can contribute to the cow contact area. The other voltage arises from differentials on various service drop neutrals on the farm.

	7 number summary	UNIT		Distribution range	% in range
Average	1.2	Volts		0 - 0.5	24.6
Minimum	0.008	Volts		0.51 - 1.0	31.2
1st quartile	0.51	Volts		1.1 – 2.0	31.2
Median	0.91	Volts		2.1 – 3.0	8.1
3rd quartile	1.46	Volts		3.1 – 4.0	2.5
Maximum	40	Volts		4.1 & up	2.4
Entries, N	6,444				



Overall, 95.1% of the readings are at or less than 3.0 Volts. The data was not recorded before 1992. From 1992 to 2005, the value of Vs has decreased an overall 16%. The trend was not favorable until after 2000 when the farm rewiring program was initiated. In the period from 1992 to 1999, it had actually increased 13%, but from 1999 to 2005 it has decreased 26%.

There is a significant statistical correlation between the average secondary neutral-to-earth voltage and the average cow contact current. This is consistent with the electrical model that shows that Vs along with Vp, Vps, and Vd are the major contributors to animal contact currents.



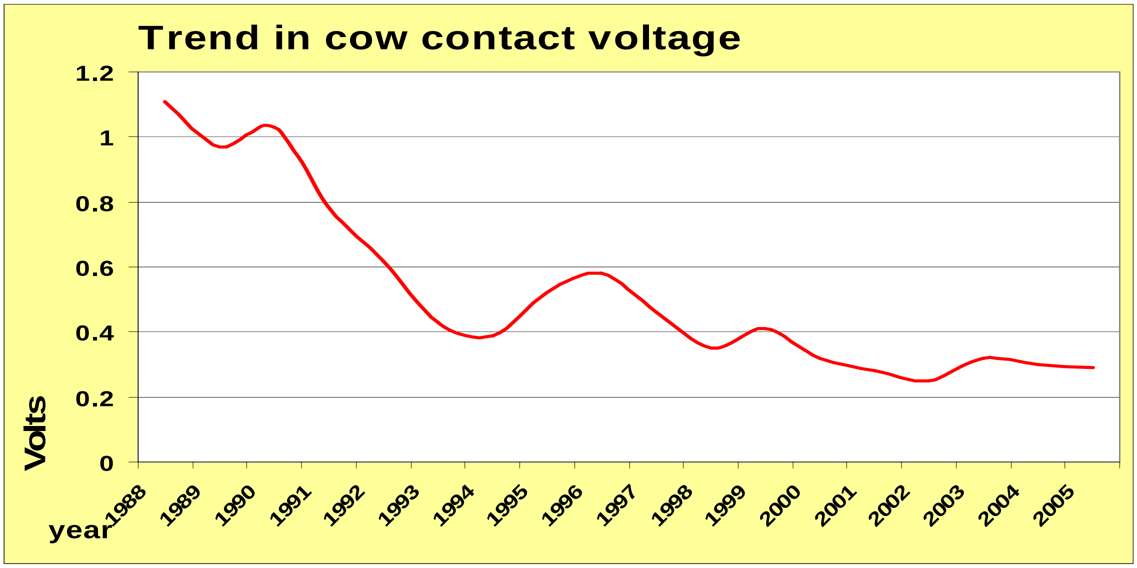
The level of average Vp and Vs is usually very close as the two neutral systems are typically bonded together at the farm. The statistical correlation coefficient between Vp and Vs is 0.736, which explains 86% of the correlation. It could be higher, but some of the data is from farms that have a neutral isolator and the relationship between Vp and Vs is then arbitrary or the farm may have a moderately high resistance between the primary and the secondary neutrals.

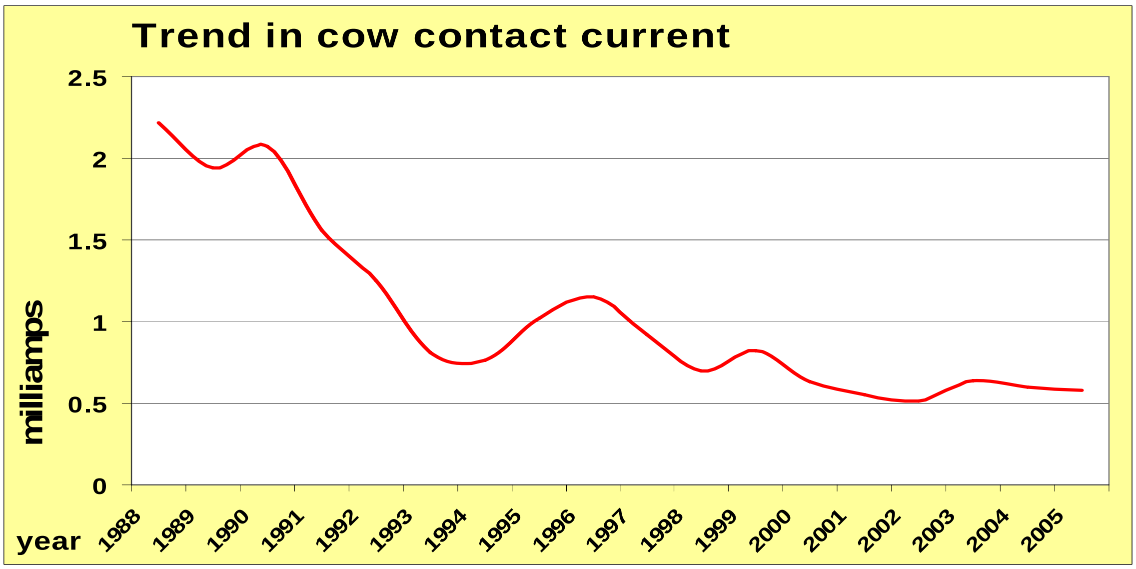
11) Cow contact voltage, Vcc and cow contact current, Icc

These parameters represent the worst case (highest) steady state values found at an animal contact point during the course of the investigation, regardless of the test from which they were measured.

7 number summaries	Vcc	Unit	Icc	Unit		Distribution Range, Vcc	% in range	Distribution Range, Icc	% in range
Average	0.43	Volt	0.85	milliAmp		0 - 0.125	33.4	0 - 0.125	21.0
Minimum	0.001	Volt	0.002	milliAmp		0.126 - 0.25	18.9	0.126 - 0.25	12.8
1st quartile	0.086	Volt	0.17	milliAmp		0.251 - 0.5	21.9	0.251 - 0.5	18.8
Median	0.239	Volt	0.47	milliAmp		0.501 - 1	18.3	0.501 - 1	22.0
3rd quartile	0.513	Volt	1	milliAmp		1.01 - 2	5.2	1.01 - 2	18.0
Maximum	20	Volt	40	milliAmp		2.01 - 4	1.7	2.01 - 4	5.0
Entries, N	7,084		7,083			4.01 & up	0.6	4.01 & up	2.4

Both graphs on the next page show the most important trend in the database, namely a significant reduction in animal contact voltage and current. They have decreased by 74% from 1988 to 2005.





When Icc > 1.0 mA	avg Icc	Unit	N =
off farm source	2.19	mA	1,067
on farm source	2.39	mA	660
When Icc > 2.0 mA	avg Icc	Unit	N =
off farm source	3.88	mA	314
on farm source	4.94	mA	189

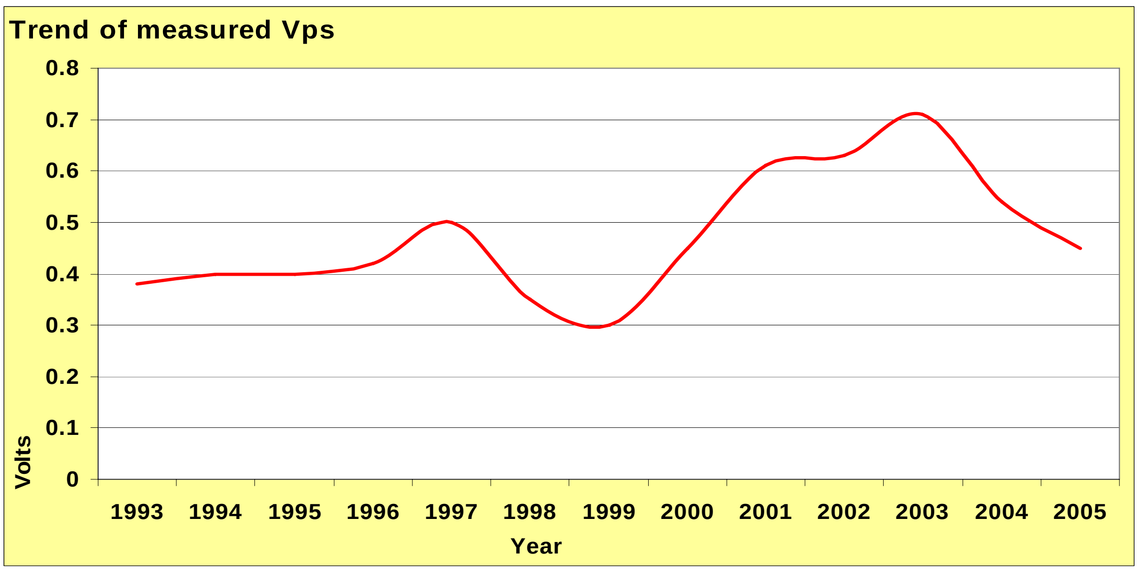
This table shows that when the source of significant amounts of stray animal contact current is identified as on-farm, it is likely to be a greater contributor to animal contact current than that from an off-farm source.

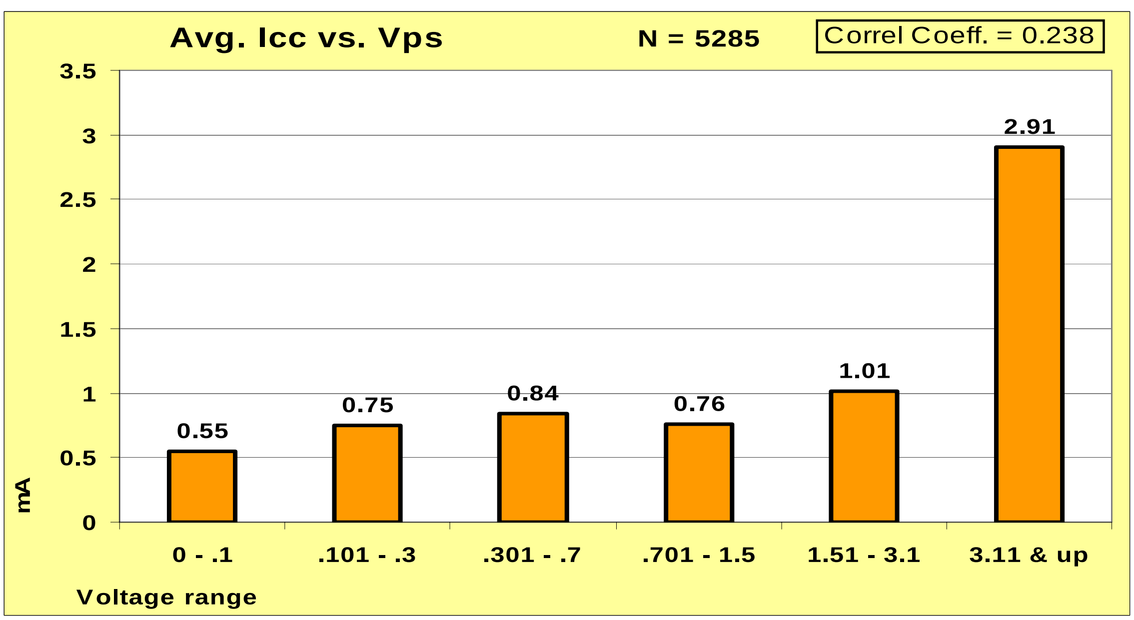
12) Voltage drop, Vps or Vd

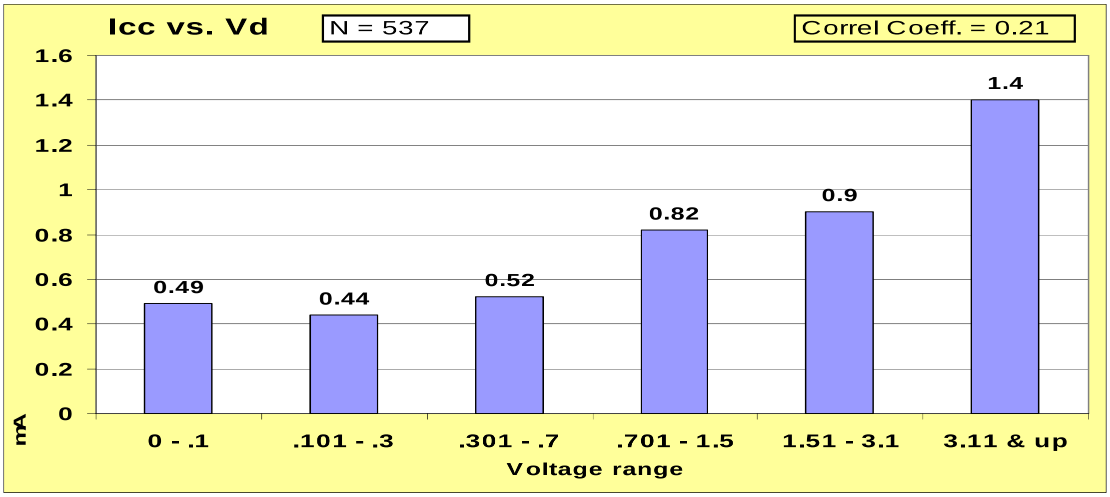
The main voltage drop parameter is always measured between the primary neutral and the main secondary neutral as Vps in any Phase I or Phase II investigation. Other farm service drops are recorded as Vd from a secondary neutral voltage drop test during a Phase II investigation. Only the worst case measured Vd is reported in the Phase II database.

	7 number summary	UNIT		Distribution Range Vps&Vd	% in range
Average	0.49	Volts		0 - .1	21.5
Minimum	0.001	Volts		.101 - .3	36.8
1st quartile	0.12	Volts		.301 - .7	25.0
Median	0.24	Volts		.701 - 1.5	11.2
3rd quartile	0.5	Volts		1.51 - 3.1	3.8
Maximum	20	Volts		3.11 & up	1.7
Entries, N	5,859				

The two voltage drops are combined in the above table. The trend of Vps in the chart below shows the highest on-farm drops were recorded during 2000-2003, but since then, they are decreasing. The overall trend is an 18% increase from 1993 to 2005.







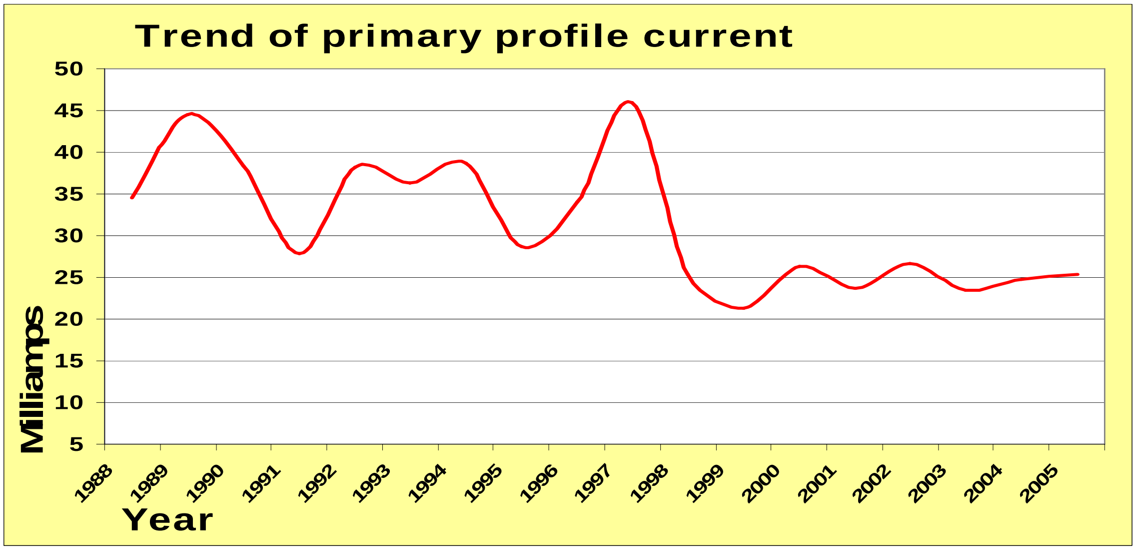
There is moderate correlation between the measured voltage drops and cow contact current, as one would expect. The data suggest that when the drop is 3.0 Volts or more, it can be a major contributor to elevated cow contact voltage.

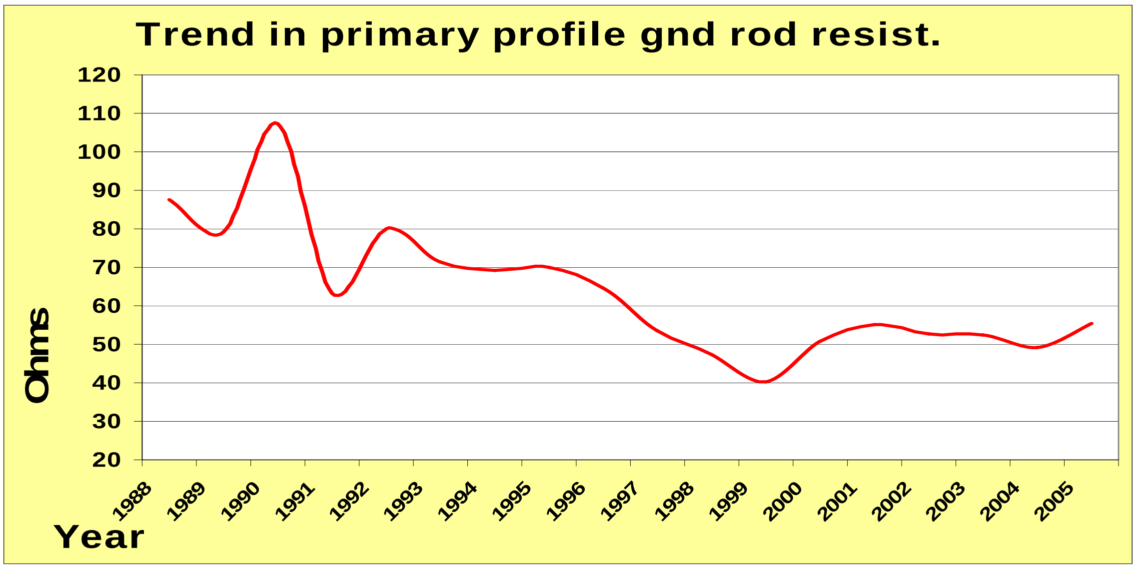
13) Primary profile data, Ipp, Rpp, Vne

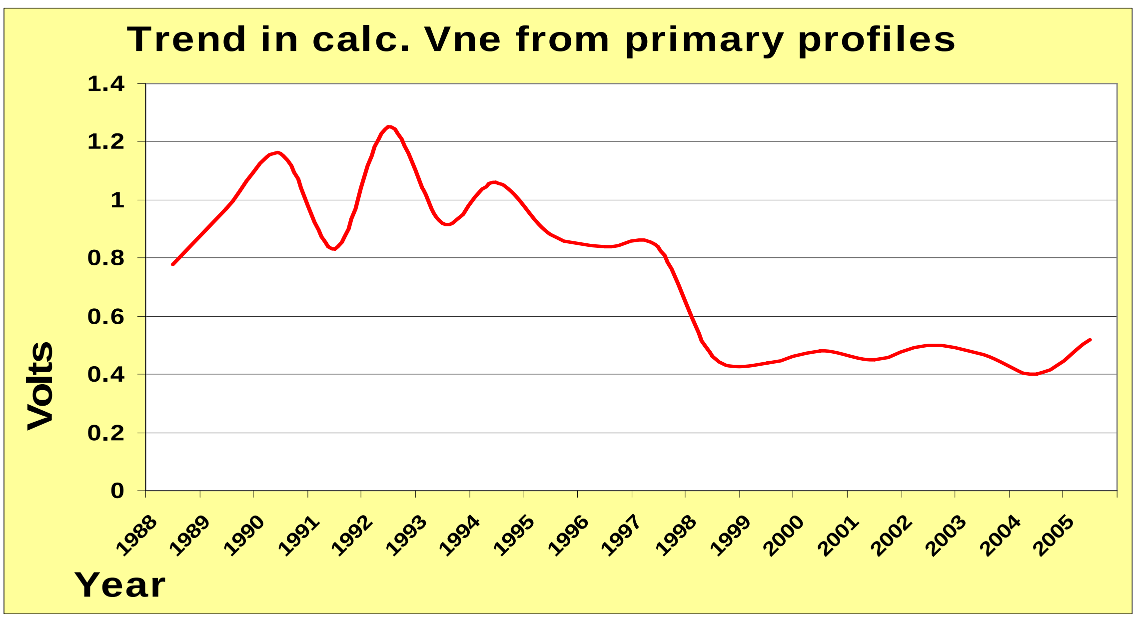
The Phase II protocol requires a primary profile be taken during a SV investigation. This is usually done during a period of peak electrical use on the distribution system, i.e. during morning or evening milkings. It is accomplished by using an AEMC meter to record the ground rod current, Ipp, and ground rod resistance, Rpp, at each grounded primary pole in the area of the farm being investigated. Ideally, about 14 poles should be recorded for each farm. A corresponding neutral-to-earth voltage, Vne for each pole can then be calculated using Ohm's Law.

	7 number Summary Ipp	UNIT		7 number Summary Rpp	UNIT		7 number Summary Vne	UNIT
Average	29.1	milliAmps		60	Ohms		0.64	Volts
Minimum	0.007	milliAmps		0.1	Ohms		0.001	Volts
1st quartile	4.6	milliAmps		16	Ohms		0.16	Volts
Median	12	milliAmps		27	Ohms		0.36	Volts
3rd quartile	26	milliAmps		56	Ohms		0.76	Volts
Maximum	4,200	milliAmps		2,703	Ohms		43.4	Volts
Entries, N	12,340			12,340			12,340	

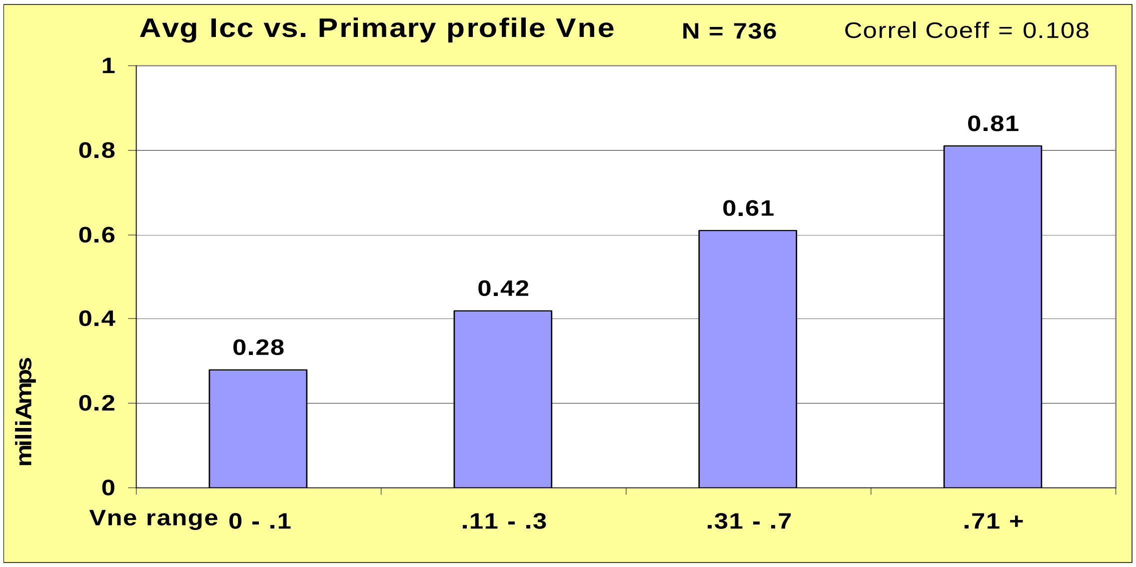
This table shows that most ground rods in the state carry a small proportion of the overall neutral return current to and from the earth, averaging just less than 30 milliAmps AC rms. Individual ground rods are moderately resistive throughout the state, averaging 60 Ohms overall. The PSC would like to see individual primary system ground rods at 100 Ohms or less, but this is sometimes difficult to achieve given the soil conditions. In the database, 87% of the ground rods measured were at 100 Ohms or below. The associated neutral-to-earth voltages calculated from the data are very low, however, considering the size of the distribution system in this state. The trend of ground rod current shows a decrease of 27% from 1988 to 2005 and has leveled out at about 25 milliAmps average for each pole. The trend in ground rod resistance found during the primary profile test shows a decrease of 37% from 1988 to 2005. It has varied between 40 to 60 Ohms since 1997.


Trend of primary profile current
Milliamps
50
45
40
35
30
25
20
15
10
5
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year


Trend in primary profile gnd rod resist.
Ohms
120
110
100
90
80
70
60
50
40
30
20
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year


Trend in calc. Vne from primary profiles
Volts
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

From 1988 to 2005, the calculated neutral to earth voltage on distribution pole ground rods has decreased 33%. To 2005, it has decreased 58% from the high recorded in 1992. The value has stayed within the range of 0.4 to 0.6 Volts for the last eight years.



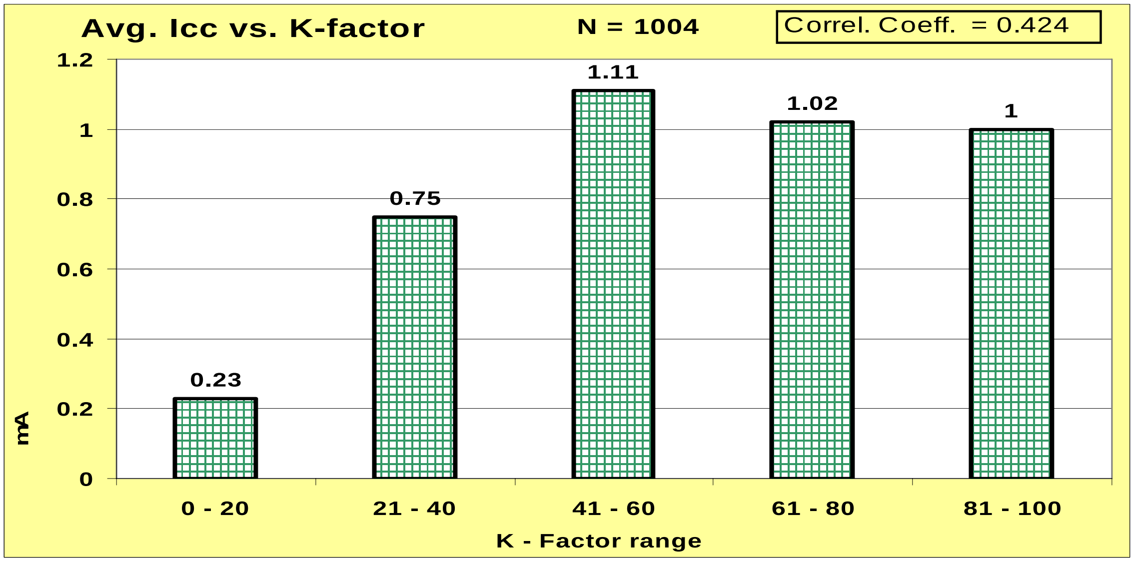
The statistical correlation coefficient between Vne and average cow contact current shows only a moderate correlation. This makes sense, as one would not expect certain ground rods, which have a great physical separation distance from the cow contact point, would have any great influence on the amount of current found there. The correlation coefficient for this Vne and the Vp measured at the farm is 0.243, where N = 733. This confirms that the farm's primary ground rod is a part of the primary profile, but the average ground rod neutral-to-earth voltage away from the farm is determined by local topology and soil conditions and decreases the correlation with the neutral-to-earth voltage measured at the farm.

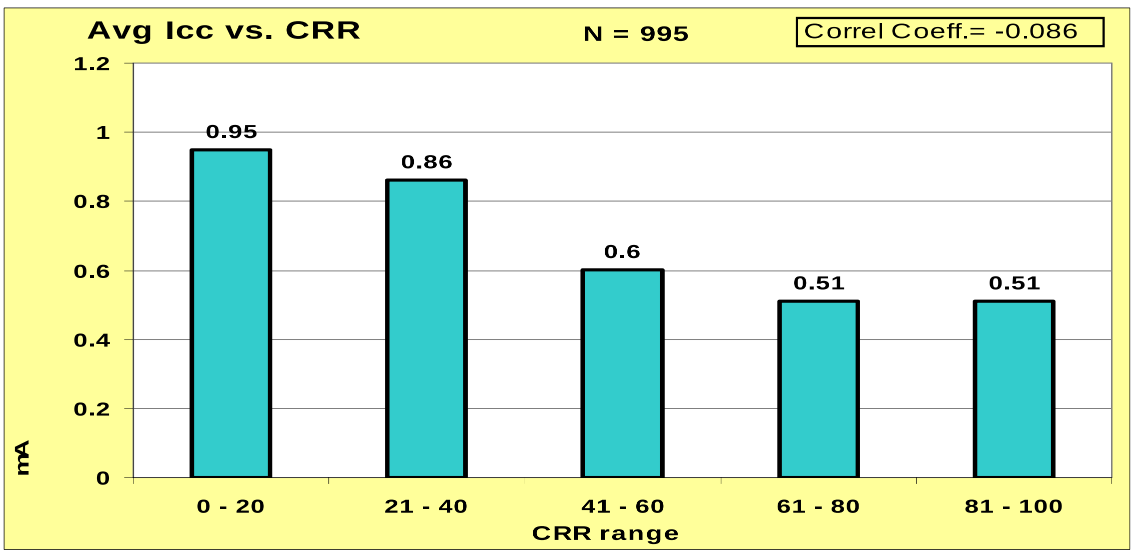
14) Load box test data: K-Factor and Current Return Ratio (CRR)

Both of these parameters are calculated from a load box test. K-factor is defined as the ratio between cow contact voltage, Vcc, and secondary neutral-to-reference voltage, Vs expressed as a percent. The current return ratio is determined by dividing the current returning on the primary neutral conductor by the primary phase current supplied to the transformer at full load with the farm off, also expressed as a percent.

						Distributions				
	7 number Summary K-factor	unit		7 number Summary CRR	unit	K-Factor range	% In range		CRR range	% In range
Average	22.7	%		74	%	0 - 20	51.8		0 - 20	1.6
Minimum	0.01	%		1	%	21 - 40	31.1		21 - 40	2.2
1st quartile	7	%		65	%	41 - 60	13.3		41 - 60	14.0
Median	19.1	%		77	%	61 - 80	2.8		61 - 80	39.7
3rd quartile	34.2	%		87	%	81 - 100	1.0		81 - 100	42.5
Maximum	100	%		100	%					
Entries, N	1,005			1,190						

The average expected K-factor is about 33%. Seventy-four percent of the farms in the database have K-factors equal to or less than the 33% level. For 7,200-Volt or lower system farms, a CRR of 66% or greater is expected, while on 12,470-Volt or greater farms, a CRR of 50% or greater is expected. Overall, 73% of the farms tested had CRR's greater than the 66% level and 92% of the farms tested had CRR's greater than the 50% level.



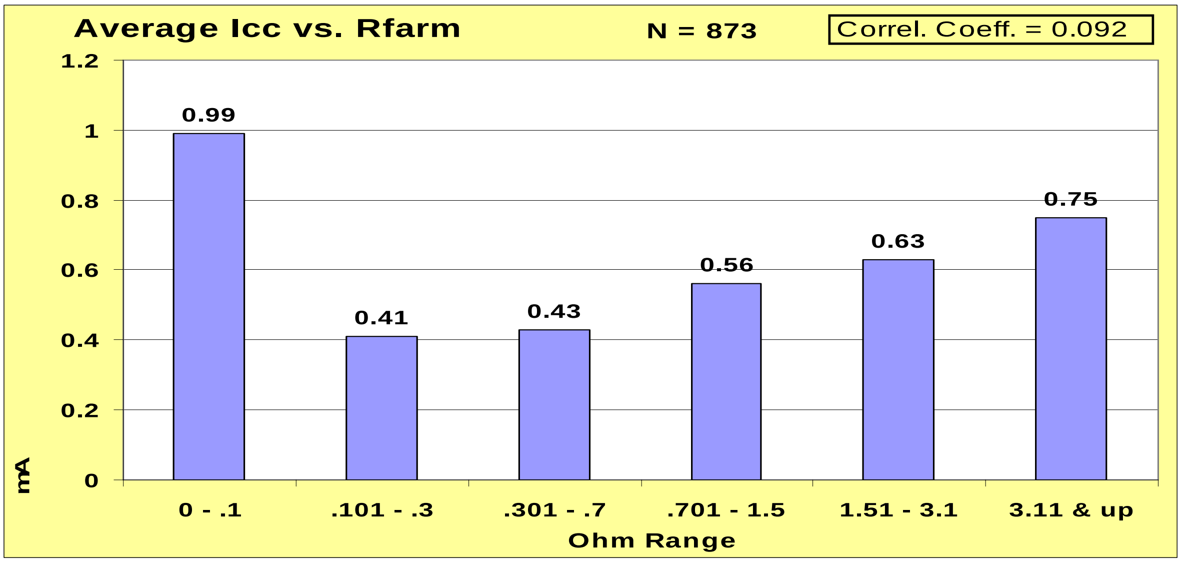


There is good correlation between the K-factor and cow contact current, which should be expected since part of the definition of K-factor includes cow contact voltage (proportional to cow contact current). There is a much less strong correlation coefficient between the CRR and cow contact current. This is counter-intuitive as one would expect a strong correlation for current that does not return on the primary neutral conductor which should thereby contribute strongly to the current in cow contact areas. One can conclude that it has other paths for return that do not usually include the cow contact areas.

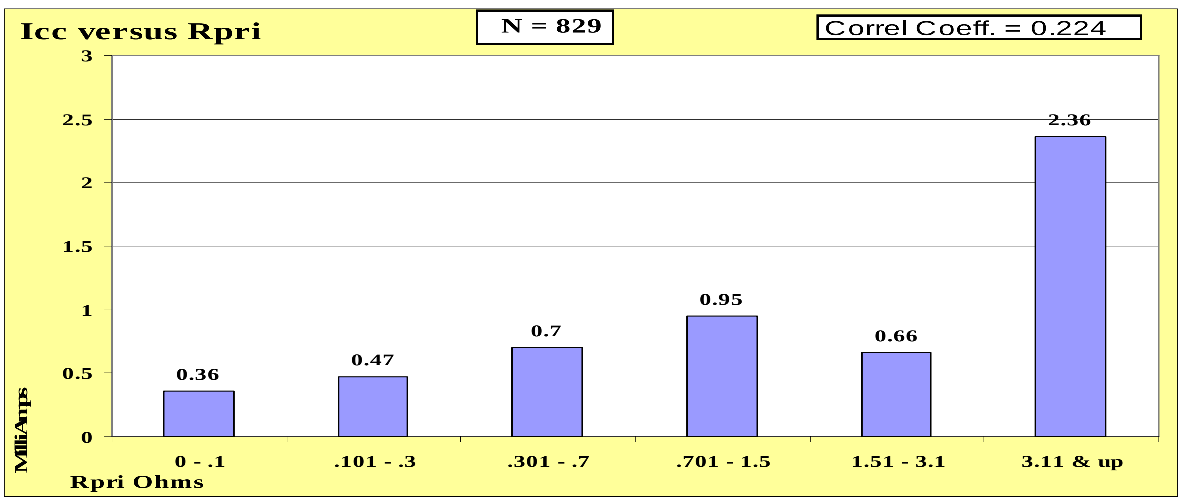
15) Load box test data: $R_{primary}$ and R_{farm}

These two parameters are calculated from the load box data, specifically Vp and $I_{primary\text{-}neutral}$ for the first; and Vs and $I_{secondary\text{-}neutral}$ for the second. They are a measure of how effective the grounding is on each side of the main transformer. It is hoped the condition of the neutral/grounding system is such that $R_{primary}$ be equal to or less than 0.7 Ohms and that R_{farm} to be equal to or less than 1.5 Ohms. Over 90% of the primary distribution system's reported apparent neutral resistance is at or below 0.7 Ohms. Only about 58% of farms reported have an equivalent on-farm neutral resistance at or below 1.5 Ohms.

						Distributions			
	7 number Summary $R_{primary}$	UNIT		7 number Summary R_{farm}	UNIT	Range Rp or Rf Ohms	$R_{primary}$ % in range		R_{farm} % in range
Average	0.39	Ohms		2.21	Ohms	0 - 0.1	12.7		2.1
Minimum	0.002	Ohms		0.01	Ohms	.101 - .3	46.0		6.9
1st quartile	0.16	Ohms		0.62	Ohms	.301 - .7	31.4		19.2
Median	0.26	Ohms		1.25	Ohms	.701 - 1.5	7.6		29.7
3rd quartile	0.44	Ohms		2.28	Ohms	1.51 - 3.1	1.7		24.1
Maximum	8	Ohms		57.5	Ohms	3.11 +	0.6		18.0
Entries, N	826			826					



There is a very weak correlation coefficient between R_{farm} and average cow contact current. There are too few points reported at this time in the minimum range. One can assume that very resistive ground/neutral systems on farms have many alternate conductive paths for return currents but these paths may not always include the cow contact area.



There is a small correlation between $R_{primary}$ and cow contact current. There are presently too few data points reported at the upper two ranges for an accurate picture.

16) Mitigation data

Several standard mitigation techniques and devices are usually employed to reduce measurable current levels at cow contact points. These include equipotential planes, EGS systems, 4-wire systems, balancing phases, adding or improving neutrals and/or grounds, rebuilding the neutral system and installation of a neutral isolation device.

As found mitigation in place	% found	N =
Equipotential Plane (EPP)	10.7%	7,036
4- Wire system	10.3%	6,453
EGS system	0.5%	6,804
Recommended on-farm mitigation	**% of time**	**N =**
Improve/Add Grounding	21.2%	5,916
Enlarge/repair Neutral Conductor	15.5%	5,829
Balance 120 Volt loads	14.2%	5,885
Install 4-Wire System	10.6%	5,829
Install EPP	5.0%	6,474
Add EGS System	0.2%	6,563
Recommended off-farm mitigation	**% of time**	**N =**
Improve/Add Grounding	10.5%	5,830
Enlarge/repair Neutral Conductor	9.3%	5,888
Rebuild primary system	4.3%	5,830
Balance three phases	1.2%	5,888
Bury parallel counterpoise conductor	1.1%	5,830

On farms where the mitigation recommended is the neutral isolator, the following table shows the average cow contact current measured for each case.

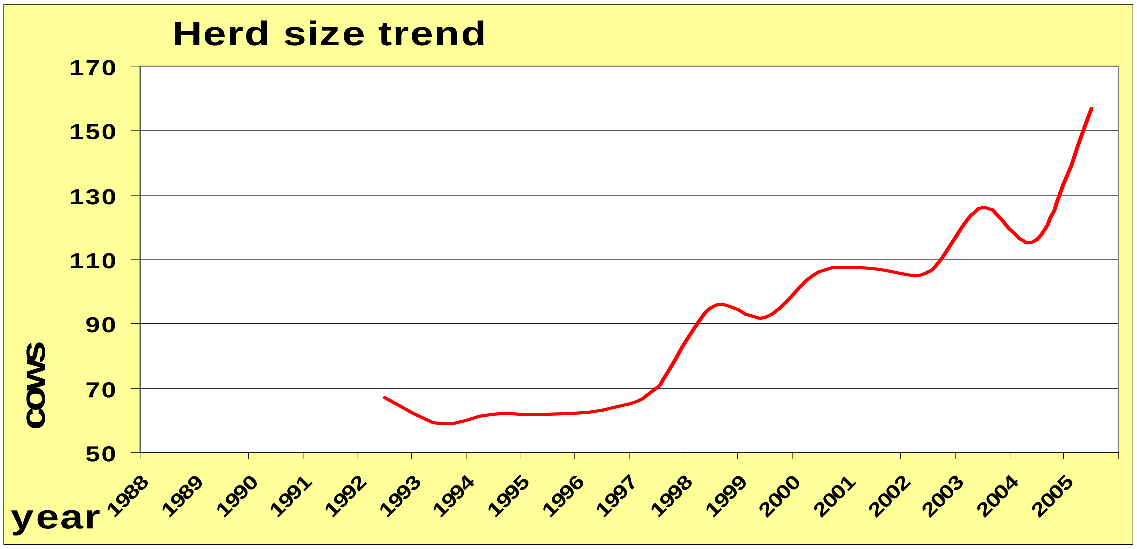
Recommend	average Icc mA	N =
No isolation	0.74	5,999
Isolation	1.67	680

FARM DATA PARAMETERS

17) Herd Size

This parameter records the number of cows being milked on the day of the SV test.

	7 number Summary	UNIT		Herd size range (cows)	% in range
Average	88	Cows		1 - 30	9.3
Minimum	3	Cows		31 - 60	48.3
1st quartile	42	Cows		61 - 90	21.8
Median	58	Cows		91 - 120	7.2
3rd quartile	80	Cows		121 - 150	3.7
Maximum	1,640	Cows		151 - 300	5.9
Entries, N	5,689			301 & UP	3.8

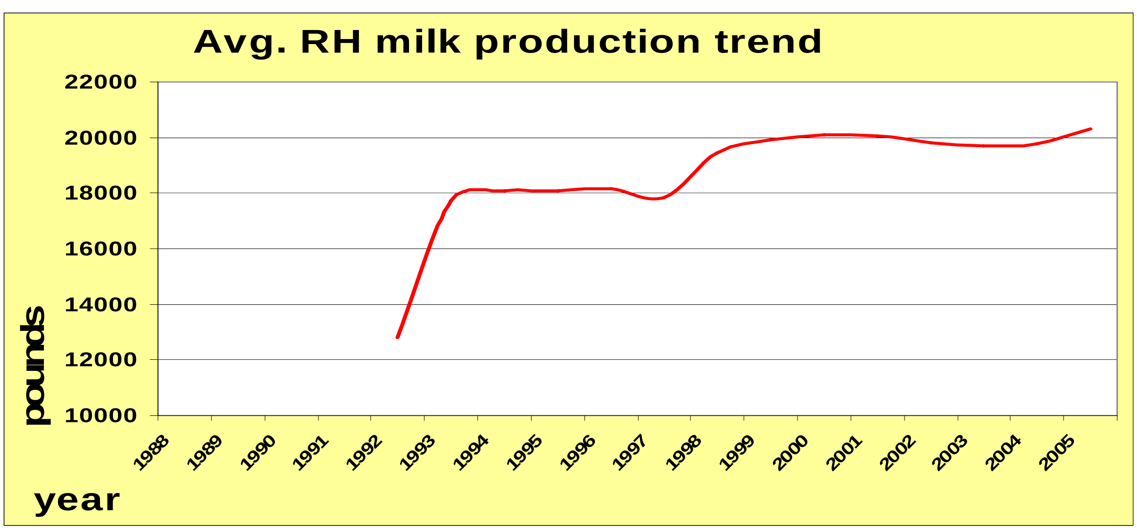


This parameter was not reported until 1992. The trend shows that the size of the typical Wisconsin dairy farm is growing despite the total number of dairy farms decreasing in the state. The correlation coefficient between herd size and average cow contact current is very weak at -0.0964.

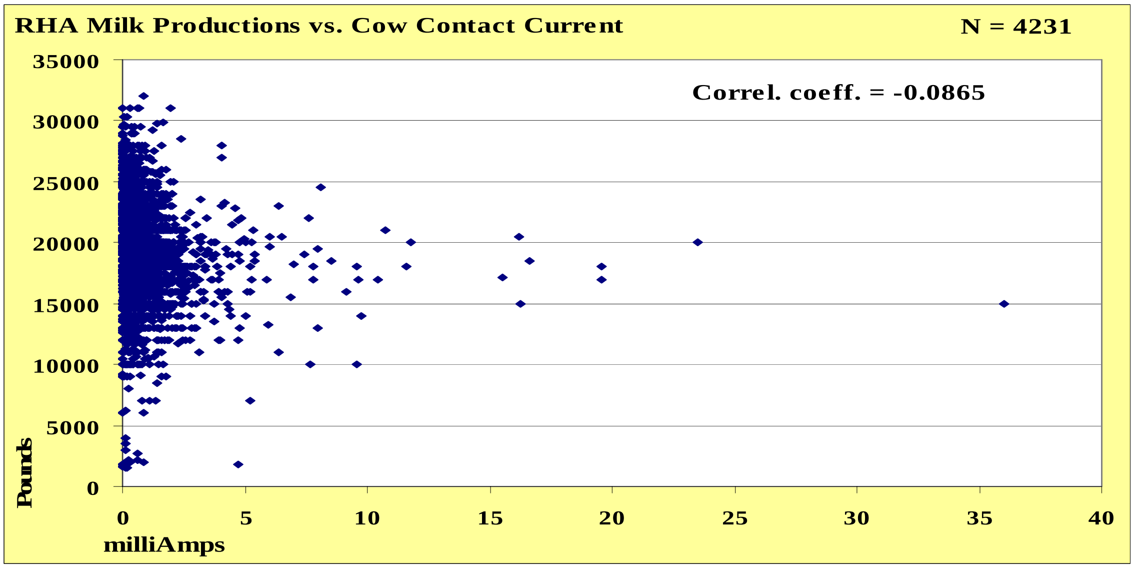
18) Milk production

This parameter is the rolling herd average (RHA) milk production per cow at the time of the SV test. It is usually derived from DHIA or equivalent records.

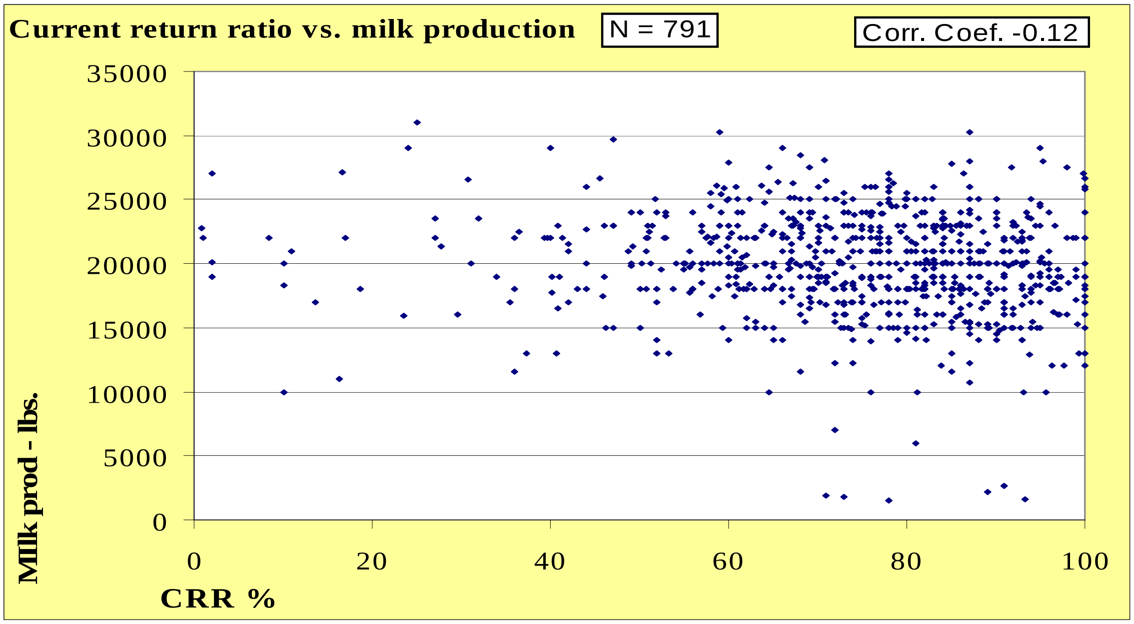
	7 number Summary	UNIT		Production range (pounds)	% in range
Average	18,982	pounds		UP TO 5,000	0.3
Minimum	1,500	pounds		5,001 – 10,000	1.0
1st quartile	17,000	pounds		10,001 -15,000	11.8
Median	19,000	pounds		15,001 – 20,000	55.3
3rd quartile	21,000	pounds		20,001 – 25,000	27.4
Maximum	32,000	pounds		25,001 – 30,000	4.0
Entries, N	4,371			30,001 and up	0.2



This parameter was not recorded until 1992. There was only one data point recorded in that first year. The production level reported has created an odd pattern over the period since then. It was fairly level at about 18,000 pounds for 5 years and then jumped to about 20,000 pounds for the last 8 years. One of the main concerns in stray voltage is herd health and production. There is a very weak correlation of production with average levels of cow contact current, however, as the scatter graph below reveals. Any influence must therefore be more of a secondary or cascading effect.



The same can be shown for the relationship of current return ratio and milk production. It has a slightly greater correlation coefficient, but the scatter graph below shows a considerable amount of randomness. In fact, since the coefficient is negative, it hints at a counterintuitive conclusion that higher CRR's (more current returning on the neutral conductor) correlate to lower production.

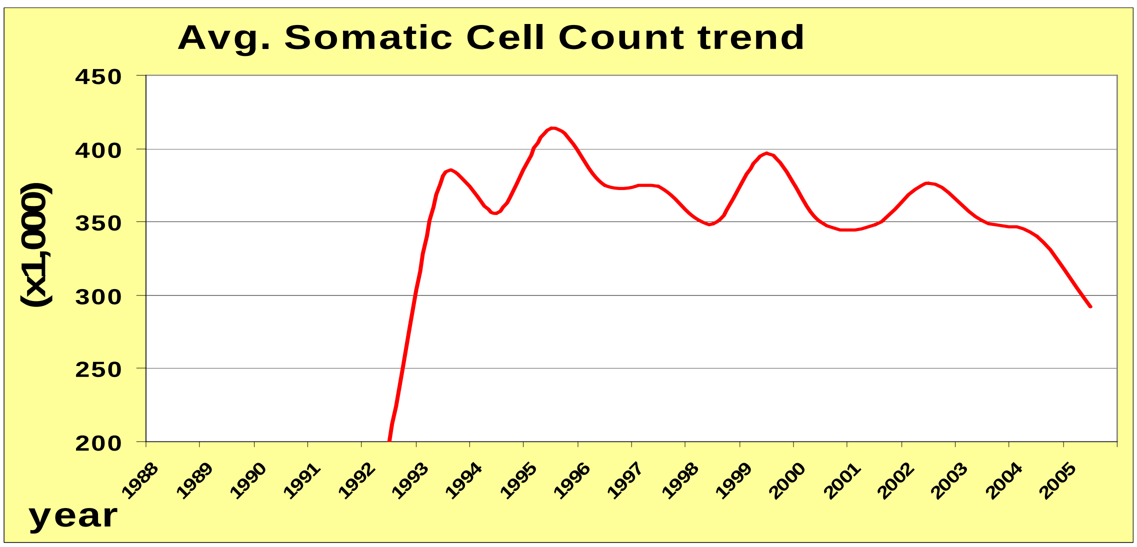


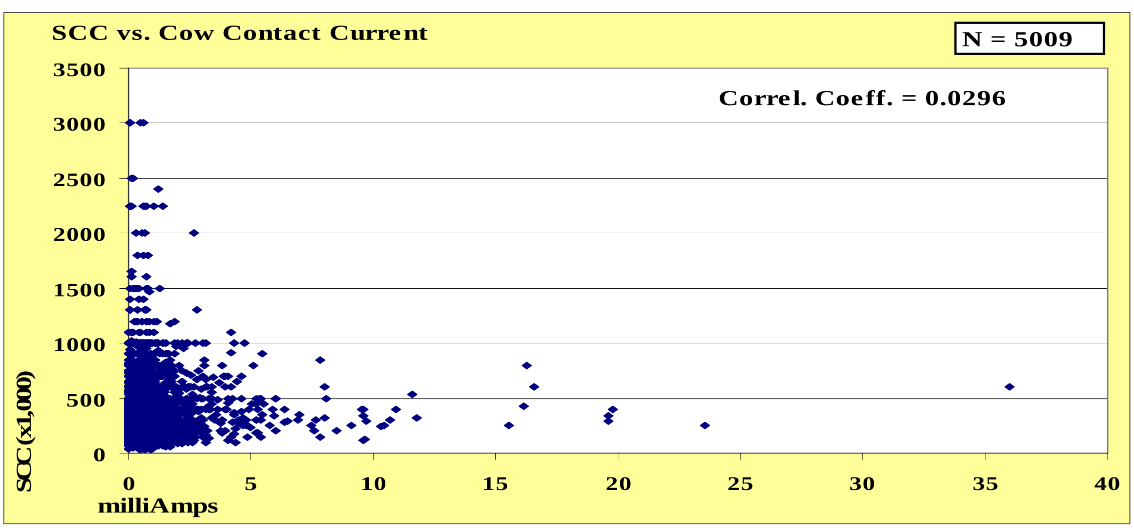
19) Somatic cell count, SCC

This parameter is one measure of herd health. It is measured in 'thousands' units, i.e. a report of 100 means 100,000 units.

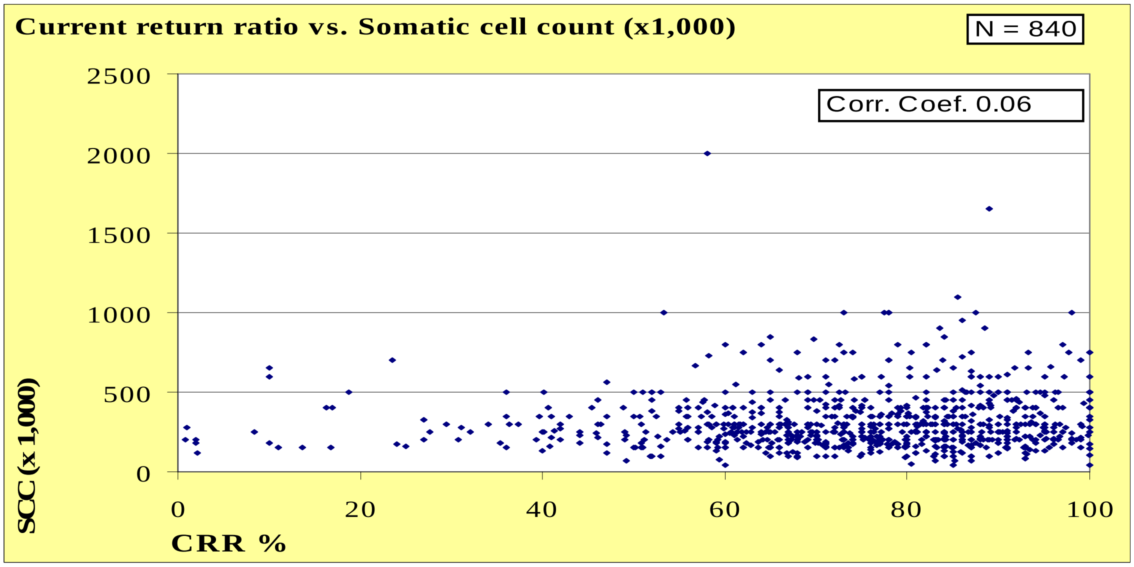
Again, no data was recorded before 1992. Just one data point was recorded in that first year. Since 1993, the reported somatic cell count has varied a great amount each year, but the overall trend is decreasing. From 1993 to 2005, the average somatic cell count has decreased 23%.

	7 number Summary	UNIT		SCC range (x1,000) units	% in range
Average	367	(x1,000) units		Up to 200	27.1
Minimum	25	(x1,000) units		201 - 300	28.5
1st quartile	200	(x1,000) units		301 - 400	17.4
Median	300	(x1,000) units		401 - 500	11.0
3rd quartile	450	(x1,000) units		501 - 750	9.7
Maximum	5,800	(x1,000) units		751 – 1,000	4.8
Entries, N	5,164			1,001 & up	1.5





Somatic cell count is another parameter that does not correlate well with average cow contact current as shown in the scatter graph above. The same can be said for correlation of somatic cell count with current return ratio in the scatter graph below.



20) Test program and miscellaneous data

The SV report contains the type of record management system used for tracking milk production and somatic cell count data. The usual method employed is DHIA (dairy herd improvement association), but there are other recognized ones in use as well. The data on 5,365 farms reported shows the effectiveness of these programs.

On DHIA	57.9%
On another program	4.5%
No program	37.6%

Management type	Herd size	N	RHA Production (pounds)	N	Somatic Cell Count (x1,000)	N	Average Cow contact Current	N
On DHIA	95	3,046	19,813	2,804	334	2,993	0.7	3,005
On another program	107	240	18,894	213	374	232	0.67	229
No program	68	1,803	17,168	1,184	422	1,596	0.84	1,949

Miscellaneous data

1. 77.8% of the farms have a stanchion set-up for milking, while 87.4% of the farms tested have a milk pipeline.
2. The fencers are installed correctly on only 25.3% of the recorded farms.
3. Electric pulsation milking claws are used on 82.8% of the farms reported in the database.

Appendix A
Selected Word Glossary

Aluminum Conductor, Steel Reinforced Cable (ACSR) – A modern type of conductor presently being used to conduct electricity on many primary distribution and transmission systems. It consists of a number of strands of solid aluminum wire wrapped around a central steel cable for strength. The ACSR conductor may have an overall plastic insulating jacket or may be bare. Sizes may vary from as small as #6 or #4 to very large wires measured in MCM (thousands of circular mils). The standard most used in rural areas is 1/0 ACSR conductor which has about 1/4th the resistance of the older (#8A) copperweld conductors.

Ampere – The unit of measure of electrical current. Current is the flow of electron charges in a conductive medium. One Ampere of current is equivalent to about six and a quarter billion, billion electron charges past a designated point per second. This makes the basic unit of current a fairly large one, so the usual measures of currents are in milliAmperes (1/1,000th of an Ampere) or microAmperes (1/1,000,000th of an Ampere). Physics dictates that current will not flow without an energy source (voltage source) to push it and it will not flow in an incomplete circuit. It must always have some complete conductive path to follow from the source to some type of load and back to the source again.

Balanced Phases – A condition on either a primary (transmission or distribution) or a secondary AC electrical system where all hot phases carry the same or nearly the same current. In this condition, there is little or no neutral current, if a neutral is present. On a three-phase transmission system, the currents in all three phases are nearly balanced because of the inherent nature of the system design. The only discrepancies are due to the inevitable losses of energy to the surrounding environment due to the laws of physics as energy is transmitted great distances. Changing customer load requirements constantly affect three-phase system balance in the distribution system. End customer's secondary systems are rarely balanced because of constantly changing load requirements for the two phases.

Cooperative Utility (Coop) – An electrical utility formed under the laws of Wisconsin allowing such entities that are member-owned. These utilities are not under the direct jurisdiction of the Public Service Commission of Wisconsin. They do adhere to the NEC and NESC as they are usually subject to USDA guidelines.

Copperweld Cable (CW) – A type of conductor used in distribution systems made necessary during WW II because of the shortage of copper. This conductor is made up of a mix of copper clad steel wire and solid copper conductors. It becomes somewhat brittle over many years of service and is moderately resistive per mile of conductor. This type of conductor has been generally superseded by the use of all aluminum or ACSR conductors.

Counterpoise System – A buried conductor system used to aid in establishing a lower resistance ground path for an electrical distribution or secondary system. In soil conditions where a number of individual ground rods in parallel do not lower neutral-to-earth voltage sufficiently, a counterpoise, usually of #4 bare copper wire, is buried creating a lower resistance ground to earth connection. This system is connected to the existing ground rod system in the area.

Cow Contact Area – a cow contact is established by specific PSC protocol to measure the voltage a cow may be subject to in its normal environment. The usual method of establishing a cow contact is to solidly connect one measurement lead to a metallic water line or stanchion rail and the other measurement lead to the concrete floor not more than five or six feet from the first lead. A method of weighting down the floor contact is used along with a brine-soaked towel to minimize contact resistance. A properly established cow contact will only meet this definition if a mature cow could simultaneously contact both of the selected measurement points. A resistor must be used between the leads for the voltage measurement to represent the cow in the measurement circuit. The value most often used (required by the PSC) is 500 Ohms.

Current (I) – An electrical parameter that is the flow or amount of electricity past any single point in a conductor or conductive element per unit of time. The current may be AC, DC, or a mix of both in character. Current is one of the three parameters used in Ohm's Law. Electrical current cannot exist without the push (force) of a source voltage. It requires non-zero voltage or potential to move the electron charges. Any temperature above absolute zero will make electrons active and vibrate and capable of relaying negative charge energies in the form of an electric current in a conductor. A temperature difference can create a voltage and therefore a current as happens in a thermocouple. Current will only flow in a complete circuit. Its unit of measure is the Ampere.

Current Return Ratio (CRR) – The ratio of the amount of current returning on the neutral conductor to that supplied by the phase conductor during a load box test, usually expressed as a percentage. For a 7,200-Volt primary system, the PSC would like to see at least a minimum 66% return. For a 14,400 Volt or higher primary system, the PSC would like to see at least a minimum 50% return. These numbers are only guidelines, as the amount of return current is affected by many different elements on the distribution system as well as the customer's grounding system that may not be easily controlled. The PSC database indicates that, at the farm's transformer, the average return current is 74% through the neutral conductor and 26% through alternate conductive paths including, but not limited to, the earth.

Distribution System – A portion of the electrical power delivery system that efficiently delivers energy from the transmission system to end-users. A generation system creates the force (voltage) that allows current to flow as needed. The uni-grounded transmission system steps up the generated voltage to levels that afford large amounts of energy to be carried over large distances with minimal loss. A distribution system connects to the transmission system at a substation, steps the voltage down to reasonably safe levels, and thereafter connects it to each customer desiring energy service in a massively parallel circuit that is multi-grounded for safety, reliability, and proper operation. The table below shows some of the various phase-to-phase voltages and their corresponding phase-to-neutral voltages common to Wisconsin.

Phase to Phase Voltage	**Phase to Neutral Voltage**		**Phase to Phase Voltage**	**Phase to Neutral Voltage**
24,900	**14,400**		**8,300**	**4,800**
14,400	**8,300**		**7,200**	**4,160**
13,800	**7,960**		**4,160**	**2,400**
12,470	**7,200**			

Table 1: Common Wisconsin distribution voltage levels

Earth – A point on the Earth can be considered a universal reference point (lower end terminal) for the measurement of voltages. The Earth represents a vast volume of low resistance material that can be considered to source or to sink as much electricity as needed by utility and customer electrical power networks to balance their systems. A voltage measurement made to the Earth well away from any electrical system or buried metallic structure is defined as being made to a zero-valued reference.

Electric Utility – A business for generating, transmitting and/or distributing electric energy. It may be municipally-owned, investor-owned or a cooperative.

End-of-line Customer (EOL Customer) – By definition of the PSC, a customer is considered end-of-line if s/he is the last customer of a radial feeder or is on a tap at least 1/2 mile from a distribution line going in two different directions from the tap.

Equipotential Plane (EPP) – EPP's are an electrical industry standard method used to reduce the possibility of electric shock. They are also a method used to mitigate SV on-farm. EPP's are required by the NEC, with certain exceptions in Wisconsin. An EPP is created by physically bonding together all metal structures and reinforcement rods in concrete within a farm floor structure. These are then bonded to the ground/neutral system of the farm's electrical service. This action creates a low resistance network that cannot support significant differences in voltage no matter how much current may flow through it. EPP's must be designed such that any transition area from off the plane to on the plane has a low enough gradient of voltage that no step potential exists which exceeds the PSC level of concern.

Four Main SV Electrical Parameters – The minimum electrical parameters that are recommended to be monitored during Phase I and Phase II stray voltage testing by the PSC. They are: primary neutral end of the circuit to reference voltage (Vpnref), secondary neutral end of the circuit to reference voltage (Vsnref), voltage drop between primary and secondary neutrals (Vps), and cow contact voltage (Vcc).

Four-wire System – A wiring method for secondary electrical systems that have single (bi-) phase (120/240 V.) service. In this system, there are two phase wires, a uni-grounded neutral wire, and a multi-grounded grounding conductor. At each sub-panel, the four wires are independent of one another. In the main disconnect panel, the neutral and grounding conductors are bonded to each other and are grounded.

Generation System – An electrical system that converts the energy of heat or motion into electrical energy. The generator may be powered by many different mechanical or chemical sources such as hot steam created by the combustion of natural gas, coal, fuel oil or nuclear material disintegration, or by wind, falling water, or tides. The usual type of electricity generated is AC in a three-phase wye configuration typically between 5,000 and 15,000 Volts.

Ground – A term used in electrical science meaning the point of lowest potential for an electrical system. In most circuits, the Earth is used as a ground for current return and a common voltage reference point. As a verb, to 'ground' a part of an electrical system means to provide an electrically conductive path to the ground and/or Earth system.

Ground-Referenced System – A system that has all its basic voltage measurements referenced to a grounded (earthed) system, as opposed to a floated system. Ground referenced systems are safer to work on, less noisy and usually are more reliable to operate than floated systems. Even AC systems that are purposely floated have an inescapable high impedance ground reference because of capacitive and inductive coupling due to the laws of physics.

Grounded Conductor – In a typical primary or secondary power delivery system, there are three basic types of conductors (1) phase or hot conductors, (2) a grounded conductor, also known as the neutral conductor, and (3) a grounding conductor, which connects the grounded conductor to the Earth and all system non-current carrying metallic parts at specific points per the requirements of the NEC and the NESC.

Grounding Conductor – A conductor that normally does not carry any load current but is designed to carry fault current in emergency conditions for safety reasons. On a secondary electrical system, this conductor should be bonded to all the metallic enclosures, structures and non-current carrying metallic elements of the branch circuit of which it is a part. Also, it is defined as a conductor that is designed to connect the grounded neutral bus bar of a service entrance panel to a grounding electrode element. On an operating electrical system and/or where there are multiple connections to the Earth separated by some distances, there will normally always be some minor incidental current, both inductively and/or capacitively coupled as well as directly conducted, on the grounding conductors.

Grounding Electrode – Usually, a driven ground rod or system of multiple parallel ground rods that connects a grounded neutral system to the Earth via a grounding conductor. In cases where multiple ground rods must be driven, they are connected in parallel with appropriate hardware and wire designed for the purpose to achieve an effective grounding electrode system. In general, a single driven rod for buildings must be measured as 25 Ohms to ground or less. If this condition is not met, a second ground rod must be driven and connected in parallel to the first. In Wisconsin, all one- and two-family dwellings automatically now require two made ground electrodes. Continuous metallic water piping systems and other like systems are also effective grounding electrodes and are required to be bonded to this system, if available.

Icc – Cow Contact Current – The AC current a cow is subject to in its normal environment can be very difficult to measure directly using conventional current measuring techniques and instruments. Therefore, a cow contact voltage measurement is taken across a nominal 500-Ohm resistor known as R_{shunt}, which simulates the average resistance (muzzle to rear hooves) of a mature cow. From Ohm's Law (I = V/R), a voltage across this resistance is directly proportional to the current through that resistance. Therefore, by measuring the cow contact voltage, one is indirectly and easily measuring the cow contact current.

Investor-owned Utility (IOU) – A for-profit utility that is owned by investors through stock purchase. In Wisconsin, there are 5 large and 6 small IOU's. They are all under the regulative authority of the PSC.

Ipp – primary profile current – the current flowing through the grounding conductor on a primary distribution system pole that has an associated ground rod. The grounding conductor connects the primary neutral conductor to the driven ground rod.

Isolation Transformer – A transformer that does not have the primary neutral terminal conductively connected to the secondary neutral terminal. Each neutral must be grounded to the earth for safety, but the grounding is independent. Since the metallic frame of this transformer might become energized at high voltage levels during a fault condition, isolation transformers must be mounted on a non-conducting (wooden) pole system at least 8 feet in the air for safety and at least three feet away from a non-energized conductive element. The amount of isolation (the attenuation of the primary neutral to reference voltage measured on the secondary side of isolation) is about the same as for a utility installed neutral isolator device. In no case shall the system be designed or implemented such that the earth becomes the sole fault current path. Because these devices use AC current to energize their magnetic cores for their operation, they may consume appreciable power that is continuously expended as waste heat.

K-factor – A number useful in SV analysis. It is formally defined by the PSC as the ratio of cow contact voltage (Vcc) to secondary neutral-to-reference voltage (Vs) made during a load box test. The PSC uses a guideline of 33% to 50% as being a desirable number, but not a strict limit. It is often found that numbers calculated greater than this may indicate that the reference rod location is too close to the electrical system under test. When conditions dictate the reference rod should be relocated, a retest should be performed. In essence, the K-factor indicates how tightly coupled the voltage in the cow contact area is to the neutral voltage of the farm's electrical service.

kilo- (k) – A numerical prefix denoting 1,000. An example is a kiloWatt meaning 1,000 Watts.

kVA – kiloVoltAmpere – A unit of measure for the power rating of transformers. A kVA is 1,000 Volt-Amperes. When one multiplies the voltage rating and the current rating of either the primary side or the secondary side of a transformer and divides by 1,000, the kVA rating is established. For example, a transformer primary rated for 7,200 volts and drawing 6.94 Amps at full load is rated 50 kVA. On the secondary side, the voltage is 240 Volts with an available current of 208.3 Amps.

Level-of-concern (LOC) – In Wisconsin, the present "level of concern" is derived from the 1996 PSC docket 05-EI-115. The LOC is formally defined by the PSC as 2.0 milliAmps, AC, rms (root mean square), steady-state or 1.0 volt, AC, rms, steady-state across a 500-Ohm resistor in the cow contact area. The PSC 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 performance or milk production would be harmed. The "level of concern" is further broken down into two parts. The first part is a 1.0-milliAmp contribution from the utility, at which level mitigative action must be taken by that utility to reduce its contribution to below the 1.0-milliAmp level. The second part is a 1-milliAmp contribution from the farm system, at which level some form of mitigative action should be undertaken by the farm operator.

Load Box Test (LB test) – A test that is part of the PSC Phase II test protocol. This test is used to help determine the amount of utility contribution to any cow contact voltage/current exclusive of any contribution from on-farm sources. In this test, all farm loads are disconnected from the electrical system. The primary transformer has a 240-Volt resistive load box of 18 to 25 kW size connected to it. Various currents and voltages are measured to determine if the utility system has the ability to contribute 1 milliAmp of current or more to the cow contact area under that maximum proxy load of 18 to 25 kW.

MCM – (Thousand circular mils) this abbreviation is used in wire sizes larger than 4/0 gauge. The diameter of 4/0 wire is 0.563 inches. The next two common sizes are 266 MCM at 0.633 inch diameter and 336 MCM at 0.721 inch diameter.

milli- (m) – A numerical prefix denoting a thousandth (1/1,000) as in milliAmp meaning 1/1,000 or 0.001 of an Ampere.

Multi-grounded System – The system of electrical distribution used in this country in which the neutral circuit is tied at distinct intervals to the Earth for reasons of safety, protection coordination, voltage stability, lightning protection, and proper system performance. The NESC calls for a minimum of four Earth connections per mile of system. Wisconsin has always specified nine grounds per mile and the PSC has recently required a ground at every pole in new rural construction.

Municipal Utility (muni) – A not-for-profit utility owned and operated by a municipal entity. There are 82 such utilities in Wisconsin ranging in size from about 400 to 17,500 customers. These utilities serve an aggregate total of over a quarter million Wisconsin customers. These utilities are regulated by the PSC.

Neutral Conductor – A conductor designed to carry imbalance current returning from 120-Volt loads in a 240-Volt 3-wire electrical system or imbalance current in a 3-phase multi-grounded wye electrical system. In most electrical systems, it is a grounded conductor. On three-phase grounded wye primary systems and single-phase secondary systems this conductor must be connected to Earth (be grounded) by code for safety, reliability, and system performance reasons. Because of its connection to the Earth, it usually will not carry 100% of the return current.

Neutral Current – The current found in the neutral conductor. When this conductor is connected to the Earth via a grounding conductor, that portion of the neutral current that flows down the grounding conductor structure is known as ground current.

Neutral Isolator Device (Electronic switch) – An electronic device designed to separate the normal conductive connection of the primary and secondary neutrals on a farm. One could simply forego the wiring of these together, but that would create an intolerable safety hazard. Both neutral systems must be connected to the earth for safety reasons. By disconnecting them without a neutral isolator device in place, the earth becomes the sole fault current path for certain fault conditions. This condition is not allowed by either the NEC or the NESC. The physical neutral isolation device contains circuitry to nearly instantaneously reconnect the two neutrals should either of them rise above about 26 Volts from earth reference. The isolated condition returns when the neutral voltages return below the trip threshold. (See also Variable Threshold Neutral Isolator Device.)

Neutral to Earth Voltage (NEV or Vne) – The voltage between the neutral conductor and the (remote) Earth of either the primary or the secondary electrical system. When measured at the customer's main transformer to a remote reference rod, this voltage is known as primary neutral-to-reference voltage. When measured at the customer's main grounded service entrance panel, this voltage is known as secondary neutral-to-reference voltage. Despite the fact that neutral conductors are grounded (Earth assumed to be at nominally zero potential), some localized non-zero neutral voltage to Earth usually exists.

Off-farm – Any part of the electrical system beyond the farm's main transformer.

Ohm – The basic unit of resistance. A potential difference of one Volt is created across the resistance when one Ampere of current flows through one Ohm.

Ohm's Law – The most basic law governing the phenomenon of electricity. The DC version of this law can be stated three equivalent ways:

(1) A voltage (in Volts) is created by a current flowing through a resistance. The voltage across that resistance is the product of the current (in Amperes) times the resistance (in Ohms). {V=I*R}

(2) Current will be drawn when a source voltage is connected to a load resistance. The current (in Amperes) is calculated as the source voltage (in Volts) divided by resistance (in Ohms) that the voltage is across. {I=V/R}

(3) A resistance (in Ohms) is equal to a voltage (in Volts) across that resistance divided by a current (in Amperes) through that resistance. {R=V/I}

Because AC systems involve a frequency component and are calculated using vector mathematics, Ohm's Law for AC systems can be much more complex, which belies the simplified formula V = I * Z.

On-farm – Any part of the electrical system on the load (farm) side of the farm's main transformer.

Phase Conductor – An ungrounded conductor designed to carry current (and electrical energy) to the load device. If a system has no neutral conductor, then all current carrying conductors are phase conductors.

Phase I Protocol – A PSC designated method of first time on-farm stray voltage testing to determine initial levels of cow contact voltage and possible sources. First time investigation data of each investor owned utility is submitted semiannually to the PSC.

Phase II Protocol – A comprehensive test strategy designed by the PSC and used to determine all sources of cow contact voltage both from on-farm and off-farm sources. There are five specific tests, as well as an overall data record form. The five tests are: (1) the load box test, (2) the secondary neutral voltage drop test, (3) the signature test, (4) the primary profile, and (5) the twenty-four hour test. Other tests may be performed as necessary to give a complete account of the electrical activity on the farm.

Primary Electrical System – A term that describes the utility electrical system including the generation, transmission, and distribution systems.

Primary Neutral to Reference Voltage (Vp) – The voltage that exists between the primary grounding electrode/grounding conductor point of an electrical system's utility transformer and a remote reference rod. The grounding electrode is connected to the primary neutral at the transformer via the grounding conductor.

Primary Profile Test – A test specified by the PSC Phase II protocol where nearly simultaneous readings of primary system grounding current and ground rod system resistance are made. These readings are taken for all grounded primary distribution poles for ¾ths of a mile on each side of the farm's tap pole. From this data and using Ohm's Law, a primary neutral to earth voltage profile can be calculated for each pole. This data is useful in analyzing the character and capabilities of the distribution neutral/ground system in the vicinity of the farm.

Primary Underground Conductor – A conductor or cable that carries the utility service electrical power underground instead of overhead. It is rated for the primary line voltage that it is energized to and for the amount of expected current it must carry. The cable may be either fully jacketed or have a bare concentric neutral.

Reference Rod – A metal rod driven into the ground and used as an Earth reference point for the measurement of voltages (or potential differences) on a ground-referenced electrical system. The rod is usually driven about two feet into the ground at a point well away from any electrical system grounding electrodes and away from any other buried metallic structures. When properly placed, a voltage measured between the reference rod and any point on the electrical system will represent a measurement to true zero reference potential.

Resistance (R) – An electrical quantity that quantifies a physical material's ability to conduct or not conduct electricity. It is one of three parameters used in Ohm's Law. It is measured in the unit of Ohms. In general terms, resistances up to the range of 100 or so Ohms represent a very good conductor. Moderate conductors range from 100 Ohms or so to perhaps as much as 100,000 Ohms. Poor conductors range from about 100,000 Ohms to perhaps as high as 500 MegOhms and insulators have resistances generally above many hundred MegOhms.

R_{farm} – Apparent Farm Neutral system resistance – A resistance that is calculated from Ohm's Law (R = V/I). During a Load Box Test, the Vs is measured with full load and the farm loads off along with the current on the secondary neutral (Isn). R_{farm} is Vs/Isn. The lower this number is, the more effective the farm's neutral system grounding is in keeping Vs low.

Root Mean Square (rms) – A mathematical conversion used to equate AC and DC currents and voltages on similar terms. For both AC (at unity power factor) and DC circuits, the power to a resistive load is its voltage drop times its current. For a DC power supply of one Volt feeding a one-Ohm resistor (drawing one Amp of current), the power dissipated would be one Watt. This would generate a certain amount of heat per hour of the power being supplied. If instead, a voltage of one Volt AC, rms (drawing a current of one Amp AC, rms) were supplied, the amount of heat derived over the same period would be the exact same value as in the DC case. One can convert any single frequency sinusoidal peak voltage or current to rms by dividing the peak value by 1.414 (same as multiplying by 0.707). The assumption necessary to use the mathematical rms conversion process is that the AC waveform is periodic, non-distorted and steady state.

$R_{primary}$ – Apparent Primary Neutral System Resistance – A resistance that is calculated from Ohm's Law (R = V/I). During a Load Box Test, the Vp is measured with full load and the farm loads off along with the current on the primary neutral (Ipn). $R_{primary}$ is Vp/Ipn. The lower this number is, the more effective the primary's neutral system grounding is at keeping Vp low.

Rpp – Primary Profile Resistance – The resistance of the individual ground rod electrode to remote earth during a primary profile test. It is measured with an AEMC meter which measures ground rod resistance on those ground rods connected to a massively parallel grounding system, not on isolated ground rods.

SCC – Somatic Cell Count – A measure of herd health. Specifically, it refers to the number of somatic cells (white blood cells (a.k.a. leukocytes) that are secreted in increasing amounts into the milk within the udder when an inflammation such as an infection such as mastitis occurs) at the time of testing.

Secondary Electrical System – This term refers to that part of the electrical system on the customer's side of the meter or transformer.

Secondary Neutral to Reference Voltage (Vs) – The voltage that exists between the secondary grounding electrode/grounding conductor point of an electrical system's service entrance panel and a remote reference rod. The grounding electrode is connected to the secondary neutral at the service entrance panel's neutral/ground bus via a grounding conductor.

Secondary Neutral Voltage Drop Test (SNVD test) – A test that is part of a PSC Phase II SV testing protocol that looks at each farm electrical service to determine its possible contribution to cow contact voltage. For this test, one service at a time is energized and only one proxy load is powered. This load is usually a hair dryer or paint peeler having a uniform current draw at 120 V rms AC in excess of 10 Amps. Measurements are made of the physical length of the neutral from the main distribution panel to the sub-panel or load point being tested. The exact type of wire used for that neutral is noted so that its resistance per hundred feet can be ascertained. A calculation is made of the product of the distance of the neutral (in hundreds of feet) and the resistance per hundred feet resulting in the total resistance of the neutral conductor. A measurement is made of the proxy load current and, using Ohm's Law, a calculation is made of the expected voltage drop on the neutral wire at full load. The voltage drop from the source point to the load point is then measured and compared to the calculated value. If they differ significantly, this may indicate some unexpected resistance in the neutral circuit. The contribution to the cow contact voltage of this source is also measured and if it is significant, the condition is noted for possible mitigation.

Service Entrance Panel – The main electric service panel in each building. It has a main breaker and many other breakers for each branch service. It has a code-required bond between the neutral and the grounding bars.

Seven Number Summary – This is a standard statistical enumeration process for expressing the distribution characteristic of a set of number values. The numbers are arranged in ascending order from least to most. The seven number summary consists of the minimum value, the maximum value, the median value (the number that is half way down the list between the minimum and maximum values) the first and third quartile values (the values that are one-quarter and three quarters of the way down the list from the minimum to the maximum value), the total number of values in the set and the statistical average or mean value (the sum of all the values in the set divided by the number of values in the set).

Shunt Resistance – (Rshunt) **–** A physical resistor component used to simulate a cow during the measurement of cow contact voltage. Usually set by PSC rules to nominally be 500 Ohms, which is a conservative value that represents the average cow (muzzle to rear hooves) and many of the contact and other source resistances in the cow contact area. Using Ohm's Law, a cow contact current can be calculated from the known value of this shunt resistance and the measured voltage across the resistance.

Single Phase System – A reference to a system of primary power wiring utilizing one phase conductor to deliver electrical energy to a load and a neutral conductor to return current to the source.

Source Resistance – (**R_{source}**) **–** A term used to refer to all the various physical resistances that exist between a source voltage and a cow contact area. It cannot be measured directly by an Ohmmeter, but can be calculated by measuring the voltages at a cow contact both with and without a shunt resistance in place. The formula is as follows: subtract the voltage measured with a shunt resistance (Vw) from the voltage measured without the shunt resistance (Vw/o). Divide that difference by the voltage measured with the shunt resistance. Multiply that result by the value of the shunt resistance and the answer is the value of the source resistance in Ohms. (R_{source} = (Vw/o – Vw)/Vw * R_{shunt}). The PSC would like, as a guideline, all source resistances calculated in a cow contact area to be less than 500 Ohms. This is, on rare occasions, not possible due to the materials involved and the configuration of the barn wiring system.

Source Voltage – A potential or electromotive force that produces an electrical current when attached to a complete circuit

Steady-State - Steady state is defined by the Institute of Electrical and Electronics Engineers (IEEE) as the value of a current or voltage after all transients have decayed to a negligible value.

Stray Voltage (SV) – A term with a specific definition from the PSC. It is defined by the PSC 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 July 16, 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 defines “steady-state” as “the value of a current or voltage after all transients have decayed to a negligible value.” The PSC 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 in the animals 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 voluntarily taken by the farmer. Stray voltage is not electrocution and is not associated with DC voltages and current or with electromagnetic fields. It only refers to farm animals that are confined in areas of electrical use and not to humans.

Substation – An area of electrical equipment within a utility power system that allows for the interface between a transmission system and either a sub-transmission system or a distribution system. It may contain a combination of transformers, switching gear, busses, circuit breakers, metering devices, and other system protective gear to accomplish this task. Substations are one of the current return nodes for the three-phase multi-grounded neutral distribution circuit. The three-phase multi-grounded neutral distribution system may have other balance nodes where the return currents sum to zero along its length.

Tap Pole – The pole on an electrical distribution system that supplies energy to an individual or group of customers. In some instances, the tap pole is the point from which a feeder branches off, extending several spans to a rural customer's transformer pole. In other instances, it may be a pole along a distribution system circuit where a transformer is placed that supplies energy to one or more customers in parallel.

Three-Phase System – A power delivery system that uses three energized conductors with or without a neutral conductor. A wye-system may have a neutral conductor. The individual phases have their cycles start at a mutual 120 electrical degree separation. One of the advantages of using three-phase loads is that they are inherently balanced and do not generate neutral current. Only various single-phase loads wired to individual phases of the three-phase system generate neutral current because they do not all draw the same amount of current at the same time.

Three-wire System – The original style of single-phase wiring system used in farm wiring. In this system, there are two energized conductors and a grounded neutral conductor. In every panel and sub-panel, any grounding conductor present is bonded to the neutral such that it functions merely as a parallel neutral conductor. The NEC code has required a four-wire system (i.e. with separated neutral and grounding conductors) in agricultural facilities for many years, but true implementation to code is rarely achieved.

Transformer (xfmr) – An electrical component, used in AC systems, that transforms voltage and current levels through magnetic coupling and induction. A transformer is physically constructed by wrapping a number of turns of a primary winding and a secondary winding around a core of specific magnetic material. The primary winding and the secondary winding are usually not conductively connected within the transformer. The ratio of the number of turns for the primary to the secondary determines the ratio of voltage and current increase or decrease. For example, if a transformer's primary is designed for 7,200 volts and its secondary is designed for 240 volts, the turns (and voltage ratio) is 30 to one. That ratio also describes the increase in current on the secondary side. If the primary current is 5.2 Amps, then the secondary current will be 156 Amps. Note that the Volt-Amp products of the primary and the secondary sides are equal, i.e. 7,200 x 5.2 = 240 x 156 = about 37.5 kVA.

Transmission System – A part of the primary electrical system that receives energy from the generation system and delivers it to the distribution system, sometimes over significant distances. Higher voltages are designed into transmission systems so that the current that must be carried on the non-zero resistance conductors is relatively low for a fixed amount of delivered power. Losses are calculated using Ohm's Law, meaning that the lower the current in the fixed resistance conductors, the less voltage drop will occur and therefore the less power will be lost as heat delivering the electrical energy to the load. To afford a measure of lightning protection, a grounded static wire is mounted at the highest point above all transmission lines. Many Wisconsin transmission systems have a wye-connected transformer with the neutral center tap at the sending end grounded for reference. Because the transmission system is always a balanced three-phase system, little ground current is created. Because of the high voltages and currents used in transmission systems, the area underneath the system usually is an area that can have significant levels of electric and magnetic fields.

Transmission Voltage Level – The voltage levels of transmission systems are higher than 60,000 and may range up to as high as 345,000 Volts AC, rms, phase-to-phase in Wisconsin.

Variable Threshold Neutral Isolator Device – A recently designed variation of the neutral isolator device that re-closes the neutral connection at different (higher) voltage levels depending on the (shorter) duration of transient voltages across the device. For steady-state voltages of about 26 volts on either neutral, the switch will close and connect the primary and secondary neutrals for as long as the voltage remains above that level. The shorter duration the transient is, the higher the voltage level needed to close the switch.

Vcc - Cow Contact Voltage – The AC, 60 Hz, rms, steady-state voltage across the 500-Ohm resistor established in a cow contact area. A measurement protocol has been established by the PSC for the correct set-up of a cow contact so that the value measured will be worst-case (i.e. the largest value possible).

Vps – Primary Neutral to Secondary Neutral Voltage – The voltage that exists as a voltage drop or voltage differential across the service drop neutral conductor that connects the transformer's secondary lugs to the main service entrance panel in the animal housing facility.

Volt – The basic unit of electric potential or electromotive force. It is sufficient potential to produce a current of one Ampere through a resistance of one Ohm.

Voltage (V) – The electrical quantity that describes the push or potential that electrical energy needs to flow in a circuit. It is one of three parameters used in Ohm's Law. It is always measured as a difference between a higher potential and a lower potential, even if the lower potential is zero (Earth reference). Voltage can appear as a source that exists in either an open circuit (producing no current) or closed circuit (producing current) or as a closed loop voltage drop that is the Ohm's Law reaction of a current to a resistance. Voltage is never measured 'on' something, but is always measured as *between* two points.

Voltage Drop – (**Vd**) **–** Whenever a current passes through a resistance or impedance in a closed loop circuit, a voltage drop (or IR drop, according to Ohm's Law) is produced across that resistance or impedance. The neutral conductor voltage drops on other services in addition to Vps are recorded in a Phase II investigation.

Watt (W) – An electrical unit describing power expended. In formulas for simple DC circuits, power is equal to voltage times current or voltage squared over resistance or current squared times resistance. For an electrical system having a one-Volt source feeding a load (of one Ohm) drawing one Amp of current, one Watt of power is being supplied. In AC circuits, because of the inclusion of frequency and multi-phase circuits, AC power formulas can be more complex. Power is an instantaneous quantity, as opposed to energy, which is defined as power utilized over a specific time. Electrical energy is measured in Watt-seconds, Watt-hours or, most commonly, in kiloWatt-hours.

Wye (Y) Configuration – A term used to describe a three-phase electrical system with or without a neutral conductor. Schematically, the phases are connected to transformer or load terminals shown as resembling the letter 'Y'. Any neutral connection will be made to the junction of the three legs forming the "Y." When a neutral conductor is present, it will carry any imbalance current from the three phase wires. The value of the imbalance current is calculated using vector mathematics for the currents. For example, a system having a phase A current of 12 Amps, a phase B current of 10 Amps and a phase C current of 18 Amps will have a neutral current of just over 7.2 Amps. The phase angle will be minus 106 degrees (slightly out-of-phase with phase C).