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STRAY VOLTAGE STEERING COMMITTEE

Test to Investigate Primary Neutral Grounding Practices and their Effects on Dairy Herd Health and Production

Report and Supporting Documents

Submitted to the
Minnesota Environmental Quality Board
by the
Riley C. Hendrickson, Consultant to the Board

September 15, 1994

___ Consultant's Report

STRAY VOLTAGE TEST
TO INVESTIGATE
PRIMARY NEUTRAL GROUNDING PRACTICES
AND THEIR EFFECTS
ON DAIRY HERD HEALTH AND PRODUCTION

AN ANALYSIS OF THE DATA BASE

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By:

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____ Consultant's Report

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Introduction

From the test protocol (Dahlberg, Mairs, Hendrickson, 2/93). . . "The Minnesota Environmental Quality Board Stray Voltage Steering Committee requested the development of a test protocol to examine the effects, if any, of primary neutral grounding practices of rural distribution systems on dairy herd health and production. Initiation of protocol development was in response to reports from dairy operators from both Wisconsin and Minnesota that disconnecting grounds on the primary neutral has had immediate and significant positive effects on production and the health of their dairy cattle.

"The test as here designed is limited in that measurements will be made at just one farm over a relatively short time period. Extrapolation of conclusions to other farms may be problematic, considering the variability of electrical installations and other factors among farms. The test has been carefully designed to include the issue of quality control. The measurement strategy has been reduced to a set of relatively simple, specific, appropriate and easily documented observations which can serve as indicators of the effect, should it exist on the test farm."

This test was conducted from 3/15/93 through 4/15/93 on the David Lusty farm in Miltona, MN, using materials and methods described in (Hendrickson, 8/25/93). The data was reduced and presented by the Minnesota Environmental Quality Board for review and interpretation. The test protocol states "Interpretations including recommendations will be provided by the representatives of the dairy farmers and the utilities to the EQB staff. Staff will submit these interpretations and their own interpretation in a report to the EQB via the Stray Voltage Steering Committee." This report constitutes an interpretation of the data base for the MEQB.

Summary

It has been hypothesized that disconnecting the grounds on the electrical system primary neutral near dairy farms has had immediate and significant positive effects on production, health and behavior of dairy cattle. A test was designed and conducted to measure electrical and herd quantities to determine if they changed as a result of disconnecting the primary neutral grounds at a test farm.

An analysis of the data base was conducted to answer the questions: As a result of disconnecting primary neutral grounds, did electrical quantities change at the transformer pole (Section 1), in the barn (Section 2), or did indicators of herd health, behavior or production change (Section 3)? A discussion of anomalies in the data base is found in Section 4. Section 5 discusses the relationship between electrical and herd data, and Section 6 evaluates the electrical data. Wherever possible, intermediate results are provided to allow alternative interpretations. Summaries of the findings in each of these sections follow.

1. Transformer Pole Electrical Data and P/N Ground Status.
No instantaneous changes were found in the primary neutral voltage data when the ground connections were switched on or off. No consistent, longer term changes were found to be associated with switching.

2. Barn Electrical data and P/N Ground Status.

No instantaneous changes in one-second data were found in the magnitudes of cow contact potentials and other electrical quantities being measured in the barn as a result of switching the P/N grounds on or off. A possible exception was a change in the variability of the dc voltage between front and rear hoof.

An examination of one-minute data indicated a possible change in variability in the ac voltage between the water line and rear hoof. It occurred only once. Other changes were attributed to other causes.

Changes were noted in hour-average data near switch events but were attributable to other causes with the exception of the dc voltage between front and rear hoof; a long-term decline in this measurement began near the first switch event but was not repeated at subsequent switch events.

3. Evaluation of Herd Data Relative to P/N Grounding.
Data compiled by the test veterinarian was analyzed with respect to the status of the P/N grounds on the basis that indicators either did or did not support the hypothesis that P/N ground currents caused health, behavior or production problems in the herd. Many indicators included exceptions to the following conclusions; Refer to Section 3 for intermediate results and a discussion of exceptions.

Notations of disease incidence in the herd did not provide support for the hypothesis.

Daily herd water consumption data did not support the hypothesis.

Daily herd milk production rates did not support the hypothesis. An analysis of milk production by individual cows gave weak support to the hypothesis; However, bias in the data and analysis method is noted and a suggestion for a more detailed and bias-free analysis is provided.

An analysis of blood parameters indicative of stress and disease was made on the basis of change relative to P/N ground changes. Overall, the blood test results were ambivalent. The blood parameter offering some support to the hypothesis was the eosinophil count (decreases with disease, inflammation and stress). Most other blood parameters scored near zero. Changes in the red blood cell counts, hematocrit and hemoglobin (which decrease with disease) somewhat countersupported the working hypothesis; they changed in the opposite direction. Average blood test scores (across all blood parameters) for individual cows ranged between "ambivalent-to-somewhat-countersupportive" of the hypothesis.

Mastitis (bacterial infection/inflammation of the udder) data were of three types: Clinical observations provided weak support. Bulk tank somatic cell counts showed some support though the overall results were inconclusive. A bulk tank milk microbiological analysis provided results which were somewhat supportive of the working hypothesis.

Cow appearance resulted in no net support; On one hand, the occurrence of erythema and soreness supported, but cud chewing, hock/leg swelling and manure consistency countersupported the hypothesis.

General cow behavior changes averaged 0.75 on a support scale of -3 to +3. No behavior category scored below zero (countersupported the hypothesis). Three scored +2; these were dancing, licking and "grace/ease rising". Cow behavior provided some support to the hypothesis.

Cow behavior at milking time also was somewhat supportive, scoring +.55 on a support scale of -1 to +1. Tail switching scored highest (+1.00) followed by dancing/shifting (+0.33) and cud chewing (+0.33).

Many individual observations of cows were documented by the veterinarian and dairy operator. These are tabulated to provide a measure of support/countersupport for the hypothesis.; no overall pattern could be determined.

4. Electrical Data Anomalies

Early in the test, electrical data show that the primary and secondary neutrals became connected through a path other than through the isolator at the transformer pole. The event lasted several hours and resulted in changes in cow contact potentials and other electrical measurements in the barn.

A few instances were noted when the primary neutral ground resistance changed from a normal 28 Ω to a much lower value for several minutes at a time. These events did not involve the secondary neutral system.

Miscellaneous anomalies involved the ac magnetic field (caused by monitoring equipment installation), current data in the barn (unreliable contact) and an unexplained long-term change in the dc voltage between front and rear hoof.

A repeating anomaly in cow contact potentials was identified as an interaction caused by the current measurement between water line and gutter chain.

A number of anomalous cow behaviors were documented; In one case a cow fell flat. The electrical record was examined to determine if the incident could be explained. Nothing could be identified other than a cow contact voltage impulse which may or may not have occurred at the exact time of the fall.

5. Relationship of Electrical and Herd Data

Aside from the question of herd data changes with P/N ground status, was there a relationship between electrical and herd data in general?

One-day averages of electrical data were compared to daily herd data using correlation coefficients to identify possible relationships between them. Weak associations were found between dc cow contact potentials and both herd milk production and water consumption. These associations were coincidental. Somatic cell counts did not correlate well with any electrical data.

Herd data collected weekly was compared to one-week averages of four cow contact potentials (two ac and two dc). The herd data included all the blood parameters, somatic cell counts, bacterial counts, and cow behavior categories. First, consideration was given to a comparison of directions of change. The cow contact potential achieving the highest score average across all herd parameters was the ac voltage between the water line and rear hoof; it scored 0.22 on a scale of -3 to +3. Overall, the mean of the score distribution was near zero. No clear association could be found. A consideration of the average magnitudes of the cow contacts led to the conclusion that they probably could not have caused a standard stray voltage response.

6. Barn and Distribution Electrical Data, Evaluation and Correlations

A statistical description of the electrical data was developed.

The ac voltage of the primary neutral at the test farm was typically about 1 volt, causing a ground current of about 39 mA through a 28 Ω (calculated) ground rod resistance at the transformer pole. The ground at the next pole had a much higher resistance allowing only about 1 mA to flow to ground.

In the barn, the secondary neutral ac voltage was typically about 11 to 21 mV reflecting low electrical use and/or a balanced load. Cow contact potentials were relatively low: Water line to rear hoof open circuit potentials were 4-7 mVac and about 400 mVdc (including the contact potential). Front to rear hoof potentials across 300 Ω were typically less than 1 mVac and much less than 1 mVdc. A component of the ac magnetic field was about 0.03-0.06 mG throughout the test, a very small field. A portion of this could not be accounted for by electrical use on the farm implying an off-farm source.

Correlation coefficients were determined between all pairs of electrical data to document associations. A number of associations were noted. The quantity central to the purpose of this test, the ac primary neutral current to ground, did not correlate with electrical quantities in the barn indicating a lack of effect.

Suggestions for Additional Analysis:

A number of data sets were not considered in this analysis because the data form did not allow a detailed examination in the time available. Other data was not considered since it was not as central to the purpose of the test as that data considered here.

A large amount of individual cow data was available, notably observations by the dairy operator and by the test veterinarian; further analysis of this data as well as the data presented with ON/OFF status in this report by a qualified animal expert would be of use. Particularly, herd parameters showing support for the working hypothesis need further investigation.

A more detailed statistical description of the power quality data, particularly the voltage impulse information, would be of great value.

A thorough analysis of the distribution operating data as it relates to conditions seen on the primary neutral at the test farm could be performed.

An examination of the neutral grounds at the transformer pole should be made to determine if the anomaly which happened early in the test may be reoccurring.

1. Transformer Pole Electrical Data and P/N Ground Status

Three sets of data were analyzed: One-second data, one-minute data and one-hour averages of the minute data.

<u>One-Second Data</u>

On four occasions during the test the switches in the primary neutral ground (P/N GRD) wires at the transformer pole (pole 1) and at the next grounded pole (pole 2) were operated; coincident with this procedure the data logger at the transformer pole was set to record data once a second for a period of approximately 20 minutes in order to determine if the electrical parameters, Vac and Vdc between P/N and reference ground, changed instantaneously with P/N GRD switch changes.

Graphs of one-second data logged at the transformer pole are found in Data Item #17. The traces on these graphs were carefully marked with on/off times and examined to determine if the magnitude, trend or variation of the data changed as a result of changing the status of the P/N GRD at pole 1 and pole 2. Figures 1.1a and 1.1b are examples of this procedure. Table 1.1 presents a summary of the results.

			PN Electrical Parameters at Pole 1			
Date	Pole	On/Off	PN-RG Vac	PN-RG mVdc	PN-TG mAac	PN-TG mAdc
3/24	2	off	no	no	no	no
	1	off	**	**	*	*
3/31	2	on	no	no	*	*
	1	on	no	no	*	*
4/8	2	off	no	no	no	no
	1	off	no	no	*	*
4/14	2	on	no	no	*	*
	1	on	no	no	*	*
	1	off	no	no	*	*
	1	on	no	no	*	*

<u>Table 1.1</u> Did the transformer pole 1-second electrical data change when the P/N GRD switches at poles 1 and 2 were changed?

* - Currents in the ground wire were interrupted by switch at pole 1 (changed as expected with switch operation).
** - Missing data
PN - Primary Neutral
RG - Remote Ground
TG - Transformer Pole Ground
Vac - AC Volts
mVdc - DC Millivolts
mAac - AC milliamps
mAdc - DC milliamps

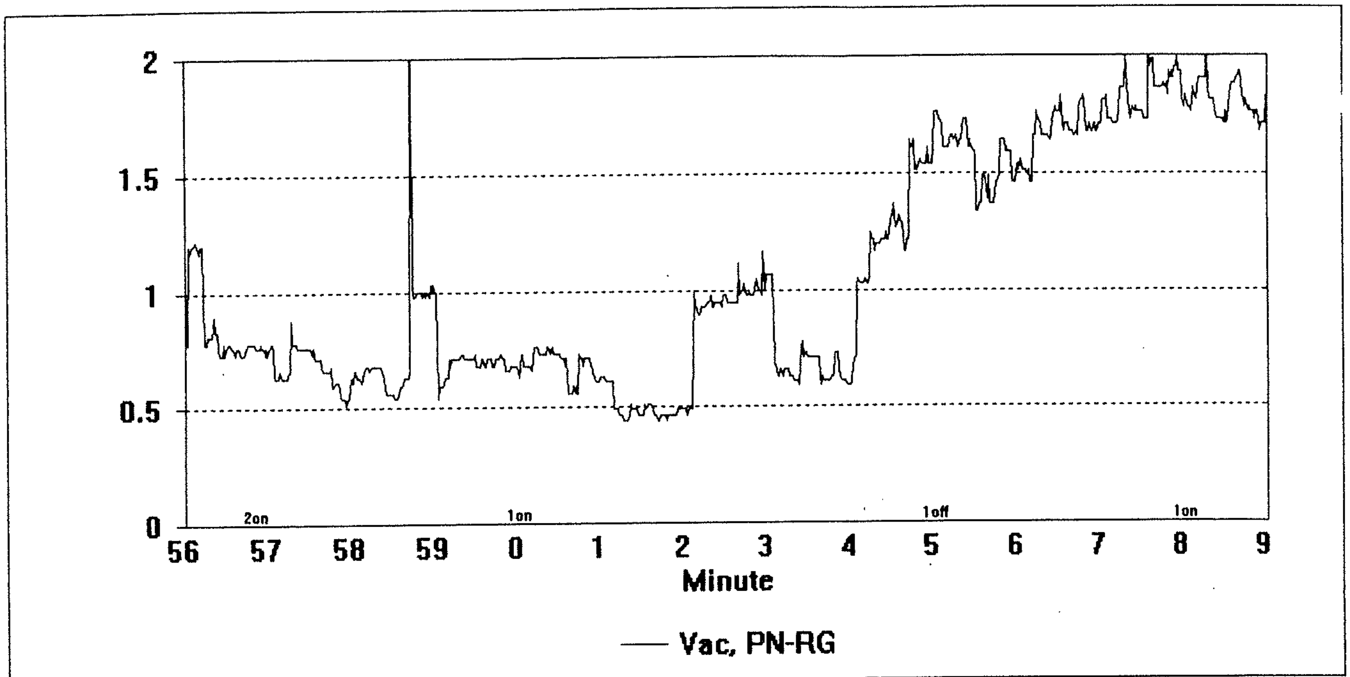


Figure 1.1a

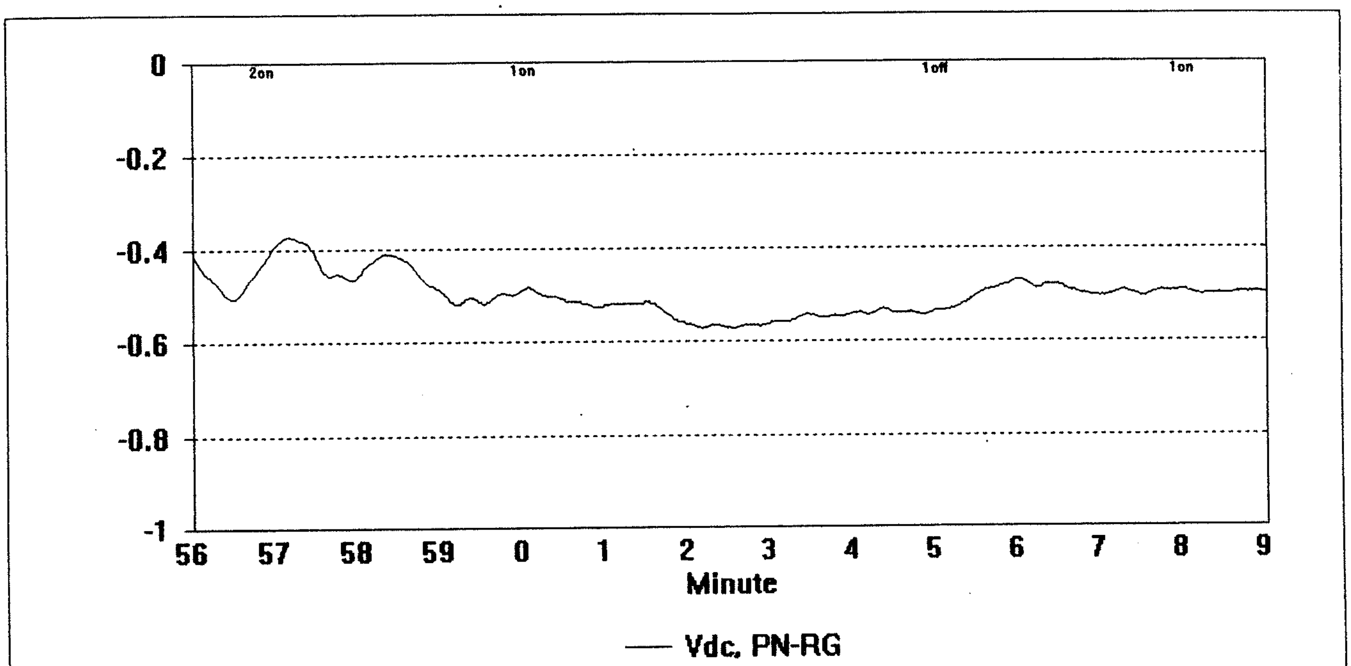


Figure 1.1b Example of 1-second electrical data at the transformer pole during switching on 4/14/93. Vac and Vdc are the voltages of the distribution primary neutral relative to remote ground. The annotations refer to:

2on = P/N Ground switched on at pole 2
1on = P/N Ground switched on at pole 1 (transformer pole)
1off = P/N Ground switched off at pole 1

No obvious instantaneous changes were noted in the 1-second P/N voltage data at the transformer pole as a result of changes in the primary neutral grounding.

<u>One-Minute Data</u>
Except for switching times described above, electrical data at the distribution pole is in the form of one-minute averages of measurements made once per second. Graphs of this data are found in Data Item #15. These graphs were examined to determine if there were obvious differences in the traces before and after switching. Table 1.2 summarizes the findings.

		PN Electrical Parameters at Pole 1			
Date	On/Off	PN-RG Vac	PN-RG mVdc	PN-TG mAac	PN-TG mAdc
3/24	off	no	yes(#1)	*	*
3/31	on	no	no	*	*
4/8	off	no	no	*	*
4/14	on	yes(#2)	no	*	*

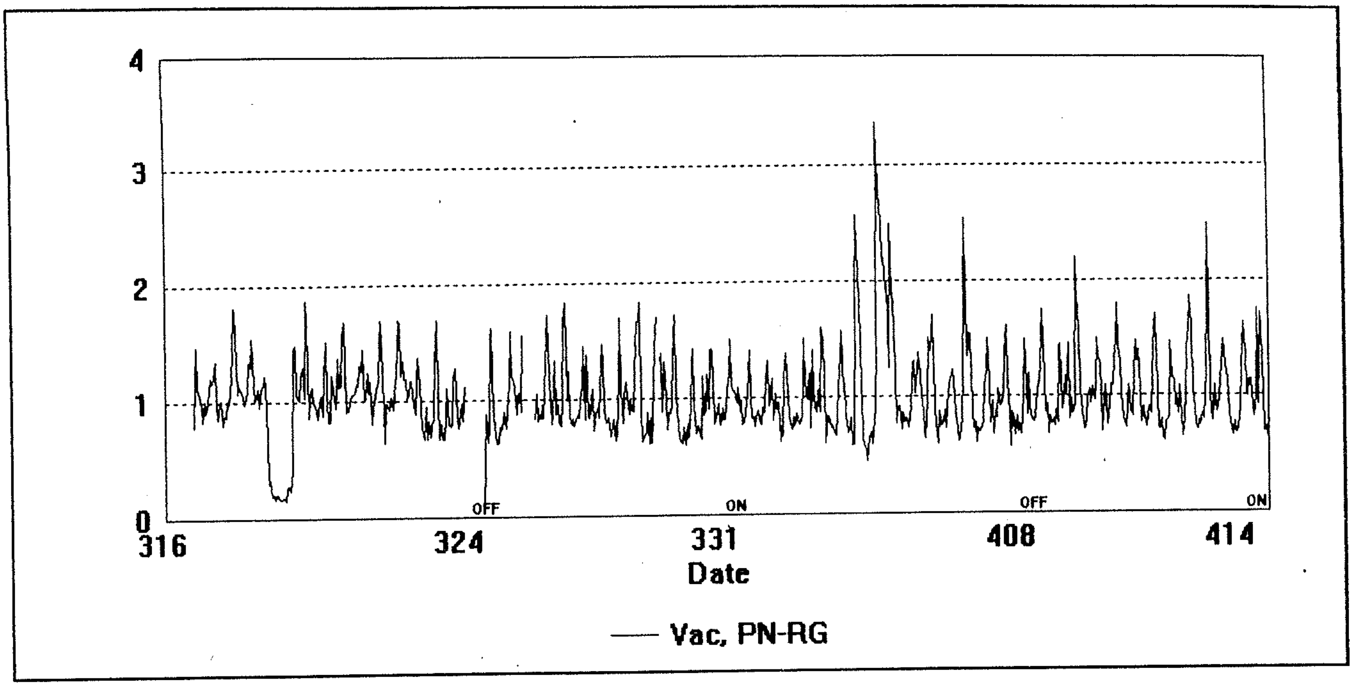
<u>Table 1.2</u> Did the transformer pole 1-minute electrical data change when the P/N GRD switches were changed?

* - Currents in the ground wire were interrupted by switch at pole 1 (changed as expected with switch operation).
#1 - Variability decreased (also changed without switching as on 3/23).
#2 - Variability decreased (also changed without switching at approximately same time on 4/13).

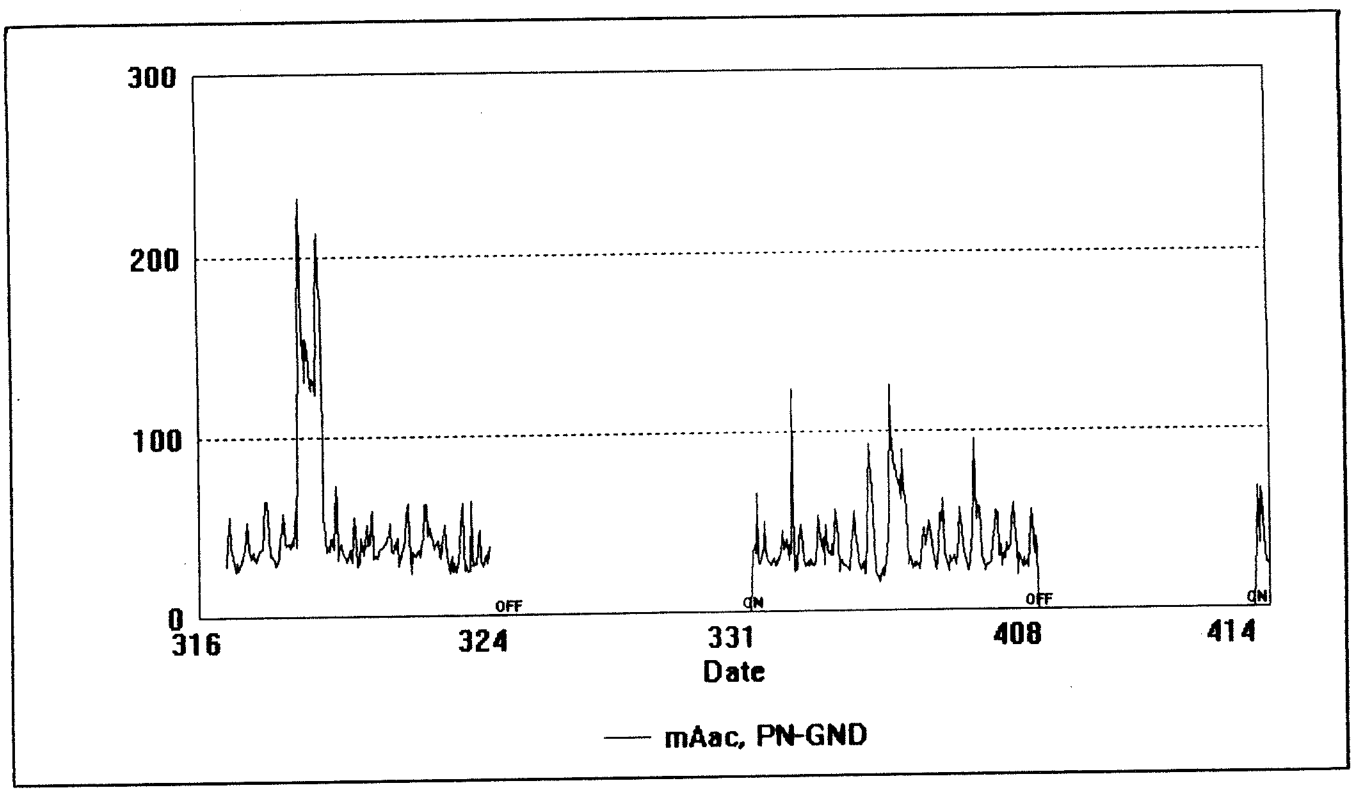
The ac and dc voltages between the primary neutral and reference ground (as minute averages) did not indicate a consistent change coincident with switch events. Two instances were noted where the variability in the data seemed to change at some point during the 20 minutes of missing one-minute data (data loggers operating in one-second mode during switching). The one-minute data do not conclusively link these changes to switching because: 1) The changes in variability occurred only once, not all four times the P/N ground was changed. 2) The changes occurred at other times than during switching. 3) The one-second data do not support such a link. 4) Changes such as these are the result of changing load on the distribution system.

<u>One-Hour Average Data</u>
All of the one-minute data was reduced to hourly average data and is presented in Figures 1.2 through 1.5. Each graph represents a record of a parameter for the length of the one-month test. This allows a search for long-term changes in the data as a result of switching. A summary of the results is found in Table 1.3.

Distribution Pole 1-Hour Average Data



<u>Figure 1.2</u> Vac, primary neutral to reference ground. One-hour average data with switch events shown.



<u>Figure 1.3</u> mAac, primary neutral to transformer pole ground. One-hour average data with switch events shown.

Distribution Pole 1-Hour Average Data

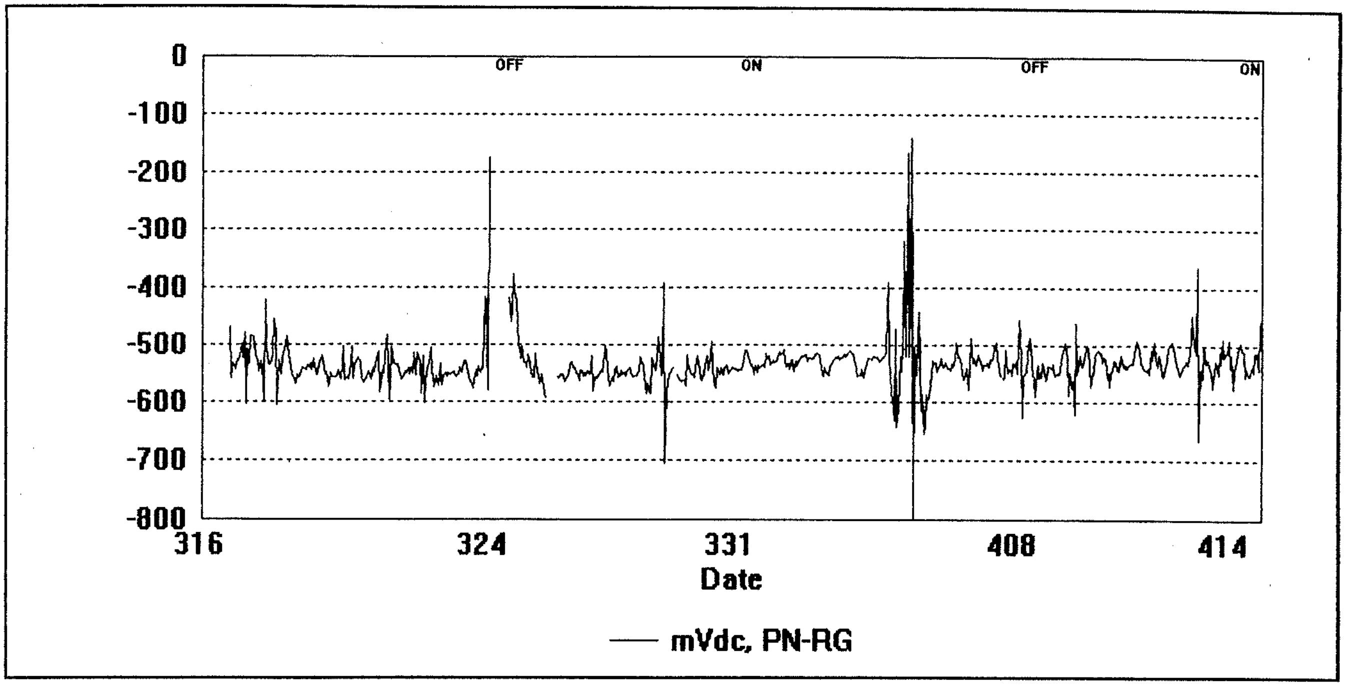


Figure 1.4 mVdc, primary neutral to reference ground. One-hour average data with switch events shown.

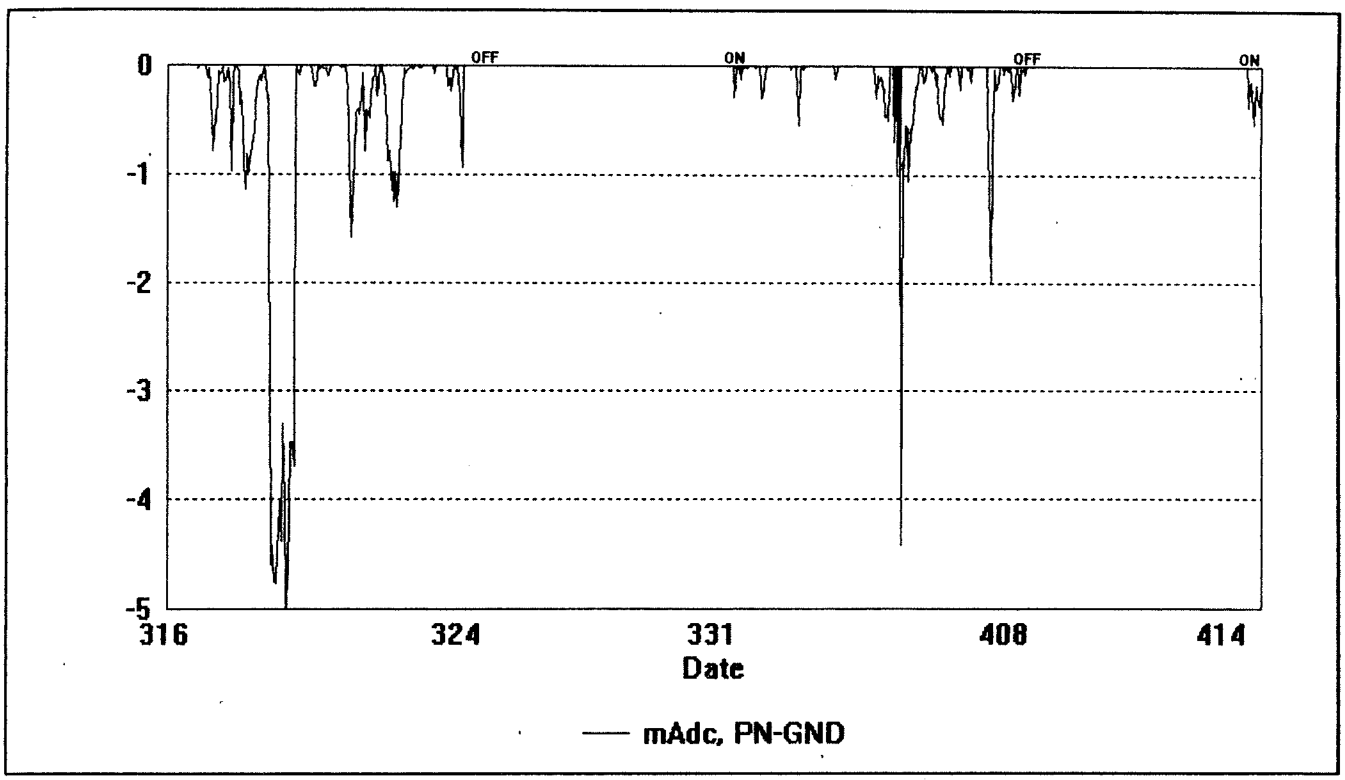


Figure 1.5 mAdc, primary neutral to transformer pole ground. One-hour average data with switch events shown.

		PN Electrical Parameters at Pole 1			
Date	On/Off	PN-RG Vac	PN-RG mVdc	PN-TG mAac	PN-TG mAdc
3/24	off	no	?(#1)	*	*
3/31	on	no	no	*	*
4/8	off	no	no	*	*
4/14	on	?(#2)	?(#2)	*	*

Table 1.3 Did the transformer pole 1-hour electrical data change when the P/N GRD switches were changed?

* - Currents in the ground wire were interrupted by switch at pole 1 (changed as expected with switch operation).
#1 - Data were unstable before and after switching. No long-term change.
#2 - Not enough data after switching to tell if a change occurred.

One-hour averages of P/N ac and dc voltages did not change consistently with changes in primary neutral grounding.

2. Barn Electrical Data and P/N Ground Status

Electrical data logged in the barn include one-second data, one-minute data, one-hour averages of one-minute data and voltage impulse data.

<u>One-Second Data</u>

On four occasions during the test the switches in the primary neutral ground (P/N GRD) wires at the transformer pole (pole 1) and at the next grounded pole (pole 2) were operated; coincident with this procedure the data logger in the barn was set to record data once a second for a period of approximately 20 minutes in order to determine if the electrical parameters being monitored in the barn (cow contact potentials, for example) changed immediately as a result of P/N GRD changes.

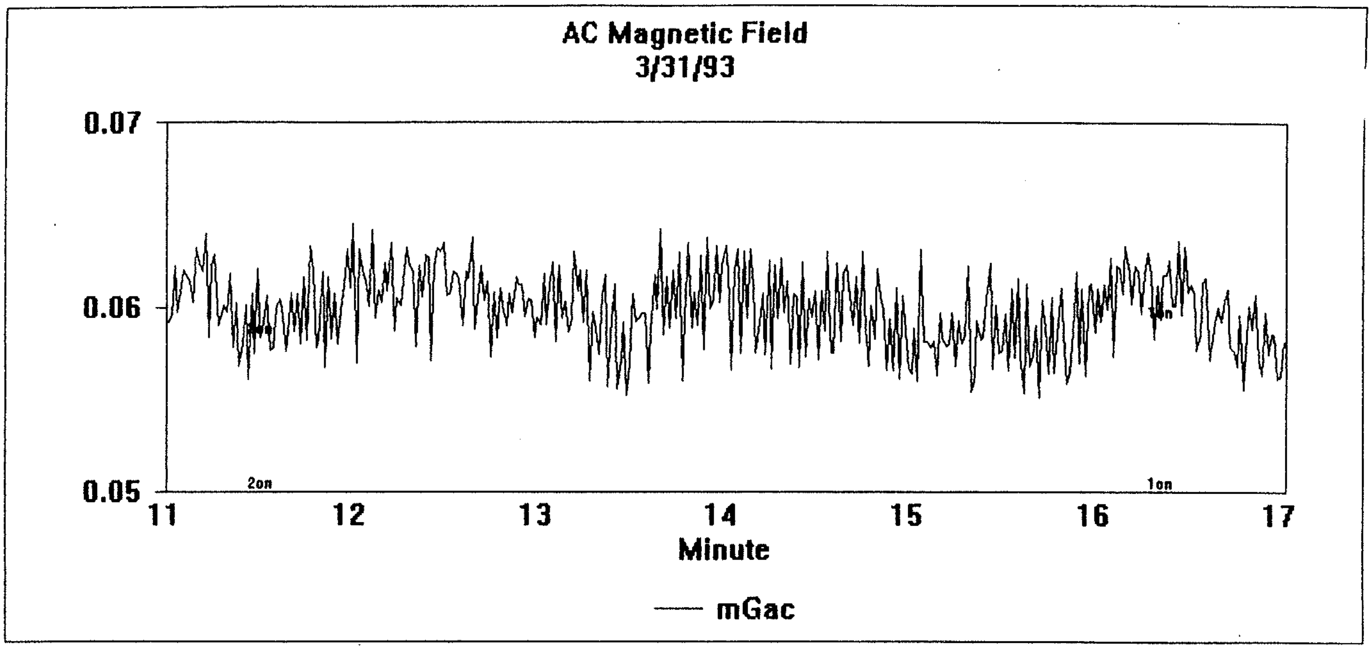
Graphs of one-second data logged in the barn are found in Data Item #10. The traces on these graphs were carefully marked with on/off times and examined to determine if the magnitude, trend or variation of the data changed as a result of changing the status of the P/N GRD at pole 1 and pole 2. Figures 2.1 to 2.7 are examples of this procedure. Table 2.1 presents a summary of the results.

			Electrical Parameters in the Barn						
Date	Pole	On-Off	WL-RH mVac	WL-RH mVdc	RH-FH mVac	RH-FH mVdc	2N-RG mVac	WL-GC mAac	Bac
3/24	2	off	*	*	*	*	*	*	*
	1	off	*	*	*	*	*	*	*
3/31	2	on	no	no	no	no	no	no	no
	1	on	no	no	no	yes	no	no	no
4/8	2	off	no	no	no	no	no	no	no
	1	off	no	no	no	no	no	no	no
4/14	2	on	no	no	no	yes	no	no	no
	1	on	no	no	no	no	no	no	no
	1	off	no	no	no	no	no	no	no
	1	on	no	no	no	no	no	no	no

<u>Table 2.1</u> Did the barn electrical data change as a result of changing the P/N GRD status at distribution poles 1 and 2?

* - Missing data
WL - Water Line
RH - Rear Hoof
FH - Front Hoof
2N - Secondary Neutral
RG - Remote Ground

mVac - AC millivolts
mVdc - DC millivolts
mAac - AC milliamps
Bac - AC magnetic field (vertical)



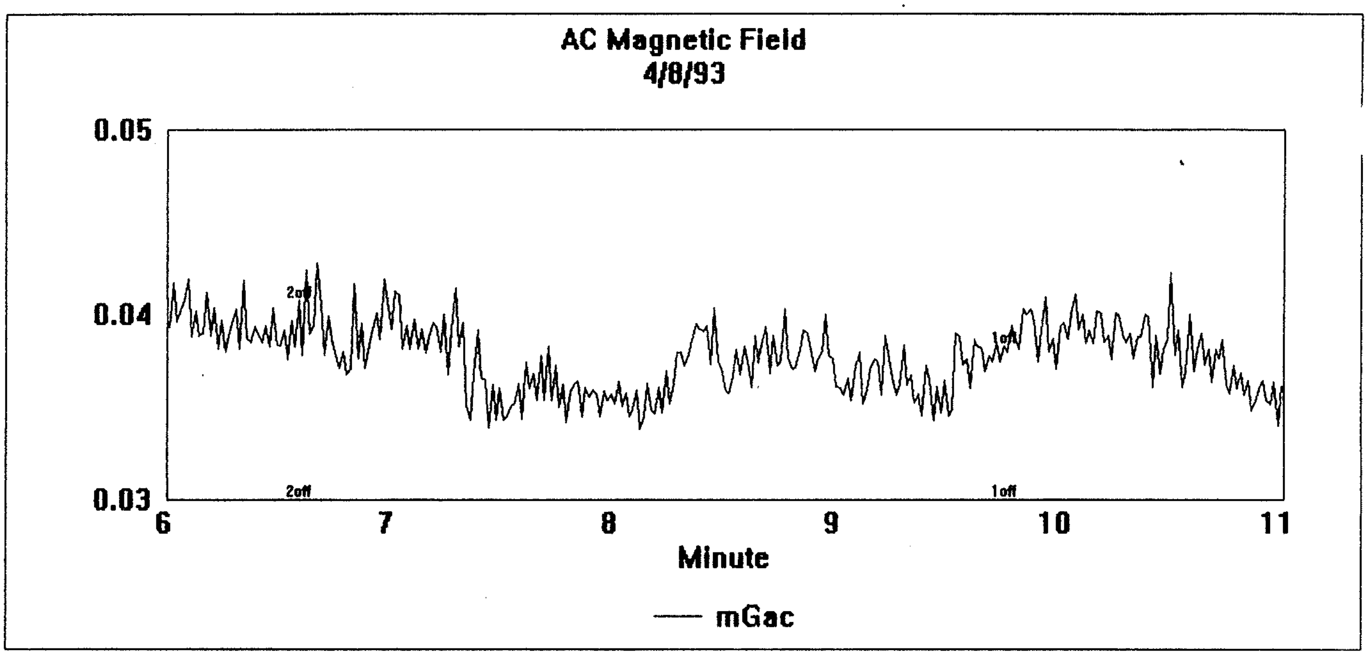


Figure 2.1 mGac, magnetic field vertical component at stall floor. One-second data on 3/31 and 4/8/93 with switch events shown. Annotations refer to:

2on/2off = P/N ground switched at pole 2
1on/1off = P/N ground switched at pole 1 (transformer pole)

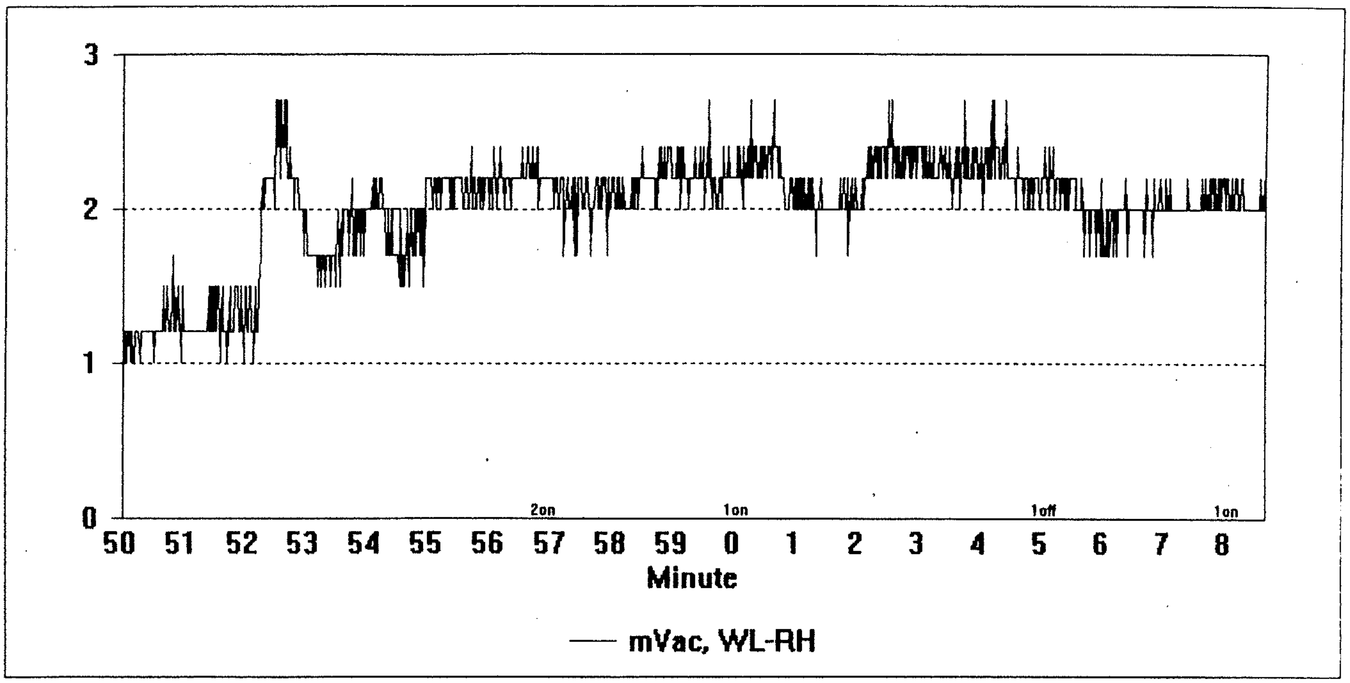


Figure 2.2 mVac, barn water line to rear hoof. One-second electrical data on 4/14/93 with switch events shown.

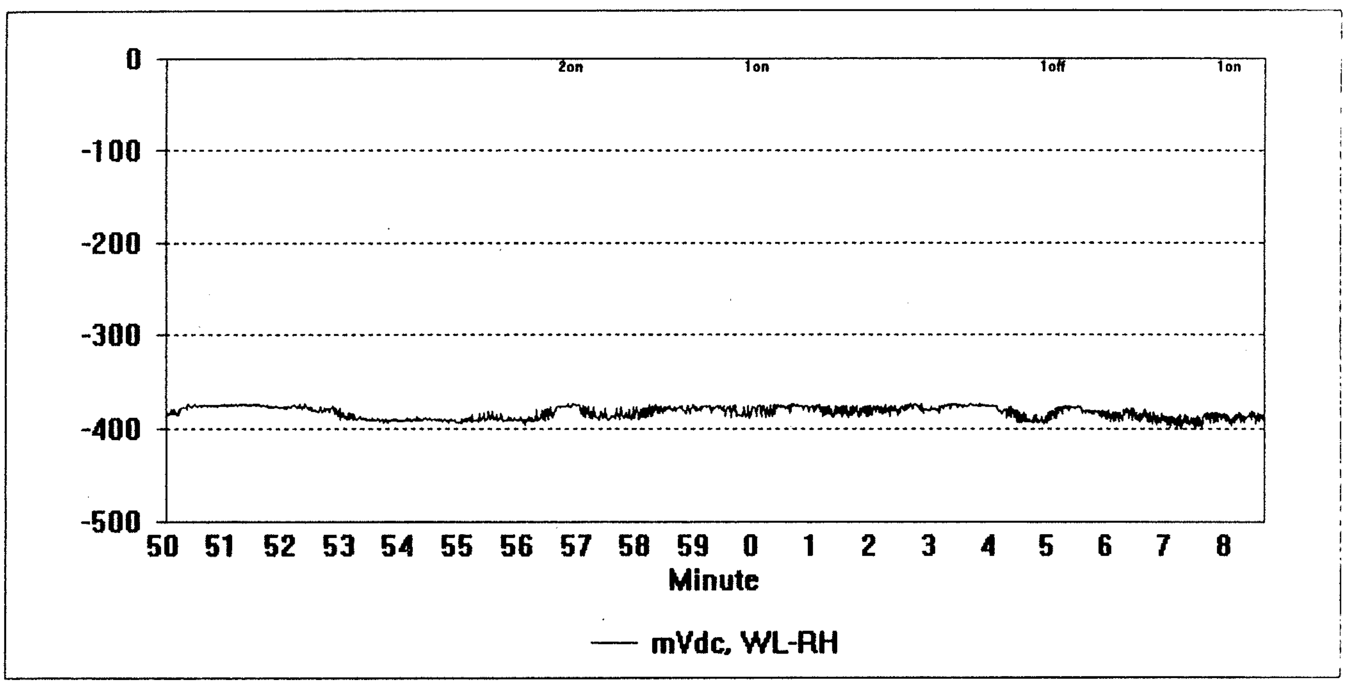


Figure 2.3 mVdc, barn water line to rear hoof. One-second electrical data on 4/14/93 with switch events shown.

Barn 1-Second Data, 4/14/93

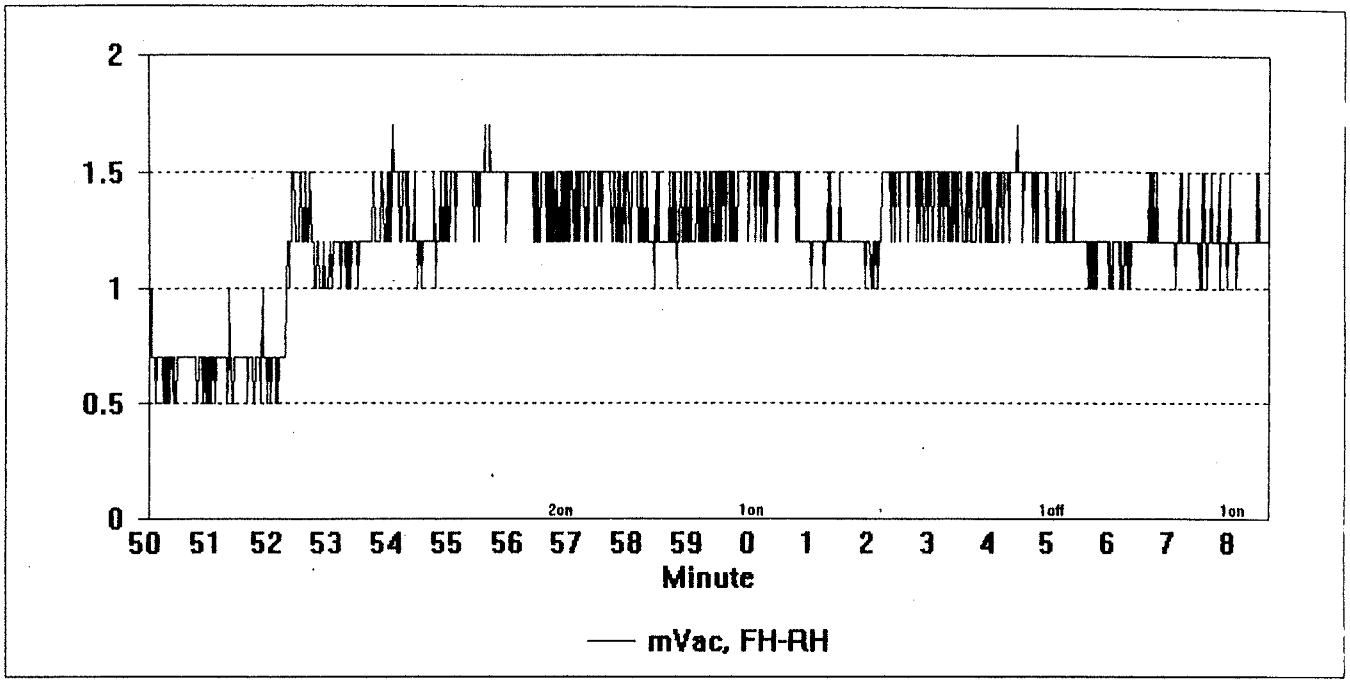


Figure 2.4 mVac, barn front hoof to rear hoof. One-second electrical data on 4/14/93 with switch events shown.

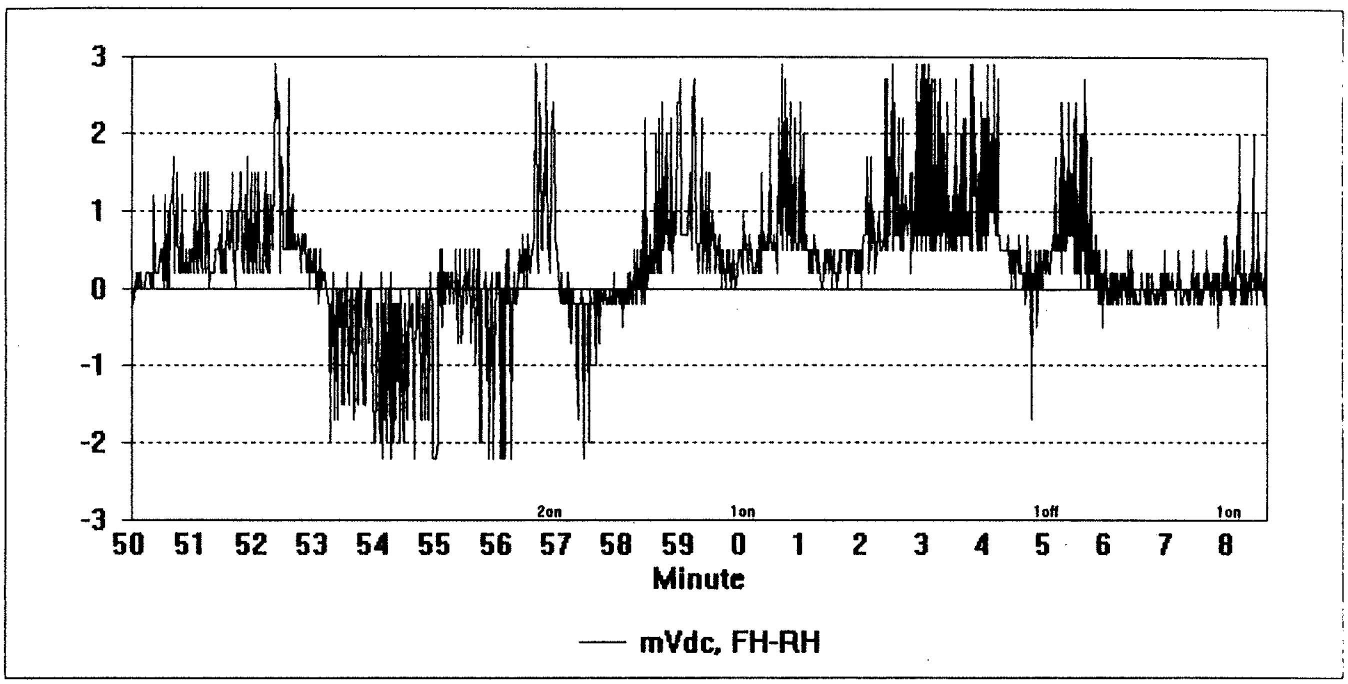


Figure 2.5 mVdc, barn front hoof to rear hoof. One-second electrical data on 4/14/93 with switch events shown.

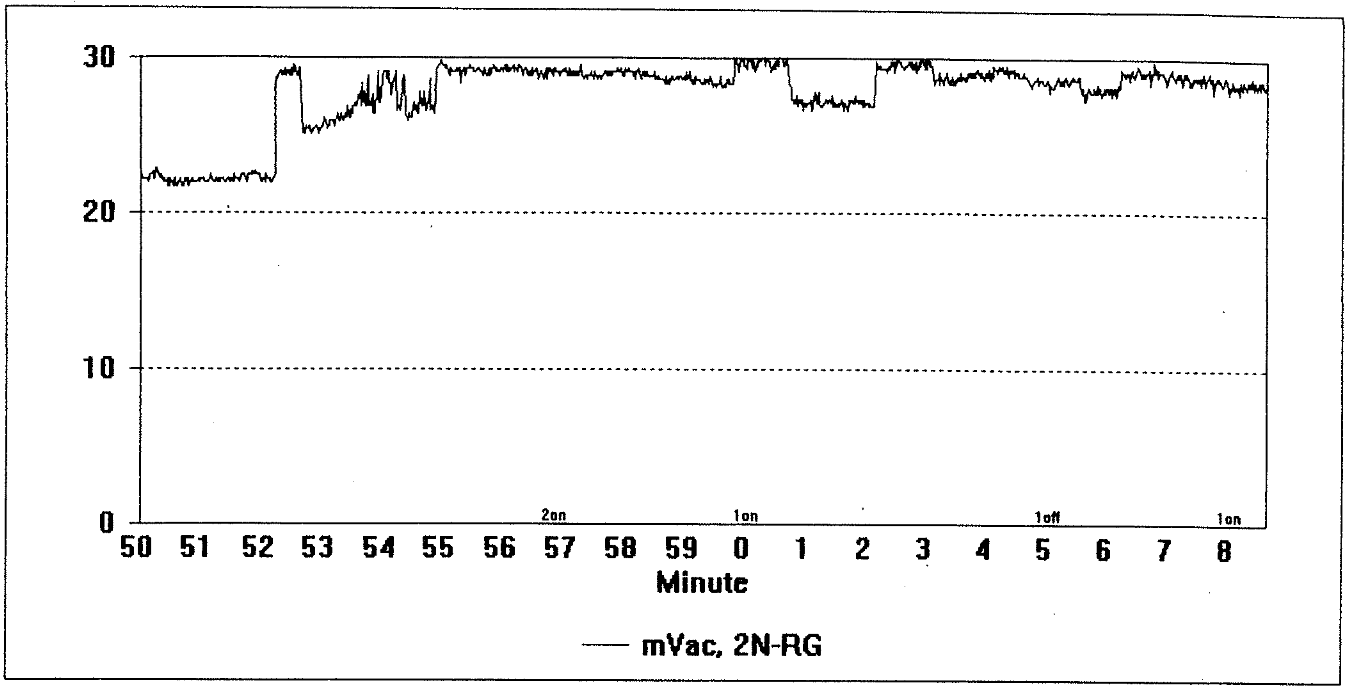


Figure 2.6 mVac, barn secondary neutral to remote ground. One-second electrical data on 4/14/93 with switch events shown.

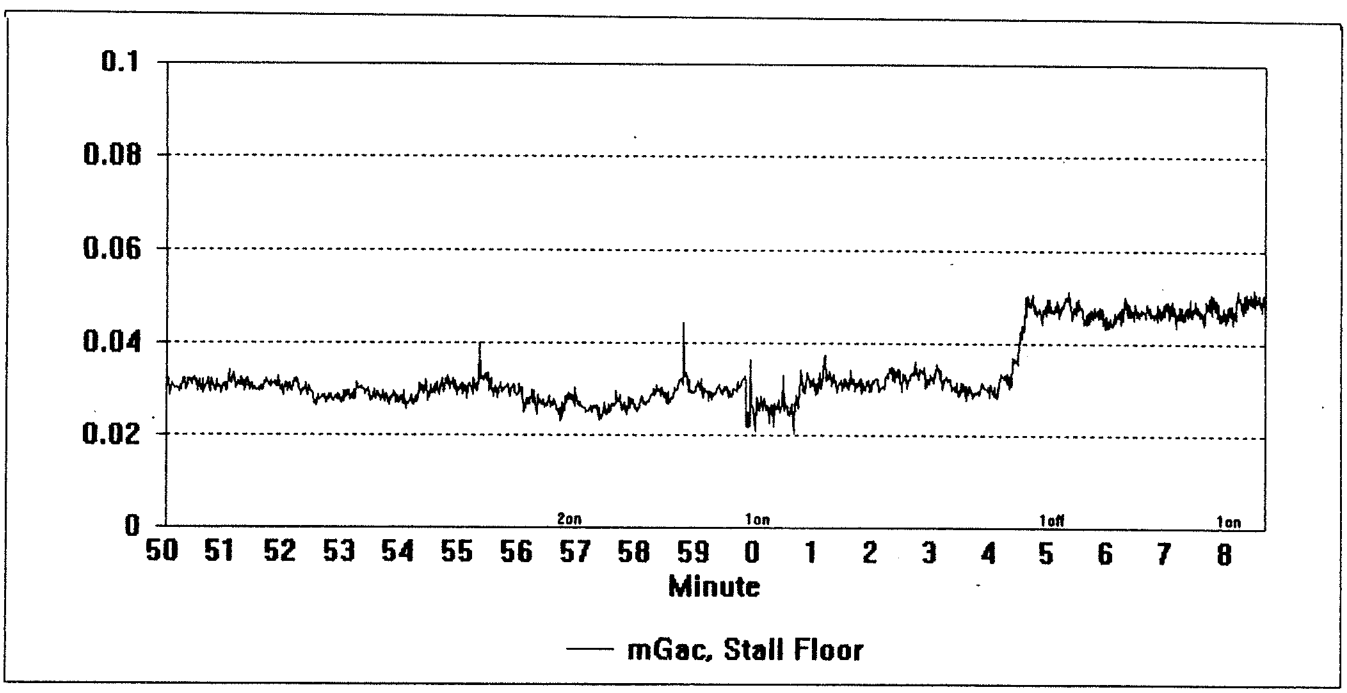


Figure 2.7 mGac, magnetic field vertical component at stall floor. One-second electrical data on 4/14/93 with switch events shown.

In general, there were no obvious instantaneous changes in the logge electrical data in the barn coincident with changing the P/N GRD status. Two times a small change was noted in Vdc RH-FH (dc voltage between rear hoof and front hoof) on switching the P/N ground, once at pole 2 and another time at pole 1. Other similar changes were noted for this parameter on the same graphs at times other than switching. Without additional evidence the changes shoui be considered coincidental.

One-Minute Data
At all times other than during switching, one-minute averages of one-second measurements were recorded for cow contact potentials and other parameters in the barn. These data are presented in Data Item #8 as daily graphs for each parameter. An examination was made of these graphs to determine if the one-minute data support the hypothesis that P/N ground currents alter electrical potentials and currents in the barn. Table 2.2 summarizes the results.

Electrical Parameters in the Barn

Date	On-Off	WL-RH mVac	WL-RH mVdc	RH-FH mVac	RH-FH mVdc	2N-RG mVac	WL-GC mAac	Bac
3/24	Off	yes#1	no	no	no	yes#1	yes#1	no
3/31	On	no	no	no	no	yes#2	no	no
4/8	Off	no	no	no	no	no	no	no
4/14	On	no#3	no	no#3	no	no#3	no#3	no

Table 2.2 Did the barn one-minute data change as a result of changing the P/N GRD status at distribution poles 1 and 2?

* - Missing data
#1 - Variability decreased.
#2 - Variability increased.
#3 - See below.

A change was noted in Vac 2N-RG across the first two switch events; the magnitude did not shift but the variability changed. This was not confirmed during the next two switch events however.

Some possible changes were also noted on 4/14 which were nearly coincident with the gap in one-minute data during switching. These changes were studied; it was determined that they were almost certainly not due to switching. Rather, the changes were caused by the disconnection of the wire between the water line and gutter chain (used for measurement of Iac WL-GC) during barn cleaning. The relevant times are as follows:

Barn cleaning	14:44 to 15:38
Data gap	14:47 to 15:12

The 3/31 one-minute data clearly show that the change occurred before the data gap, that is, when the wire was disconnected three minutes before to allow operation of the gutter chain. The connection was restored 26 minutes after data logging resumed; this is also evident in the graphs.

(Note: In the original graphs of Data Item #8 the current between water line and gutter chain (WL-GC mAac) seemed to change by a factor of 10 on 3/31. This change occurred exactly between logging one-second data (during switching) and logging one-minute data. The original data files were scanned but no such change was found. Further, the strip chart record of Iac WL-GC was matched against the graphs of one-minute data. An error in data conversion was discovered in the one-minute graphs; the one-minute data as presented in the graphs is high by a factor of 10 for the following dates: 3/16 to 3/31 (about noon) and 4/5 to 4/15 (end). This made the one-minute data on 3/31 appear to change at a switch event.)

<u>One-Hour Average Data</u>
All of the one-minute data was averaged for each hour, then graphed as illustrated in Figures 2.8 through 2.14. On/off notations on these graphs were used to determine if long term (or other) changes were evident in the barn electrical data. Table 2.3 presents the results.

Electrical Parameters in the Barn

Date	On-Off	WL-RH mVac	WL-RH mVdc	RH-FH mVac	RH-FH mVdc	2N-RG mVac	WL-GC mAac	Bac
3/24	Off	no	no	no	yes#1	no#2	no	no
3/31	On	no	no	no	no#3	no	no	no#4
4/8	Off	no	no	no	no	no	no	no
4/14	On	no#5	no	no	no	no	?#6	no

<u>Table 2.3</u> Did the barn one-hour data appear to change in Figures 2.8 to 2.14 coincident with changing the P/N GRD status?

#1 - Started long-term decline.
#2 - Appeared to increase from near 0+ to 10+ mVac. (See below)
#3 - Appeared to increase from .14 to .38 mVdc. (")
#4 - Appeared to decrease from .055 to .045 mGac. (")
#5 - Appeared to increase by about 50%. (")
#6 - Data ends.

Barn 1-Hour Average Data

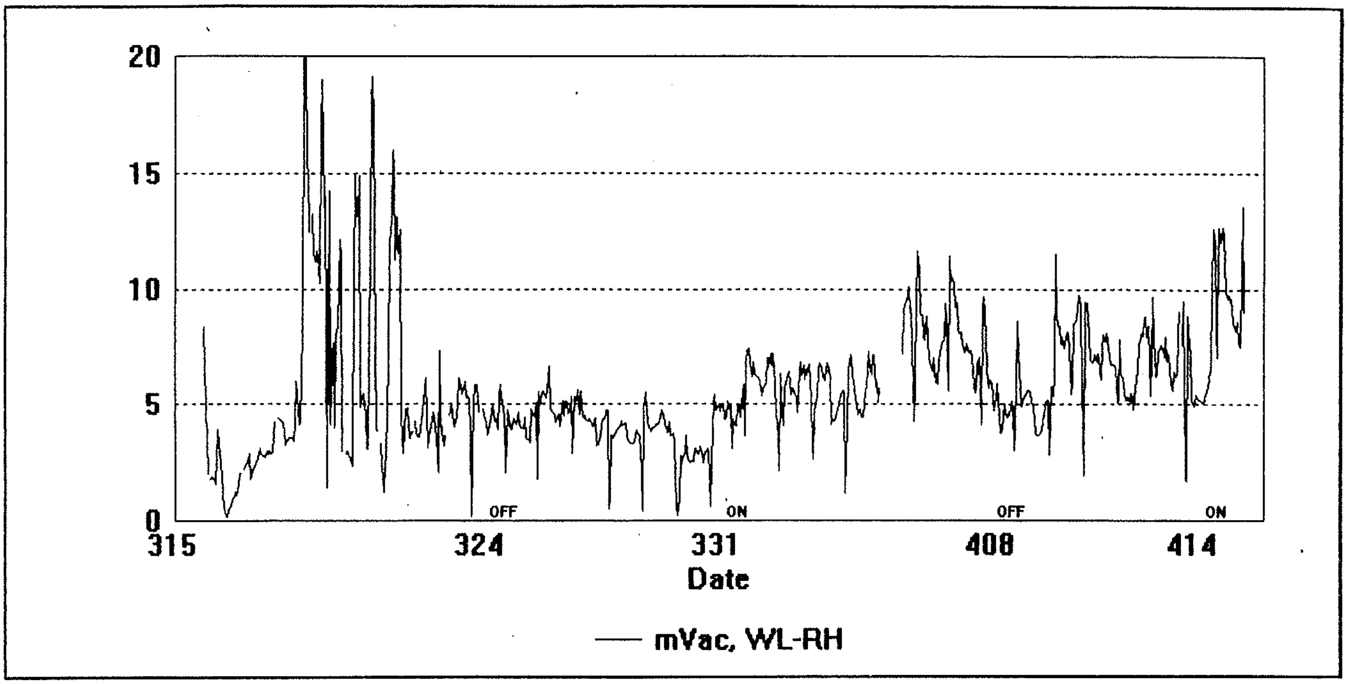


Figure 2.8 mVac, barn water line to rear hoof. One-hour average electrical data for the entire test with switch events shown.

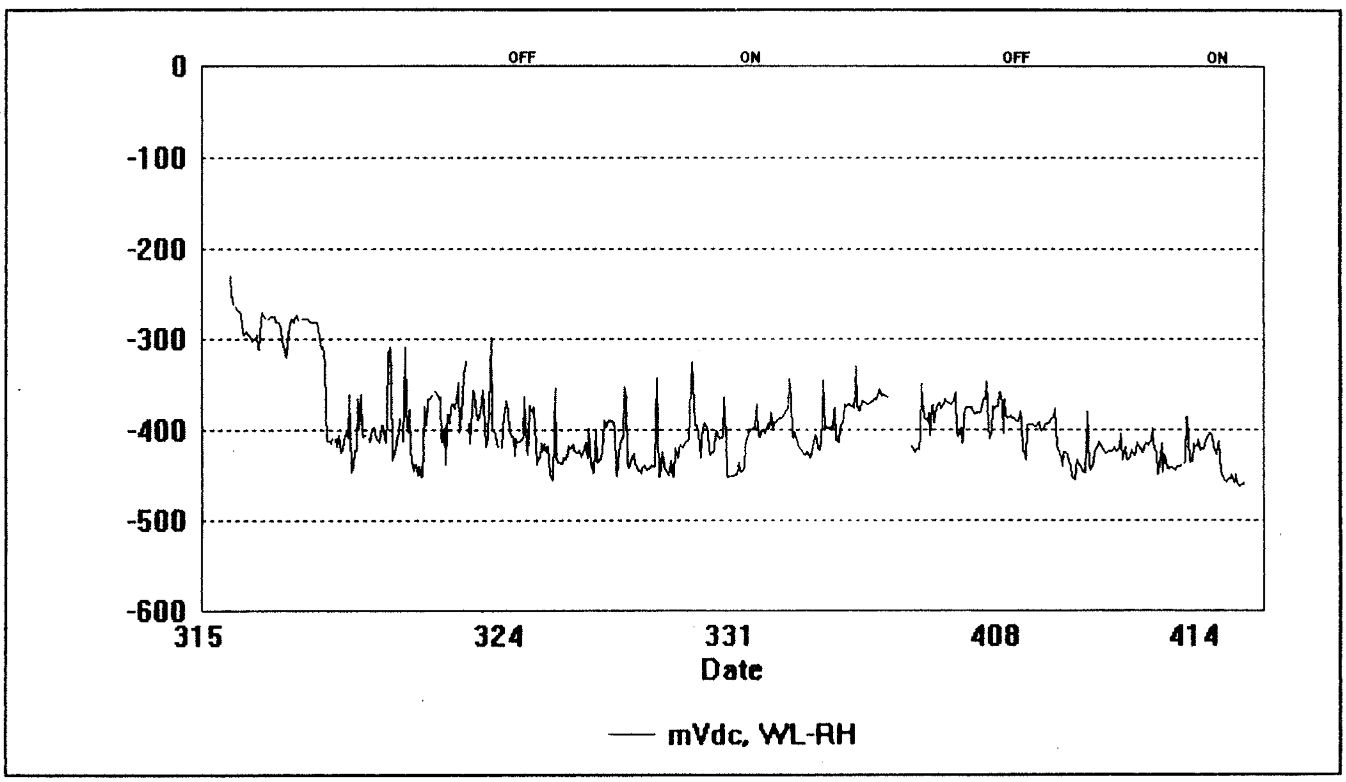


Figure 2.9 mVdc, barn water line to rear hoof. One-hour average electrical data for the entire test with switch events shown.

Barn 1-Hour Average Data

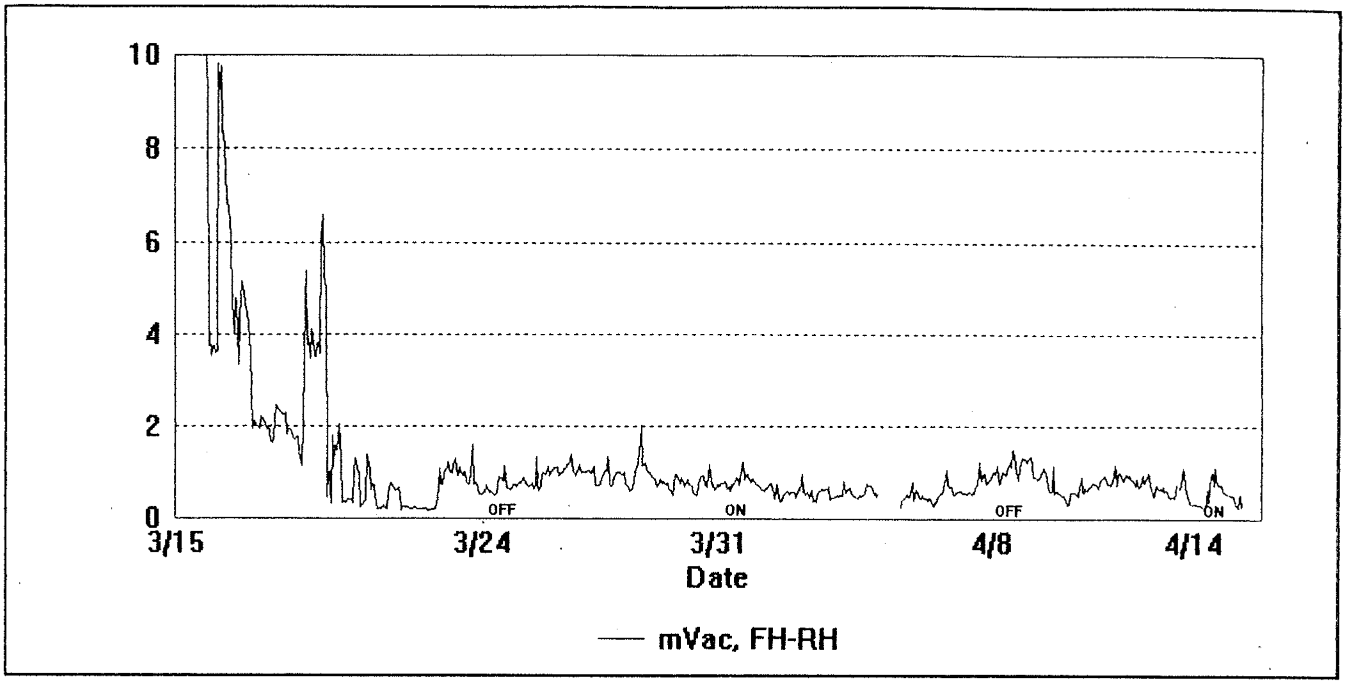


Figure 2.10 mVac across 300Ω, barn front hoof to rear hoof. One-hour average electrical data for the entire test with switch events.

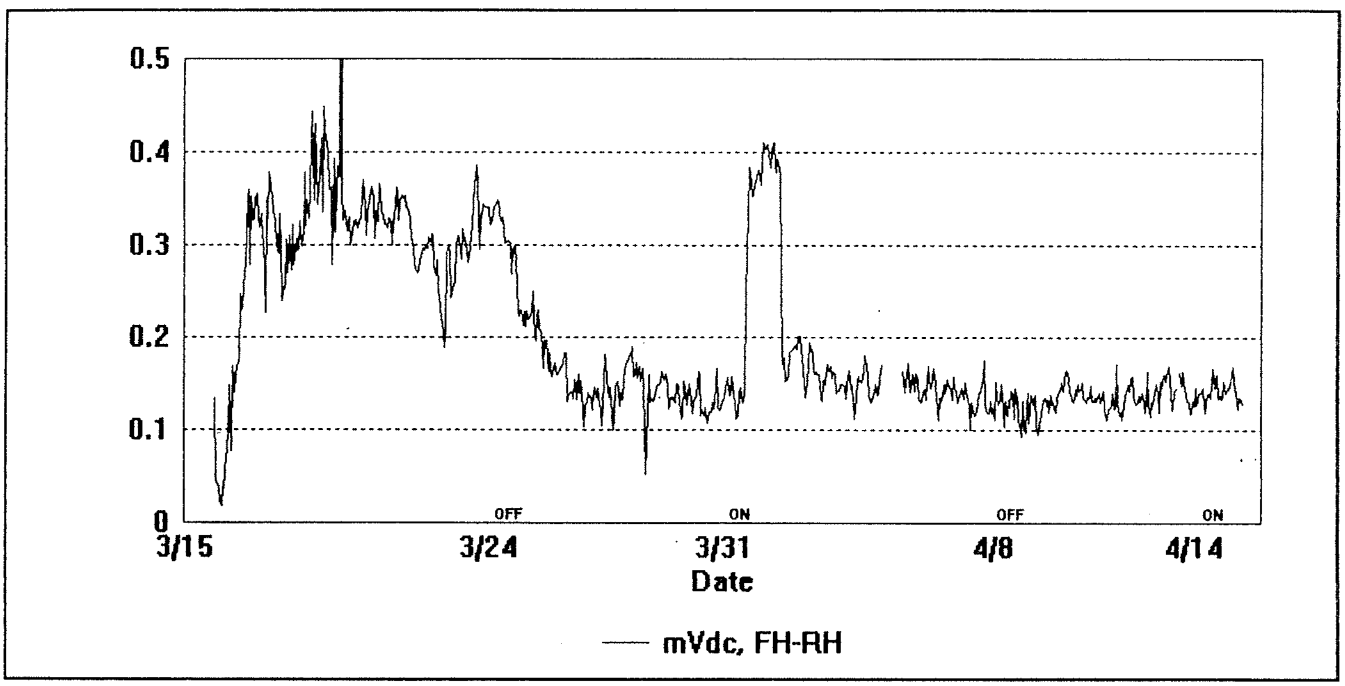


Figure 2.11 mVdc across 300Ω, barn front hoof to rear hoof. One-hour average electrical data for the entire test with switch events shown.

Barn 1-Hour Average Data

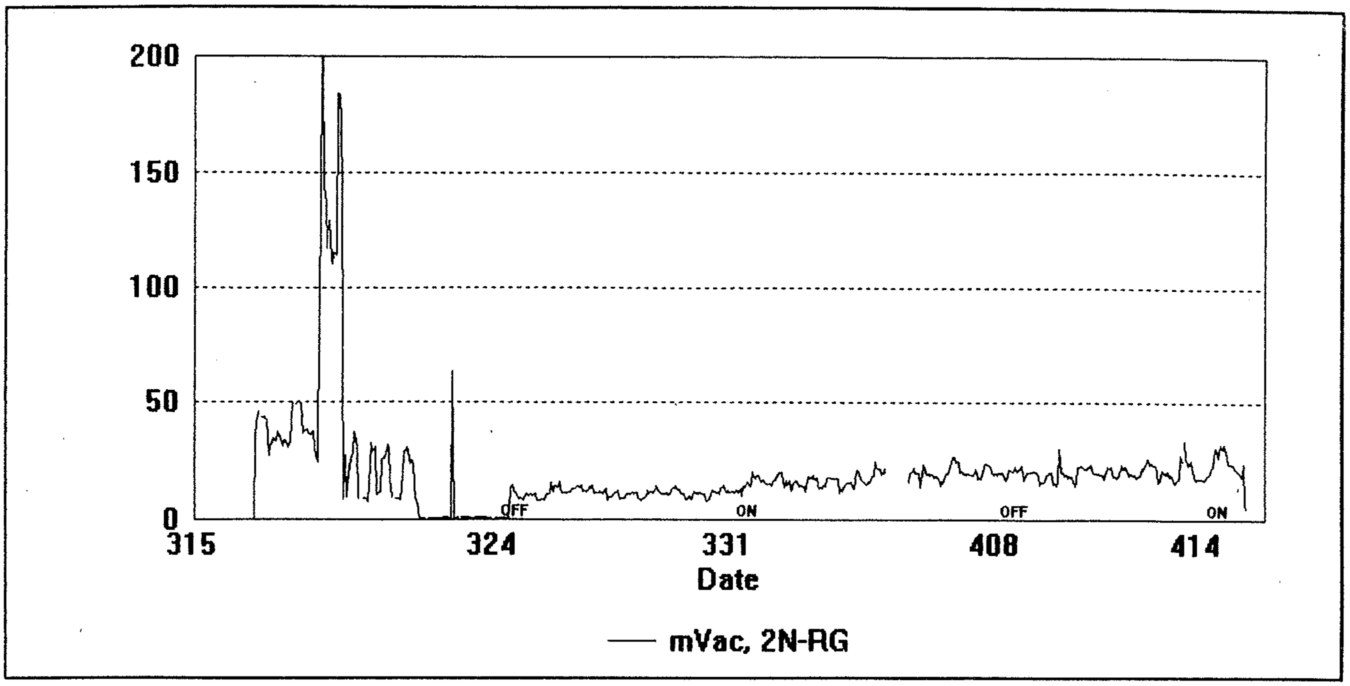


Figure 2.12 mVac, barn secondary neutral to remote ground. One-hour average electrical data for the entire test with switch events shown.

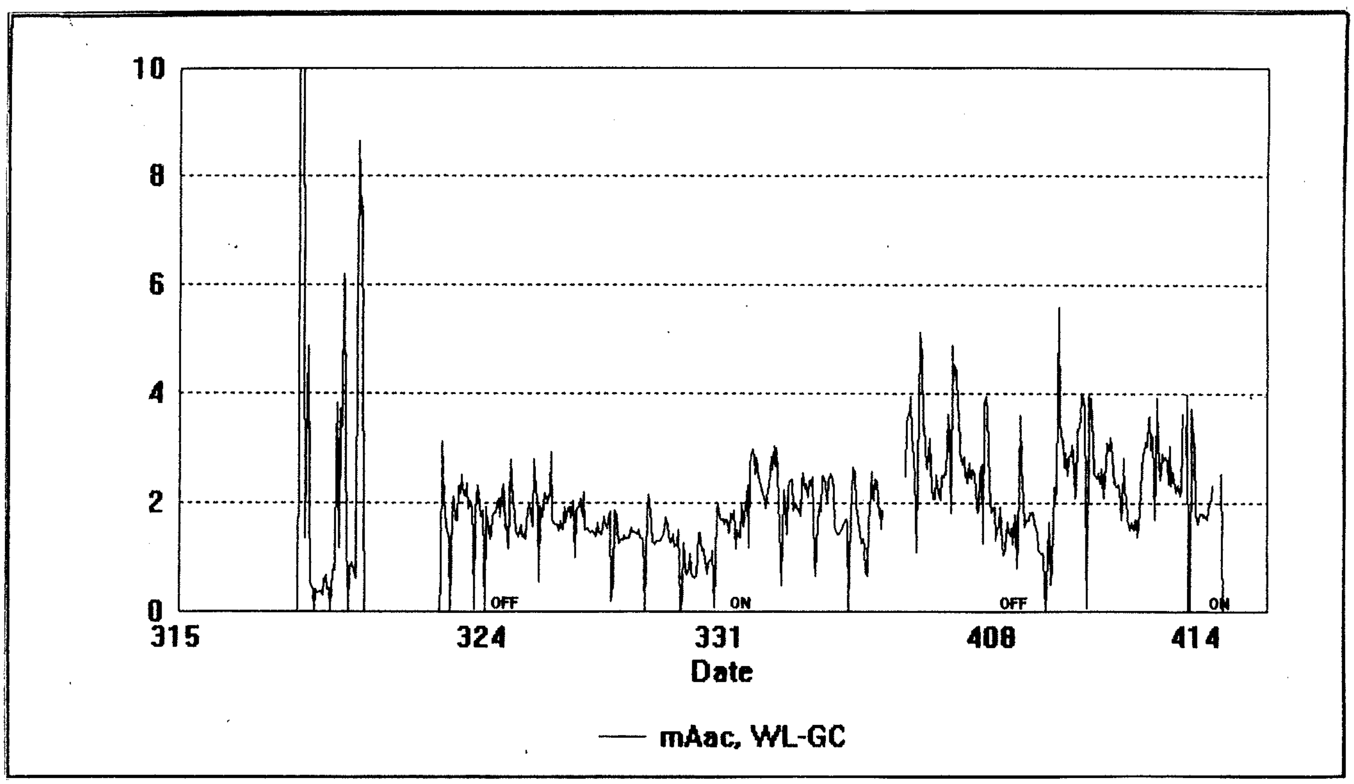


Figure 2.13 mAac, barn water line to gutter chain. One-hour average electrical data for the entire test with switch events shown.

Barn 1-Hour Average Data

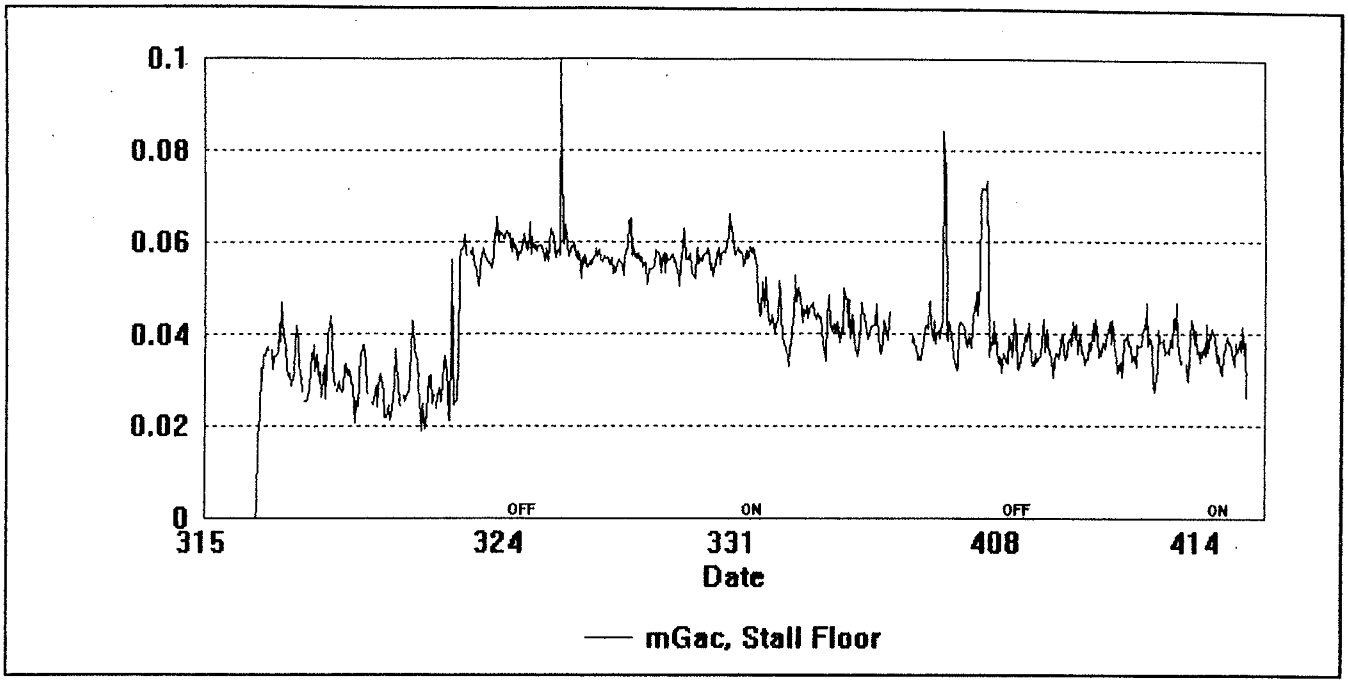


Figure 2.14 mGac, magnetic field vertical component at stall floor. One-hour average electrical data for the entire test with switch events shown.

Referring to Table 2.3 notes:

#1) Vdc RH-FH appears to begin a three-day decline coincident with the first switch event (off). No other long-term increases or declines were noted (excluding the step increase/decrease discussed in #3 below).

#2) Vac 2N-RG increased suddenly. Minute data show that this increase occurred at 10:29 on 3/24, 4 hr 20 min before the switch event (therefore, not related to it).

#3) Vdc RH-FH more than doubled suddenly. Minute data show that this change occurred at about 16:00 on 3/31, 3hr 45min after the switch event. The higher level persisted until 4/1 at 17:00.

#4) The ac magnetic field in the stall decreased suddenly by about 20%. Minute data show that this change occurred at about 16:00 on 3/31 (see also note #3 above), 3hr 45 min after the switch event. This step change did not repeat again during the test.

#5) Vac WL-RH increased by about 50%. Minute data show that this occurred at 11:19 on 4/14, 3hr 41min before the switch event.

#6) The current clamp/meter was removed from the system on the last day to conduct special tests.

Of the six changes in the one-hour data noted near switching events, five have been shown to be not coincident using one-minute data. Change #1 above is the exception; no reasonable explanation for this change comes to mind.

<u>Voltage Impulse Data</u>
Two power quality monitors were used to collect voltage impulse data in the barn; a BMI 8800 logged voltage impulses greater than 20 V peak between the lines (L1 and L2) and neutral. A BMI 4800 logged voltage impulses greater than 5 V peak between: 1) water line and rear hoof, and 2) front hoof and rear hoof. (No FH-RH impulses were captured.)

The number of Line-to-Neutral impulses/hour are profiled for each of three periods when the PN Ground was switched OFF, ON and OFF in Figures 2.15 to 2.17 to explore whether the daily pattern changed as a result of switching. All periods show a peak late in the evening. Other minor increases can be seen from mid- to late morning during each of the three periods. No consistent change in pattern is evident relative to PN ground status.

The number of Line-to-Neutral impulses/hour are profiled by hour for the entire test period in Figure 2.18. This graph indicates that the largest number of L-to-N impulses/hour occurred late in the evening after all dairy operations ceased for the day. Secondary impulse peaks occurred at about 9 AM (near end of morning milking) and at approximately 3 PM (near barn cleaning time). These two peaks may be due to automatic switching of equipment such as the transfer pump and barn cleaner. No on-farm source for the late evening peak was apparent. Possibly this reflects off-peak loads on the distribution

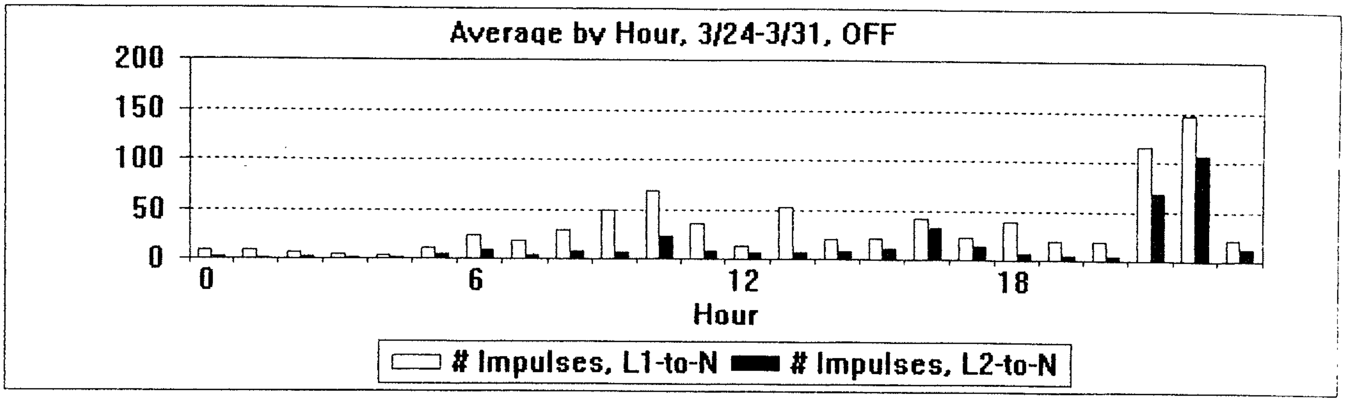


Figure 2.15 Average daily profile of line-to-neutral voltage impulses > 20 V peak. Includes all L-to-N impulse data during first OFF period, 3/24 - 3/31.

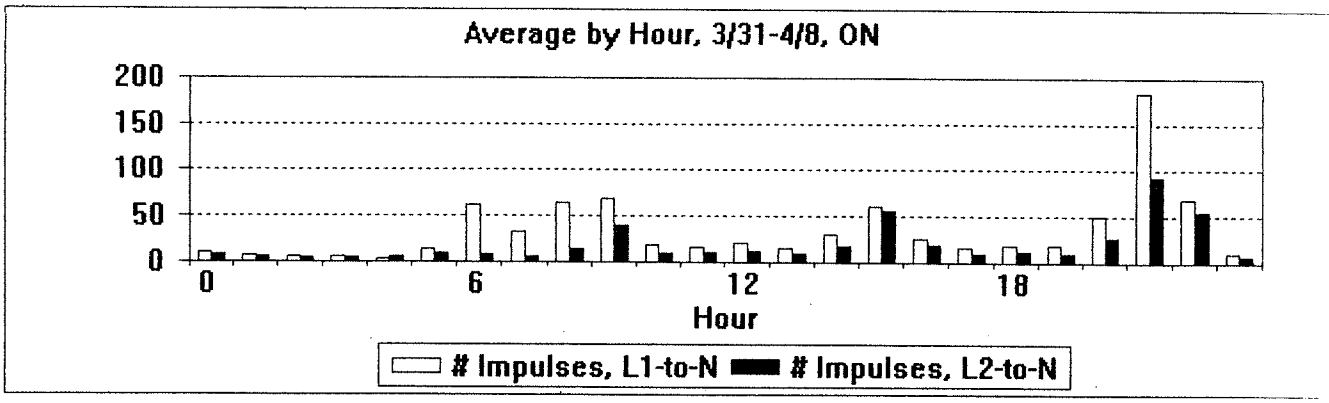


Figure 2.16 Average daily profile of line-to-neutral voltage impulses > 20 V peak. Includes all L-to-N impulse data during second ON period, 3/31 - 4/8.

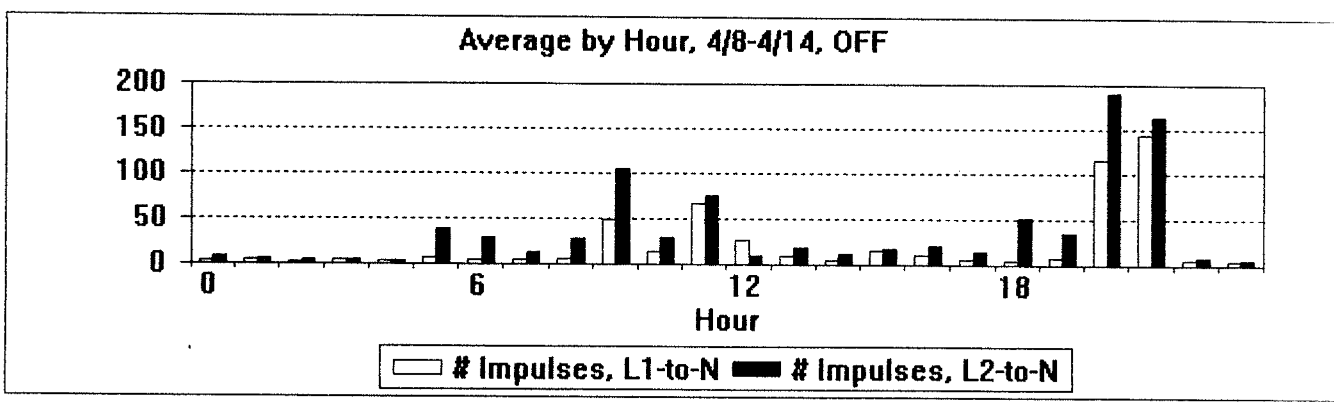
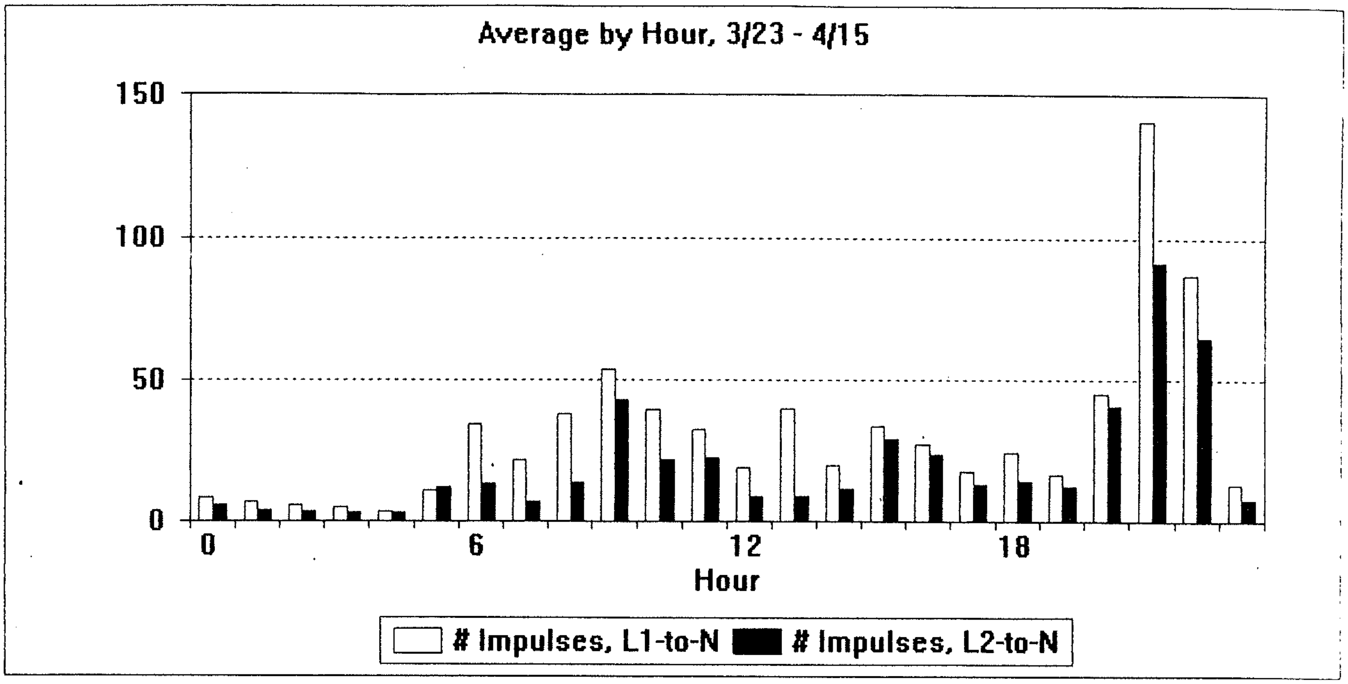
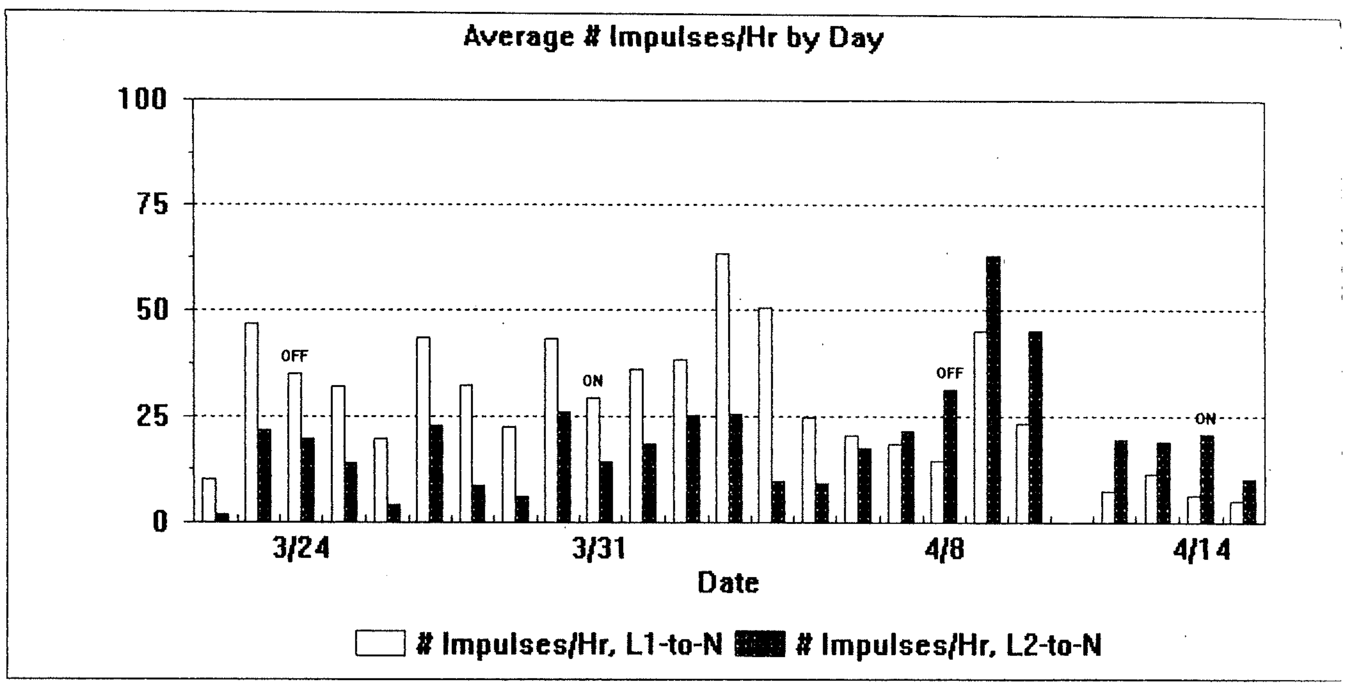


Figure 2.17 Average daily profile of line-to-neutral voltage impulses > 20 V peak. Includes all L-to-N impulse data during second OFF period, 4/8 - 4/14.



<u>Figure 2.18</u> Average daily profile of line-to-neutral voltage impulses > 20 V peak. Includes all L-to-N impulse data collected during the test.



<u>Figure 2.19</u> Profile by day of average number of L-to-N voltage impulses per hour; switch events shown.

systems. Phase and neutral current graphs for the Carlos substation, Data Item #30, seem to show double peaks, one late in the day, though the same graphs for Parkers Prairie substation, Data Item 32, do not.

L-to-N impulses/hour are profiled by day in Figure 2.19 to determine whether P/N GRD switching influenced the impulse rate. L1 impulses dominate until about 4/6; after that, L2 impulses dominate. No pattern relative to switch status is evident.

L-to-N impulses relative to P/N GRD status are summarized in Table 2.4. If the hypothesis is that voltage impulses access the farm's secondary electrical system through the primary neutral ground, then L1-N impulse/hour data support the hypothesis two of three times. L2-N impulses support the hypothesis one of three times. Total impulses support it two of three times.

			Average Number Impulses/Hour					
From	To	On/Off	L1-N	Supports?	L2-N	Supports?	TOT	Supports?
3/22	3/23	On	28.4		11.8		40.2	
				n		n		n
3/25	3/30	Off	32.1		14.4		46.5	
				y		y		y
4/1	4/7	On	35.9		18.1		54.0	
				y		n		y
4/9	4/13	Off	17.3		29.2		46.5	

<u>Table 2.4</u> Did the changes in L-to-N voltage impulses/hour support the hypothesis that impulses access the farm's secondary electrical system through the primary neutral ground?

Low voltage (>5 V peak) impulses between the water line and rear hoof are profiled in Figure 2.20. As with L-to-N impulses, the peak rate occurs late in the evening suggesting a possible link between impulses on the barn wiring and cow contact impulses. (This was later confirmed by simultaneous, similar impulse waveforms.)

WL-RH impulses are summarized across the test in the profile shown in Figure 2.21. It seems apparent that this data does not support the hypothesis that disconnecting the P/N GRD decreases this particular cow contact impulse rate, though it should be understood that this is based on only one before/after comparison across a switch event.

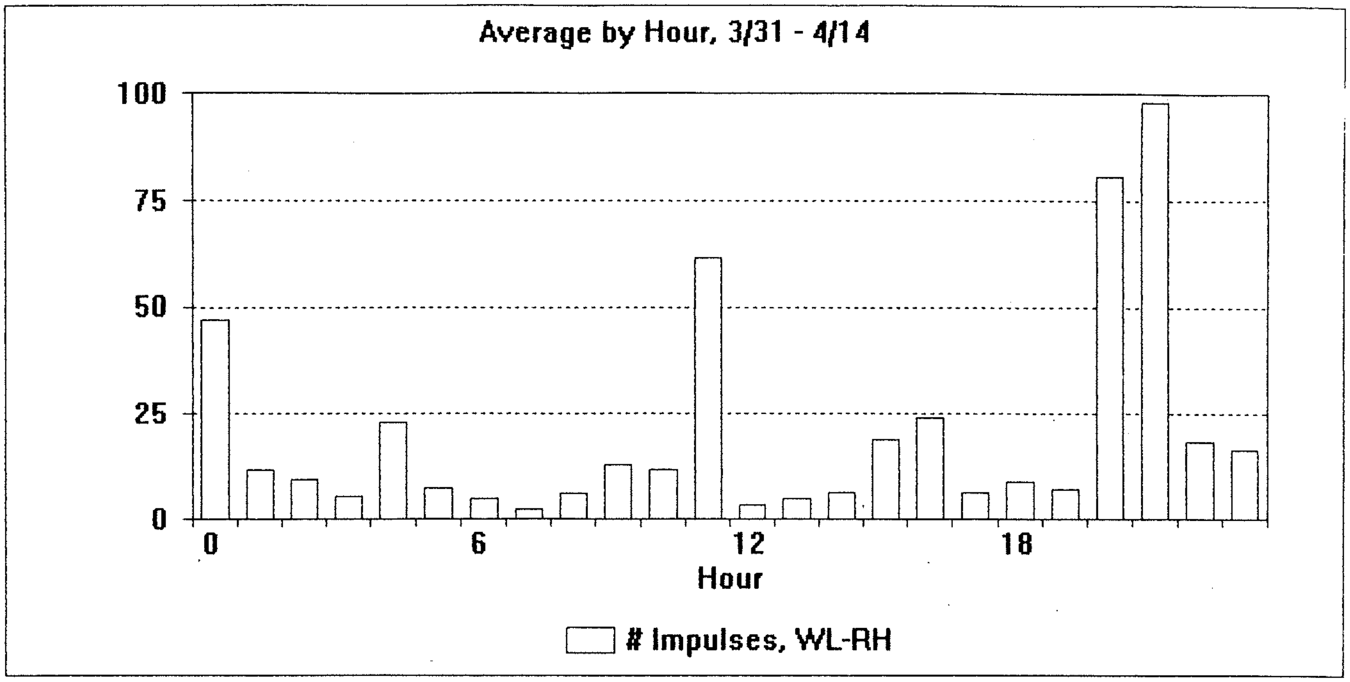


Figure 2.20 Average daily profile of water line-to-rear hoof voltage impulses > 5 V peak. Includes all WL-to-RH impulse data collected during the test.

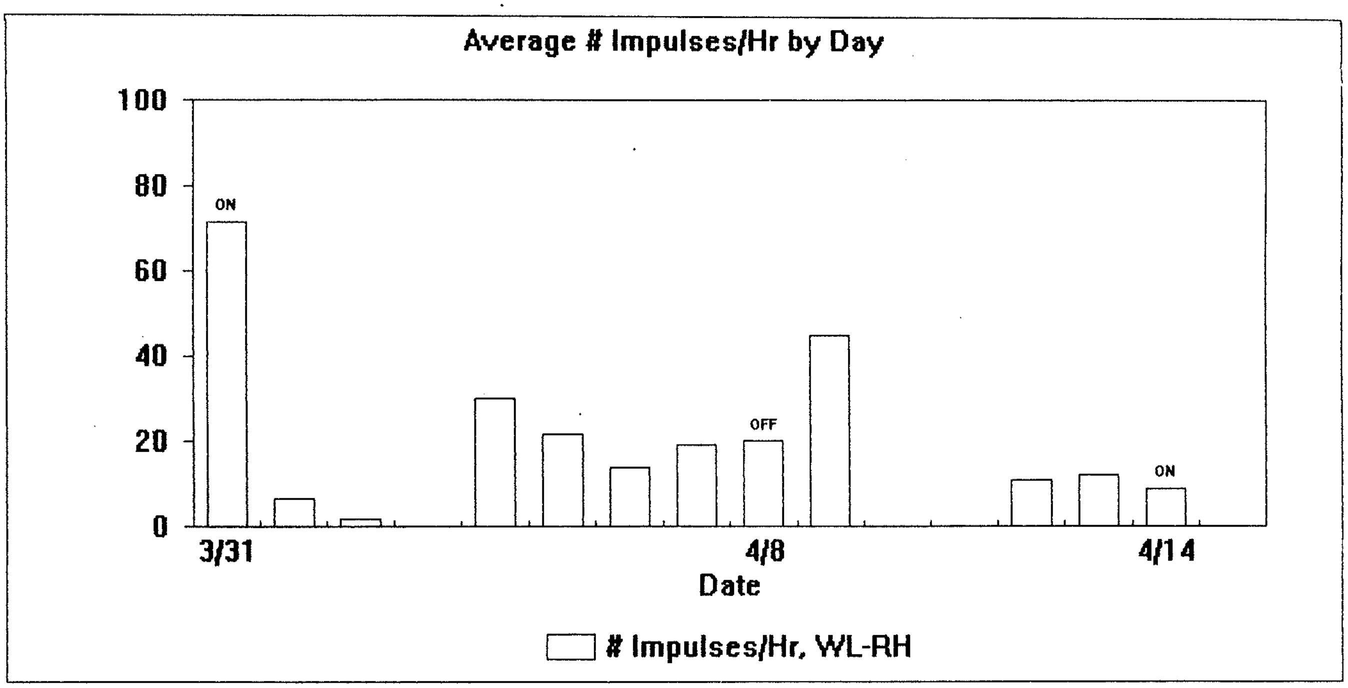


Figure 2.21 Profile by day of average number of WL-to-RH voltage impulses per hour; switch events shown.

3. Herd Data and P/N Ground Status

Data describing herd management, health, appearance and behavior are presented in (Beehler, GR), Data Item #2 and hereafter refered to as the Beehler report. These data have been presented by the veterinarian without foreknowledge of the status of the P/N ground connections during the test. Here, these herd data are analyzed only with respect to changes in grounding, since this reviewer is not a qualified veterinarian.

The analysis is made on the basis of support or countersupport for the following hypothesis: The connection of the distribution system primary neutral at the farm results in ground currents which are picked up by conducting elements in the barn and show up as ac and dc currents which access the cow in some way resulting in health and behavior problems.

The analysis attempts to quantify support for the hypothesis based on the coincidence of negative health and behavior characteristics during periods when the P/N ground was on (connected) or, similarly, with the coincidence of positive health and behavior characteristics during OFF periods. All characteristics were treated with equal weight. Wherever possible, data intermediate between the raw data and the conclusion are presented to allow for alternate interpretations.

<u>Disease Incidence and P/N Grounding</u>

Can the observations of disease incidence noted in the Beehler report, p.5 be associated with connecting or disconnecting the PN ground?

Incident	Supports?
50% of herd have enlarged hocks or swollen knees	See "Individual Observations" at end of this section.
#27 treated for dry cow mastitis on 3/16 through 3/21. Calved on 3/27 and culled due to mastitis.	First OFF period started 3/24.
#25 freshened on 3/22, had retained placenta, was stiff and sore most of test.	" "
#30 freshened on 3/16, had retained placenta & right displaced abomasum.	" "
#24 treated for pneumonia & ketosis on 3/15.	" "
#1 treated for ketosis on 3/30.	No. Occurred at end of OFF period.

#35 had mastitis on 3/19, resolved by 3/21.	No. First OFF period started on 3/24.

Observations of disease incidence did not offer evidence implicating the status of the primary neutral ground connection.

Water Intake and P/N Grounding

One of the most sensitive and direct indicators of stray voltage may be a decrease in water intake due to voltage on the water cup. Water meter readings were used to determine daily herd water consumption. Water intake per cow per day was determined and presented in the Beehler report, Table 16. It was noted that water intake rose throughout the study and that there were two plateaus in the data. This data set was analyzed to determine whether the plateaus coincided with P/N ground ON or OFF periods.

Figure 3.1 presents the water consumption data throughout the test. A best fit polynomial curve illustrates the trends in the data over time. P/N switching events are noted on the graph. It can be seen that the first plateau period occurred from 3/13 to 3/21. The increasing trend had already resumed by the time the P/N ground was switched off on 3/24. The second plateau started about 3/29, three days before the P/N ground was switched back on. Again, the rate began increasing about three days before the next OFF period began on 3/31. The trends in water consumption do not coincided with P/N ground changes. (The plateaus seen in the data may be due to other factors: A possible influence could be environmental, eg. ambient temperature; The plateaus coincide loosely with periods of relatively low temperature. Probably water consumption follows trends in milk production which is governed by the lactation cycle.)

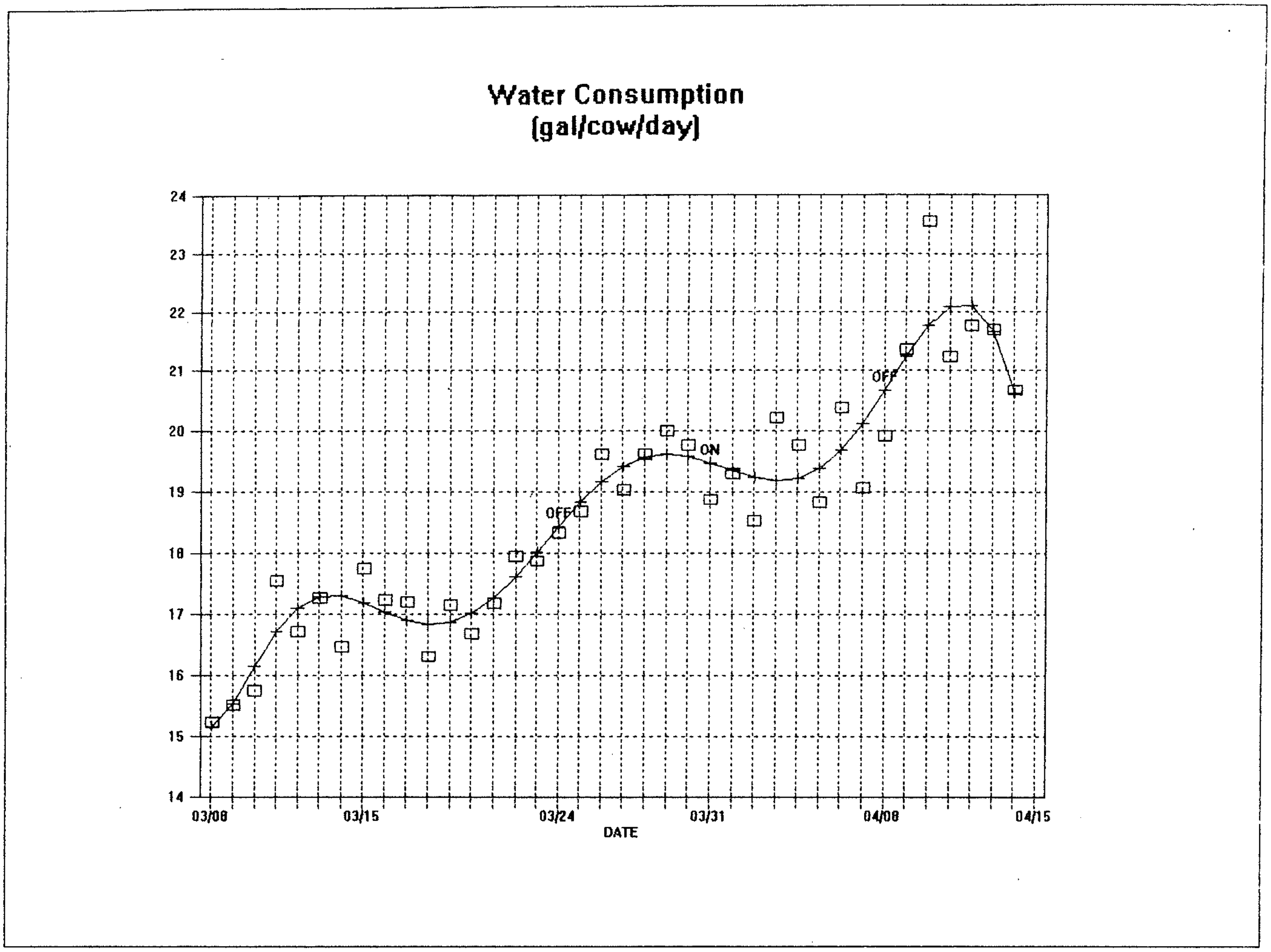
Milk Production and P/N Grounding

Milk production data are of two types: Herd averages and data for individual selected cows.

Herd milk production data are found in the Beehler report, Table 16. Milk data and daily information on cows in the barn allowed the calculation of milk production per cow per day. This production rate was analyzed in a manner identical to that for water consumption above. A polynomial was fitted to the data to identify trends which were then compared to P/N ground ON/OFF periods.

Figure 3.2 shows the herd milk production rate per cow per day before and through the test. The trend of milk data is similar to that of the water data: There is a general production increase throughout the period shown. Two plateaus are evident, (3/10 - 3/19) and (3/28 - 4/5). These do not coincide with changes in the P/N ground status. The onset of increases in milk production precede the ground disconnections by three or four days in both cases (similar to water consumption).

Milk production for individual cows is shown in Figure 3.3.



<u>Figure 3.1</u> Water Consumption Rate vs. Date

From Data Item #2, Table 16 (WATER G/COW/). ON and OFF notations illustrate when the P/N ground was connected and disconnected. The curve represents the 8th-order polynomial which best fits the data based on least squares regression. Trends in this curve near the endpoints are not necessarily representative of real trends in the data. The order of the polynomial was chosen initially by presuming two plateaus on an upward trend. Final adjustment to order 8 was made based on minimizing the mean squared error between the curve and data. The calculation is documented in the appendix.

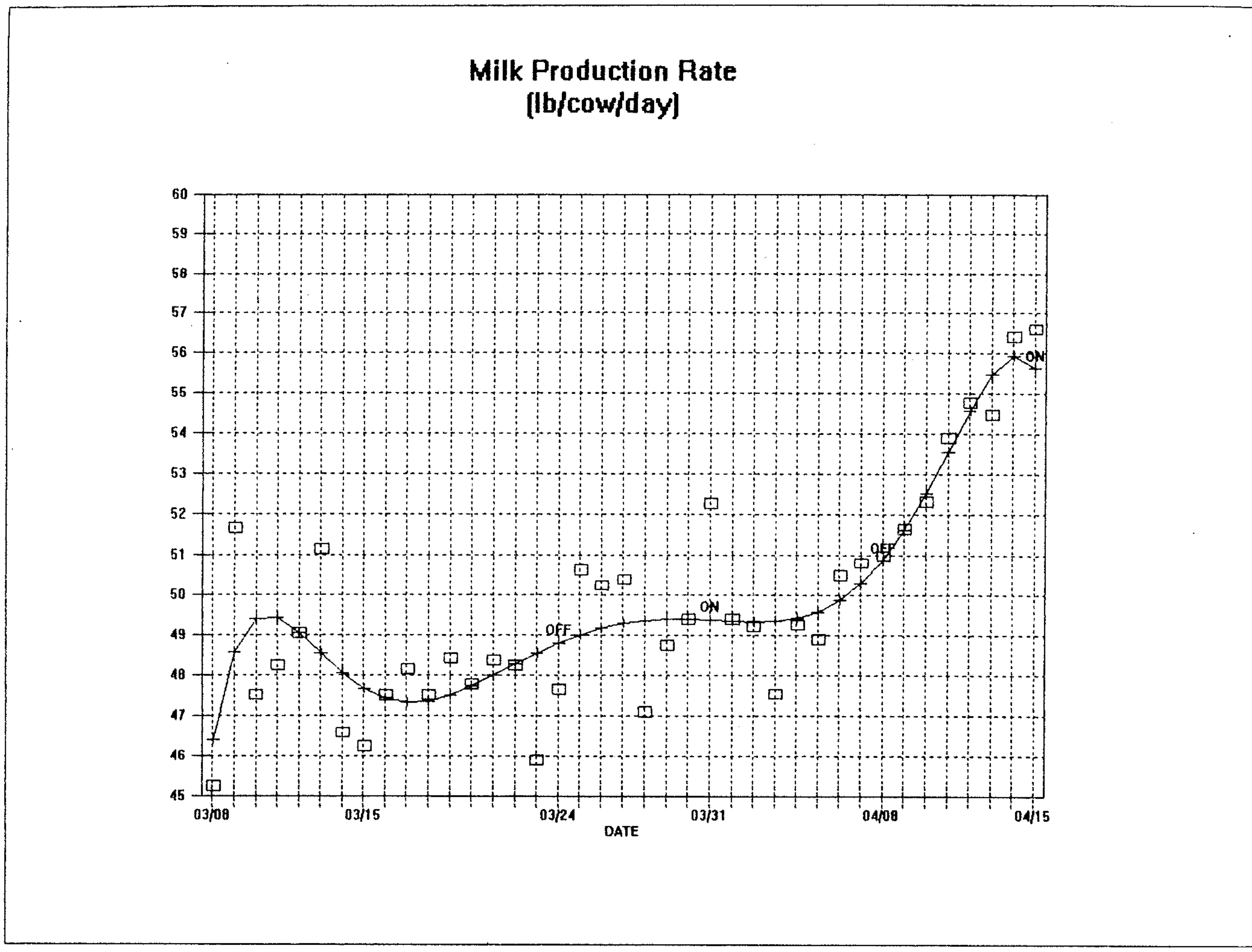


Figure 3.2 Milk Production Rate vs. Date

From Data Item #2, Table 16,

MILK lb/cow/day = (LBS MIL SOLD)/(COW # MILK)

ON and OFF notations illustrate when the P/N ground was connected and disconnected. The curve represents the 8th-order polynomial which best fits the data based on least squares regression. Trends in this curve near the endpoints are not necessarily representative of real trends in the data. The order of the polynomial was chosen to minimize the mean square error between the curve and data and to examine the occurrence of two plateaus in the data. The calculation is documented in the appendix.

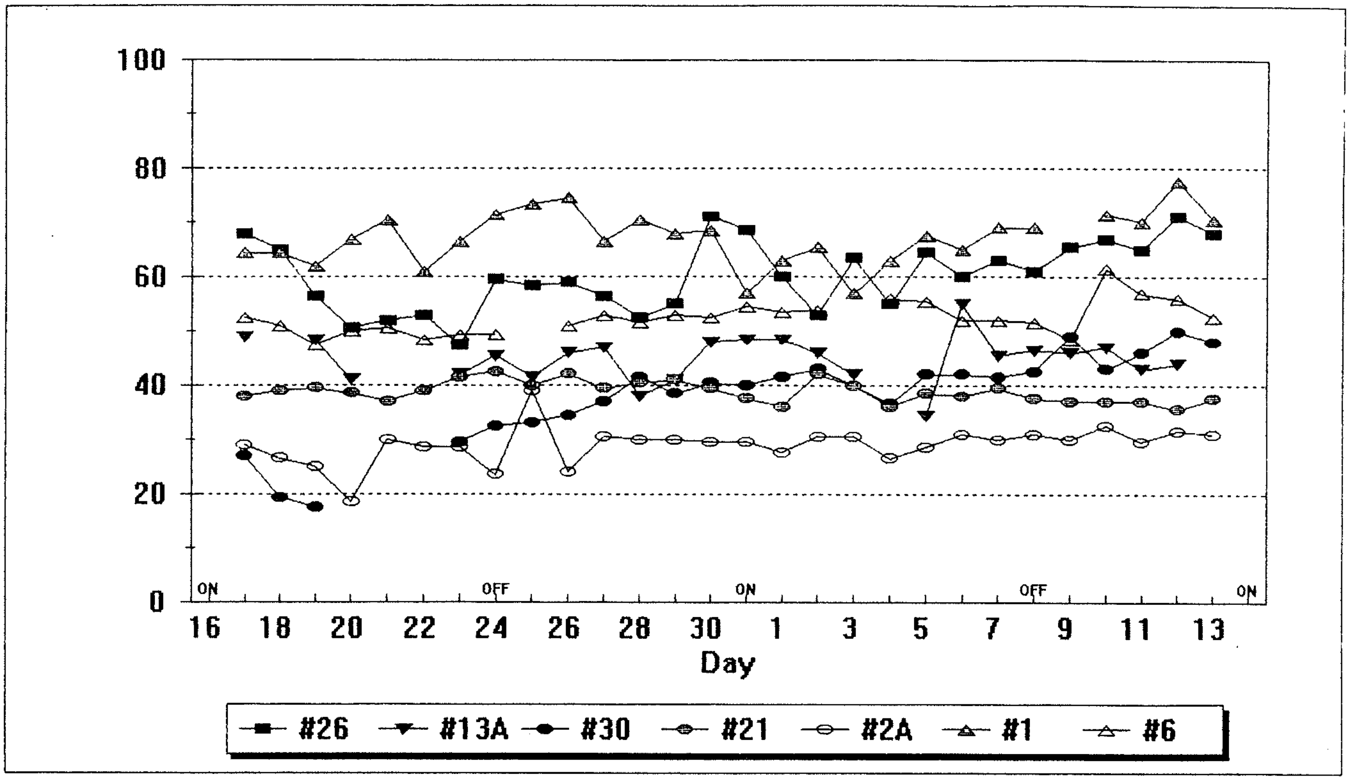
Summary statistics are provided in Table 3.1 which shows the average production for each cow during each of the four periods of the test. A comparison of the four time periods for each cow allows a measure of how it responded at each change in the P/N ground status; A score of +1 was given if a cow's production increased across an OFF event or decreased across an ON event. A score of -1 was given for the opposite result. Average scores for each cow indicate whether changes in that cow's production rate support the hypothesis or not. Several average scores of 1.0 seem to indicate support. These results are biased toward support because milk production rates rise throughout the test; two of the three scores for each cow are positive for an increase vs. only one that is negative for an increase. The overall average of 0.35 (weak support) must be seen as overrated for this type of data. Milk data extending beyond the end of the test would have eliminated some of this bias in the data set though not all of it. A more detailed and time-intensive study could be made; for example, variations about the regression line for each cow could be examined for changes at switch times (to eliminate bias due to the fact that each cow is on a different portion of its lactation curve). Time restraints precluded this approach.

	ON 3/16-3/24			OFF 3/24-3/31			ON 3/31-4/8			OFF 4/8-4/14		AVG
COW	#	AVG	SCORE	#	AVG	SCORE	#	AVG	SCORE	#	AVG	SCORE
1	16	32.8	1	14	34.7	1	16	32.1	1	11	36.2	1.0
2A	16	13.3	1	14	15.1	1	16	14.7	1	11	15.4	1.0
4							8	32.5	1	12	41.7	*
5				4	36.6	-1	15	38.8	1	12	43.7	*
6	16	25.2	1	13	26.0	1	15	24.9	1	12	27.4	1.0
8				14	33.1	-1	16	36.6	1	12	38.7	*
13A	13	22.7	-1	14	21.9	-1	15	22.5	-1	11	21.6	-1.0
18										9	16.9	*
21	16	19.8	1	14	20.1	1	16	19.2	-1	12	18.4	0.3
22	1	22.0	-1	14	20.5	1	16	20.2	-1	12	19.8	-0.3
24	13	27.5	1	14	28.8	1	16	26.0	1	12	28.1	1.0
25				6	29.6	-1	16	33.1	1	12	39.7	*
26	16	28.0	1	14	29.4	-1	16	30.4	1	12	33.6	0.3
30	11	12.3	1	14	18.6	-1	16	20.6	1	12	23.8	0.3
TOTAL			5			0			7			3.6
AVERAGE			.56			0			.54			0.4

Table 3.1 Milk production by individual cows grouped by P/N Ground "ON" and "OFF" periods.

\# = Number of metered milkings per period
* = Not scored because of missing data
AVG = Average lb. of milk per metered milking
SCORE = 1 if change supported hypothesis
= -1 if change counter-supported hypothesis

Individual Milk Production, Lb/Day



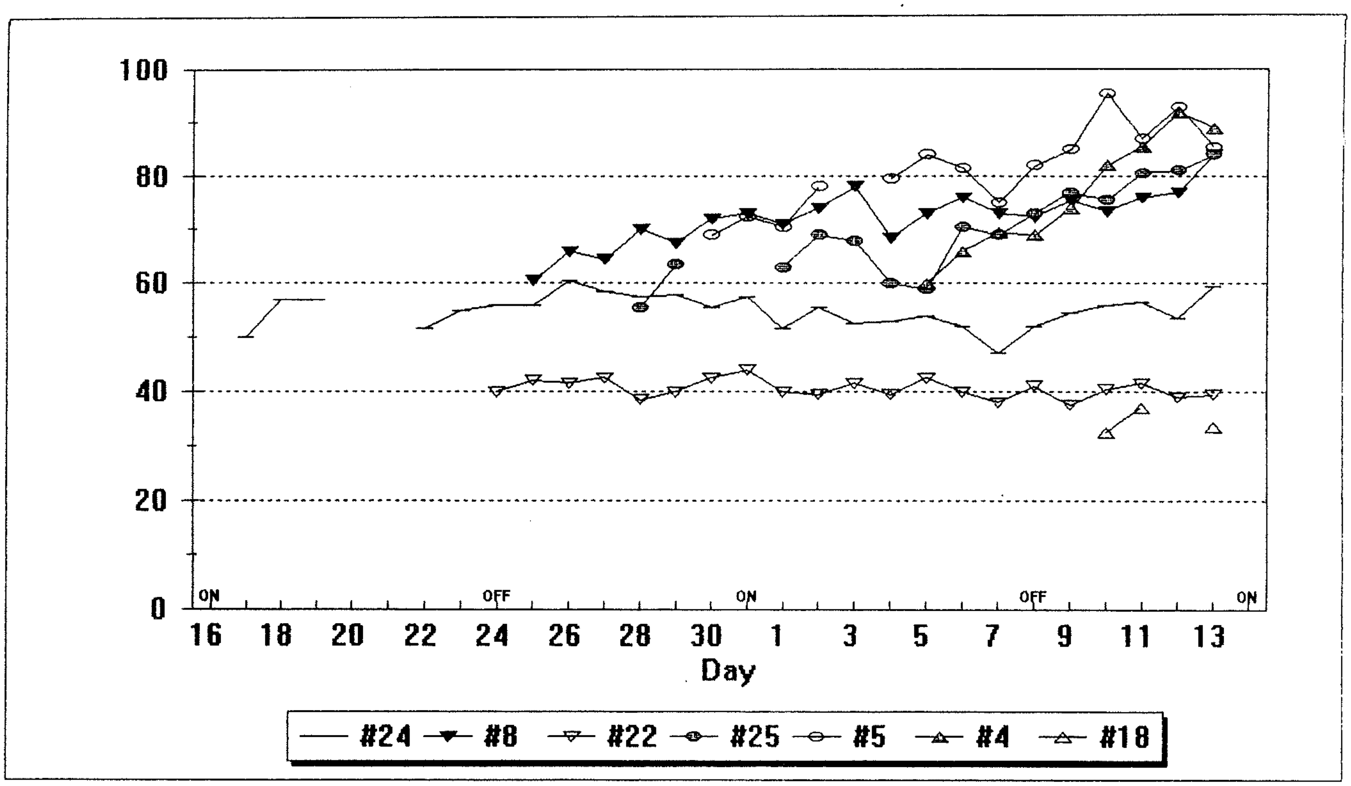


Figure 3.3 Daily milk production (lb) of individual cows plotted versus day of the month. PN ground switch status shown as ON/OFF.

Blood Parameters

Nine blood parameters were monitored for twenty cows on eight separate dates during the test. The status of the primary neutral (P/N) ground was changed by the test supervisor at approximately weekly intervals; these changes were timed to closely follow a blood test to provide at least five days for blood chemistry to change in hypothetical response to stray voltage induced stress. Relevant dates are as follows:

Date	Event
	P/N ground ON
3/8	Blood samples drawn (pre-test)
3/10	Blood samples drawn (pre-test)
3/17	Blood samples drawn
3/24	Blood samples drawn
3/24	P/N ground switched OFF
3/30	Blood samples drawn
3/31	P/N ground switched ON
4/6	Blood samples drawn
4/8	P/N ground switched OFF
4/13	Blood samples drawn
4/14	P/N ground switched ON
4/21	Blood samples drawn

The blood samples were analyzed for parameters indicative of stress as described in the Beehler report. These parameters were fibrinogen, CPK (creatine phosphokinase), total protein, WBC (white blood cell count), neutrophils, lymphocytes, eosinophils, hematocrit and hemoglobin.

The resulting blood parameter data are found in the Beehler report, Tables 17 through 25; these data were analyzed with respect to the P/N ground status according to the following hypotheses:

Parameter	Hypothesis
Fibrinogen	Increases with inflammatory disease caused by stray voltage due to P/N ground currents.
CPK	Increases with muscle injury caused by stray voltage due to P/N ground currents.
Total protein	Increases with inflammatory disease caused by stray voltage due to P/N ground currents.
WBC	Increases with inflammation, infection or stress caused by stray voltage.

Neutrophils	Increases with disease, inflammation and stress caused by stray voltage due to P/N ground currents.
Eosinophils	Decreases with disease, inflammation and stress caused by stray voltage due to P/N ground currents.
Hematocrit	Decreases with disease or debilitation caused stray voltage due to P/N ground currents.
Hemoglobin	Decreases with disease or debilitation caused by stray voltage due to P/N ground currents.

In deciding how to analyze the blood chemistry data, two methods were considered. The first involved summing the magnitude of changes in blood values; the other method involved summing the direction of changes in blood values. It is evident from Graphs 6 through 50 in the Beehler report that large changes occurred in several blood parameters for several cows. A large change in just one cow caused by a condition unrelated to stray voltage stress could completely mask the net effect of small but otherwise meaningful changes in the other 19 cows. By considering only the direction of change, the weight of confounders is limited to that of each other datum. Therefore, the blood chemistry analysis is based on direction of change only.

Blood data for samples drawn on 3/24, 3/30, 4/6, 4/13 and 4/21 were examined. These data represent the blood chemistry at the end of five 6-to-7 day periods when the P/N ground was ON, OFF, ON, OFF and then ON. The direction of change in parameters were noted for each cow and parameter and date. Each direction of change was then evaluated as supporting the stray voltage/stress hypothesis or not. First these evaluations were summed by cow and parameter across all sample dates. Second, these changes were summed by sample date and parameter across all cows.

The results of the first summation (by cow and parameter across all sample dates) are presented in Table 3.2. Each datum is a value assigned to a cow for a particular blood parameter. If the parameter changed all four times in the direction predicted by the hypothesis, it was assigned a value of 4. If it changed as expected 3 times out of four it was assigned a value of 2. Two times of four received a 0. One out of four received a -2. Zero out of four received a -4. This scale assigns equal weight to outcomes showing support and countersupport (or support for a counterhypothesis; it also allows a meaningful total for each cow across all blood parameters as well as for each blood parameter across all cows.

Table 3.2 indicates that some cows supported the hypothesis all four times for some parameters (single 4's). But given an either/or choice four times, a random outcome is expected once in sixteen tries (1 in 2 x 2 x 2 x 2). This translates to 1 or 2 cows in 20. That a particular cow supported the hypothesis four times for a particular blood parameter is expected due to coincidence. The table should be useful in identifying areas in the barn where stress levels are highest. No definite pattern was noted.

COW	FIBR	CPK	TPRO	WBC	NEUT	LYMP	EOSI	HEMA	HEMO	TOT	AVG
1	0	2	-2	-2	4	0	4	-4	-4	-2	- .22
2A	-2	0	0	-4	2	4	2	-4	-2	-4	- .44
6	0	-4	2	-2	2	2	0	-4	-2	-6	- .67
7	2	-2	2	-4	-2	0	4	-2	-2	-4	- .44
8	-4	-2	-2	2	2	4	2	-2	-2	-2	- .22
9	-2	-2	0	-2	-2	-2	0	-4	-4	-18	-2.00
10	0	2	0	2	0	0	0	-2	-2	0	0
13A	0	-2	2	2	0	-2	-2	-2	0	-4	- .44
15A	-4	-4	0	-2	2	2	2	-4	-2	-10	-1.11
21	4	2	0	2	-2	-2	2	-4	-4	-2	- .22
22	-4	-2	0	-2	2	2	4	0	0	0	0
24	-4	4	-2	-2	0	2	2	2	-4	-2	- .22
26	-2	2	-2	0	-2	0	2	-4	-4	-10	-1.11
29	-2	0	4	-4	-4	0	4	-4	-2	-8	- .89
30	0	-2	-2	0	0	-2	0	-4	-4	-14	-1.56
31	2	0	0	4	2	-4	2	-4	-2	0	0
32	4	-2	2	-4	-4	2	2	-4	-2	-6	- .67
33	2	-2	0	-2	-4	0	0	-4	0	-10	-1.11
34	2	-2	0	-4	-4	2	0	-4	0	-10	-1.11
35	4	-2	0	-4	0	2	4	-4	0	0	0
TOT	-4	-16	2	-26	-8	10	34	-62	-42	-112	- 12.44
AVG	-.1	-.8	.1	-1.3	-.4	.5	1.7	-3.1	-2.1	-5.6	-.62

Table 3.2 Which cows and blood parameters support the stray voltage/stress hypothesis? The direction of change in blood parameters for each cow at the end of four test periods were evaluated as supporting the hypothesis or not. The number of positive changes for each cow was determined, then assigned value indicative of the level of support.

Value	Meaning
4	4 of 4 changes in parameter support hypothesis. (perfectly supportive)
2	3 of 4 changes in parameter support hypothesis. (somewhat supportive)
0	2 of 4 changes in parameter support hypothesis. (ambivalent)
-2	1 of 4 changes in parameter support hypothesis. (somewhat countersupportive)
-4	0 of 4 changes in parameter support hypothesis. (perfectly countersupportive)

No cow's blood analysis supported the hypothesis across all blood parameters (all 4s). Only three cows (#1, #29 and #35) supported the hypothesis in two blood parameters; eight others (#2A, #7, #21, #22, #24, #31 and #32) supported the hypothesis in one blood parameter. Considering the averages in the right hand column, it should be noted that the average blood analysis for each cow is between -2 and zero. This indicates that, considering changes in all blood parameters for each cow, the results are ambivalent or countersupportive of the hypothesis.

The averages presented in Table 3.2 should not be used to answer questions broader than those described below. They do not disprove a stress response in individual cows as measured by individual blood parameters.

The averages in the bottom row can be used to gauge how supportive of the hypothesis is each parameter across all cows. Only three parameters showed a positive outcome: eosinophils (1.7), lymphocytes (.5) and total protein (.1). These are only ambivalent to somewhat supportive of the hypothesis. The rest are ambivalent to somewhat unsupportive. The parameters faring poorest were the red blood cell counts: hematocrit (-3.1) and hemoglobin (-2.1); however these parameters were identified by the veterinarian as not good indicators of acute stress.

The averages in the right-most column measure how supportive of the hypothesis is each cow across all parameters. All cows scored zero or negative; that is, the outcomes were ambivalent to somewhat countersupportive of the blood parameter hypothesese taken as a group.

The average of the averages (bottom right) rates all the blood parameters across all the cows with respect to the hypothesis; the result again is in the range of ambivalent to somewhat countersupportive.

In a similar fashion, the change direction in blood parameters were summed for each test date and blood parameter across all cows. The results are shown in Table 3.3.

Table 3.3 shows that some blood sample parameters changed in a direction supporting the P/N grounding/stress hypothesis. These were for total protein on 3/31 (18), lymphocytes on 4/14 (16), and eosinophils on 4/14 (16). In other instances, strong countersupport is evident, particularly for hematocrit and hemoglobin. No consistent pattern is evident in the individual scores in this analysis.

No blood sample date resulted in a net positive support of the hypothesis across all parameters as shown in the AVG column. The level of support ranges from ambivalent to weakly countersupportive. Elimination of the poorest indicators (hematocrit and hemoglobin) would improve the level of support somewhat but then would not raise the averages to better than weakly supportive.

DATE	ON/OFF	FIBR	CPK	TPRO	WBC	NEUT	LYMP	EOSI	HEM	HEMO	TOT	AVG
3/24	OFF	2	-14	2	2	-6	-12	5	-16	-14	-51	-5.7
3/31	ON	5	-6	18	-6	-2	0	0	-18	-16	-25	-2.8
4/8	OFF	-10	-6	-2	-8	4	6	14	-18	-8	-28	-3.1
4/14	ON	-2	10	-16	-14	0	16	16	-8	-2	0	0
TOT		-5	-16	2	-26	-4	10	35	-60	-40	-104	-11.6
AVG		-1.2	-4.0	0.5	-6.5	-1.0	2.5	8.75	-15.0	-10.0	-26.0	-2.89

Table 3.3 Which test dates and blood parameters support the stray voltage/stress hypothesis? The direction of change in blood parameters for each cow at the end of four test periods were evaluated as supporting the hypothesis or not. The number of supporting outcomes for each test date was determined, then assigned a value indicative of the level of support.

Value = #cows changing in expected direction - #cows changing the other way or not at all

Value	Meaning
20	20 cows of 20 changed in the expected direction (perfectly supportive of hypothesis)
10	15 cows of 20 changed in the expected direction (somewhat supportive of hypothesis)
0	10 cows of 20 changed in the expected direction (ambivalent)
-10	5 cows of 20 changed in the expected direction (somewhat countersupportive of hypothesis)
-20	0 cows of 20 changed in the expected direction (perfectly countersupportive of hypothesis)

Only three tests had a positive outcome when summed across all blood sample dates. These were eosinophils (8.75), lymphocytes (2.5) and total protein (0.5); support by these parameters is weak to "somewhat". The red blood cell parameters, hematocrit and hemoglobin, showed strong countersupport in this table (as in the previous one).

Mastitis

Mastitis or bacterial infection/inflammation of the udder was monitored by the veterinarian using three methods: 1) Clinical observation, 2) Bulk tank somatic cell count records, and 3) Bulk tank microbiological analysis.

1) Clinical observation

Individual cases of mastitis or possible mastitis were noted by the veterinarian and presented here in Table 3.4.

Date	Cow	Observation	P/N Ground
3/16	#27	Treated for dry cow mastitis.	ON
3/20	#35	Mild case of mastitis.	ON
3/24	#35	Slight mastitis.	ON/OFF
	#25	Blood or mastitis in both rear quarters.	
3/30	#35	Milked out well, less swelling, lack of clinical milk clots.	OFF
4/5	#25	Stepped on teat which required opening.	ON

Table 3.4 Clinical observations of mastitis and the status of the PN ground.

The first four observations were made before P/N ground switching (off on 3/24). By themselves they do not explicitly support the hypothesis that a connected P/N ground causes stray voltage induced mastitis. The lack of new mastitis cases during the first OFF week and the improvement in #35 toward the end of the week support the hypothesis. No new cases were reported during the next ON week or the final OFF week. Clinical mastitis data provide weak support for the hypothesis primarily by its lack of countersupporting observations.

2) Bulk Tank Somatic Cell Counts

Bulk tank SCC's are given in the Beehler report, Table 26. This data is combined with P/N ground status and statistics here in Table 3.5.

Before the P/N ground was switched, the SCC was rising slowly at an average rate of +5500/day. During the first OFF period, the rate of change increased by +20,000/day. Then during the next ON week the rate of increase slowed to +15,000/day and peaked. In the final OFF week the rate fell rapidly at -24,000/day.

Does the SCC data support the P/N ground hypothesis? The data are inconclusive. Support would be obvious if the SCC fell during the first OFF week. Rather, it increased more rapidly. The steep decline during the last OFF week lends some support, however. SCC data after 4/14 could lend additional support if the numbers go up again after the test.

DATE	P/N GND STATUS	SCC (1000)	AVG (1000)	SLOPE (1000/DAY)
3/9	ON	206		
3/11		256		
3/13		235		
3/15		214	248	5.5
3/17		228		
3/19		272		
3/21		248		
3/23		326		
3/25	OFF	213		
3/27		262		
3/29		311	279	20
3/31		329		
4/2	ON	290		
4/4		252		
4/6		425	326	15
4/8		335		
4/10	OFF	287		
4/12		239	239	-24
4/14		191		

Table 3.5

Bulk tank somatic cell counts (determined at the milk plant) presented with the status of the P/N ground and the average and slope (change rate determined by least squares linear regression) of each ON or OFF period.

3) Bulk tank milk microbiological analysis

Bulk tank milk samples were taken every two days. Average weekly data are presented in the Beehler report, Table 27. This information is adapted with P/N ground status here in Table 3.6.

The hypothesis is: P/N ground currents access the cows resulting in bacterial infection in the udder and thus higher bacterial counts in the milk. Do changes in bacteria counts in Table 3.6 support the P/N ground hypothesis? Taken by type, none change three times out of three in a direction indicated by the hypothesis. Changes in the first four bacteria types in this table support the hypothesis two times of three, somewhat supportive; the last type, zero of three (countersupportive). At best, the microbiological data are somewhat supportive of the hypothesis though this conclusion would be stronger if the pre-switching variability in the data (first three data columns) was lower.

TYPE OF BACTERIA	3/8-3/10 ON	3/11-3/17 ON	3/18-3/24 ON	3/25-3/31 OFF	4/1-4/7 ON	4/8-4/14 OFF
Strep Ag	45	45	50	100	200	100
Staph Aureus	15	30	60	35	55	100
Coliform	15	30	0	0	25	15
Staph Epi	800	700	800	700	1200	1400
Non-ag Strep	150	200	500	600	300	350

Table 3.6

Bulk tank milk microbiological analysis as averages of samples collected every other day and averaged over the time periods shown. P/N ground status is indicated below the dates.

Cow Appearance

A record of the general appearance of cows in the herd is found in the Beehler report Table 28. This data was scored to rate its support for or against the P/N ground/stress hypothesis. Changes were noted for each category across three switch events. A supportive change was scored +1; no change was scored 0; a countersupportive change was scored -1. Table 3.7 presents the results.

The appearance of redness (erythema) in the fetlocks an pasterns generally occurred in support of the hypothesis as did soreness in the feet to a lesser extent. These were balanced by the somewhat countersupportive changes in cud chewing, swelling of hocks and legs, and manure consistency. Cow appearance as a herd average over all changes in P/N ground status showed no net support for the hypothesis.

APPEARANCE CATEGORY	ON-OFF 3/24	OFF-ON 3/31	ON-OFF 4/8	TOTAL
Contentment	0	0	0	0
Healthy	0	0	0	0
Hair coat	0	0	0	0
Hydration	0	0	0	0
Abdomen	0	0	0	0
Cud chewing: Gen	0	-1	0	-1
%	1	0	-1	0
Hocks/legs, swelling	-1	0	0	-1
Feet, soreness	0	1	0	1
Fetlock/pastern, erythema	1	1	0	2
Manure: amt	0	0	0	0
consistency	-1	0	0	-1
Udders	0	0	0	0
Total	0	1	-1	0

Table 3.7 Cow appearance changes relative to changes in the P/N ground status. Each appearance category was scored to indicate support for the P/N ground hypothesis.

Score	Meaning
1	Supports
0	No change
-1	Does not support

Cow Behavior

Data rating cow behavior as a herd average are found in the Beehler report, Table 29. These data were adapted to reveal the degree of support for the P/N ground hypothesis in a manner identical to that for cow appearance above and are shown here in Table 3.8.

No types of behavior changed consistently over all three P/N ground switching events. Those behaviors which changed in support of the hypothesis two times out of three were dancing, tongue playing/licking, and grace/ease rising. In addition, behaviors supporting the hypothesis one time of three were demeanor (calmness) and stanchion/chain behavior. All other behaviors as a herd average did not change significantly. It is interesting to note that no behaviors changed in countersupport of the hypothesis. On a support scale of -3 to 3, cow behavior as a herd average achieved an overall score of 0.75, that is, "standing quietly" to "occasional" (behavior).

The veterinarian observed that "From these graphs (hock and leg swelling, redness in the fetlock and pastern, amount of tail switching, and degree of uneasiness or dancing) it would appear problems occurred causing irritation and aberrant behavior on

3/15/93 to 3/21/93 and again 4/2/93 to 4/10/93." These periods coincided with ON periods (except for 4/9 and 4/10) and support the hypothesis.

BEHAVIOR CATEGORY	ON-OFF 3/24	OFF-ON 3/31	ON-OFF 4/8	TOTAL
Demeanor, comfort	1	*	*	1
calm	0	1	0	1
Dancing	1	1	0	2
Kicking	0	0	0	0
Tail switching	1	-1	0	0
Vocal resp	0	0	0	0
Tongue play/lick	1	1	0	2
Grace/ease rising	1	1	0	2
Urination/bm	0	0	0	0
Reaction milking	0	0	0	0
Water cup lapping	0	0	0	0
Stanchion/chain	1	0	0	1
Total	6	3	0	9
Avg	.5	.25	0	.75

Table 3.8 Cow behavior changes relative to changes in the P/N ground status. Each behavior category was scored to indicate support for the P/N ground hypothesis.

Score	Meaning
1	Supports
0	No change
-1	Does not support
*	Missing

Cow Behavior at Milking Time

A videotape record was made of a set group of cows to document behavior during milking. Four times per week a 20 minute tape segment was made; just after being milked, the group was taped from behind for 10 minutes to show tail switching and dancing/shifting. Then the camera was shifted to obtain a 10 minute record from the front to show cud chewing. the Beehler report, Table 30 documents the number of events noted in each pair of 10-minute tape segments. This data is presented in an annotated version here in Table 3.9.

Changes in the frequency of tail switching supported the hypothesis across each of the three switch events. "Dancing and shifting" and "cud chewing" changes each gave support two of three times. Taken in total, changes in the behavior of six cows somewhat supported the P/N ground hypothesis with an average score of+0.55 in a range of -1 to 1.

DATE	TAIL SWITCHING	AVG	DANCING/ SHIFTING	AVG	CUD CHEWING	AVG	P/N STATUS
3/19	24		7		3.0		
3/20	35	28	6	6.3	3.0	3.17	ON
3/22	25		6		3.5		
3/24pm	17		9		3.5		
3/27	16		12		3.5		
3/29	20	16	12	10.5	3.0	3.38	OFF
3/31am	11		9		3.5		
4/1	20		11		3.0		
4/4	26	22	15	13.0	3.5	3.17	ON
4/6	20		13		3.0		
4/8	25		14		3.0		
4/10	14		9		3.0		
4/12	16	17	20	12.5	2.5	2.75	OFF
4/13	13		7		2.5		

Table 3.9a Cow behavior at milking time. Data are number of observed events in 10 minute videotaped segments of six cows taken just after they were milked. Also shown is the status of the P/N ground.

BEHAVIOR CATEGORY	ON-OFF 3/24	OFF-ON 3/31	ON-OFF 4/8	AVG
Tail switching	1	1	1	1
Dancing/shifting	-1	1	1	.33
Cud chewing	1	1	-1	.33
Total	1	3	1	1.66
Avg	.33	1	.33	.55

Table 3.9b Changes in cow behavior during milking relative to changes in the P/N ground status. Each behavior category was scored to indicate support for the P/N ground hypothesis.

Score	Meaning
1	Supports
0	No change
-1	Does not support

Individual Observations

Much of the preceding analyses distilled information to extract a quantitative measure of herd characteristics; Detail was sacrificed for simplification. The following synopsis of discrete observations by the veterinarian and the dairyman are offered to partially counterbalance this effect. The observations are, however, reduced in most cases to a short phrase from their original and grouped side-by-side according to whether they might be taken as supporting or countersupporting the hypothesis. If no basis could be found to connect an observation to the status of the P/N ground, it was not included in this list. See Data Item #2, Section "On Farm Observations" for the original and full text.

DATE/ STATUS	SUPPORTING	COUNTERSUPPORTING
3/8 ON		Appearance of herd normal
		Herd appears healthy
		Good body condition
		Content
		Generally comfortable
		Good cud chewing
		Good appetites
		Normal hydration
		Normal abdominal fullness
	Several swollen hocks	Hocks appear normal
	Small amt of alopecia	Consistent with normal
	Corn in manure	Manure normal consistency
		Behavior w/in normal range
		Demeanor good
		Generally content, alert
		Not nervous
		Minimal dancing, shifting
		None to minimal tail switch
		No abnormal auditory resp
		Urination/bm normal
	Cow lapping water out	
3/15 ON	#24 less than healthy -rapid breathing	Generally appear healthy
		Cud chewing vigorous
	#8,9,10,30 particularly -uncomfortable	Hydration normal
		Good manure
		Normal urination
		Cows calm, comfortable content
3/17 ON	Cows not as comfortable	Cows generally healthy
	#1,5,8,10,30 quite uncomfortable profound tail switch	

Cud chewing only 20%
#24 treated for ketosis
& pneumonia
#27 treated for mastitis
#30 had retained placenta
treated for ketosis
Erythemia in several cows
#27 very stiff and sore

Cud chewing increased to 55%

Behavior during milking
unremarkable
Kicking not a problem

3/19
ON

Too much corn in manure
#1,5,8,30 excessive
tail switching, no
lice or mange
#28 holds nose under chain
#30 had RDA torsion

Cows appear healthy
Good cud chewing
Manure normal in amt/cons
Normal behavior & disposition

3/22
ON

A few sloppy at water cup
Cow pressed nose to stanch.
Significant amt tail switch.
Significant amt dancing
#25,27 difficulty rising

Erythema in fetlock/pastern
increased. Reddest to date

Appetites vigorous
Overall appearance good
Healthy, content
Mostly comfortable

No kicking

Urination/bm normal
Feet normal, unchanged

3/24
ON (to OFF after visit)

Dancing and tail switching
present

Cows healthy, content,
comfortable, calm
Appetites vigorous
Dancing and tail switching
less than on 3/22
No kicking
Erythemia decreased.
Manure normal
No unusual behavior

3/26
OFF

Cows healthy, content
Content

	Even more restful Appetites good "Twice as good as last week", DL Erythemia is less Very little dancing Tail switching decreased Normal manure No unusual behavior	Hock swelling the same #25 is still stiff
3/30 OFF	Cows calm Healthy, content No obvious discomfort Hydration normal Good appetites Normal hair coats No unusual behavior Today "much improved",DL #8 now totally calm, restful Fetlocks less red	Increase in swollen hocks 3-4 days ago "particularly bad for tail switching, enlarged hocks,red feet",DL #5,6,30,35 some tail switching #25 standing in gutter #27,21,22 enlargement of hock joint #25 treated for uterus infection #1 treated for ketosis Outside heifer had trouble calving
4/2 ON	#10,30 tail switching	Cows appear very healthy content Best cud chewing observed Great appetites Great amt of drinking Tail switching decreased #21,22,27 hock swelling unchanged At least 2 milking > 80 lb
4/6 ON	One cow tail switching #25 restless #26 dancing, leaking milk, increased hock swelling	Cows calm, healthy, comfortable Other cows no longer tail switching Good cud chewing #21,22 hock inflammation unchanged Herd extremely calm, comfortable, restful

4/8pm
ON (then OFF)

Generally cows healthy, content

#25 open sore in hock

Significant degree of restlessness among certain cows (about 30%)

#2,9,25,26,30,31,33 dancing

Pronounced tail switching off and on

#25 uneasy, wet from cup

#2,9,30,31,33 uncomfortable

#30 "quite irritable",DL

4/13
OFF

Urination,manure normal

Herd healthy, content in general

Tail switching remains high

#25 stands back in stall

#34 swollen front leg

Erythema is high

Subjected to irritation in last few days?

25-30% of herd is restless, uncomfortable

4. Anomalous Events

A number of features in the data suggest that electrical events occurred during the test which, though not related to primary neutral ground switching, are of some interest to the question of neutral grounding and ground currents. A selected few are discussed below.

A) Neutral Connection Anomaly

From 3/18 pm to 3/19 am, the primary neutral ground resistance at the transformer pole dropped from about 28 Ω to about 2 Ω (as calculated from Vac and Iac) as can be seen in Figures 4.1a and b. During this anomaly PN-RG Vac dropped cleanly by a factor of 10. Concurrently, 2N-RG Vac in the barn rose by about a factor of 10. This only happened once during the test as can be seen in Figure 4.2a. In a more detailed view, one-minute data are shown in Figure 4.2b. It appears from this data that the primary and secondary neutrals were connected somehow during the several hours the anomaly lasted. The correlation coefficient calculated for primary and secondary neutral Vac shows no correlation before (0.18) or after (-0.17) the event but very strong correlation during (0.96), clearly proving the connection.

One explanation for the connection between the neutrals is a failed isolator. However, this cannot be the case. The current in the primary neutral ground rose simultaneously as the voltage fell. The resulting low primary neutral ground resistance is consistent with connection to the multiple parallel grounds in the secondary neutral system through the primary ground wire. If the event was due to a failed isolator, the primary ground resistance would not have been affected. Since the current in the ground wire was measured in the switch box mounted on the pole, the neutrals must have become connected below the switch box. It is possible that the connection occurred at or below ground and may have involved a buried remnant of a wire fence in contact with both the primary and secondary ground rods, for example. Contraction of the P/N ground wire with temperature may have made the connection (the night of 3/18 was one of the coldest of the test).

Another possibility is that the primary neutral was inadvertently connected to the secondary neutral through the monitoring equipment inside the van; equipment setup was still in progress at the time. However, two facts tend to detract from this theory: 1) The anomaly reoccurred for much shorter durations later in the test (see Anomaly B below) and did not then involve the secondary neutral. 2) Anecdotal reports (D. Lusty) of primary neutral ground currents measured in December 1993 and January 1994 indicate a rise from 40 mA or so to about 200 mA (a unique signature of Anomalies A and B during the test) suggesting that the condition was repeating in the absence of the monitoring equipment. Resolution of this question can easily be approached by an examination of the primary and secondary grounds at the transformer pole.

Whatever the cause, neutral separation was certainly lost during

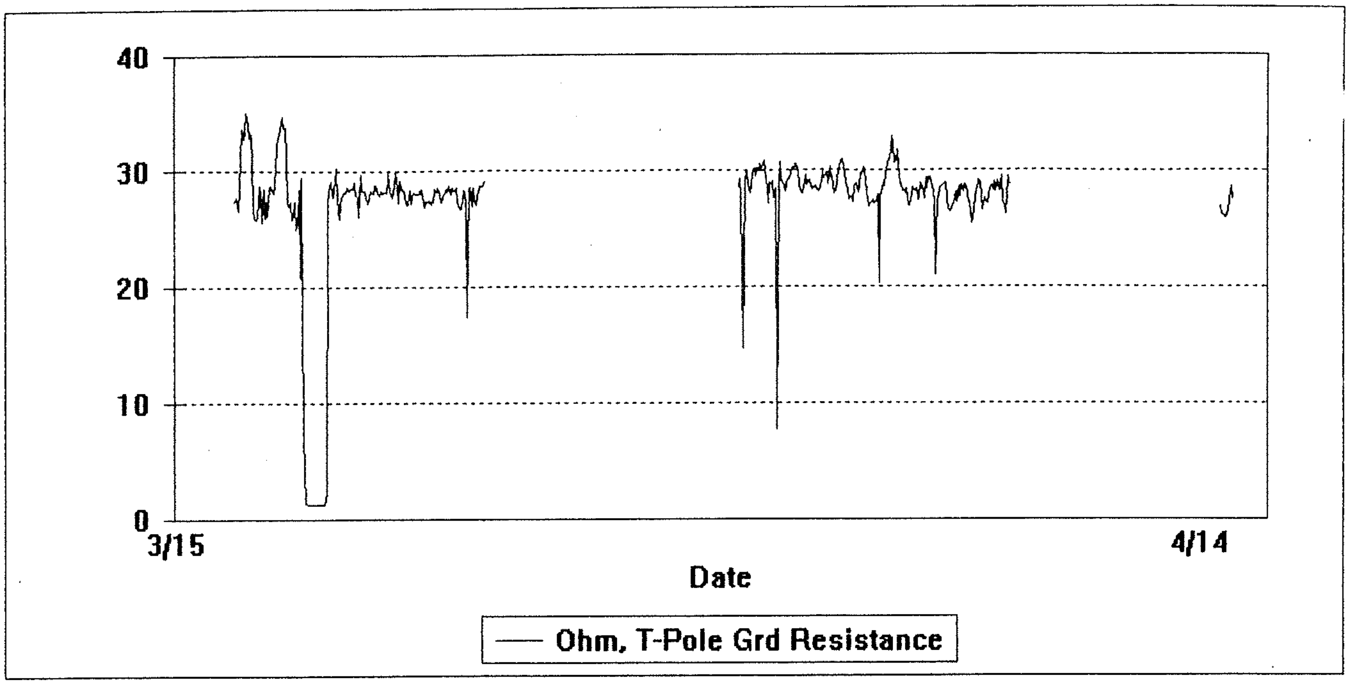


Figure 4.1a Ground resistance at transformer pole primary ground (calculated from PN-RG Vac and PN-TG Iac), one-hour average data plotted for entire test. The anomaly of interest occurred on 3/18-3/19.

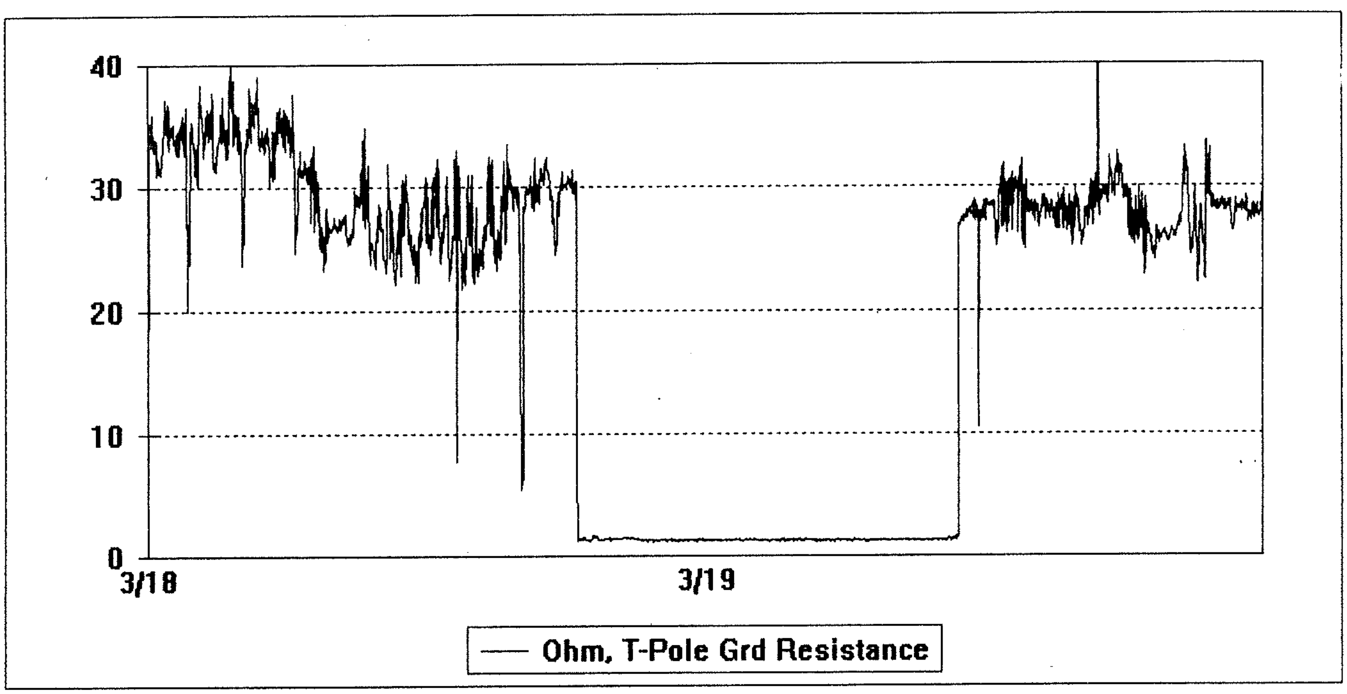
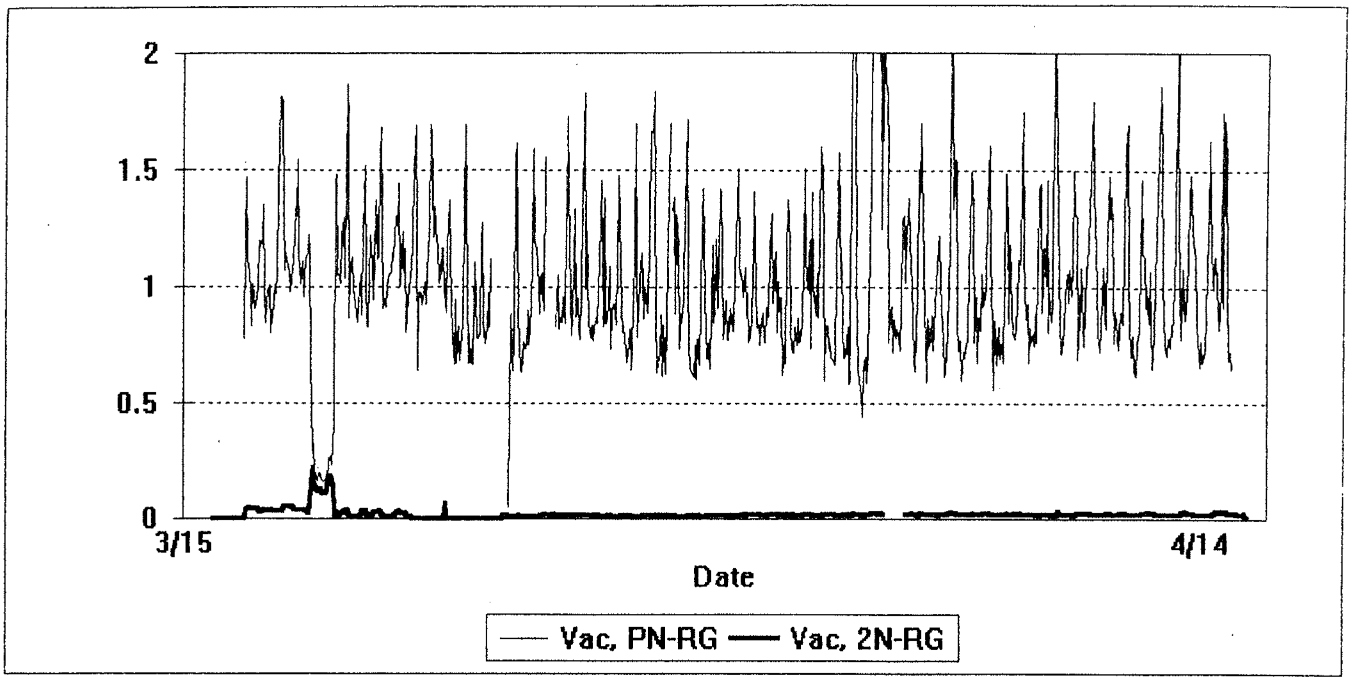
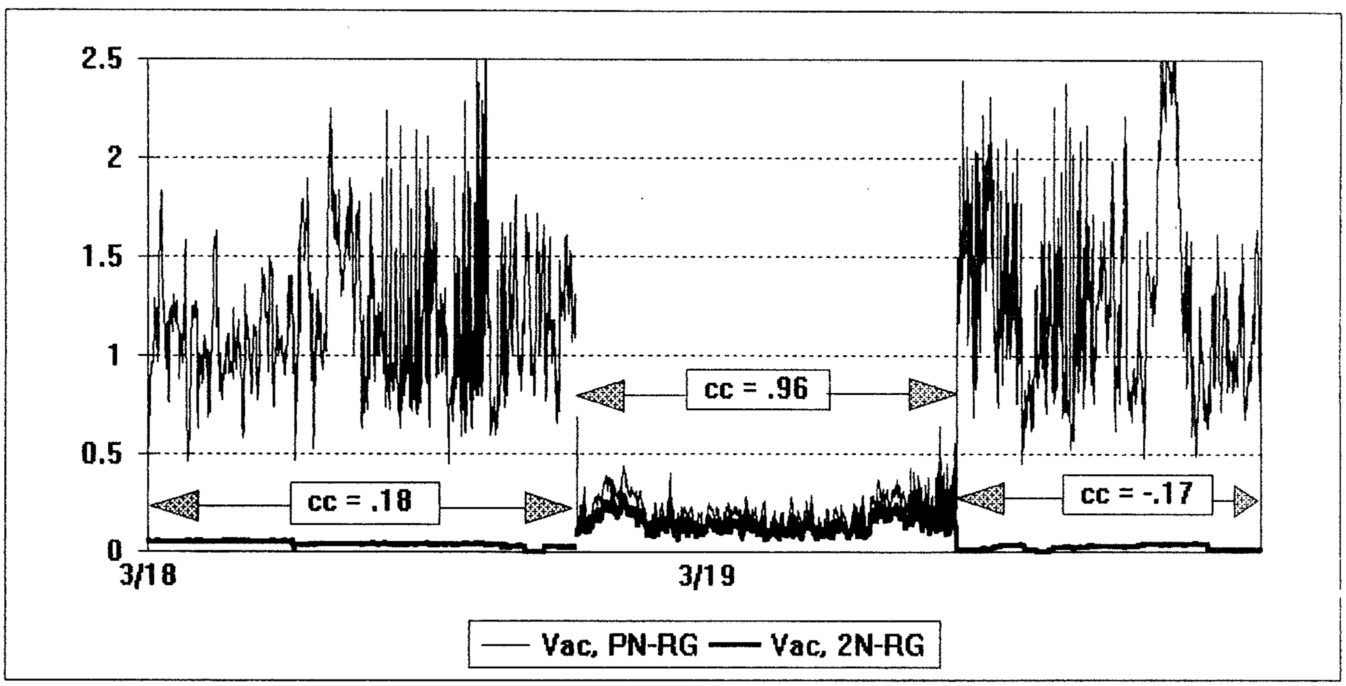


Figure 4.1b Ground resistance at transformer pole primary ground (calculated from PN-RG Vac and PN-TG Iac), one-minute average data plotted for 3/18 and 3/19.



<u>Figure</u> <u>4.2a</u> Primary neutral ac voltage (transformer pole) and secondary neutral ac voltage (barn) relative to remote ground, one-hour averages plotted for entire test. Note anomaly on 3/18 and 3/19.



<u>Figure</u> <u>4.2b</u> Primary neutral ac voltage and secondary neutral voltage relative to remote ground, one-minute averages plotted for 3/18 and 3/19. cc = correlation coefficient calculated for the time periods shown.

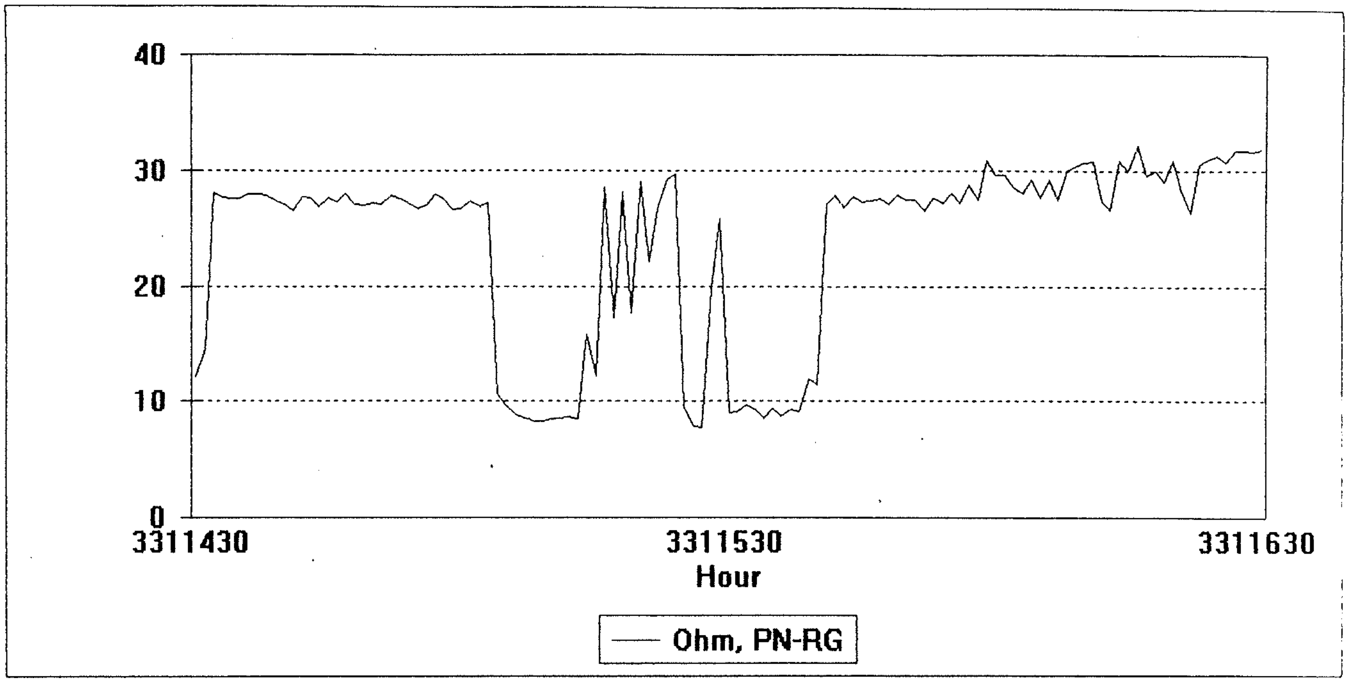
the event. This anomaly presented an unexpected bonus, a clear picture of the difference between isolation and connection of neutrals as seen in the electrical environment of the barn. Simultaneously with the rise in secondary neutral voltage, other changes were noted in the barn data: WL-RH Vac increased by a factor of three. WL-RH Vdc rose by 30% (but did not fall after the anomaly). FH-RH Vac doubled. No change was noted in the ac magnetic field, so a substantial change in ac ground current did not occur near the test stall as a result of draining the distribution system's neutral voltage into the farm's secondary grounds. The cow contact voltages did not become large enough to be considered a definite stray voltage problem; Perhaps if the primary neutral voltage was higher than its usual one volt, this event could have created cow contact potentials high enough to be of interest or possibly concern.

B) Primary Ground Resistance Anomaly
A few other short-term changes were noted for the primary neutral ground rod resistance as seen in Figure 4.1a. These occurred on 3/23, 3/31, 4/1 and 4/6 and lasted for several minutes each. Two of these events were studied, those of 3/31 and 4/1. Figures 4.3a and 4.4a show what happened to the primary ground resistance at the transformer pole on those days. As before, it fell from about 28 Ω to a much smaller value. But no obvious changes are seen in the neutral voltages at this time (Figures 4.3b and 4.4b) indicating that the neutrals remained separated. The primary ground current quadrupled to over 200 mA. This anomaly is different than that describe in A above.

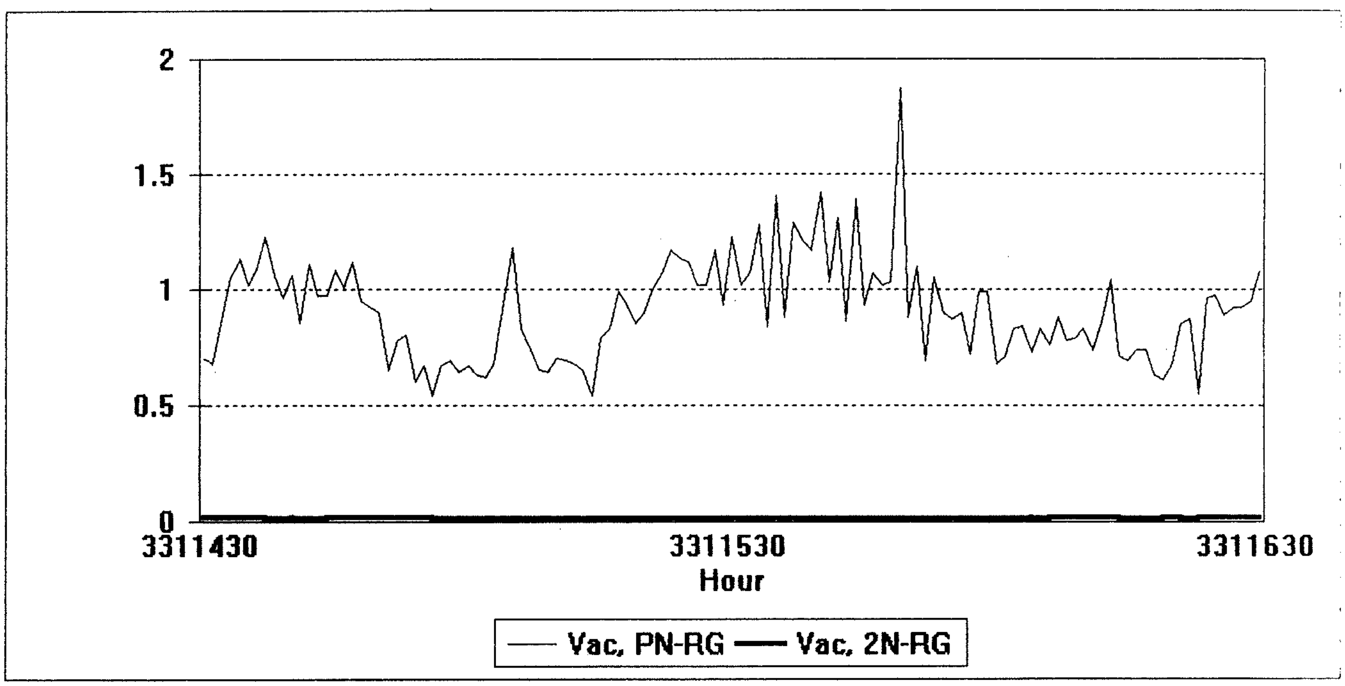
One possible explanation is that the buried fence wire fragment hypothesized above was both: 1) now only making contact with the primary ground rod (not draining primary neutral voltage onto the secondary neutral), and 2) very long and in good ground contact (to explain the large decrease in primary neutral ground resistance at the transformer pole and the resulting large increase in ground current).

C) Magnetic Field Anomaly
A number of interesting features can be seen in the ac magnetic field's vertical component measured at the stall floor. One can be seen in Figure 2.14, a graph of one-hour magnetic field data for the whole test. The magnetic field stepped up from a rather steady 0.03 mG to 0.06 mG on 3/22. Then on 3/31 it decreased to about 0.04 mG for the remainder of the test. These changes were almost certainly due to the installation of the BMI power quality monitors in the adjoining stall. The first instrument was installed on 3/22, the second on 3/31. Curiously the field decreased when the second instrument was turned on.

D) WL-GC Iac Anomalies
Figure 2.13 shows several large changes in the ac current between the water line and gutter chain. Large variability early in the record is partly due to a cow kicking the wire connector off the gutter chain. Also, anomaly A, the loss of neutral separation, caused a large increase in this quantity. Because of the confused nature of this period, the WL-GC Iac data prior to 3/22 should be



<u>Figure 4.3a</u> 3/31/93. Ground resistance at transformer pole primary ground (calculated from PN-RG Vac and PN-TG Iac), one-minute data. Note Anomaly B between 15:00 and 16:00.



<u>Figure 4.3b</u> 3/31/93. Primary neutral ac voltage and secondary neutral ac voltage relative to remote ground, one-minute averages. Note that during Anomaly B (see above), these Vac's do not correlate, indicating no connection of neutrals.

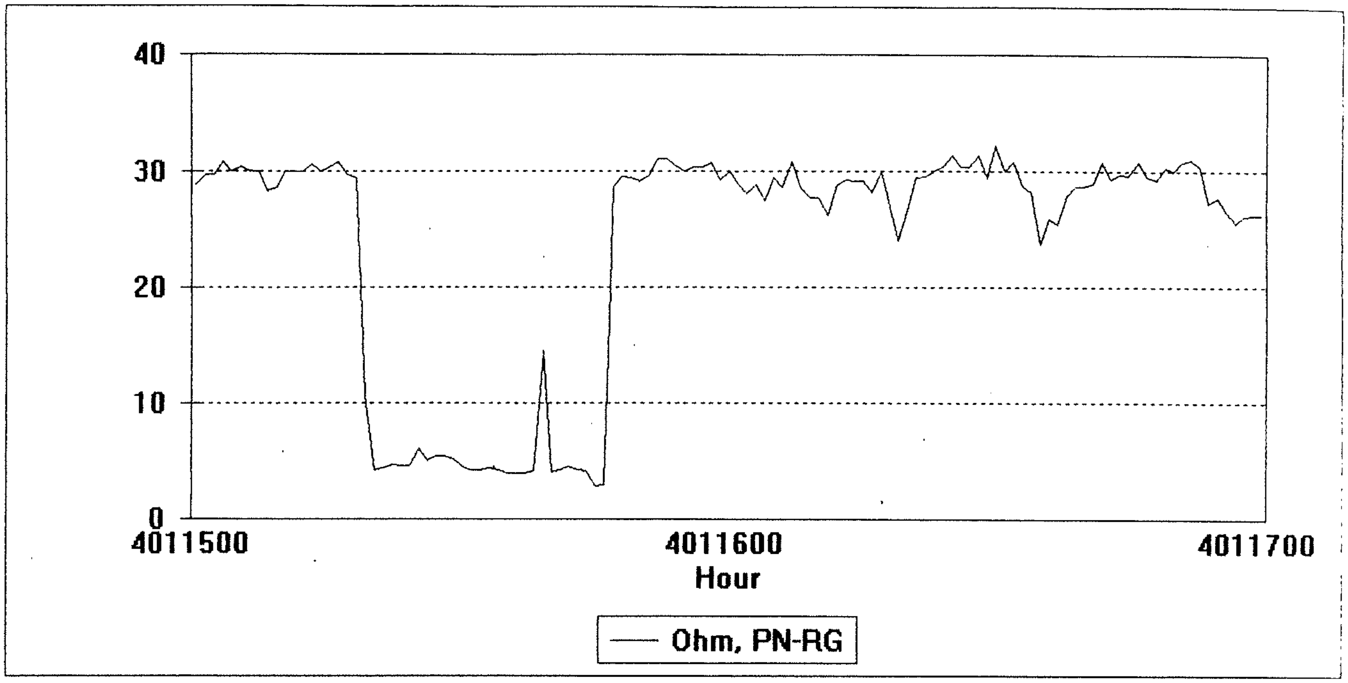


Figure 4.4a 4/1/93. Ground resistance at transformer pole primary ground (calculated from PN-RG Vac and PN-TG Iac), one-minute data. See Anomaly B between 15:00 and 16:00.

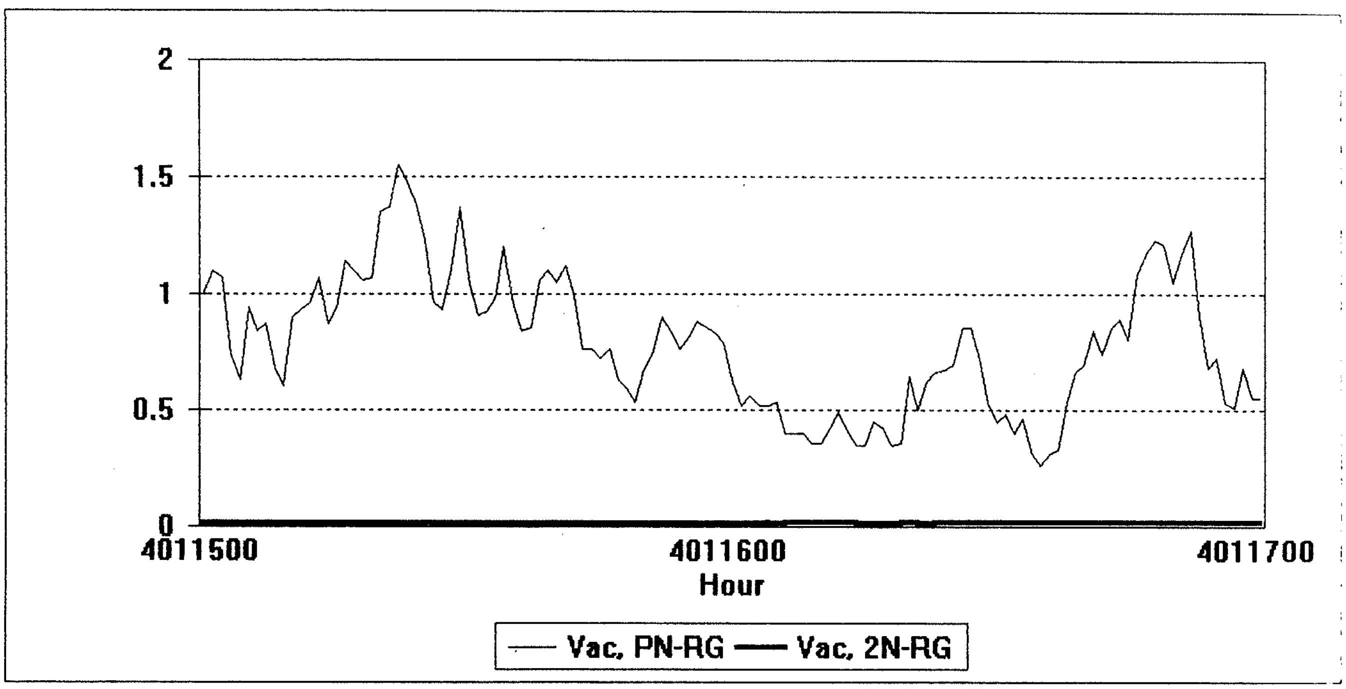


Figure 4.4b 4/1/93. Primary neutral ac voltage and secondary neutral ac voltage relative to remote ground, one-minute averages. Note that during Anomaly B (see above), these Vac's do not correlate, indicating no connection of neutrals.

disregarded.

Thereafter, daily downward spikes noted in Figure 2.13 were caused by removing the gutter chain connector each day for barn cleaning. This is evident in the one-minute graphs (Data Item 8) and serves as a time record of barn cleaning.

E) Effect of Anomaly D on Cow Contact Potentials
Connection of the water line to the gutter chain for measurement of the ac current between them had the following accidental effects:

WL-RH Vac: Increased from 0-1 mV to 3-10 mV.
WL-RH Vdc: Increased from 300-350 mV to 400-450 mV.
RH-FH Vac: Decreased from 2 mV to 1 mV.
RH-FH Vdc: No change.
2N-RG Vac: No change.

The effect of this anomaly on cow contacts with respect to changes coincident with P/N ground switching was considered. Multiple switching on 4/14 happened during barn cleaning; the water line was not connected to the gutter chain for this period. Since no changes in cow contacts were noted (see Section 2) it is unlikely that this anomaly had an effect on the outcome of P/N ground switching vs. cow contact conclusions.

F) FH-RH mVdc Anomaly

Figure 2.11 shows a large, clean step increase for this cow contact potential which lasted from about 5PM on 3/31 to about the same time the next day. No similar changes could be found in the barn one-hour data (Figures 2.8 through 2.14). The strip chart record of mGdc was examined for this period. Step changes were noted for several minutes at about 5PM on both days; a notation was made near the change on 3/31 indicating that the grate was replaced over the gutter adjacent to the test stall. Moving this gutter grate does explain the step changes in the dc magnetic field, but does not explain the one-day change in the dc voltage across the stall floor. No other explanation comes to mind.

G) Cow Fell, 4/9
A number of incidents involving individual cow behavior were reported during the test (Data Item #3). Time restraints prohibit analysis of the electrical conditions in the barn during all these events, though ample data would allow it. One event will be discussed, mostly as an example of what could be done with individual cow behavior.

At approximately 1908 on 4/9/94, cow #21 "went down to floor on belly" for no apparent reason. Milking was in progress and a video tape session was being made. Though #21 was not in the camcorder frame, the operator noted the event vocally on the tape; this record may be viewed to pinpoint the exact time of the event. The dairy operator noted the unusual nature of the event, that a cow will avoid falling flat to protect the udder. The question is, can the event have had an electrical cause?

The following may be said about electrical conditions in the barn from 1900 to 1910:

WL-RH Vac was about 6.4 mV and steady.
WL-RH Vdc was about -426 mV and steady.
FH-RH Vac was 0.7 mV and steady.
FH-RH Vdc was 0.1 mV and steady.
2N-RG Vac was about 17.5 mV and steady.
WL-GC Iac was about 2.26 mA and steady (from digital and strip chart records).
Bac was about .037 mGac. Position in cycle indicates that the ventilator fan may have been running.
Bdc was steady but showing spikes coincident with transfer pump starts, a normal observation on the strip chart record.
Line-to-neutral impulses (> 20 Vpeak) totaled 13 and 11 for the hour (not unusual). Relevant examples are:
19:06 L1-N, 28 Vpeak
19:06 L2-N, 25 Vpeak
19:09 L1-N, 21 Vpeak
19:09 L2-N, 24 Vpeak
WL-to-RH impulses > 5 V peak totaled 13 for the hour (not unusual). Relevant examples are:
19:05:34 9 Vpeak, 6 μJoules into 50 Ω, 2 μSec rise time
19:10:31 >10 Vpeak, 140 μJoules into 50 Ω, 8 μSec rise time

Nothing in the one-minute electrical data was out of the ordinary. Impulse rates were low and typical for the hour. There is perhaps a possibility that the impulse at 19:10:31 was involved, though it could be argued that the impulse energy of 140 μJoules was not high enough to cause the cow to start. It also is possible that #21 was responding to an electrical stimulus different in magnitude from that being measured some 10 feet away. However, the most likely source for an electrical stimulus would have included the water line and nothing unusual was noted. It is not likely that the electrical state of the water line could have been much different between the two stalls. In this instance, no electrical cause for the cow falling could be unequivocally identified.

5. Relationship of Electrical Data to Herd Data

Using day averages and week averages where appropriate, electrical data and herd data were analyzed to determine if relationships exist.

Day Averages

Table 5.1 is a correlation matrix of relevant electrical parameters and the herd data: Herd water consumption, herd milk production and bulk tank somatic cell count. (All other herd data were not available with one day resolution). Generally, correlation coefficients are typically higher for smaller data sets; here 30 records are a relatively small data set requiring higher correlations for the same level of association as for minute data or hour data, for example. The following can be said with respect to each herd parameter:

Water Consumption (gal/cow/day) shows a weak correlation with the two dc cow contact potentials, WL-RH Vdc (-0.561) and FH-RH Vdc (-0.421). These correlations are negative; that is, as the cow contact potential goes up, water consumption goes down. Correlations with the ac potentials are somewhat weaker, WL-RH Vac (0.168) and FH-RH Vac (-0.397).

Milk Production (lb/cow/day) shows a weak correlation with the dc cow contact potential WL-RH Vdc (-0.541), again a negative correlation. The corresponding correlations with ac cow contact potentials are weaker (WLRH mVac 0.361, FHRH mVac -0.316).

SCC (somatic cell counts) did not seem to correlate with any of the electrical parameters or water consumption or milk production.

The correlation of water consumption and milk production to WL-RH Vdc was high enough to examine the relationship further. Figure 5.1 shows day-average data for the three parameters. As the voltage goes up in <u>magnitude</u>, so does milk and water. (The minus sign in the correlation coefficients is due to the minus sign in the mVdc data.) However, milk production is probably going up due to the season and causing water consumption to follow. The correlations occurred with the cow contact potential that experienced a similar but unrelated trend and likely do not indicate cause and effect.

Week Averages

Table 5.2 presents electrical data and available herd data as averages over the period indicated or as representative herd samples for each period. For a data set of only four records, a direct comparison of data was chosen. To decide whether herd data are responses to electrical parameters on this time scale,

	PNRGmVac	PNRGmVdc	WLRHmVac	WLRHmVdc	FHRHmVac
PNRGmVac	1.000				
PNRGmVdc	-0.050	1.000			
WLRHmVac	-0.153	-0.055	1.000		
WLRHmVdc	0.224	-0.070	-0.342	1.000	
FHRHmVac	-0.078	-0.047	-0.298	0.797	1.000
FHRHmVdc	-0.427	-0.032	0.405	-0.010	0.093
2NRGmVac	-0.302	-0.068	0.541	0.068	0.037
B mGac	-0.267	0.242	-0.172	-0.642	-0.691
WATER	0.167	-0.030	0.168	-0.561	-0.397
MILK	0.033	0.182	0.361	-0.541	-0.381
SCC	-0.147	0.200	0.097	-0.179	-0.316

	FHRHmVdc	2NRGmVac	B mGac	WATER	MILK	SCC
FHRHmVdc	1.000					
2NRGmVac	0.682	1.000				
B mGac	-0.120	-0.192	1.000			
WATER	-0.421	-0.198	0.232	1.000		
MILK	-0.235	0.070	0.117	0.715	1.000	
SCC	-0.019	-0.052	0.318	0.160	-0.143	1.000

Table 5.1 Correlation coefficient matrix for electrical and herd data as day-averages. Numbers near zero indicate no correlation; perfect correlation is 1.000 (-1.000 for an inverse relationship).

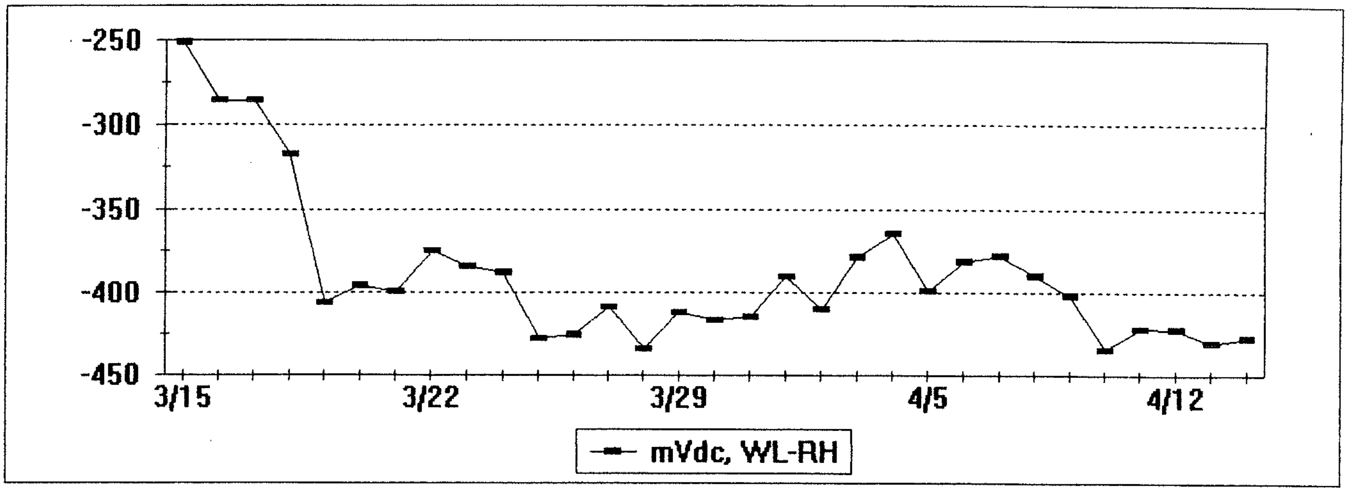


Figure 5.1a mVdc between water line and rear hoof. Day averages.

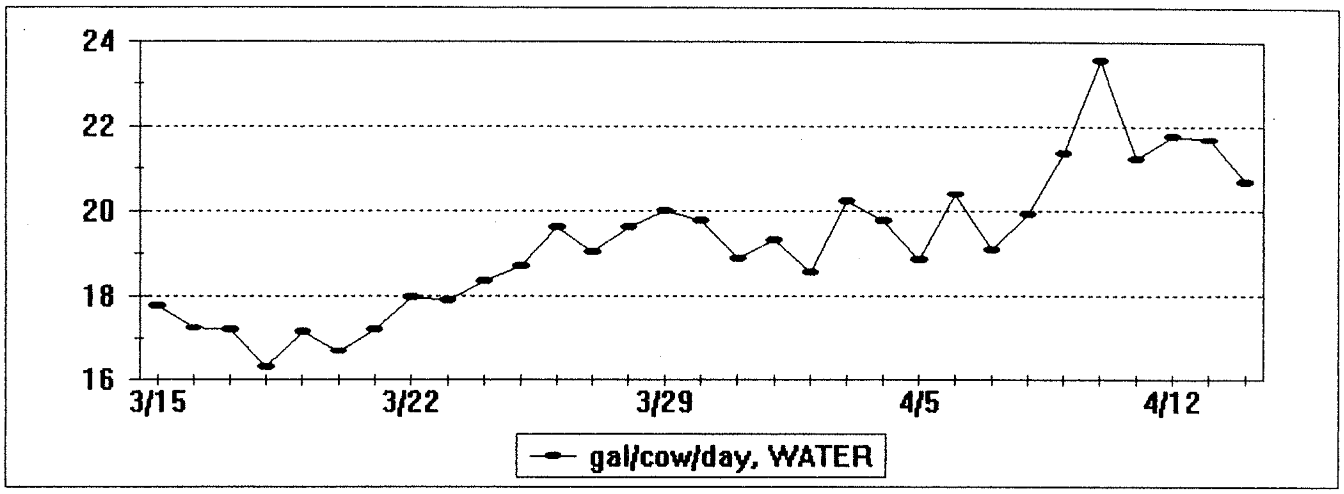


Figure 5.1b Herd water consumption, gal/cow/day.

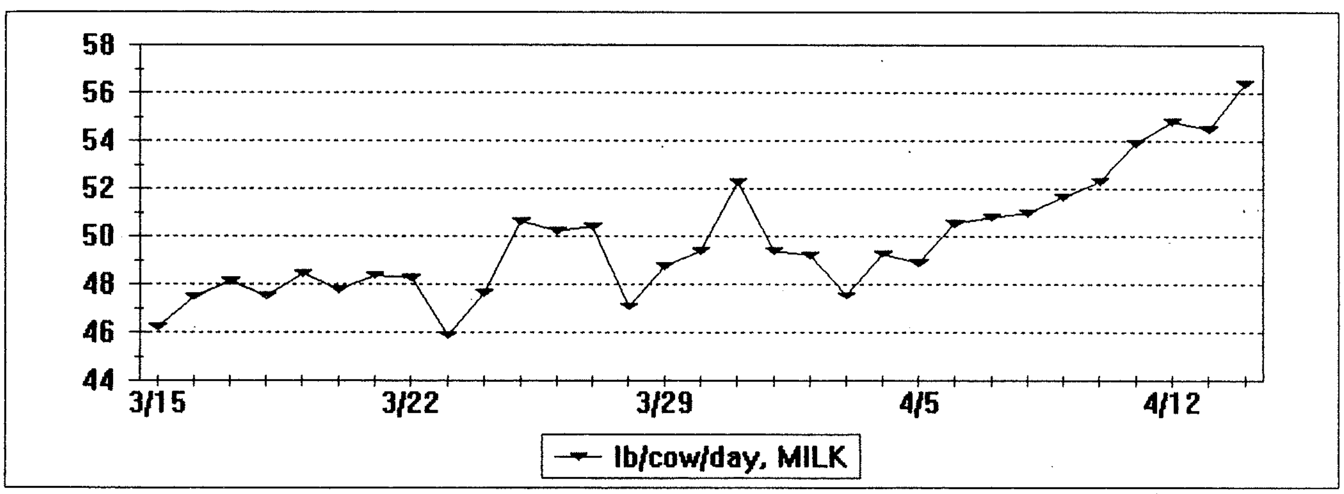


Figure 5.1c Herd milk production, lb/cow/day.

	PNRGVac	PNRGVdc	WLRHmVac	WLRHmVdc	FHRHmVac
3/15 - 3/24	1.01	-528.17	5.53	-359.45	1.87
3/24 - 3/31	0.98	-533.62	3.98	-418.79	0.86
3/31 - 4/8	1.05	-530.79	6.31	-386.65	0.66
4/8 - 4/15	1.05	-531.99	6.70	-419.96	0.79

	FHRHmVdc	2NRGmVac	B mGac	FIBR	CPK
3/15 - 3/24	0.42	24.91	0.035	335	106
3/24 - 3/31	0.16	11.17	0.058	280	210
3/31 - 4/8	0.18	18.18	0.043	390	119
4/8 - 4/15	0.13	20.67	0.037	435	149

	TPRO	WBC	NEUT	LYMP	EOSI
3/15 - 3/24	7.6	10145	3721	5551	701
3/24 - 3/31	7.6	98985	4135	4669	1000
3/31 - 4/8	8	9555	3784	4839	702
4/8 - 4/15	8	10675	3508	5859	1068

	HEMA	HEMO	SCC	STRP AG	STPH AU
3/15 - 3/24	32	10.9	248	50	60
3/24 - 3/31	30	10.5	279	100	35
3/31 - 4/8	34	11.2	326	200	55
4/8 - 4/15	32	11	239	100	100

	COLI	STPH EP	NA STRP	TAIL SW	DANC	CUD CH
3/15 - 3/24	0	800	500	28	6.3	3.17
3/24 - 3/31	0	700	600	16	10.5	3.38
3/31 - 4/8	25	1200	300	22	13	3.17
4/8 - 4/15	15	1400	350	17	12.5	2.75

Table 5.2 Week averages of electrical data and week values of herd-averaged stress/disease indicators (see Section 3 for description).

consideration must be given to the magnitude of the electrical data, the magnitude of change of electrical data and to a comparison of direction of change. Consider first the direction of change.

Table 5.3 presents scores for each herd parameter and cow contact potential rating each data pair according to how they changed from week to week. Comparing columns, it can be seen that no cow contact potential provided clear, unequivocal evidence that changes in the potential were reflected in herd parameters. The best "performer" was WL-RH mVac; changes were reflected perfectly by changes in fibrinogen, lymphocytes, staph aureus, staph epi and cud chewing. Down all herd parameters, however, this cow contact potential scored only 0.22 in a range of -3 to +3. Other associations (or lack of) may be made similarly. The mean of the distribution overall is very close to 0.

	WLRHmVac	WLRHmVdc	FHRHmVac	FHRHmVdc	SCORE
FIBR	3	-1	1	1	1.0
CPK	-1	3	1	-3	0
TPRO	-1	-3	-3	-1	-2.0
WBC	-1	3	1	-3	0
NEUT	-3	1	-1	-1	-1.0
LYMP	3	-1	1	1	1.0
EOSI	1	-3	-1	3	0
HEMA	-1	3	1	-3	0
HEMO	-1	3	1	-3	0
SCC	-1	-1	-3	-3	-1.0
STREP AG	-1	-1	-3	1	-1.0
STAPH AU	3	-1	1	1	1.0
COLIFORM	-1	-3	-3	1	-1.5
STAPH EP	3	-1	1	1	1.0
NA STREP	-1	3	1	-3	0
TAIL SW	1	-3	-1	3	0
DANCING	-1	-1	-3	1	-1.0
CUD CHEW	3	-1	1	1	1.0
TOTAL	4	-4	-8	-2	-2.5
AVERAGE	.22	-.22	-.44	-.11	-.14

Table 5.3 Do herd parameters change from week to week in the same direction as cow contact potentials?

Score	Meaning
3	Changed in same direction 3 of 3 times.
1	Changed in same direction 2 of 3 times.
-1	Changed in same direction 1 of 3 times.
-3	Changed in same direction 0 of 3 times.

Referring again to Table 5.2, are the steady state values of cow contact potentials large enough to be a cause of stress or disease in the herd as measured by the above indicators? The ac potentials seem too low for this to occur. WL-RH Vac of 5 mV is an open-circuit potential. Even if it were across 300 Ω it would result in a current of .016 mA which is very small. FH-RH mVac (across an actual 300 Ω) levels are about 10 times smaller than this. The dc potential, WL-RH mVdc, is the highest of the cow contact values, but it includes the dc contact potential inherent in the measurement. Contact potentials are very high impedance sources (see Table 6.4). This means that they cannot supply much steady current when bridged by a small impedance such as a 300 Ω cow. It seems possible that a transient charging current upon contact may be detectable by the cow; measurements to quantify this were not made.

Are the changes in cow contact potentials large enough to expect to see a stress/disease reaction in the herd? To accept the possibility, one first has to accept that potentials in this range are capable of producing an effect. The size of the changes in week-averages are on the order of 1 mV (except for the dc case), probably too small to have an effect.

6. Barn and Distribution Electrical Data, Evaluation and Correlations

The one-minute electrical data was reduced to hour-averages, then to day-averages and finally averages over each P/N ground period of 6-7 days.

Evaluation of Minute Data

Table 6.1 presents a statistical summary of the minute data. The following can be said:

PN-RG Vac The ac voltage on the primary neutral at the transformer pole got as high as 4.5 V (minute average) with a mean very close to 1.0 V which did not vary much from week to week. Disconnecting the ground at this pole had no discernible effect on the neutral voltage.

PN-TG mAac The current in the ground wire at the transformer pole was approximately 39 mAac.

PN-RG Vdc The primary neutral dc voltage as measured to a half cell reference was near 540 mV for the first two periods, then was near 530 mV for the next two. Much of the measured potential was due to the contact potential of the half cell to earth. This can be calculated using the data for the third period, for example:

$$R = Vac/Iac$$
$$= (1.06)/(.03808) = 27.84\ \Omega$$

Then the true mVdc is:

$$Vdc = Idc'R$$
$$= (.12)(27.84) = 3.34\ mV$$

The contact potential is then:

$$Vc = 530.59 - 3.34 = 527.25\ mVdc$$

PN-2G mAac The ac current in the ground wire at the second grounded pole was made daily (when connected). This current was typically very low, often about 1 mA or less. Assuming a normal value for PN-RG Vac of about one volt, this indicates that the ground resistance at this pole was several hundred ohms, perhaps up to 1000 ohm. Originally the intention was to make continuous Iac measurements at the transformer pole and manual, daily measurements at the second pole, then establish a correspondence and generate a continuous record for Iac at the second pole. This was not pursued because one milliamp flowing into the ground at such a large distance from the barn could not have had any practical effect.

WL-RH mVac This cow contact potential (open circuit) varied from 4 to 7 mVac as averages for each period. This is very low; even the maximum minute average of 44.10 mV is low by common

3/15-3/24 ON

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.09	38.96	-538.76	-0.23	4.73	-353.72	1.75	0.42	15.30	0.03
SD	0.38	14.99	66.44	0.72	3.80	59.29	2.18	7.25	17.70	0.02
Minimum	0.24	8.00	-1613.00	-16.00	0.00	-465.60	0.10	-1.00	0.00	0.00
Maximum	3.14	192.00	648.00	24.00	44.10	-203.20	35.60	496.20	269.30	0.08
Count	9572	9572	9572	9572	11482	11482	11482	11482	11482	12469

3/24-3/31 OFF

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	0.99	NA	-540.86	NA	3.94	-420.19	0.88	0.16	11.24	0.06
SD	0.41	NA	49.13	NA	1.24	27.72	0.24	0.07	2.15	0.01
Minimum	0.00	NA	-865.00	NA	-0.10	-456.80	0.00	-1.70	7.30	0.04
Maximum	3.06	NA	103.00	NA	10.20	-299.60	3.10	2.90	50.60	0.35
Count	9210	NA	9209	NA	9857	9857	9857	9857	9857	9857

3/31-4/8 ON

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.06	38.08	-530.59	-0.12	6.37	-386.69	0.63	0.18	18.06	0.04
SD	0.55	23.27	111.80	1.29	1.95	22.75	0.28	0.14	3.32	0.01
Minimum	0.21	7.00	-1863.00	-23.00	0.60	-433.90	0.00	-4.60	10.30	0.02
Maximum	4.12	330.00	1264.00	32.00	21.50	-159.70	19.30	7.10	71.60	0.35
Count	11469	11469	11469	11469	10514	10514	10514	10514	10514	10514

4/8-4/14 OFF

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.05	NA	-530.47	NA	6.97	-423.79	0.73	0.14	20.55	0.04
SD	0.47	NA	64.42	NA	2.44	21.60	0.37	0.08	4.54	0.01
Minimum	0.00	NA	-1613.00	NA	0.80	-472.00	-0.40	-0.70	0.00	0.00
Maximum	4.53	NA	88.00	NA	23.80	-349.70	21.90	2.80	127.60	0.07
Count	9234	NA	9224	NA	9853	9853	9853	9853	9853	9853

Table 6.1 Statistical description of one-minute electrical data grouped by time periods when the P/N ground connection was ON and OFF. (Anomoly A removed from data)

stray voltage standards.

WL-RH mVdc This dc cow contact voltage was higher during "OFF" periods (420 & 424 mVdc) than during "ON" periods (354 & 387 mVdc). These numbers include an unknown contact potential because the water line and rear hoof points are electromotively different. Also this was an open circuit measurement; insertion of a 300 Ω resistor lowered this voltage by more than an order of magnitude.

FH-RH mVac This cow contact voltage (across 300 Ω) ranged from 0.63 to 1.75 mV. The maximum minute average was 36 mV. These values are generally not of concern.

FH-RH mVdc The dc cow contact voltage (across 300 Ω) was a small fraction of a mV and did not vary significantly as an average from period to period (excluding the first when it was 0.42mV.)

2N-RG mVac The secondary neutral voltage measured in the barn at the test stall was 11 to 21 mV, reflecting a relatively small and/or well-balanced load. The maximum minute value was 269 mV.

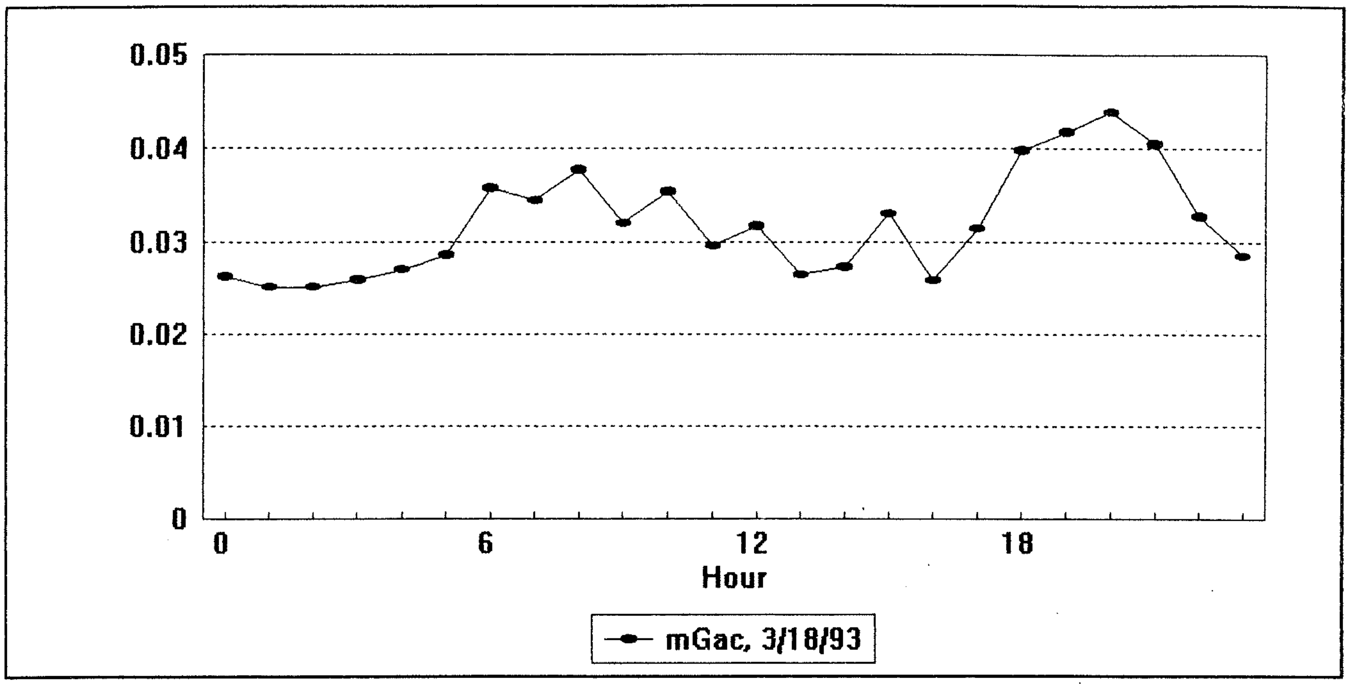
B mGac The vertical component of the ac magnetic field at the floor of the test stall remained small throughout the test (at or below the resolution limit of another milligauss meter used to map Bac in the barn). The average values ranged from .03 to .06 mG. Short term cycles can be seen in the one-minute graphs, however, possibly in response to a cycling load such as the ventilation fan.

The daily profile of Bac seemed to reflect the cycle of farm load but also did not go to zero with no load. Figures 6.1a and 6.1b show the profiles for Bac and average KW farm load for a randomly chosen date, 3/18. The correlation coefficient between Bac and KW is 0.807 which indicates a rather good relationship. Figure 6.2a shows Bac plotted against KW for 3/18. The "best fit" straight line is also plotted. If the line is extended down and to the left to where it intersects the KW=0 axis, one can see that Bac at zero farm load is projected to be 0.02 mG. It is possible that this is due to ac ground currents or distribution line currents. Figure 6.2b is a daily profile of Bac averaged over the month of the test.

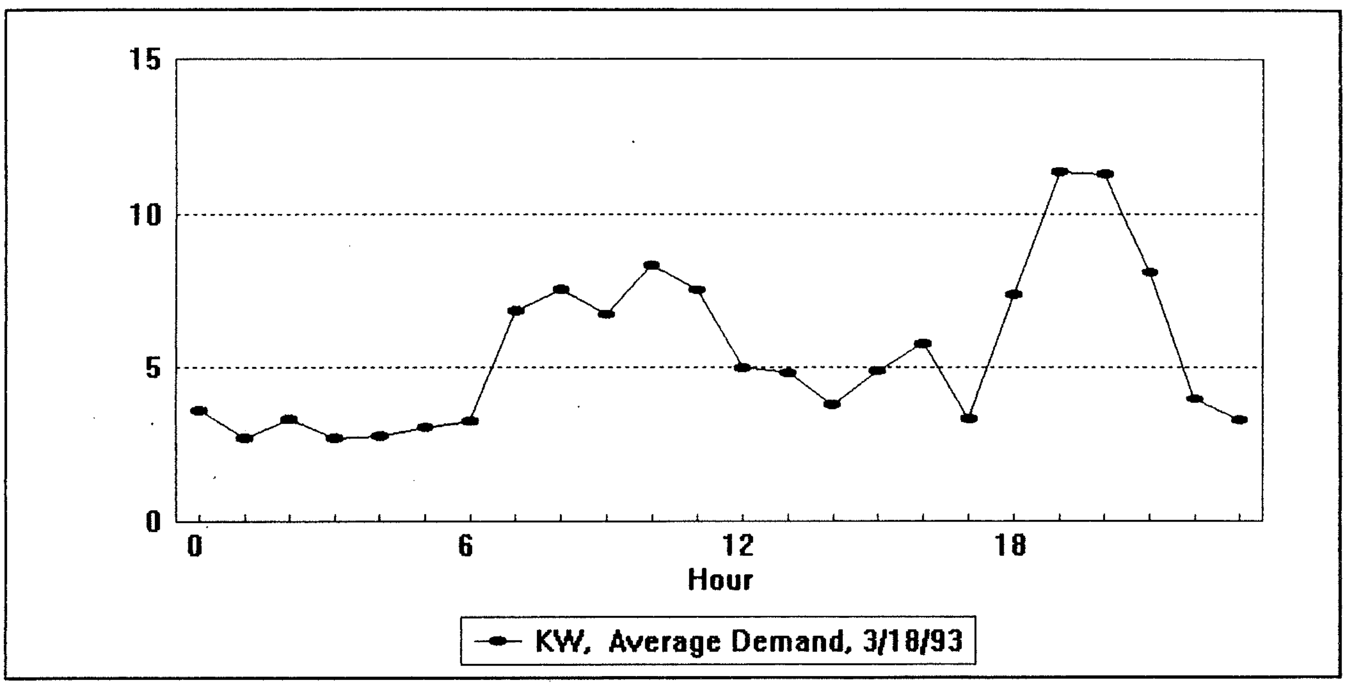
<u>Evaluation of Hour-, Day- and Period-Average Data</u>

The minute data was reduced to hour averages for the correlation work to follow. Table 6.2 is a statistical summary of one-hour data, offered as a check for errors in the reduction process and to allow comparisons between minute and hour data. There is very close agreement between means of minute and hour data. The standard deviations and the range between minimum and maximum values is smaller for the hour data as expected (averaging reduces peaks and valleys in the data).

The hour data was then reduced to daily averages and finally to



<u>Figure 6.1a</u> 3/18/93. Magnetic field vertical component at the stall floor. Hour data.



<u>Figure 6.1b</u> 3/18/93. Average KW demand on the farm. Hour data.

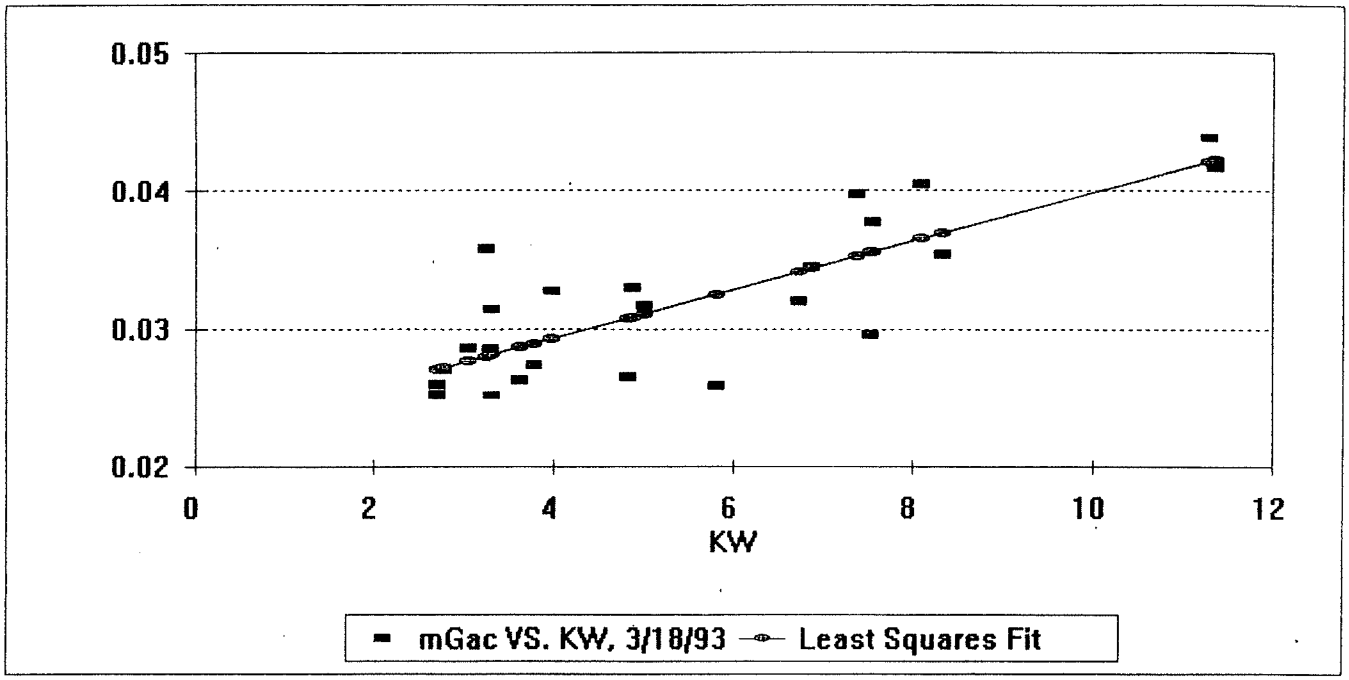


Figure 6.2a 3/18/93. Magnetic field vertical component at stall floor plotted against average KW demand on the farm. Hour data. The best fit (least squares regression) line is also shown.

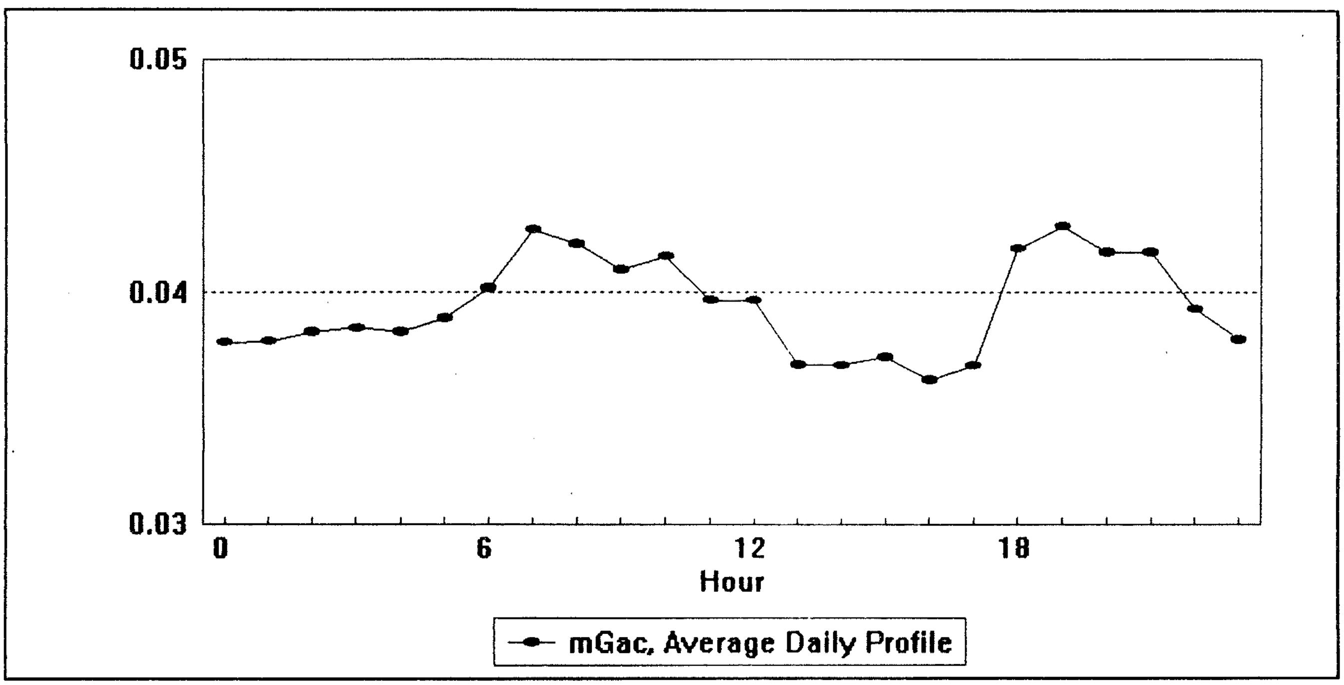


Figure 6.2b Daily profile of Bac averaged over all the days of the test. Hour data.

3/15-3/24 ON

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.09	38.90	-537.38	-0.22	4.74	-353.25	1.79	0.42	15.30	0.03
SD	0.25	9.83	41.97	0.44	3.50	58.16	2.21	1.78	16.78	0.02
Minimum	0.64	23.60	-606.18	-1.57	0.15	-451.84	0.16	0.02	0.00	0.00
Maximum	1.86	72.15	-173.60	3.13	19.11	-230.33	15.05	24.88	63.17	0.07
Count	160	160	160	160	192	192	192	192	192	209.00

3/24-3/31 OFF

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	0.99	NA	-541.21	NA	3.95	-420.07	0.88	0.16	11.25	0.06
SD	0.31	NA	34.98	NA	1.10	25.29	0.22	0.04	1.76	0.01
Minimum	0.05	NA	-705.40	NA	0.23	-454.96	0.51	0.05	7.89	0.05
Maximum	1.83	NA	-379.58	NA	6.63	-326.15	2.03	0.31	15.90	0.13
Count	157	NA	157	NA	166	166	166	166	166	166

3/31-4/8 ON

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.06	38.16	-530.70	-0.12	6.38	-386.62	0.63	0.18	18.05	0.04
SD	0.46	18.69	60.77	0.50	1.73	20.64	0.19	0.08	2.98	0.01
Minimum	0.45	15.48	-952.00	-4.42	1.16	-430.51	0.24	0.10	11.20	0.03
Maximum	3.38	126.17	-139.38	3.17	11.62	-329.73	1.23	0.41	26.56	0.08
Count	190	190	190	190	175	175	175	175	175	175

4/8-4/14 OFF

	PN - RG	PN - TG	PN - RG	PN - TG	WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc	mVac	mVdc	mVac	mVdc	mVdc	mGac
Mean	1.05	NA	-531.12	NA	6.55	-419.56	0.76	0.14	20.26	0.04
SD	0.33	NA	29.51	NA	1.87	18.16	0.28	0.02	3.21	0.00
Minimum	0.62	NA	-663.42	NA	1.69	-455.07	0.21	0.09	14.64	0.03
Maximum	2.49	NA	-364.22	NA	12.59	-376.63	1.50	0.17	33.59	0.05
Count	147	NA	147	NA	146	146	146	146	146	146

Table 6.2 Statistical description of one-hour-average electrical data grouped by time periods when the P/N ground was ON and OFF. (Anomaly A removed from data)

	PN - RG	PN - TG	PN - RG	PN - TG		WL - RH	WL - RH	FH - RH	FH - RH	2N - RG	B
	Vac	mAac	mVdc	mAdc		mVac	mVdc	mVac	mVdc	mVdc	mGac
ON											
3/15						4.39	-251.26	8.08	0.06	0.00	0.00
3/16	1.13	38.98	-533.14	-0.01		1.52	-285.90	5.75	0.17	6.98	0.01
3/17	1.10	38.20	-519.98	-0.22		2.71	-285.83	2.59	0.32	36.66	0.04
3/18	1.14	40.05	-532.56	-0.49		4.06	-287.50	1.90	0.31	39.50	0.03
3/19	1.25	44.81	-553.26	-0.03		7.16	-403.09	1.12	2.22	21.96	0.03
3/20	1.09	38.68	-544.33	-0.09		7.73	-395.67	0.65	0.34	18.54	0.03
3/21	1.13	40.08	-543.19	-0.40		6.80	-399.76	0.39	0.32	13.08	0.03
3/22	1.13	40.86	-550.10	-0.40		4.13	-375.23	0.42	0.27	3.04	0.04
3/23	0.90	33.41	-544.38	-0.05		4.83	-384.48	0.94	0.32	0.60	0.06
3/24	0.95	32.89	-437.46	-0.03		4.83	-384.48	0.94	0.32	0.60	0.06
AVG	1.09	38.66	-528.71	-0.19		4.86	-355.77	1.64	0.51	15.66	0.03
OFF											
3/24	0.87	NA	-451.90	NA		4.02	-391.87	0.75	0.26	9.54	0.06
3/25	0.97	NA	-542.24	NA		4.56	-427.92	0.83	0.20	11.09	0.06
3/26	1.07	NA	-550.53	NA		4.72	-425.53	1.07	0.15	12.59	0.06
3/27	0.97	NA	-548.72	NA		3.75	-408.72	0.93	0.14	10.57	0.06
3/28	1.03	NA	-546.17	NA		3.72	-434.15	1.02	0.15	10.90	0.06
3/29	1.00	NA	-552.07	NA		3.37	-411.94	0.78	0.14	11.18	0.06
3/30	0.92	NA	-543.20	NA		3.22	-417.02	0.74	0.13	11.26	0.06
3/31	1.00	NA	-534.14	NA		4.51	-433.19	0.72	0.14	12.24	0.06
AVG	0.98	NA	-533.62	NA		3.98	-418.79	0.86	0.16	11.17	0.06
ON											
3/31	0.95	35.63	-536.55	-0.03		5.88	-397.37	0.92	0.28	17.07	0.05
4/1	0.94	35.97	-528.01	-0.03		5.76	-390.39	0.63	0.33	16.17	0.04
4/2	1.00	34.73	-530.50	-0.04		5.69	-410.18	0.56	0.17	15.78	0.04
4/3	1.06	36.88	-530.15	-0.01		5.44	-378.75	0.56	0.15	16.08	0.04
4/4	1.49	53.08	-506.36	-0.11		5.67	-364.47	0.57	0.15	18.92	0.04
4/5	1.03	35.85	-546.76	-0.34		8.72	-398.88	0.50	0.15	19.72	0.04
4/6	1.06	38.99	-534.43	-0.11		8.02	-381.19	0.54	0.14	20.26	0.04
4/7	0.97	35.03	-535.42	-0.23		6.98	-378.11	0.70	0.13	20.05	0.05
4/8	0.93	33.20	-528.90	-0.09		4.64	-380.55	0.96	0.13	19.60	0.04
AVG	1.05	37.71	-530.79	-0.11		6.31	-386.65	0.66	0.18	18.18	0.04
OFF											
4/8	1.04	NA	-551.07	NA		5.31	-400.22	1.20	0.12	20.50	0.04
4/9	1.07	NA	-538.86	NA		5.48	-402.34	0.95	0.13	18.78	0.04
4/10	1.10	NA	-533.58	NA		7.68	-434.72	0.57	0.14	20.09	0.04
4/11	1.03	NA	-527.30	NA		6.66	-421.99	0.84	0.13	20.07	0.04
4/12	1.01	NA	-528.07	NA		6.99	-422.31	0.79	0.14	21.05	0.04
4/13	1.07	NA	-522.55	NA		6.46	-430.56	0.60	0.14	20.37	0.04
4/14	1.03	NA	-522.50	NA		8.36	-427.58	0.55	0.14	23.85	0.04
AVG	1.05	NA	-531.99	NA		6.70	-419.96	0.79	0.13	20.67	0.04

Table 6.3 Daily averages of one-hour electrical data grouped by time periods when the P/N ground connection was ON and OFF. (Anomaly A removed from data)

period averages (to check the values of the means in Table 6.1). This data is shown in Table 6.3. Interested readers may see how the averages for the electrical parameters varied from day to day.

Cow Contact Source Impedances

Weekly comparisons were made of the open circuit ac voltage and the voltage across 300 Ω for cow contacts. This allowed an estimation of the source impedance of cow contact potentials. Table 6.4 shows that the source impedance of the WL-RH cow contact potential is about 310 Ω; that for RH-FH is 41.6 KΩ.

	WL - RH			FH - RH		
Date	V_o	V_R	R_s	V_o	V_R	R_s
3/19	6.5	3.2	309	75.2	0.7	31.9 K
3/25	5.3	3.0	230	28.7	1.7	4.8 K
4/2	6.7	3.2	328	63.1	0.7	26.7 K
4/10	4.3	2.0	345	52.3	0.2	78.2 K
4/14	6.4	3.0	340	66.8	0.3	66.5 K
AVERAGE			310 Ω			41.6 KΩ

Table 6.4 Source Impedances for cow contact potentials calculated according to:

$$R_s = ((V_o/V_R) - 1)\ R$$

R_s is the source impedance, V_o is the open circuit voltage, V_R is the voltage across R (cow resistor, here 300 Ω).

Correlations of Hour-Average Data

One-hour average electrical data from the barn and distribution system were merged, then correlated in four groups according to "ON" and "OFF" status to discover relationships between the various quantities. Table 6.5 presents the four correlation tables. Correlation coefficients range from -1 to 1; 0 indicates complete lack of correlation. Negative correlation indicates that when one quantity increases, the other decreases. Positive correlation means that both quantities increase/decrease together. The absolute value is a measure of the association between each pair of quantities. Comments on degree of correlation between selected electrical quantities follow.

PN-RG Vac The primary neutral ac voltage correlated well with the Iac in the P/N ground wire (-.946, NA, .922, NA) in accord with Ohm's Law.

3/15 - 3/24

ON	PNRGVac	PNTGIac	PNRGVdc	PNTGIdc	WLRHVac	WLRHVdc	FHRHVac	FHRHVdc	2NRGVac	WLGCIac	B mGac
PNRGVac	1.000										
PNTGIac	0.946	1.000									
PNRGVdc	0.002	-0.031	1.000								
PNTGIdc	-0.002	0.045	0.413	1.000							
WLRHVac	0.180	0.174	-0.113	0.067	1.000						
WLRHVdc	0.037	-0.030	0.152	-0.094	-0.571	1.000					
FHRHVac	-0.025	-0.121	0.129	0.055	-0.261	0.641	1.000				
FHRHVdc	-0.026	-0.020	-0.026	0.041	0.066	-0.107	-0.024	1.000			
2NRGVac	0.176	0.062	0.067	-0.092	0.233	0.329	0.048	0.034	1.000		
WLGCIac	-0.119	-0.044	-0.013	0.192	-0.238	0.144	0.048	0.063	0.003	1.000	
B mGac	-0.176	-0.121	0.150	0.278	0.127	-0.365	-0.511	-0.012	-0.046	0.187	1.000

3/24 - 3/31

OFF	PNRGVac	PNTGIac	PNRGVdc	PNTGIdc	WLRHVac	WLRHVdc	FHRHVac	FHRHVdc	2NRGVac	WLGCIac	B mGac
PNRGVac	1.000										
PNTGIac	NA	1.000									
PNRGVdc	-0.027	NA	1.000								
PNTGIdc	NA	NA	NA	1.000							
WLRHVac	0.074	NA	-0.000	NA	1.000						
WLRHVdc	-0.039	NA	0.130	NA	-0.681	1.000					
FHRHVac	-0.048	NA	-0.175	NA	-0.100	0.293	1.000				
FHRHVdc	-0.129	NA	0.424	NA	0.280	-0.150	-0.291	1.000			
2NRGVac	0.081	NA	-0.228	NA	0.495	-0.153	0.379	-0.302	1.000		
WLGCIac	0.230	NA	0.174	NA	0.868	-0.621	-0.174	0.462	0.194	1.000	
B mGac	0.003	NA	0.133	NA	0.177	-0.084	-0.008	0.148	0.152	0.200	1.000

3/31 - 4/8

ON	PNRGVac	PNTGIac	PNRGVdc	PNTGIdc	WLRHVac	WLRHVdc	FHRHVac	FHRHVdc	2NRGVac	WLGCIac	B mGac
PNRGVac	1.000										
PNTGIac	0.922	1.000									
PNRGVdc	-0.001	-0.017	1.000								
PNTGIdc	-0.013	-0.004	0.687	1.000							
WLRHVac	0.150	0.117	-0.097	-0.028	1.000						
WLRHVdc	0.150	0.165	0.026	-0.100	-0.340	1.000					
FHRHVac	0.056	0.033	0.064	0.069	-0.111	0.132	1.000				
FHRHVdc	-0.130	-0.083	0.064	0.107	-0.076	-0.154	0.195	1.000			
2NRGVac	0.368	0.323	-0.090	-0.080	0.662	0.125	0.419	-0.230	1.000		
WLGCIac	0.004	0.003	-0.164	-0.165	0.763	-0.066	-0.056	-0.359	0.623	1.000	
B mGac	-0.002	0.007	0.110	-0.369	-0.106	-0.030	-0.154	-0.023	-0.233	-0.071	1.000

4/8 - 4/15

OFF	PNRGVac	PNTGIac	PNRGVdc	PNTGIdc	WLRHVac	WLRHVdc	FHRHVac	FHRHVdc	2NRGVac	WLGCIac	B mGac
PNRGVac	1.000										
PNTGIac	NA	1.000									
PNRGVdc	0.138	NA	1.000								
PNTGIdc	NA	NA	NA	1.000							
WLRHVac	0.015	NA	0.133	NA	1.000						
WLRHVdc	-0.177	NA	-0.216	NA	-0.652	1.000					
FHRHVac	-0.173	NA	-0.276	NA	-0.242	0.614	1.000				
FHRHVdc	-0.231	NA	-0.069	NA	0.174	-0.312	-0.230	1.000			
2NRGVac	-0.152	NA	-0.081	NA	0.555	-0.017	0.297	0.179	1.000		
WLGCIac	0.003	NA	-0.005	NA	0.437	-0.064	0.022	0.132	0.442	1.000	
B mGac	0.362	NA	0.153	NA	0.130	-0.275	-0.304	-0.092	-0.157	-0.016	1.000

Table 6.5 Correlation coefficients of one-hour-average electrical data grouped by periods when the PN ground was ON or OFF minus Anomaly A. (NA = no data)

PN-RG Iac The primary neutral ac ground current at the transformer pole is a quantity of great interest in this test because it is the "agent of cause" in the P/N ground stray voltage hypothesis. It did not correlate well with any quantity other than PN-RG Vac as noted above. (Iac was interrupted during periods 2 and 4, so no data was available for correlation). The lack of correlation, particularly with electrical quantities in the barn, is significant to the test hypothesis since it is the P/N ground current that hypothetically accesses the barn environment. This is an indication that it may not on a farm with neutral isolation.

PN-RG Vdc The dc voltage on the primary neutral seems not to correlate with anything. One possible weak correlation is with FH-RH Vdc (-.026, .424, .064, -.069) during the second period, though not during the others.

The lack of correlation with PN-RG Idc is interesting, considering the strong correlation between V and I in the ac case. Idc was usually very small(<1mA) and Vdc was typically about 500 mV. Using 28 Ω as the P/N ground resistance (calculated from Vac and Iac), Vdc would be about 28 mV. The remainder (500 - 28 = 472 mV) would be the contact potential of the half cell used as the dc reference ground. The low correlation is probably due, however, to the fact that PN-RG mAdc is typically about 1 mA, near the resolution limit of the data logger and therefore not very reliable for this calculation.

PN-TG Idc No data were available during the "OFF" periods (2 and 4) because the P/N ground currents were interrupted. The P/N ground dc current correlated somewhat with PN-RG Vdc (.411, NA, could be expected because of its normally small value (<1mA). A weak correlation can be seen with the ac magnetic field (.278, NA,-.369, NA); the significance is in doubt because of the switching sign and the relatively small magnitudes.

WL-RH Vac The ac voltage between the water line and rear hoof correlates consistently with its dc voltage counterpart WL-RH mVdc (-.571, -.681, -.340, -.652). Another consistent correlation is with 2N-RG Vac (.233, .495, .662, .555). This suggests a possible connection between the secondary neutral and the water line. It is possible that this connection is through the ground or through the gutter chain. The correlations with WL-GC Iac (-.238, .868, .763, .555) lend support for the gutter chain connection. No correlations with PN quantities during any of the periods indicates that the isolator reduces or eliminates the effect on this cow contact voltage.

WL-RH Vdc A variable correlation appears with FH-RH Vac (.641, .293, .132, .614). It is interesting that these numbers are greater than the correlation coefficients with FH-RH Vdc (-.107, -.150, -.154, -.312).

FH-RH Vac A rather weak correlation with 2N-RG Vac (.048, .379, .419, .297) is suggestive of a connection, possibly from the secondary neutral through ground or the gutter chain to the water line and then to the front hoof. This cow contact potential was not correlated with primary neutral parameters. The lack of any identifiable correlation with P/N parameters does not support the test hypothesis.

FH-RH Vdc A one-time, weak correlation with PN-RG Vdc (-.026, .424, .064, -.069) was noted for period 2. Complete lack of correlation during the other periods reduces interest. One other association is of note with WL-GC Iac (.063, .462, -.359, however; the link between the two may be of second order.

2N-RG Vac The secondary neutral ac voltage is a well-known indicator of possible on-farm stray voltage problems. Its association with cow contact potentials suggests inadvertent paths between the secondary neutral and cow contact points. Correlations with cow contact parameters were found in the data. These have been noted above but will be restated again in one group.

A correlation exists with WL-RH Vac (.233, .495, .662, .555).
A correlation exists with FH-RH Vac (.048, .379, .419, .297).
A correlation exists with WL-GC Iac (.003, .194, .623, .442).

It is believed that the first two of these correlation sets is due to the third via the gutter chain/water line connection used to make the measurement of Iac and not to other stray voltage connections in the barn.

WL-GC Iac Associations with other electrical parameters in the barn have been noted above; they are restated here in one place.

A correlation exists with WL-RH Vac (-.238, .868, .763, .437).
A correlation exists with FH-RH Vdc (.063, .462,-.359, .132).
A correlation exists with 2N-RG Vac (.003, .194, .623, .442).

As stated in the previous case, the link between the secondary neutral and cow contact points through the gutter chain and water line is probably the source of these correlations. The correlation with FH-RH Vdc may be incidental.

B mGac No consistent correlations were noted between the ac magnetic field near the stall floor and other electrical parameters. Isolated, weak correlations were noted, as with WL-RH Vdc (-.365, -.084, -.030, -.275). A mixed correlation with FH-RH Vac (-.511 , .008, -.154, -.304) is suggestive of a link with an ac step voltage and, by inference, an ac current in the barn floor, but the association is not strong (and oddly negative).

APPENDIX

WATER CONSUMPTION (gal/cow/day) VS. DAY by RC Hendrickson

Compute the polynomial of specified order which best fits file data.

Read data files: x := READPRN(day) y := READPRN(water)

N := length(x) N = 38 i := 0 ..N - 1

Specify order of polynomial: ORD := 8

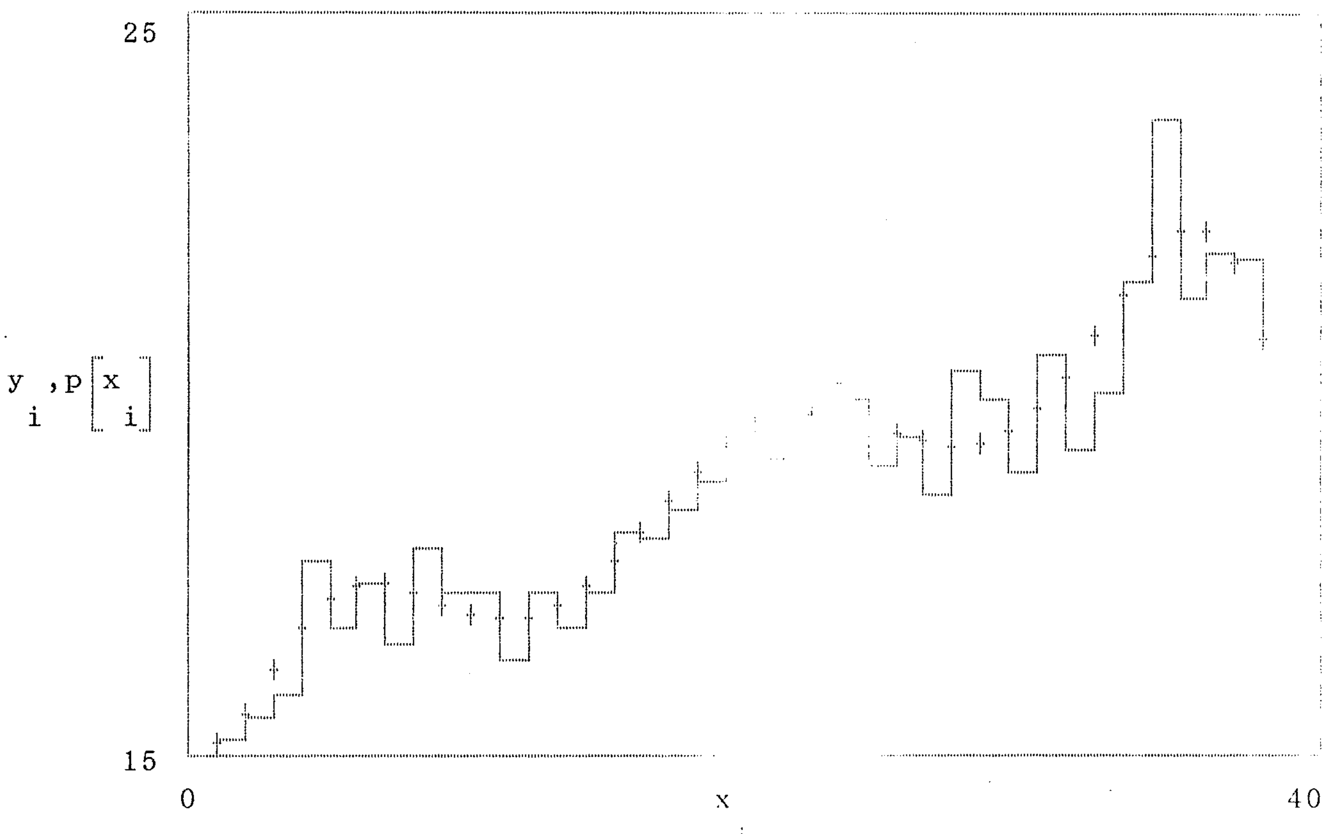
n := 0 ..ORD m := 0 ..ORD l := 0 ..2·ORD

$$a_l := \sum_i \left[x_i\right]^l \qquad b_n := \sum_i \left[x_i\right]^n \cdot y_i \qquad A_{n,m} := a_{n+m} \qquad B_n := b_n$$

$$C := A^{-1} B \qquad p(x) := \sum_n C_n \cdot x^n$$

$$C = \begin{bmatrix} 15.539850742556 \\ -0.963749620831 \\ 0.739262793912 \\ -0.156502439117 \\ 0.015462560335 \\ -8.101763418153 \cdot 10^{-4} \\ 2.317453651912 \cdot 10^{-5} \\ -3.413451050149 \cdot 10^{-7} \\ 2.022377054017 \cdot 10^{-9} \end{bmatrix} \qquad MSE := \frac{\Sigma\left[(y - p(x))^2\right]}{N - ORD - 1}$$

MSE = 0.43233731466



MILK PRODUCTION (lb/cow/day) VS. DAY by RC Hendrickson

Compute the polynomial of specified order which best fits file data.

Read data files: $x := \mathrm{READPRN}(day)$ $y := \mathrm{READPRN}(milk)$

$N := \mathrm{length}(x)$ $N = 38$ $i := 0 \,..\, N-1$

Specify order of polynomial: $ORD := 8$

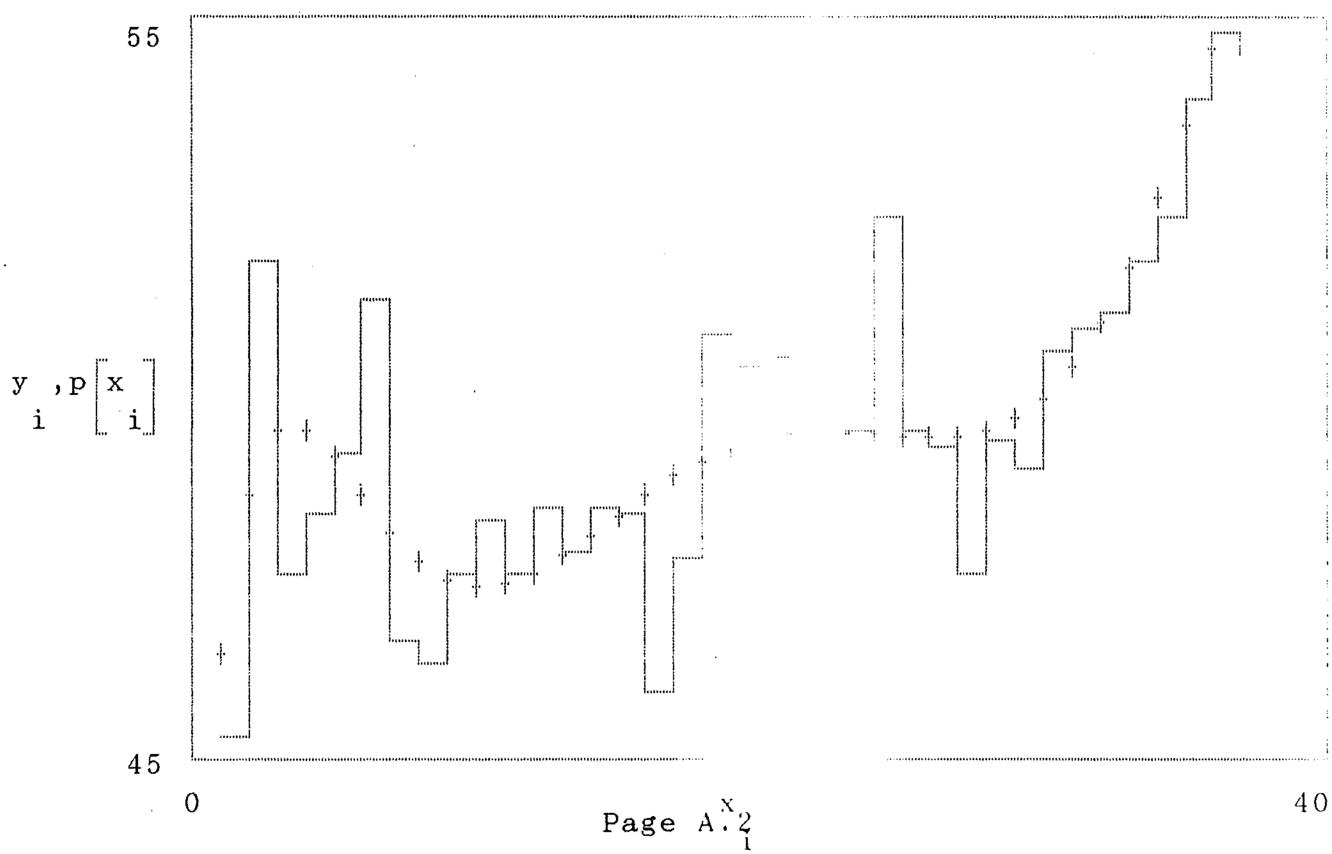
$n := 0 \,..\, ORD$ $m := 0 \,..\, ORD$ $l := 0 \,..\, 2 \cdot ORD$

$$a_l := \sum_i \left[x_i\right]^l \qquad b_n := \sum_i \left[x_i\right]^n \cdot y_i \qquad A_{n,m} := a_{n+m} \qquad B_n := b_n$$

$$C := A^{-1} \cdot B \qquad p(x) := \sum_n C_n \cdot x^n$$

$$C = \begin{bmatrix} 42.079685742036 \\ 5.715960721485 \\ -1.583921034355 \\ 0.201659598213 \\ -0.014142678112 \\ 5.915197009472 \cdot 10^{-4} \\ -1.487665086586 \cdot 10^{-5} \\ 2.090254291875 \cdot 10^{-7} \\ -1.261445929483 \cdot 10^{-9} \end{bmatrix} \qquad MSE := \frac{\Sigma\left[(y - p(x))^2\right]}{N - ORD - 1}$$

$$MSE = 2.145406942725$$



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6/10/94

Protocol
To Investigate a Possible Connection
Between Primary and Secondary Neutral Grounds
At the Lusty Farm

by:
Duane A. Dahlberg, Ph.D.
Dan D. Mairs, P.E.
Riley C. Hendrickson

Introduction
During the test "To Investigate Primary Neutral Grounding Practices and the Effects of Such Practices on Dairy Herd Health and Production" conducted on the David Lusty farm near Miltona, MN, from 3/15/93 to 4/15/93, it was determined from the data that the primary neutral and secondary neutral were anomalously connected for a period of several hours on 3/18 and 3/19 at the transformer pole, thereby rendering the isolation device ineffective. Subsequent anecdotal evidence indicated that the anomaly was reoccuring during the early months of 1994 (based on measurements of the ac current in the primary neutral ground wire). Members of the Stray Voltage Steering Committee agreed on 5/2/94 to investigate the conditions causing this possible unintended connection.

Working Hypothesis
The primary and secondary neutrals are connected at or below ground at the transformer pole by an intermittent and unintended metalic (or other low resistance) pathway.

Objective
Make electrical measurements to determine if the primary and secondary neutral conductors are connected at the transformer pole. If a connection is apparent, excavate the primary and secondary ground rods at the transformer pole as necessary to identify the cause of connection.

Test Schedule
June 29, 1pm-5pm: Set up equipment.
June 30, 8am-2pm: Make measurements.
2pm-4pm: Excavate grounds.
4pm-5pm: Restore system.
In case of rain, the test may be postponed one day.

Measurement Strategy
<u>Continuous measurements</u> will be made of the following quantities:

1. PN-RG Vac (primary neutral to reference ground ac volts)
2. PN-TG Iac (primary neutral ground current at transformer pole)
3. 2N-RG Vac (secondary neutral to reference ground)
4. 2N-TG Iac (secondary neutral ground current at transformer pole)

Currents will be calculated from the voltage across an inline 1-ohm resistor. Quantities will be continuously recorded on strip chart recorders. The effective resistances of the primary and secondary neutral grounds will be calculated periodically from the voltage and current data. Known farm loads and/or dummy loads will be operated and all farm loads will be shut off (operating recording instruments on a generator) to provide variation in primary and secondary neutral voltages.

Manual measurements will be made of the following quantities:

1. PN-TG Iac and 2N-TG Iac using the Swain ammeter and other available ammeters to compare with the continuous current measurements.
2. Primary, secondary and reference ground rod resistances using an in-circuit tester to compare with calculated values (above) at the start and end of the test.
3. Vac between reference ground rod and one or more alternate reference ground rods separated by 100 m to verify the presence or absence of a ground voltage gradient.
4. Primary and secondary neutral system impedences by the calculation method used during the original test and using a 3-point vibroground or AEMC clamp-on tester for comparison..

At the end of the measurement phase, the connection will be artificially reproduced by installing a jumper between primary and secondary grounds at ground level to determine the effect on quantities being recorded.

Ottertail Power will insure that the operation of the distribution system will be maintained in the same configuration throughout the test. A description of the system will be provided including status of all switches and capacitor banks on the system supplying the test farm.

Excavation of ground rods will be conducted as follows:
The rods will be excavated until the source of the possible connection is uncovered. (Excavation may extend beyond the test schedule indicated above). Then the existing ground rods will be removed for examination, and new primary and secondary grounds will be installed beside their original locations to insure the connection does not reoccur.

Personnel

1. Riley Hendrickson as supervisor.
2. Dave Lusty and one other TERF representative.
3. Jerry Martens and one other utility representative.
4. Ottertail Power personnel and equipment as necessary for excavation work.
5. Interested state agency and steering committee personnel.

Reporting
A report on the test including all data (as strip charts, notations and computer files) will be provided to TERF and the utilities for comment. The report and comments will then be presented in writing to the members of the Stray Voltage Steering Committee.

June 28, 1994

Riley C. Hendrickson
12914 260th Street
Milaca, MN 56353

Attn: George Durfee
Minnesota Environmental Quality Board
300 Centennial Building
658 Cedar Street
St. Paul, MN 55155

Dear George:

I have reviewed the reports submitted to the Stray Voltage Advisory Committee by the Minnesota Inter-Utility Stray Voltage Task Force (MIUSVTF) and by The Electromagnetics Research Foundation (TERF) on the Primary Neutral Grounding Test. I have noted areas of agreement and disagreement among these reports and my own (RCH), focussing on the question of whether electrical and herd data changed coincident to connecting and disconnecting the primary neutral ground on the test farm (the central question addressed by the test). These comments are presented below.

Did the electrical data collected at the transformer pole change coincident with making grounding changes?

MIUSVTF No. (Executive Summary p.7, Exhibit 2 p.7-11)

TERF Yes. (p.2)
On 4/8 PN-RG Vdc changed pattern.

On 4/14 PN-RG Vdc increased and became noisier and PN-TG Iac increased.

An objection was raised concerning the common procedure of measuring primary neutral voltages to a reference ground rod (p.8); The voltages thus measured may be in error because of a possible voltage gradient in the earth caused by ground currents (p.4).

RCH No. (p.3.2, 1.1, 1.3, 1.6)

Comments:
I examined the 1-second data graphs of PN-RG Vdc for 4/8 and could not see a change in this quantity at the time of switching.

I examined the 1-second data graphs of PN-RG Vdc for 4/14; this quantity increased at 1500 coincident with switching on, but it also increased at 1505 coincident with switching off. The graph line showed a decrease in variability at 1500.

I have not seen other references claiming that earth voltage gradients are large enough to cause significant errors in measuring primary neutral voltages relative to a reference rod; This can be tested by measuring the voltage between two or more reference rods (as proposed in the protocol to investigate the connection between primary and secondary neutrals on the Lusty farm).

Did the barn electrical data change coincident with making grounding changes?

MIUSVTF No. Executive Summary p.7, Exhibit 2 pp.1,7).

TERF Yes, the variability changed (pp.2,3,7):
On 3/24, all secondary parameters but Bac became less noisy. FH-RH Vdc decreased.

On 3/31 many secondary parameters changed size and variability.

On 4/8 All AC parameters increased slightly (but were delayed by up to one hour), Bac decreased, WL-RH Vdc slowly changed negative.

On 4/14 WL-RH Vac and 2N-RG Vac went up slightly and got noisier. Bac decreased slightly. WL-RH Vdc increased negatively and got noisier.

In general, WL-RH Vdc was less negative when the primary neutral was on than when it was off.

It was concluded that the only consistent change was an increase in variability upon switching the ground on and a decrease in variability upon switching the ground off. (p.7).

RCH No (p.2). Changes in variability were noted but did not occur consistantly during all four switch events (p.2.6). RH-FH Vdc began a 3-day decline at one switching to off but was not repeated at other switch events.

Comments:
General disagreement exists among the three reports:

MIUSVTF does not mention any changes in size or variability discussed in the other two reports. I disagree with this assessment, though the changes I noted were not consistent across all switch events and probably were not significant in terms of stray voltage effects.

TERF claims more changes in the data at switching than I can see:
On 3/24 there was no 1-second data upon which to make a decision about the instantaneous decrease in variability of all secondary parameters upon switching the grounds off. This claim

must refer to 1-minute data; If so, I only partially agree because a change in variability can be seen for only 3 of 4 ac parameters (WL-RH Vac, 2N-RG Vac and WL-GC Iac) and these cannot be proven coincident with switching because the 1-second data does not exist. I agree that the long-term decline in FH-RH Vdc began at or near switching the grounds, though I note that it did not occur at any other switching events and should be considered a coincidence without further evidence to the contrary.

On 3/31 I noted a small change in the size of RH-FH Vdc on switching the ground at the transformer pole on; This happened only once and was judged a coincidence. One-minute data showed an increase in variability for 2N-RG Vac. Excepting these two changes, I disagree that many secondary parameters changed size and variability.

On 4/8 I noted no changes in barn electrical data (1-second, 1-minute or 1-hour data) coincident with switching. I could not see a decrease in Bac (see my Figure 2.14). WL-RH Vdc may have changed slightly and momentarily, but the change was not long-term as seen in my Figure 2.9; I do not believe the change was significant.

On 4/14 I do not agree that WL-RH Vac and 2N-RG Vac changed coincident with switching; Rather the change occurred coincident with disconnection of the WL-GC wire at barn cleaning. I could not see the other two changes noted above in any data type.

In general I disagree with the TERF conclusion that there was a consistent change in variability upon switching the grounds on and off; Coming closest to this claim is 1-minute data for 2N-RG Vac which showed a variability decrease on 3/24, an increase on 3/31, no change on 4/8 and no change on 4/14.

Did voltage transients in the barn change coincident with making grounding changes?

MIUSVTF No (Exhibit 3 p.15).

TERF Not explicitly stated.

RCH No. (pp.2.12-15)

Comments:
There is no explicit disagreement about the question of changes in the rate of occurrence of voltage transients coincident with switching grounds among the three reports.

I disagree in part to some of the objections MIUSVTF has about use of the BMI 4800 with low voltage input module for measuring impulses between cow contact points (Exhibit 3 p.2-3). Ottertail Power tests of this instrument subjected it to conditions unlike those in the Lusty test. For example, I did not operate the BMI 4800 parallel to any other instrument; It was connected to its own separate contact points with the coaxial leads provided. I did not operate the instrument with leads unconnected (spurious readings under these conditions would be expected since, like a multimeter, this is a high input impedence device). I did not subject the instrument to rf bursts from a hand-held radio. I did some limited testing of this instrument and found that it performed approximately as expected. I agree however that a consensus should be developed on use of this instrument to measure low voltage impulses between cow contacts.

There was general disagreement about the source of impulses on the barn wiring and between cow contacts which occurred late in the evening. I and TERF questioned that the source was on the farm since farm electrical use was assumed to be down during those hours. MIUSVTF attributes the evening peak to chemical cleaning of the milk lines following evening milking. This impulse rate peak lasted from about 2000 through hour 2200 (CST) as seen in my Figure 2.18. An examination of the printed KW data revealed that electrical demand on the farm did not fall to night time levels until about 2115 to 2215 CST. Often another smaller demand peak occurred later in the evening, typically during hour 2200 or 2300 and lasting for less than 15 minutes. It seems that the L-N impulses at this time of night could be attributed to farm electrical use. The cow contact impulse data show a peak during hour 0000 however as seen in my Figure 2.20. This was not coincident with a L-N impulse peak or increased farm electrical demand.

TERF claims that L-N impulse rates remained regular until 4/5, then were nearly zero. My Figure 2.19 shows that the rate was variable, then decreased until 4/5, after which it increased again. Their report says that the largest number of impulses occurred near the midnight hour. This is true for cow contact impulses but not for L-N impulses (my Figure 2.18 shows the peak to occur between 2000 and 2300.)

What is the cause of the electrical anomaly on May 18 - 19?

MIUSVTF The anomaly was caused by a bypass of the isolator below the switch box on the transformer pole, possibly through the monitoring equipment (Exhibit 4 pp.1-2).

TERF A specific explaination was not provided. The anomaly is actually the normal condition for this farm based on measurements by Dave Lusty and others of the primary neutral ground current at the transformer pole and secondary neutral ground currents on the farm. It is held that the utility operated the distribution line in a manner to minimize the primary neutral voltage and consequently the primary neutral ground current during all of the test but the anomaly in order to limit the effects of ground current (pp.8-10).

RCH The anomaly was caused by a bypass of the isolator below the switch box on the transformer pole based on a convincingly high correlation coefficient (.96) between primary and secondary neutral voltages and lack of correlation before (.18) and after (-.17). It is speculated that there is an intermittent low resistance path below ground, possibly a buried remnant of fence in contact with the primary and secondary ground rods. A short in the test equipment could not be ruled out but was deemed less likely because anecdotal evidence suggests the anomaly is reocurring in the absence of the monitoring system (pp. 4.1-4).

Comment:
General disagreement persists on this question. I and MIUSVTF agree on the mechanism (a bypass of the isolator), though not the necessarily the cause. I disagree with TERF because I believe the utility could not have changed the ground rod resistance (which evidence strongly suggests did change). The increased primary neutral ground currents which Dave Lusty is reporting could be caused by a reoccurrence of the bypass as easily as they could by a rise in the primary neutral voltage. Only an examination of the grounds can settle this question.

Did disease incidence (as noted by the test veterinarian) change coincident with changing the grounds?

MIUSVTF No. (JK Ryder pp. 4-5)

TERF Not explicitly stated, though, "On 3-24 . . . there was beginning to be a greater incidence of swollen hocks and redness erythema." (p.4)

RCH No. (p.3.2)

Did water intake change coincident with changing the grounds?

MIUSVTF No. (Exhibit 1 pp.1 - 5, JK Ryder p.3)

TERF Not explicitly stated, though, "Plateaus in the increase coincided with the ground connections and the 3-18 and 3-19 excursion." (p.4)

RCH No. Beginning and end of plateaus preceded switch events by about three days. The effect (increased water consumption) is unlikely to precede its purported cause (disconnecting the grounds). (p.3.2)

Comment: The disagreement between TERF and me apparently results from different methods being applied to the determination of the start and end dates of the plateaus in the data. TERF did not present a description of their method.

Apart from agreeing with MIUSVTF's conclusion, I take issue with their discussion of the water data in which they discredit my water meter readings in favor of the Beehler water data. First, the Beehler data is actually Lusty data (Dr. Beehler was not on the farm on a daily basis). Next, much is made of the fact that my water meter readings were not taken at exactly the same time every day. (I documented the time of each reading allowing for normalization to a 24-hour period, a provision not recognized or taken advantage of in the utility report. Further, the exact times of the "Beehler" water meter readings were not presented and were not, to my knowledge, available; What proof is there that the Beehler data was taken on an exact 24-hour basis, and if not, how can it be normalized to a 24-hour day?) Next, the water data in the utility report is not even normalized to the number of cows in the barn (see Exhibit 1 p.4). For these reasons the discussion is both inaccurate and misleading. It is also irrelevant since all parties relied on the Lusty water data as presented in Dr. Beehler's report.

Did milk production changes coincide with changing the grounds?

MIUSVTF No. (Exhibit 1 p.11, JK Ryder p.3).

TERF Not explicitly stated, though, "The increases in milk production bagan on 3-25 and continued through 3-15 (sic)." (p.4)

RCH No. The onset of increases in milk production precede the ground disconnections by three or four days. (p.3.2)

Comment: MIUSVTF makes the same mistake with milk data that they did with the water data. In presenting a graph of milk/day versus date (Exhibit 1 p.7), they fail to normalize the data to the variable number of cows being milked. This graph is of no use in an analysis of milk production vs. ground status.

Did blood chemistry parameters change coincident with changing the grounds?

MIUSVTF No. (JK Ryder p.5)

CPK: High due to stanchion trauma but no correlation with grounding.
Total Protein: Elevated in herd but no correlation with grounding.
Fibrinogen: No correlation with grounding.
Hematocrit: No correlation with grounding.
Hemoglobin: Normal.
White Blood Cell Count: No correlation with grounding.

TERF Not explicitly stated. Though (p.5):

CPK: High throughout the test.
Cows were never free of effects of stray voltage. (p.7)
Total Protein: High throughout the test.
Cows were never free of effects of stray voltage. (p.7)
White Blood Cell Count: Elevated for entire test for five cows and periodically elevated for others.
Other parameters: Increase and decrease but no pattern.

Small primary neutral ground currents could not likely provide very conclusive information. Short duration of on/off period was not sufficient.. 1992 blood tests showed significant change. (p.8)

RCH Overall, no, though changes in eosinofils and lymphocites showed weak support while the red blood cell counts (hematocrit and hemoglobin) changed counter to the working hypothesis. (pp.3.7-11)

Comment: None of the three analyses claimed strong evidence that any of the blood parameters changed coincident with grounding changes. The TERF criticism concerning the length of the on/off periods has merit. During protocol development, the choice was between replication of results (two on- and two off-periods) and doubling the length of the periods (one on- and one off-period); Replication won out with the understanding that some of the herd parameters might not have sufficient time to change in the time allowed.

The method by which Dr. Ryder reached his conclusions about changes in blood parameters with grounding changes was not clearly stated; It appears from his graphs that his method was based on the numbers of cows testing outside wide "normal" ranges rather than on direction or magnitude of change per se. It seems to me that a more illuminating approach would be to first ask, "Were there changes?" and then ask "Were they significant?"

Did mastitis based on clinical observations change coincident with changes in grounding?

MIUSVTF Not stated.

TERF Not stated.

RCH Six observations provide weak support to hypothesis primarily by lack of countersupporting observations.

Did mastitis based on bulk tank somatic cell counts change coincident with changes in grounding?

MIUSVTF No. (Executive Summary p.2, JK Ryder p.4)

TERF Not explicitly stated.

RCH Inconclusive. SCC increased during first "off" week and decreased during second "off" week. (p.3.13)

Did mastitis based on bulk tank microbiological analysis change coincident with changes in grounding?

MIUSVTF Not explicitly stated. Implied the increase in contageous pathogens was due to other causes. (JK Ryder p.4)

TERF Not discussed.

RCH Data was less than somewhat supportive of hypothesis. Note large pre-test variability in these quantities. (p.3.14)

Did cow appearance change coincident with changes in grounding?

MIUSVTF No. (JK Ryder p.5). "No correlation to the scoring of leg and foot problems by Dr. Beehler were seen that related to the primary neutral grounding test protocol."

TERF Not explicitly stated, though (p.4), "On 3/24 . . . beginning to be a greater incidence of swollen hocks and redness erythema."

RCH Overall, no. "Though erythema in fetlocks and pasterns generally supported . . . cud chewing, swelling of hocks and legs, and manure consistency somewhat countersupported . . .") (p.3.14)

Comment: I found that the incidence of erythema changed two times of three in support of the hypothesis, which is partially confirmed by TERF but counter to the MIUSVTF conclusion.

Did general cow behavior change coincident with changing the grounds?

MIUSVTF No correlation. (JK Ryder pp.1-3)

TERF Yes. (p.4) "The restlessness decreased after 3/24 and increased again 4-8 and 4-13". (p.4) "In general the comments seem to lean in the direction of more problems when the grounds were connected". (It is implied that this is based on the written comments of Dave Lusty.) (p.5)

RCH Yes, somewhat supportive. Changes in dancing, tongue playing/licking, grace/ease rising each supported the hypothosis two of three times.

Comment: As in much of the MIUSVTF report, no basis is presented for evaluating the method(s) used to reach their conclusions. I agree with TERF that the behavior data somewhat supports the primary neutral ground hypothesis.

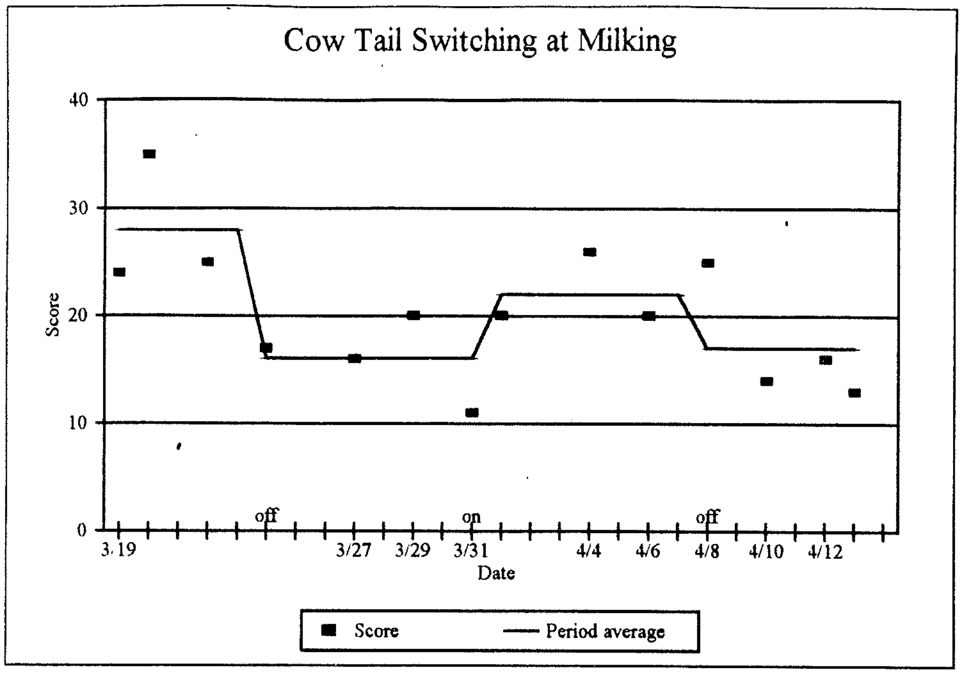
Did cow behavior during milking change coincident with changing the grounds?

MIUSVTF No correlation. (JK Ryder pp.2-3)

TERF Not stated.

RCH Yes, somewhat supportive. Tail switching convincingly supported the hypothesis (three times of three). Dancing/shifting and cud chewing somewhat supported the hypothesis (two times of three).

Comment: Based on Dr. Beehler's scoring of cow behavior during milking (documented on video tape), tail switching data changed coincident with changes in the primary neutral grounding as can be seen in the following figure:



It seems clear that tail switching did in fact increase when the grounds were connected and decrease when the grounds were disconnected based on period averages and also by changes across the switch events.

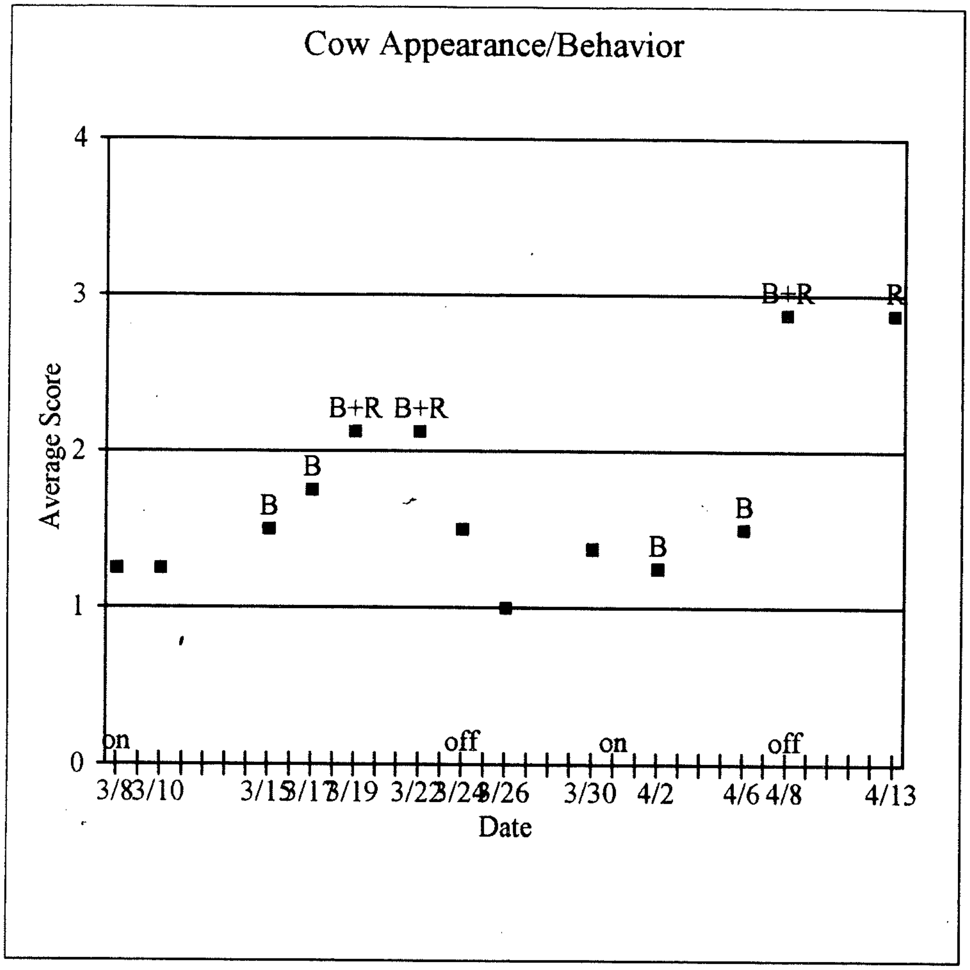
Dr. Beehler in his section on Cow Appearance and Cow Behavior commented that "From these graphs it would appear problems occurred causing irritation and aberrant behavior on 3/15/73 (sic) to 3/21/93 and again 4/2/93 to 4/10/93." Do these periods correlate with times when the ground was connected?

MIUSVTF No. "The objective scoring of cow behavior by Dr. Behler (sic) showed two periods when cow behavior would be considered more active. Characteristics of cow discomfort were increased in both of these time periods. The first period was on the observation days of 3/19 and 3/22, during which time the primary neutral grounds were connected. The second period of time was on 4/8 and 4/13, when the primary neutral grounds were disconnected. Therefore, there is no correlation between these periods of increased activity and restlessness and the test parameters involving the primary neutral grounds. (JK Ryder pp.2-3)

TERF Not stated.

RCH Yes, except for 4/9 and 4/10. (pp.3.16-17)

Comment: It seemed clear to me that Dr. Beehler's comment on behavior did indicate correlation with periods when the ground was connected, except for 4/9 and 4/10. Dr. Ryder's comment contains different dates than Dr. Beehler's; Amplifying information was not included to explain why. I examined the graphs referred to by Dr. Beehler; It was not immediately apparent to my eye that these graphs clearly indicated periods of discomfort, so I averaged the scores for: Hock/Leg Swelling, Fetlock/Pastern (Erythema), Tail Switching, and Dancing/Shifting (the graphs to which Dr. Beehler refers). Then I plotted the average scores vs. date and attached "B" for a Beehler date and an "R" for a Ryder date to try to intuit the reasoning behind each conclusion.



Assuming both veterinarians used a method similar to this to arrive at their respective conclusions, it is apparent that Dr. Ryder invoked the highest possible burden of proof by including only dates when the score was at its peak. Dr. Beehler appeared to include the beginning of the trend as well as the peaks. It seems more logical to attribute a rising response to a hypothetical cause rather than merely the end result, assuming some delay between cause and effect; I agree with Dr. Beehler's assessment.

Overall, was there an effect from disconnecting and reconnecting the grounds?

MIUSVTF "The results of the testing done at the Lusty farm does not support the theory that the cutting of primary pole grounds results in immediate and substantial improvements in dairy performance on the Dave Lusty farm." (Executive Summary p.6)

TERF A concise, summary statement was not provided. In lieu of that, I will paraphrase the general conclusions offered on pp.6-10.

1. A large amount of information exists . . .

2. The primary neutral to earth voltage is an unreliable predictor of current reaching the barn from distribution system grounding.

3. Unexplained inconsistencies exist in the data jeopardizing the purpose of the study . . .

4. The normal operating condition (150mA primary ground current) was not in effect during most of the test, thereby limiting the observed response.

RCH Not explicitly stated.

Comment: These reports illustrate three different styles:

The MIUSVTF report provides a large amount of background information, does not provide the methods used to reach conclusions about the effects of grounding, and simply states at the end of each topic that there was no correlation. It reflects an analysis requiring the highest burden of proof (changes must be significant as well as observable before being stated).

The TERF report discusses many observations in detail, implies that some are effects of grounding changes, but concludes that the results are questionable because of the complexity of the electrical environment, manipulation of the distribution system, and inappropriate standard measurement methods. It reflects an analysis requiring the lowest burden of proof of the three (changes must be observable).

My (RCH) report gives a clear analysis method, provides intermediate results (to allow alternative conclusions) and states my own conclusion at each step. It reflects an analysis requiring an intermediate burden of proof (changes must be observable, then significance may be attached). //

I intend to formulate an abbreviated conclusion about the results of this test based on my own examination of the data. Perhaps the time to state this conclusion would be at the August MEQB meeting. Please let me know if this is agreeable to you.

Sincerely,

Riley C. Hendrickson

Riley C. Hendrickson
(612)532-4019

June 30, 1994

Riley C. Hendrickson
12914 260th Street
Milaca, MN 56353

Mr. George Durfee
Minnesota Environmental Quality Board
300 Centennial Building
658 Cedar Street
St. Paul, MN 55155

Dear George:

The following are my responses to questions submitted by the Minnesota Inter-Utility Stray Voltage Task Force regarding my reports on the Primary Neutral Grounding Test.

1. "Please provide the frequency operating or response range of the AC magnetic field transducer that was used in the barn for this test."

The Monitor Industries 42B-1 Milligaussmeter (operating in flat mode) has a pass band which is flat between 50 Hz and 1 kHz; Response falls off to approximately 90% at 30 Hz and 2 kHz.

2. "Please describe the battery condition of the TERF provided Swain meter that was in part of this test."

The "Test Battery" function of the Swain AC ammeter was determined to be faulty during instrument calibration following the test (Materials and Methods of Electrical Measurements . . ., RC Hendrickson, Aug. 25,1993, pp.20-21). The meter indicated a 90+% battery state until the connector between the coil and meter was manipulated; Then the battery state fell to approximately 70%, which I took to be a true indication. (The manufacturer recommends maintaining the battery state above 85% for full accuracy.) Because this fault was not discovered until after the test, reliable information on battery condition during the test is not available.

Sincerely,

Riley C. Hendrickson

Riley C. Hendrickson
(612)532-4019

August 19, 1994

Riley C. Hendrickson
12914 260th Street
Milaca, MN 56353

Attn: Mr. George Durfee
Minnesota Environmental Quality Board
300 Centennial Building
658 Cedar Street
St. Paul, MN 55155

Dear George:

I have written at length about my interpretation of the various data sets from the Primary Neutral Grounding Test. To date I have refrained from stating an overall conclusion to allow other parties the opportunity to comment. Having reviewed all the comments you forwarded to me, I am now ready to state my conclusions in a more compact form.

The test protocol declares as its objective: "Relate electrical grounding . . . to currents and voltages on the farm and specific selected indicators of herd health and production." Herd appearance and behavior were added in the section, Quantities to be Measured. For each of these categories I conclude as follows:

Currents and Voltages:
When examining the electrical data, I looked for *any* indication that it changed when the primary neutral ground was switched. Changes in magnitude, trend or variation were considered using 1-second data, 1-minute data and 1-hour data. No changes were found in the primary neutral voltage at the transformer pole when the grounds were switched on or off. No consistent changes were found in the electrical data collected in the barn; The exceptions were a few instances when the variability of cow contact potentials changed and one case when a dc cow contact potential began a long-term decline near the time of the first switch event. These changes did not reoccur at other switch events. The occurrence of voltage transients on the barn wiring and between cow contacts showed no correlation with primary neutral ground status.

In sum, I find no convincing evidence that disconnecting or reconnecting the primary neutral grounds on the test farm had any immediate effect on currents or voltages in the barn.

Herd Health: Notations of disease incidence provided by the test veterinarian did not provide evidence of increased disease in the herd when the grounds were connected. Changes in blood chemistry data did not offer convincing evidence that the herd was afflicted with more stress during 'on' periods than during 'off' periods. Mastitis data weakly correlated with primary neutral ground status. (Clinical mastitis observations weakly supported the hypothesis. Changes in somatic cell counts were inconclusive. Microbiological analysis of bacteria counts in the milk was "less than somewhat supportive" of the hypothesis.) Water consumption data did not indicate an effect correlated with grounding.

Herd health appeared to be not significantly affected by changing the primary neutral ground status.

Herd Production: Milk production generally increased during the month-long test. Changes in the rate of increase were not coincident with changes in grounding. Production appeared to be unaffected by primary neutral ground status.

Herd Appearance: Changes in erythema (redness) in fetlocks and pasterns seemed to correlate somewhat with ground status; On the other hand, changes in cud chewing, swelling of hocks and legs, and manure consistency did not correlate with ground status.

Overall, an evaluation of herd appearance by the test veterinarian did not offer evidence in support of the hypothesis that herd appearance changed as a result of altering the primary neutral grounds on the farm.

Herd Behavior:
Of twelve general behavior categories scored by the test veterinarian, three changed in support of the grounding hypothesis 2 of 3 times (dancing, tongue play/licking, grace/ease rising). Three others changed in support 1 of 3 times (demeanor, stanchion/chain behavior). The other categories showed no net change (kicking, tail switching, vocal response, urination/bowel movement, reaction to milking, water cup lapping). The test veterinarian specifically commented that ". . . it would appear problems occurred causing irritation and aberant behavior on 3/15/(93) to 3/21/93 and again 4/2/93 to 4/10/93. Except for 4/9 and 4/10, these are dates when the grounds were connected. Overall, changes in general cow behavior offered weak support to the primary neutral grounding hypothesis.

Of three categories scoring behavior during milking, one changed in support of the grounding hypothesis 3 of 3 times (tail switching). Tail switching behavior data were supportive; Period averages consistently changed in the hypothesized direction and by magnitudes that were not trivial (+/-34%, on average). The other two categories changed in support 2 of 3 times (dancing/shifting, cud chewing) but the magnitudes of change were less than convincing. Overall, changes in behavior during milking offered some support to the primary neutral grounding hypothesis (weighted primarily by tail switching).

Conclusion:
The data from the Primary Neutral Grounding Test indicate that herd health, production and appearance did not significantly change as a result of disconnecting or reconnecting

the primary neutral grounds on the test farm for approximately 1-week intervals. Herd behavior data suggest the possibility of an effect. The electrical data did not offer substantiating evidence supporting the hypothesis that ground currents originating at the primary neutral ground rods on the farm were the mechanism.

I assert that the conclusions stated above are my own and do not reflect any overt influence other than from the data record itself.

Acknowledgments:
A large number of people were instrumental in the conduct of this test. Without their assistance and cooperation, it would not have been successful.

I thank Dr. Gerald R. Beehler, DVM, the test veterinarian of Lake Region Veterinary Center, Ltd., Fergus Falls MN, for his consistently thorough and careful reporting of herd information under contract with the Minnesota Department of Agriculture as managed by Mr. William Coleman. Dr. Dan Hartzell, DVM, was instrumental in establishing appropriate herd parameters for the test. Ottertail Power Company, Fergus Falls MN, generously provided information, personnel and equipment under the coordination of Mr. Jerry Martens and management of Mr. Brian Malchert whenever requested to fulfill the requirements of the test protocol and more. Also of particular note, Mr. Harvey MacMahon freely assisted me in obtaining and understanding power quality data. Runestone Electric Association and Cooperative Power Association readily provided personnel and equipment to produce substation and transmission data. Mr. John Hynes of the Minnesota Environmental Quality Board accomplished the mammoth task of turning a mountain of test data into a very usable form, and offered helpful and stimulating dialog throughout. Dr. Duane Dahlberg Ph.D. of Concordia College, Moorehead MN, and Mr. Dan Mairs PE of Runestone Electric Association, Alexandria, MN, provided the deep thought and cooperation necessary for design of the test and for the lively debate over its results. I thank Mr. Mike Michaud and Mr. Al Bierbaum of the Public Utilities Commission and Mr. Chris Davis of the Department of Public Service for their helpful suggestions and criticisms regarding data analysis and reporting. The members of the Stray Voltage Steering Committee chaired by Mr. George Durfee deserve special recognition for their leadership contributions. The process that they guided was a masterpiece of research direction and equitable attention to the concerns of all parties involved; The process should be used as a model for future state research. I would most like to thank and acknowledge Dave and Sue Lusty, owners of the test farm, who tirelessly and cheerfully worked long, arduous, extra hours without compensation to help me do the job of collecting data on their farm.

Sincerely,

Riley C. Hendrickson

Riley C. Hendrickson
(612)532-4019

Primary Neutral Grounding Test: Conclusions Presented to the Environmental Quality Board

September 15, 1994

By: Riley C. Hendrickson

Good morning. I am Riley Hendrickson. In 1992 I served as representative of the EQB on a subcommittee of the Stray Voltage Steering Committee to draft a test protocol to examine the effects of primary neutral grounding practices on dairy herd health and production. In March and April of 1993, I supervised this test on the David Lusty farm. During the month-long test, two of the distribution system's ground rods on the test farm were disconnected and reconnected for one-week intervals to see whether this had any effect on the barn's electrical environment or on the health and production of the cows. Subsequently, I was contracted to analyze the resulting data, to compare my results to those of the utilities and the farm group (TERF), and to then state my conclusions based on these analyses. My purpose here today is to tell you about my conclusions.

The test protocol states as its objective: "Relate electrical grounding . . . to currents and voltages on the farm and specific . . . indicators of herd health and production." Herd appearance and behavior were added in the section, Quantities to be Measured. The following are my conclusions along with my assessment of the degree of agreement I found among the three reports.

Currents and Voltages were continuously logged throughout the test, both in the barn and at the transformer pole, to establish a record of the electrical environment and to detect changes when the ground connections were changed. I examined the electrical data for *any* changes in magnitude, trend or variation using 1-second data, 1-minute data and 1-hour data. At the transformer pole no changes were found in the primary neutral voltage when the grounds were switched on or off. In the barn no consistent changes were found in the electrical data; The exceptions were a few instances when the variability of cow contact potentials changed and one case when a dc cow contact potential began a long-term decline near the time of the first switch event. These changes did not reoccur at other switch events, and, as such, should be considered coincidental. The occurrence of voltage transients on the barn wiring and between cow contacts showed no correlation with primary neutral ground status.
In sum, I find no convincing evidence that disconnecting or reconnecting the primary neutral grounds on the test farm had any immediate effect on currents or voltages in the barn. On this point I am in general agreement with the conclusions in the utility report though I would add that the utility report did not discuss of the exceptions I noted above. The TERF report listed more changes in the electrical data than I did. I found that some of these changes occurred at times other than when the grounds were switched; I would not attribute delayed changes in AC quantities to ground switching; These should be instantaneous. Delayed DC changes however remain an unresolved issue.

Herd Health was documented by tracking disease incidence, changes in blood chemistry, mastitis and water consumption.

Notations of disease incidence by the test veterinarian did not provide evidence of increased disease in the herd while the grounds were connected. On this point I and the utilities agree; TERF did not explicitly disagree.

As a measure of stress, nine blood parameters were monitored for twenty cows on eight separate dates during the test, then evaluated for changes when the grounding was changed. The blood chemistry data did not offer convincing evidence that the herd was afflicted with more stress during 'on' periods than during 'off' periods. I and the utilities agree; TERF did not specify an explicit conclusion.

Mastitis, a bacterial inflammation of the udder sometimes associated with stray voltage, was measured by three methods: Clinical observations, somatic cell counts and by microbiological analysis of the milk. Mastitis data weakly correlated with primary neutral ground status. (Clinical mastitis observations weakly supported the stray voltage hypothesis. Changes in somatic cell counts were inconclusive. Microbiological analysis of bacteria counts in the milk was "less than somewhat supportive" of the hypothesis.) Neither the utilities nor TERF found a correlation between mastitis and primary neutral ground status.

Water consumption data did not indicate an effect correlated with grounding. I agree with the utility assessment; In opposition, TERF would link changes in water consumption to ground switching.

My overall conclusion regarding herd health is that it appeared to be not significantly affected by changing the primary neutral grounding.

Herd Milk Production was measured daily. Milk production generally increased during the month-long test, a normal change for the season. Changes in the rate of increase did not coincide with changes in grounding. Production appeared to be unaffected by primary neutral ground status. No overt disagreement exists among the three reports on this question.

Herd Appearance was rated by the test veterinarian as scores of thirteen appearance categories. Of these, changes in erythema (or redness) in fetlocks and pasterns seemed to correlate somewhat with ground status; On the other hand, changes in cud chewing, swelling of hocks and legs, manure consistency, or any of the other categories did not correlate with ground status.

Overall, an evaluation of herd appearance did not offer evidence in support of the hypothesis that it changed as a result of altering the primary neutral grounds on the farm. The utility report concurred; TERF did no explicitly disagree.

Herd Behavior was evaluated by the test veterinarian as general behavior and as behavior during milking as documented on video tape.

Of twelve general behavior categories, three changed in support of the grounding hypothesis 2 of 3 times; These were dancing, tongue playing & licking, and grace & ease in rising. Three other categories changed in support 1 of 3 times; These were comfort demeanor, calmness demeanor, and stanchion-chain behavior. The remaining six categories showed no net change; These were kicking, tail switching, vocal response, urination/bowel movement, reaction to milking, and water cup lapping.

As a separate observation, the test veterinarian specifically commented that ". . . it would appear problems occurred causing irritation and aberrant behavior on 3/15/(93) to 3/21/93 and again 4/2/93 to 4/10/93." Except for two days, these are intervals when the grounds were connected, thus supporting the working hypothesis.

Overall, changes in general cow behavior offered weak support to the primary neutral grounding hypothesis. I agree with TERF and disagree with the utility assessment on this point.

Of three categories scoring behavior during milking, one changed in support of the grounding hypothesis 3 of 3 times; This was tail switching. Period averages for tail switching consistently changed in the hypothesized direction and by magnitudes that were not trivial, +/-34 on average. The other two categories changed in support 2 of 3 times (dancing & shifting, and cud chewing) but the magnitudes of change were less than convincing.

Overall, changes in behavior during milking offered some support to the primary neutral grounding hypothesis weighted primarily by tail switching. On this point I stand alone; The utility assessment is "No correlation". TERF did not state a conclusion.

To summarize my conclusions on the results of this test:
The data from the Primary Neutral Grounding Test indicate that herd health, production and appearance did not significantly change as a result of disconnecting or reconnecting the primary neutral grounds on the test farm for approximately 1-week intervals. Herd behavior data suggest the possibility of an effect. However, the electrical data did not offer substantiating evidence supporting the hypothesis that ground currents originating at the primary neutral ground rods on the farm were the mechanism.

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