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

A REPORT ON MATERIALS AND METHODS OF ELECTRICAL MEASUREMENTS, A DESCRIPTION OF MISCELLANEOUS TESTS AND THE DISTRIBUTION SYSTEM

For:

The State of Minnesota
Minnesota Environmental Quality Board
Stray Voltage Steering Committee

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Consultant's Report

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A. Introduction

A test was conducted to investigate primary neutral grounding practices of rural electrical distribution systems as they relate to dairy operations. This test was initiated by the Minnesota Environmental Quality Board, Stray Voltage Steering Committee. It was conducted in accordance with a test design described in the Test Protocol To Investigate Primary Neutral Grounding Practices and the Effects of Such Practices on Dairy Herd Health and Production by Duane A. Dahlberg, Ph.D., Dan D. Mairs, PE and Riley C. Hendrickson, 2/24/93. The test was held on the David Lusty farm, Miltona, MN, which is served by Ottertail Power Company, from 3/15/93 to 4/19/93.

During the test, the primary neutral ground connection at the transformer pole and the second grounded pole were either connected or not connected on a weekly basis. The object of the test was to record pertinent data related to the primary and secondary electrical systems, cow contact electrical parameters, and herd health, behavior and production in order to determine whether these grounding practices were in some way contributing to a stray voltage problem on the test farm.

This report describes the materials and methods used to make measurements of the electrical quantities. It contains a description and results of special and miscellaneous tests not presented elsewhere and a description of the electrical distribution system serving the test farm.

B. Materials and Methods

B1. Measurements of Cow Contact Potentials and Secondary Electrical System Quantities

Instrumentation was installed in the barn to make and record measurements of electrical quantities pertinent to cow contact potentials and secondary electrical system quantities. Most measurement points were established in a pair of adjacent stalls on the east side of the barn; a data acquisition system was set up in the milk room on the west side and connected to the measurement points via signal cable.

The barn contains 26 stalls in three rows oriented approximately north/south; the west two rows of nine stalls each face each other across a feed isle and are served by a barn cleaner. The east row of eight stalls faces its feed isle on the east side of the barn and is cleaned manually. A transverse isle separates the north six stalls in each row from the rest. The barn cleaner is located outside of the southeast corner of the barn; the milk room is located off the northwest corner. The two stalls selected for electrical measurements were near the center of the east row of stalls and next to the transverse isle.

The measurements of cow contact potentials and secondary electrical system quantities were of two types; "continuous" measurements were made to quantify levels and variations of currents and voltages over the length of the test and logged by a computer; additionally, two power quality monitors recorded fast transient voltages, one monitoring the secondary system, the other cow contact potentials.

Continuous Measurements

Continuous measurements were logged automatically using a Xerox 6064 personal computer equipped with a Dash-16 analog-to-digital data acquisition board and custom software, powered through an uninterruptable power supply (for continuous operation through power outages), all contained in a sealable, ventilated enclosure located in the milk room. Each variable was measured once each second, averaged at the end of each minute, and written to disk every 10 minutes.

The analog-to-digital data acquisition board was operated on its most sensitive bipolar range, -500 to 500 mVdc. Input impedance was 10 Megohm. The twelve bit resolution was 0.24 mV with a nominal accuracy of .01% + 0.24mV. The actual accuracy of individual conversions was lower due to random noise induced along the signal path; An estimate of the overall accuracy of single a/d conversions made under conditions found in operating dairy barns is .01% + 0.48mV (Hendrickson, 12/92). Random noise reduction was accomplished by averaging 60 readings per one-minute average.

All measurements were differential and independent of one another, as if they were made by eight separate multimeters.

The analog signals were transmitted from the point of measurement in the stall to the data logger over a 100 ft multiconductor cable providing one shielded, twisted pair of wires per channel. The time base of the data logger was checked and corrected periodically using a time mark supplied by the Ottertail Power Company Operations Center.

Two quantities were recorded on a Soltec 1242 strip chart recorder in order to capture events faster than the data logger was set to record.

A schematic of the electrical measurements in the stall is presented in Figure B1. As noted, the data logger recorded ac and dc voltages, an ac current and a magnetic field.

Connections for the voltage and current measurements were made as follows.

AC measurements: The steel water line was sanded to a bright finish, a stainless steel hose clamp was tightened around the pipe and the signal wire attached to the clamp with a gold-plated alligator clip. The connection to the gutter chain was made using a chrome-plated vise grip and gold-plated alligator clip. Connections to concrete were made using a 2.5" x 2.5" aluminum block "glued" to clean concrete with electrode gel and held in place by a 24 lb. steel weight.

DC measurements: An effort was made to use all-copper leads in order to reduce contact potentials by "losing" them as common mode voltages wherever possible. Copper blocks and copper leads were used to attach to cleaned concrete, again with electrode gel and 24 lb. weights. A copper wire was clamped directly to the water line with a hose clamp.

Signal conditioning was necessary for the ac voltage measurements which were made using true rms-dc converters. True rms measurements are necessary when the ac waveform is not a pure sine wave, as is the case when higher frequency components add significantly to the relatively low 60 Hz voltage levels between cow contact points. (See Section C3, Cow Contact Voltage Waveforms). The converters were constructed around the integrated circuit AD736AN according to the manufacturer's product sheet recommendations. They are battery powered and have a 10 Megohm input impedance voltage divider providing attenuation factors of 1, 0.1, 0.01 and 0.001. The accuracy of each device was established prior to and during use; it was within +/- 5%.

The dc voltage measurements were made without the necessity of signal conditioning since the data logger could accept them directly at their actual levels.

A 300 ohm (1%) resistor was used to simulate the presence of a cow between the front and rear hoof connections. No resistor was used between the water line and the rear hoof in order to record the voltage that a cow would experience upon first contacting the drinking cup. These conditions were reversed momentarily

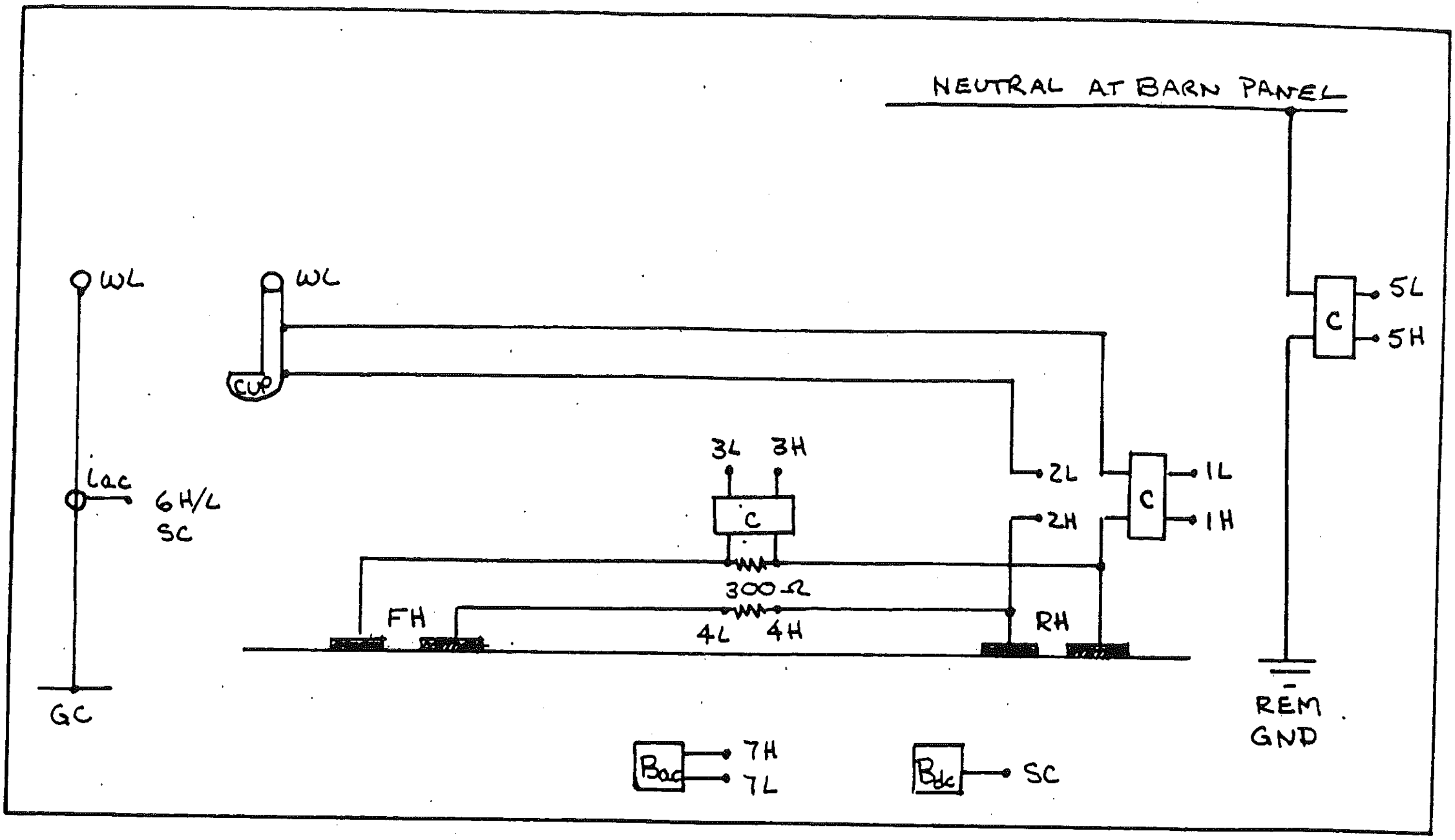


Figure B1
Measurement schematic, cow contact potentials and secondary electrical system quantities.

Abbreviations:
#H = data logger differential input channel number/high
#L = data logger differential input channel number/low
SC = strip chart recorder
c = converter (true rms Vac to Vdc)
WL = water line
GC = gutter chain
FH = front hoof contact block
RH = rear hoof contact block
REM GND = remote ground
Bac = ac magnetic field
Bdc = dc magnetic field
N = barn service panel neutral wire

Data Logger Channels:
CH#1 = mVac water cup to rear hoof
CH#2 = mVdc water cup to rear hoof
CH#3 = mVac front hoof to rear hoof across 300 ohm
CH#4 = mVdc front hoof to rear hoof across 300 ohm
CH#5 = mVac barn neutral to remote ground
CH#6 = mAac water line to gutter chain
CH#7 = mG ac magnetic field at center floor of stall

during quality control checks to record the difference in voltage levels with and without the presence of the resistor.

The following continuous measurements were made:

1. mVac, WL to RH. Millivolts ac between the water line and rear hoof using a true rms ac-to-dc converter and no cow resistor.

2. mVdc, WL to RH. Millivolts dc between the water line and rear hoof using no cow resistor.

3. mVac FH to RH. Millivolts ac between front and rear hoof using a true rms ac-to-dc converter and Rcow=300 ohm.

4. mVdc FH to RH. Millivolts dc between front and rear hoof using Rcow=300 ohm.

5. mVac N to REM GND. Millivolts ac between the barn neutral and remote ground. The barn neutral connection was made at the barn service panel. The remote ground was an 8-foot driven ground rod located approximately 150 yards southwest of the barn.

6. mAac WL to GC. Milliamps ac between the water line and gutter chain. This measurement was made using a Swain ac ammeter with recorder output. This measurement was both data logged and recorded as the red trace on the strip chart recorder. Because the gutter chain moved each day during barn cleaning, this signal was lost during that chore.

7. mGac. Milligauss ac, the vertical component of the ac magnetic field measured at floor level near the center of the stall using a Monitor Industries Model 42B Milligauss Meter with dc recorder output. This measurement provides an integrated indication of changes in the flow of ac current along various conducting paths in the barn.

Once during the test the ac magnetic field was measured in the center of each stall at floor level. The instrument used for this purpose was a Field Star 1000 Magnetic Field Recorder (Serial Number 31400191). Mapped data was uploaded to a Halikan LA3540 Laptop Computer equipped with Field Star Software "FS" Version 2.54 for storage and graphic display. No readings were obtained in the stalls which were above the detection/resolution limit of this instrument (0.04 mG) even when milking equipment was operating. For this reason mapping the barn in this manner was discontinued. Also, midway through the test, the Spring thaw resulted in the cows not being turned out each day, ruling out further measurement in the stalls. However, with the addition of a Field Star Mapping Wheel, the ac magnetic field in the barn was mapped along each isle twice during the remainder of the test. Again, no readings were obtained in the barn proper which were above the 0.04 mG detection/resolution limit of the instrument except in the milk room itself and immediately adjacent to the barn cleaner when it was operating.

8. mAdc between two points in the barn. This measurement was called for in the test protocol but not made. No dc currents larger than a few microamps could be found between points in the barn, excluding those pairs of points already used to make voltage measurements. The two measurements are mutually exclusive unless connected by a resistor (in which case the current can be calculated.)

9. mGdc. Milligauss dc, a component of the dc magnetic field at floor level near the center of a stall. A dc milligauss meter with recorder output was used to record this quantity as the green trace on the strip chart recorder. The Hall probe was oriented in the direction of minimum field strength in order to operate the meter on a sensitive range. It was inserted into a slot cut in a stiff foam block taped to the floor. It was determined that the zero level of the signal from this instrument changed continuously as the battery drained. This invalidates the actual levels recorded as well as conclusions about long term variations in the data; the data is interesting and useful however as a record of on/off events of some electrical equipment in the barn. See analysis of the event log of 3/26 and strip chart traces to follow.

Event Log

A record of electrical events was made on the afternoon of 3/26/93 that included the operation of nearly all of the equipment in the barn. The purpose of the record is to allow an examination of the data record to determine if equipment operation has an effect on the currents, voltages and fields measured in the barn. That event log follows:

Time	Event
1526	Lights and ventilating fan only are on.
153237	barn cleaner (bc) on
55	bc off
153447	bc on
55	bc off
153436	bc on
46	bc off
153558	bc on
3609	bc off
153734	bc on
54	bc off
154001	fan off. bc on
4158	bc off
154227	bc on
4853	bc off. fan on.
1552	note: replacing grate near Bdc doubled that reading.
155313	next nearest grate replaced
1842	begin evening milking
184240	vacuum pump on (sanitize cycle)
184455	transfer pump (tp) on
4515	tp off. vacuum pump off.
185710	tp on, then off

185843	bulk tank agitator on
185857	vacuum pump on for milking
191050	tp on (5 sec)
191515	tp on (5 sec)
191817	bulk tank on

End event logging. Transfer pump continues to cause spikes in Bdc trace for remainder of milking.

A more extensive record of equipment on/off times would be desirable. It was recognized early in the test that the strip chart record contains enough information to determine when milking and barn cleaning (the two activities requiring the use of electrical equipment) were occurring. By relating the above event log to the concurrent strip chart record, one can then use the strip chart record to identify all other occurrences of these activities.

Strip chart traces were kept of two measurements:

Red pen = mAac between water line and gutter chain
green pen = mGdc, the dc magnetic field in stall

Since the vice grip connection on the gutter chain had to be broken to use the barn cleaner, the red pen trace goes to zero (centered) each time barn cleaning took place.

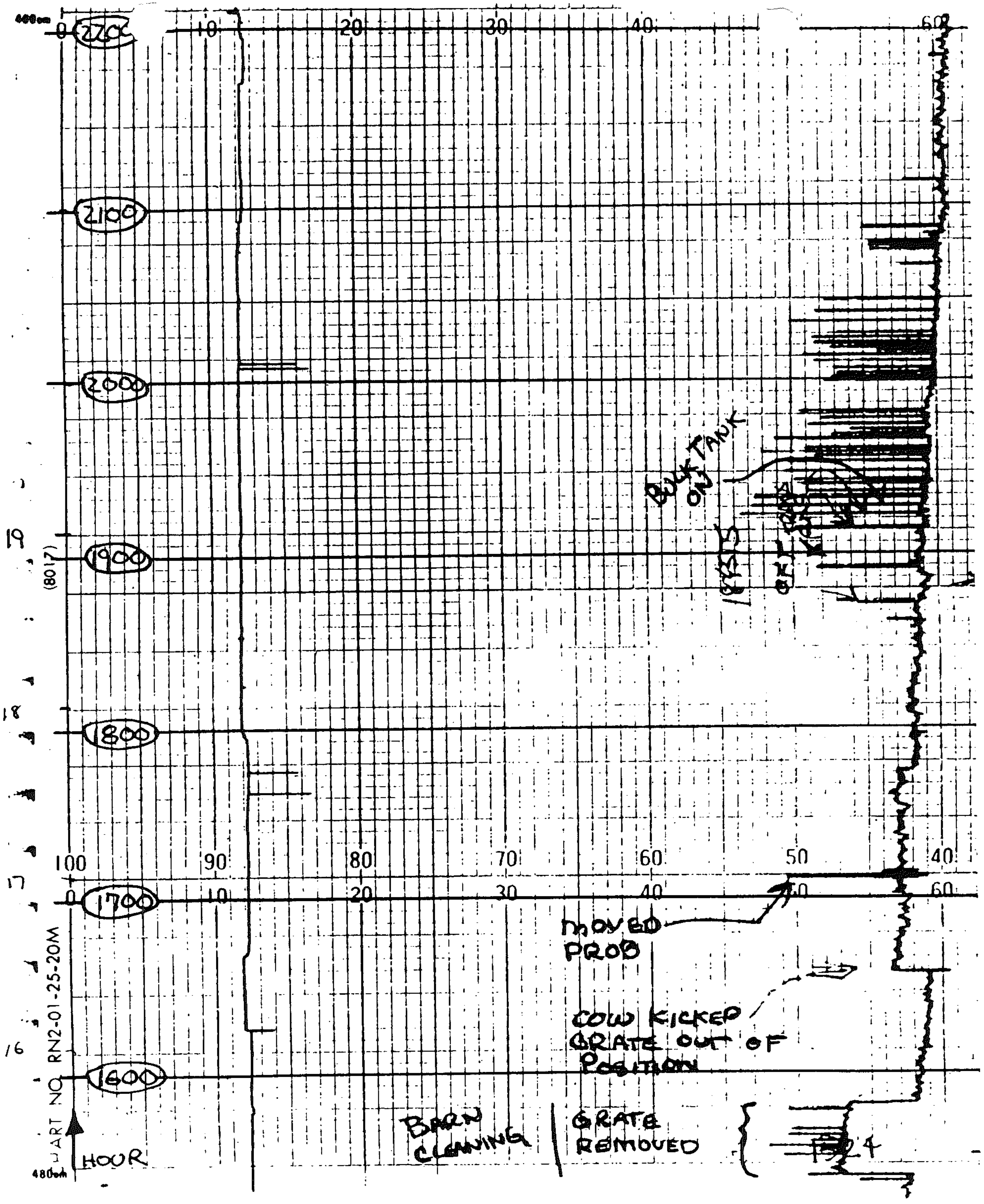
The green pen trace representing the dc magnetic field in the stall spiked each time the transfer pump and the barn cleaner were turned on and off. The transfer pump was operated during milk line sanitizing and milking operations, so the chart spikes can be used to identify those time periods each day when those activities were occurring. The barn cleaner spikes identify barn cleaning; Also, the dc magnetic field meter was sensitive enough to detect when the nearest steel gutter grate was moved in order to clean the east gutter by hand.

Figure B2, a copy of the chart record, illustrates the use of the green magnetic field trace to identify milking and barn cleaning. (On this day the red pen channel was being used to record the ac magnetic field as a special investigation, so it cannot be used to illustrate barn cleaning in this example as suggested above). This pattern can be easily recognized in the strip chart record throughout the test.

Power Quality, Transient Voltage Measurements

Two BMI Power Quality Monitors were used, one to monitor transient voltages on the barn's electrical system and the other to measure transient voltages between cow contact points. These instruments were operated in the same pair of stalls used for the other barn electrical measurements.

Power quality of the barn electrical system was measured using a BMI 8800 Power Quality Monitor. Two channels of this four channel instrument were connected between the barn's secondary



<u>Figure</u> B2

Strip Chart Record for 3/26/93

Green trace: dc magnetic field component in stall
-zero centered
-uncalibrated

Refer to time base on left. Note that each minor time division represents 4 minutes. Major divisions are 20 minutes.

From the event log, barn cleaning lasted from 1522 to 1548. Note spikes representing on/off times for the barn cleaner. Also note the step change in this trace when the grate was removed. This pattern can be used to identify barn cleaning times during the test.

From the event log, milking began at 1842. Subsequent on/off times for the transfer pump (mainly) and for other equipment show as spikes in the trace. These spikes do not occur without equipment being turned on or off. They may be used to identify milking times as a surrogate for an event log throughout the test.

phase conductors (P1 and P2) and neutral; access to these was obtained in a switch box (for a ventilating fan) located near the stall.

In its normal mode of operation during this test, the BMI 8800 was programmed to count voltage impulses with peak values larger than 20 volts (the minimum setting allowed by this instrument) and to produce hourly strip chart records on paper showing these impulses and their sizes along with some statistics describing the data. This data was also recorded on a 3.5" diskette (though this function was not always reliable). At times during the test the instrument was programmed to also produce snapshot graphs of these impulses as they occurred; waveshapes can be used to deduce possible impulse sources.

Periodically the BMI 8800 was used to measure the presence of 60 Hz harmonics on the phase conductors. The monitor was relieved of its transient counting function and programmed to produce harmonic spectra and associated statistics for each line voltage. The presence of odd-numbered harmonics with content greater than a few percent indicated the presence of non-linear loads somewhere on the distribution system. On two occasions, harmonic spectra were obtained with power to the farm on and off to determine whether the source of the harmonics was on the farm itself. No discernible change in the spectra was observed, leading to the conclusion that the source was off the farm. A later survey indicated that the harmonic distortion existed throughout the distribution system.

To measure transient voltages between cow contact points it was necessary to obtain another BMI power quality monitor capable of being fitted with a low voltage input module to allow measurement of transient voltages down to 2 V peak. For this purpose a BMI 4800 was used. Attachment to cow contact points was made using shielded coaxial leads of equal length terminated with alligator clips. Two of the four channels were set up to measure between front/rear hoofs across 300 ohm and between the water line and rear hoof without a resistor. A dedicated pair of contact blocks similar to those used for continuous measurements were used to make the hoof connections.

The BMI 4800 was programmed to count impulses in a manner similar to that of the other monitor except that the firmware required a paper graph output upon detection of each impulse. No hourly strip chart graph was available in this firmware version although hourly impulse statistics were produced. Testing revealed that no impulses of greater than 2 V peak could be measured between the front and rear hoof points so the threshold value for this pair was left at this minimum 2 V value. Between the water line and rear hoof a steady output of impulse graphs at the 2 V peak threshold lead to raising this value to 4 - 5 V peak in order to limit the output to a reasonable level. This instrument was not capable of doing a harmonic spectrum analysis.

An attempt was made to determine how the voltage impulses between the water line and rear hoof were apportioned between those two points. A remote ground rod was established approximately 100 yards south of the barn. A coaxial cable to this ground allowed the measurement of low voltage impulses between the water line and remote ground and between the rear hoof block and remote ground. Comparisons between the simultaneously obtained impulse graphs should allow an apportionment to be made.

Near the end of the test period both power quality monitors were programmed to produce impulse graphs in order to determine whether transients existed simultaneously on the barn's wiring and between cow contact points. Some correspondence was noted both in the time of impulses and in impulse shape.

Calibration certificates were available for the BMI 8800. None was available for the BMI 4800; further, a firmware-produced message was printed stating that the calibration of this unit was no longer in effect. Therefore, an independent effort to confirm the impulse detection function was made. A resistor/capacitor discharge device was constructed to produce an RC discharge of a known voltage and time constant. This was tested using a Tectronix 222 Digital Storage Oscilloscope and then used as an input to the BMI 4800 low voltage module to determine whether or not the unit detected these known impulses. Results, reproduced elsewhere, were generally acceptable.

B2. Measurement of Primary Electrical System Quantities

Instrumentation to measure quantities related to the primary electrical system were installed in a van parked near the transformer pole in the farmyard. Additional equipment was installed at the nearest adjacent pole with a neutral/ground connection and at other locations on the distribution system and by Ottertail Power Company and in two related substations by Cooperative Power Association. See Figure B3 for a summary of these measurements.

Switching of the primary neutral ground connections at the transformer pole and the second grounded pole at weekly intervals provided the basis for this test. At these poles, the primary neutral ground wire was unstapled from the pole. Plastic conduit was installed over the ground wire and a meter box installed to provide housing for the switch (a jumper fitted to the meter socket receptacle) and a series one ohm wire-wound resistor used to make the current measurements. The above were fastened to the pole. Plastic "U-Guard" was then installed over the conduit as an added security measure. Access to the switch was protected by numbered seals on the meter box cover plate. Finally plastic snow fence was erected around each pole and No Trespassing signs were posted. At the transformer pole, access to the van was limited by covering all windows and keeping it locked when not occupied.

Measurements at the Transformer Pole
Measurements made on the primary distribution system are summarized in Figure B3.

Continuous measurement of electrical quantities at the transformer pole was done in a manner similar to that in the barn. The measurements were logged using a Zenith Data Systems (AT-style) personal computer equipped with an Industrial Computer Source AIO8G-P analog-to-digital data acquisition board and custom software. Each variable was measured once each second, averaged at the end of each minute, and written to disk every 10 minutes. The analog-to-digital data acquisition board was operated on a -5V to 5V range. Input impedance was 10 Megohm. The twelve bit resolution was 2.4 mV with a nominal accuracy of independent of one another. The analog signals were transmitted from the point of measurement to the data logger over multiconductor cable providing one shielded, twisted pair of wires per channel. The time base was checked periodically and adjusted as needed.

Two quantities were recorded on a Soltec 1242 strip chart recorder in order to capture events faster than the data logger was set to record.

Measurement of ac current and voltage required the use of true rms ac-to-dc converters as described in Section B1. Also as before, the dc quantities were input directly into the data logger without further conditioning.

The following continuous measurements were made:

1. mVac, PN to REM GND. Millivolts ac between the primary neutral and remote ground. The remote ground rod was the same reference used for barn measurements; it was approximately 150 yards south of the transformer pole/van. The ac-to-dc converter was operated with an attenuation factor of 10 to protect the data logger from potentially damaging voltage levels on the primary neutral. Zener diodes were also added to the data acquisition board inputs for added electronic protection.

2. mAac, PN to TRA GND. Milliamps ac in the transformer pole primary ground wire (when connected). A 1.0 ohm resistor in series with the ground wire provided a means to measure millivolts and convert without calculation to milliamps. The extra one ohm added minimally to the ground rod resistance at this pole. The ac voltage was converted to a numerically equal dc voltage using a true rms ac-to-dc converter with no attenuation. This parameter was also recorded on strip chart when the ground wire was connected.

3. mVdc PN to REM GND (half cell). Millivolts dc between the primary neutral and remote ground. The remote ground in this case was a half cell located 150 yards south of the transformer pole/van near the remote ground rod. The half cell was a sealed plastic tube with a copper electrode suspended in a solution of copper sulfate and antifreeze; the bottom plug was a porous

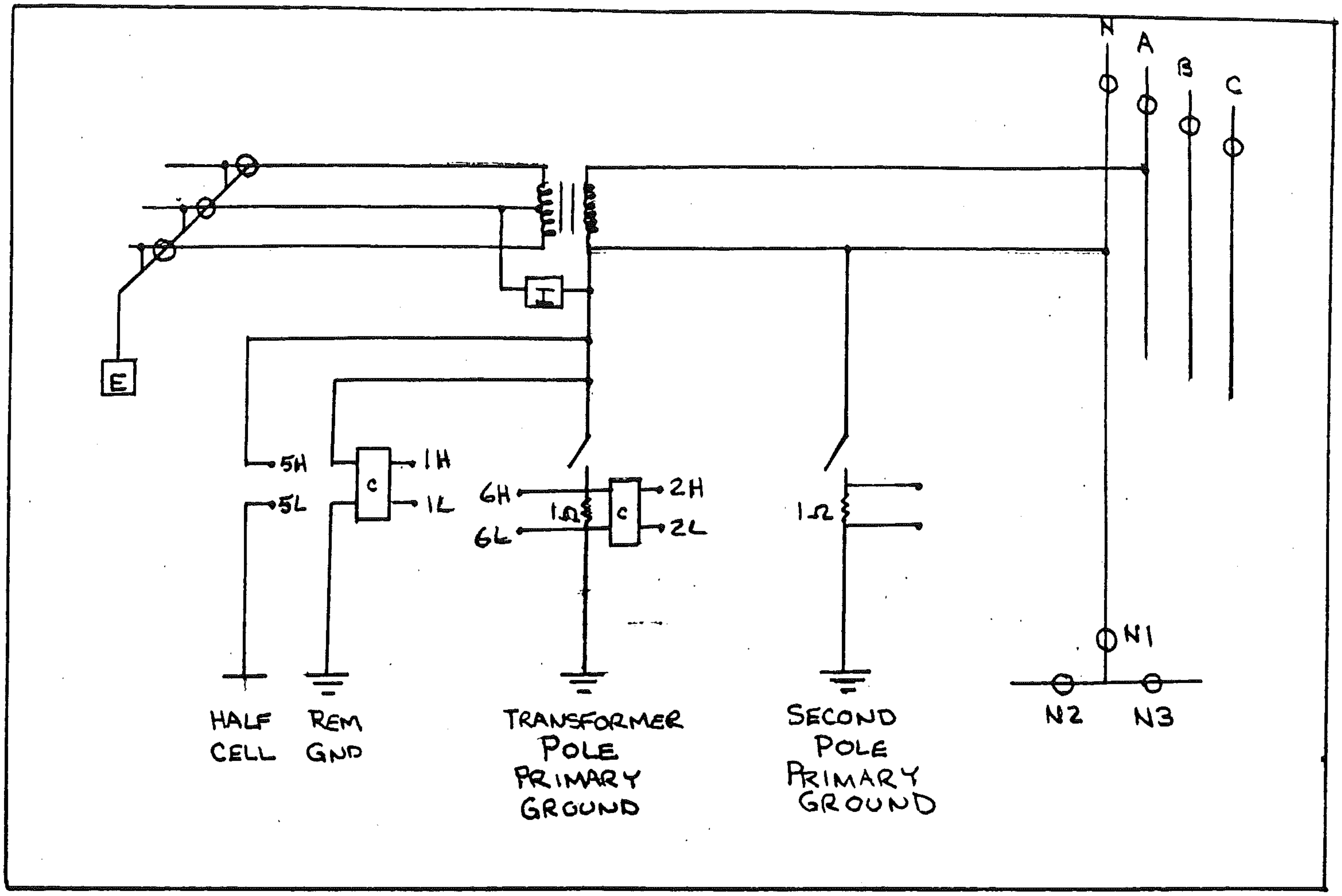


Figure E3
Measurement schematic, primary system electrical quantities.

Abbreviations:
#H = data logger differential input channel number/high
#L = data logger differential input channel number/low
MM = multimeter measurement
O = current measurement using clamp-on ammeter
c = converter, true rms Vac to Vdc
E = energy monitor
I = isolator
N = primary neutral conductor
A, B, C = primary phase conductors
N1, N2, N3 = three neutral conductors a mile west of farm

Data Logger Channels:
CH#1 = mVac primary neutral to remote ground
CH#2 = mAac primary neutral to transformer pole ground using 1 ohm shunt
CH#5 = mVdc primary neutral to remote ground (half cell)
CH#6 = mAdc primary neutral to transformer pole ground using 1 ohm shunt

ceramic plug which allowed the $CuSO_4$ solution to saturate the ground completing the connection. Use of the half cell as a ground connection reduced the variation in the contact potential at this point.

4. mAdc, PN to TRA GND. Milliamps dc in the transformer pole primary ground wire (when connected). The dc voltage measured across the 1.0 ohm series resistor provided a direct measure of the dc current. This parameter was also recorded on the strip chart when the ground wire was connected.

5. mAac, PN to 2ND GND. Milliamps ac in the 2nd pole primary neutral ground wire. Because of the distance involved it was impractical to record this measurement using the data logger. Daily multimeter measurements were made of this current and the ground wire current in the transformer pole ground to establish a correspondence. In actuality, the ground rod resistances changed so much over the length of the test that this correspondence may be meaningless. The resistance change was attributed to thawing of the ground.

Electric power demand by the test farm was monitored using a Dranetz 808 Electric Power/Demand Analyzer (SN 137191098). In order to access the phase wires and neutral of the secondary system at the transformer pole, a loop of these three conductors was dropped from the transformer. Current clamps were installed around the two phase wires and voltage connections were made to the phase wires and secondary neutral for input into the analyzer. The instrument was programmed to print the instantaneous power demand of the farm (including the instrumentation van) and power factor each 15 minutes. An electrical use summary was also printed each day at midnight.

Measurements on the Distribution System

Monitoring of currents in the conductors of the distribution system was provided by Ottertail Power Company. A total of 15 self-contained current measuring/recording devices were installed; these devices were programmed to measure and record the instantaneous ac current with a resolution of one amp every five minutes. These devices were removed near the middle and at the end of the test for data transfer to disk. Current monitoring was provided for:

1. Three phase conductors and the neutral of the test farm distribution line just prior to the single phase feeder supplying the test farm.

2. Three neutral conductors at the corner one mile west of the test farm. At this point the test farm three-phase line from the Parkers Prairie Substation arrives from the east and ends at an open switch, a three-phase line from the Carlos Substation arrives from the south and turns west to supply the town of Miltona. The three legs at this intersection share a common neutral conductor which is not switched.

3. Three phase conductors and the neutral of the test farm distribution line coming out of the Parkers Prairie Substation.

4. Three phase conductors and the neutral of the distribution line coming out of the Carlos Substation.

In addition, load data for the four nearest substations were provided. Runestone Electric Association furnished 15 minute load data for its Belle River and Carlos substations; this data was collected over a telecommunication SCADA link. Ottertail Power Company provided 15 minute load data for its Parkers Prairie and Carlos substations. This data was measured using instruments installed by Cooperative Power Association specifically for the test. Downloading of this data to disk was done halfway through the test and at the end.

Hourly load data from bulk power substations at Alexandria, Henning and Brandon were provided. These substations feed the 41.6 kV transmission line serving the distribution systems near the test farm.

B3. Quality Control

The quality of the data recorded in the barn and at the transformer pole was determined by audits using a high quality multimeter (Fluke 27). The multimeter was submitted to an independent testing laboratory which specialized in calibrations of this manufacturer's multimeters both before and after the test to determine its accuracy. Results are presented elsewhere; the meter exceeded it's stated accuracy on all functions.

Weekly during the test the multimeter was used to formally audit all measurements being recorded by the data loggers. No malfunction of instruments was noted. The multimeter was also used informally on a daily basis to check operation of the systems.

Prior to installation in the field the data acquisition boards in the data loggers were calibrated using a known voltage source and a calibrated multimeter to insure that these boards were operating within their stated accuracy limits. A calibration of the ac-to-dc converters established their accuracy to within 5%. The ac milligauss meter was calibrated using a long solenoid device and determined to be accurate to within 3%.

C. Miscellaneous and Special Tests

C1. Ground Rod Resistance Measurements

The resistance of the ground rods used in this test was measured at the start and the end of the test. An in-circuit tester was used by Ottertail Power Company personnel to make the measurements. The results are as follows:

Ground	3/15/93	4/16/93
transformer pole primary	53 ohm	10
transformer pole secondary	21	20
2nd grounded pole	600	300
barn egs ground	112	
meter pole ground	83	
test remote ground	20	

C2. Secondary Phase Voltage Waveforms

Upon installing the BMI 8800 Power Quality Monitor in the barn, a harmonic analysis was performed to determine the frequency content of the farm's secondary system voltage. The spectrum indicated an odd numbered harmonic content somewhat higher than was expected. In order to determine if this harmonic distortion was present throughout the farm's secondary system as expected, a series of waveforms were recorded. A Tektronix 222 Digital Storage Oscilloscope (Serial Number B015154) was used to capture and store four line-to-neutral waveforms. These were uploaded to a Halikan LA3540 Laptop Computer using a Tektronix Virtual Instrument Software System, then printed.

The waveforms represented below are line-to-neutral voltage waveforms representing:

1. P1-N at transformer pole.
2. P1-N at the test stall in barn.
3. P1-N in milk room.
4. P2-N at the test stall in barn.

It was concluded that the distortion was farm-wide.

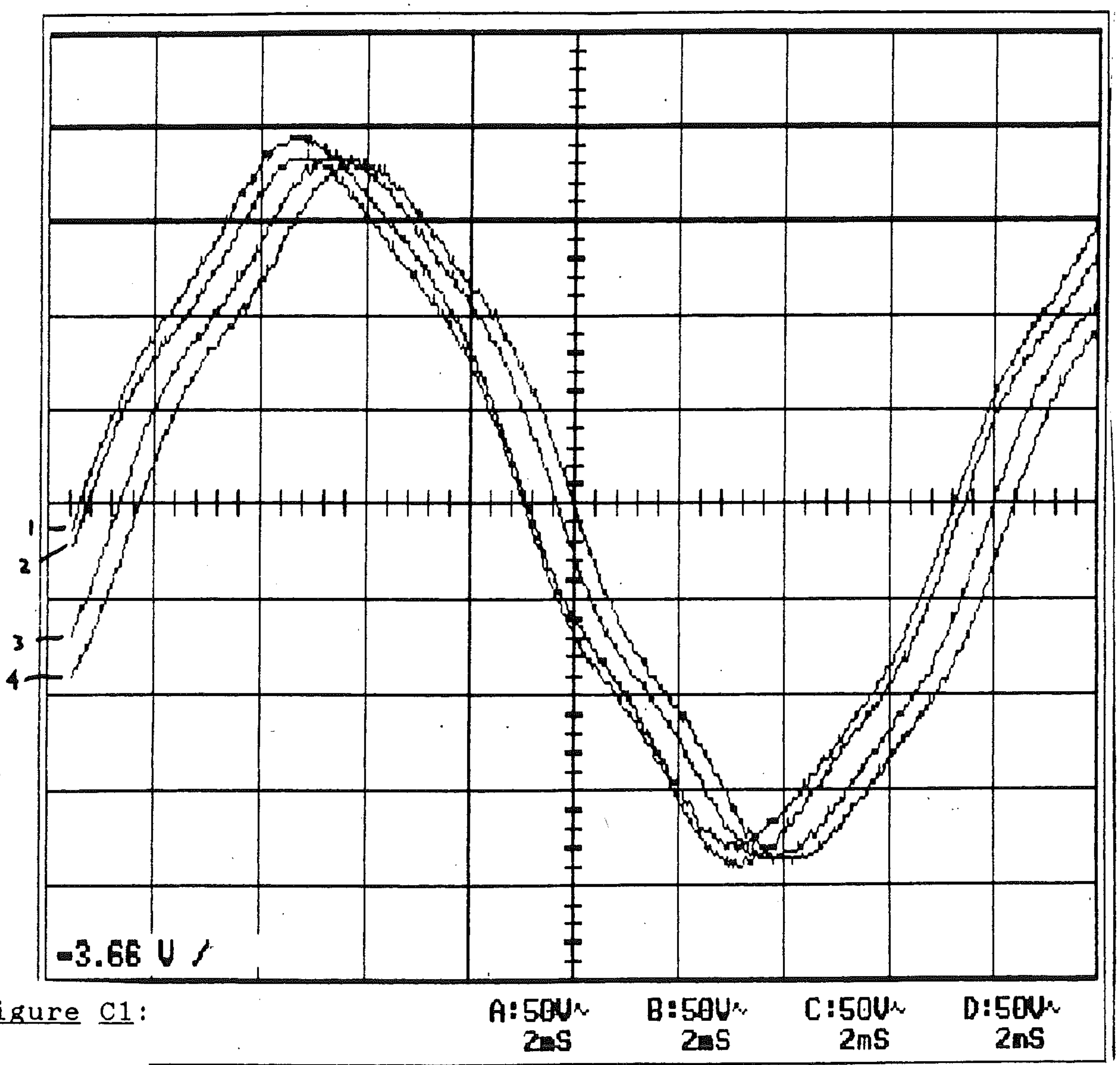


Figure C1:

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C3. Cow Contact Voltage Waveforms

The Tectronix 222 Digital Storage Oscilloscope was used as in Section C2 to record sample voltage waveforms across the pairs of cow contact points used for continuous monitoring in the barn. The following figures present these waveforms. At bottom center of each figure are two numbers. The top number is the number of millivolts per division vertically. The bottom number is milliseconds/microseconds per division horizontally. A caption identifies the contact points.

Note that none of these waveforms are pure 60 Hz sine waves. These illustrate the need to use a true-rms instrument when measuring ac voltages on cow contact points.

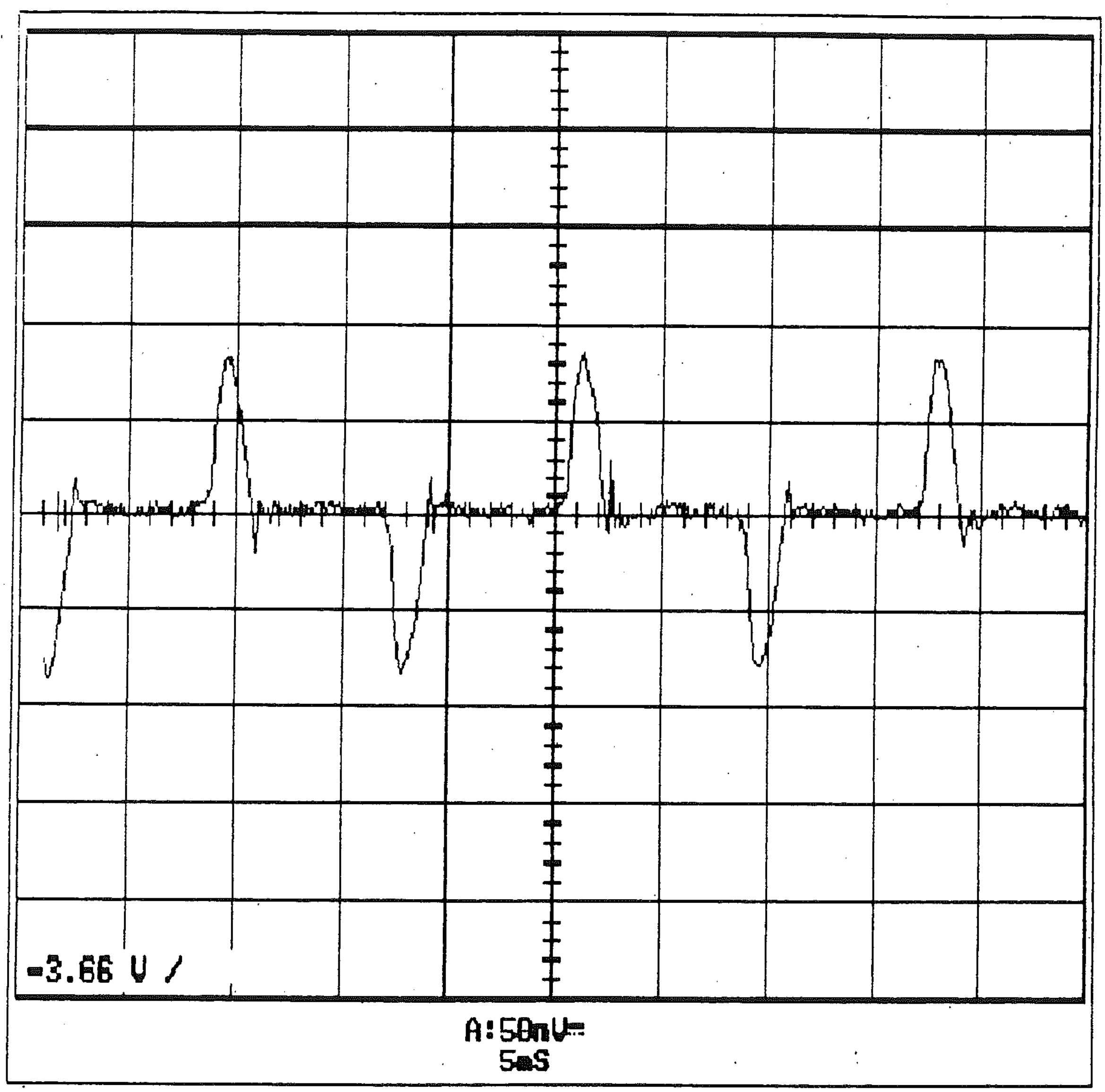

Figure C2: Water line to rear hoof voltage waveform.

C4. Power Quality Special Tests

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C5. Electrical System Impedance

On the last day of the test (4/16/93) measurements were made to determine the impedance of the primary and secondary neutral-ground systems as seen from the test farm transformer pole. The procedure is described in Minnesota Utility Stray Voltage Guidelines, Appendix B4. It involved measuring the ac voltage between the primary neutral and a reference ground with and without a 10 HP load and with and without the primary and secondary neutrals connected. These measurements were made three times and the averages used to calculate the impedances. They were:

Z_c = Equivalent neutral to earth impedance with the primary and secondary neutrals connected
= 1.46 ohm

Z_{ps} = Equivalent primary neutral to earth impedance with the primary and secondary neutrals disconnected
= 1.89 ohm

Z_{ss} = Equivalent secondary neutral to earth impedance with the primary and secondary neutrals disconnected
= 6.53 ohm

C6. TERF Equipment Calibration and Testing

The test protocol required that TERF current-measuring instruments be calibrated by an independent laboratory before or after the test. Swain ac and dc ammeters were available for continuous measurements in the barn. The dc current measurement was not made for reasons described in Section B1, Continuous Measurements. The ac ammeter was used to measure mAac between the water line and gutter chain. This measurement was recorded on channel 6 of the data logger and as the red trace on the strip chart recorder.

Immediately after the test, the Swain ac amperes meter, its 5" ac clamp and signal rectifier were delivered to an independent laboratory for calibration according to instructions furnished by the test supervisor. Some weeks later, the laboratory returned the instruments, stating that they could not complete the calibration because the manufacturer would not agree to supply them with unspecified information they deemed necessary to perform the calibration. By mutual agreement between TERF and utility representatives, the calibration was made by the test supervisor.

Various currents in the range 0.10 mA to 100 mA were generated using a variable transformer and a series of resistors. The transformer output was checked for waveform distortion with an oscilloscope and judged to be sinusoidal. The currents were measured directly with a calibrated Fluke 27 multimeter using its current input terminals. The currents were simultaneously measured using the Swain ammeter; the input current, meter and rectifier meter readings and the rectifier Vdc output were recorded. See the following page for the results. Generally, the Swain ammeter was shown to be accurate to within about two percent (excluding two outlying points, 3.6% and 5.8%) for currents larger than one milliamp. Below that current, the meter reading and rectifier output erred increasingly.

During the test a feature was noticed in the strip chart trace of the Swain ammeter output. Occasionally, sometimes a few times an hour, a spike would occur in the trace as if a voltage spike produced a transient current between the water line and the gutter chain. An effort was made to identify the cause of this spike. The clamp was removed from the wire between the two points; the spike still occurred. Then it was postulated that the spike was magnetically induced by a transient current elsewhere in the barn. The clamp was placed in different orientations and locations, on the floor for instance. The chart spike still occurred. After the test, the ammeter and strip chart were tested elsewhere (author's basement) and the spike still persisted. Further examination revealed that the meter batteries were weak, contrary to the Test Battery indication built into the meter. This function was faulty. Upon installing fresh batteries, the spikes did not occur again. The low battery condition seemed not to have a noticeable effect on meter accuracy however.

CALIBRATION PROCEDURE

Swain 5" AC Clamp (SN 1830A)
Swain AC Amperes Meter (SN 1830)
Swain Signal Rectifier (SN 1952)

- Connect clamp to "AC AMP CLIP" input on meter.
- Connect meter "SCOPE" output to "INPUT" of signal rectifier.
- Mechanically zero meters.
- Clean clamp lips with a clean, dry cloth.
- Turn both meters on.
- Record TB (test battery) meter readings.
- Set rectifier range to "0.1".
- Install clamp axially and centered around a straight wire carrying a known current.
- Provide 60 Hz pure sine wave currents (known to +/- 1%) and record meter readings and Vdc output.
- Note calibration sheets for Fluke 27 Multimeter, SN4400256, used to measure inputs and outputs.

Meter TB (test battery) reading 98%
Rectifier TB (test battery) reading 93%

Meter Range	Fluke Iac(mA) Input	Iac(mA) Meter	δ%	Iac(mA) Rectifier Meter	δ%	Fluke Vdc(mV) Output	δ%
.01	0.10	0.10	0	0.10	0	14.0	40
	0.18	0.20	11.1	0.19	5.6	22.7	26.1
	0.30	0.32	6.7	0.30	0	33.5	11.7
	0.37	0.40	8.1	0.37	0	41.2	11.4
	0.46	0.49	6.5	0.45	-2.2	47.9	4.1
	0.56	0.59	5.4	0.54	-3.6	57.8	3.2
	0.85	0.89	4.7	0.85	0	86.5	1.8
	1.00	1.00	0	0.98	-2.0	99.0	-1.0
	1.78	1.79	0.6	1.75	-1.7	179.5	0.8
	3.75	3.79	1.6	3.76	0.3	378	0.8
	5.65	5.72	1.2	5.72	1.2	571	1.1
	8.32	8.28	-0.5	8.38	0.7	844	1.4
	9.99	9.92	-0.7	10.0	0.1	1017	1.8
.1	9.97	10.0	0.3	9.4	-5.7	97.0	-2.7
	17.8	17.8	0	17.0	-4.5	177.4	-0.3
	36.3	36.3	0	36.9	1.7	376	3.6
	53.5	53.6	0.2	53.8	0.6	566	5.8
	83.7	83.0	-0.8	84.0	0.4	843	0.7
	97.8	97.0	-0.8	98.5	0.7	985	0.7

Signed: Riley C. Hawkinson Date 5/19/93

D. Distribution System Description

Bulk power is supplied to the area via a 41.6 kV transmission line linking bulk power substations at Henning to the north and Alexandria and Brandon to the south. Figures D1 - D3 are system schematics with the transmission system highlighted.

The distribution system serving the test farm is owned and operated by Ottertail Power Company of Fergus Falls, MN. It is a three-phase wye distribution system which has, in addition to the three phase conductors, a multigrounded neutral conductor which with the ground itself carries the net unbalanced current back to the substation. The line voltage is 12.5 kV line-to-line (between phase conductors) and 7.2 kV line-to-ground (between each phase conductor and ground).

Figure D4 is a map showing the route of the distribution line from its substation in Parkers Prairie (top of figure) to the test farm (right center). Figure D5 is a schematic which shows the electrical components of the system. In Figure D4 the 41.6 kV transmission line corridor is shown running north/south past the towns of Parkers Prairie and Carlos. Both the Parkers Prairie Substation and the Carlos Substation are supplied by this transmission line. Note the location of the open switch #924 terminating the Parkers Prairie line just west of the test farm. In the event of a fault in the system, this switch and others could be altered in order to supply customers from the Carlos substation. The Carlos distribution line is not shown highlighted but runs east from the Carlos Substation to Carlos and Bell River Store, then north past the open switch #924 and east to Miltona. Only the neutral conductors are connected at the switch. No changes were made to the power flow path during the test.

Figure D5 also shows the location of fixed capacitor banks at four locations along the distribution line. These capacitor banks together with switched capacitor banks at the substation balance the inductive load on the system thereby correcting the power factor and maintaining the line voltage within specified limits. Automatic switching of capacitor banks at substations has been suggested as one source of transient voltages which may contribute to stray voltage problems on farms. At the conclusion of the test it was reported to the test supervisor that the Parkers Prairie Substation capacitors had not switched for nearly two years including the test period. The capacitors at the Carlos Substation were reported to have switched three times since the previous September but not at all during the test period.

During a tour of the distribution line the test supervisor determined which phases were used for supplying electricity to neighbors of the test farm. Figure D6 shows the distribution line phase allocation for customers along the first four miles of line from the test farm. Beyond Rose City the phases were rolled (reordered) several times, precluding further investigation.

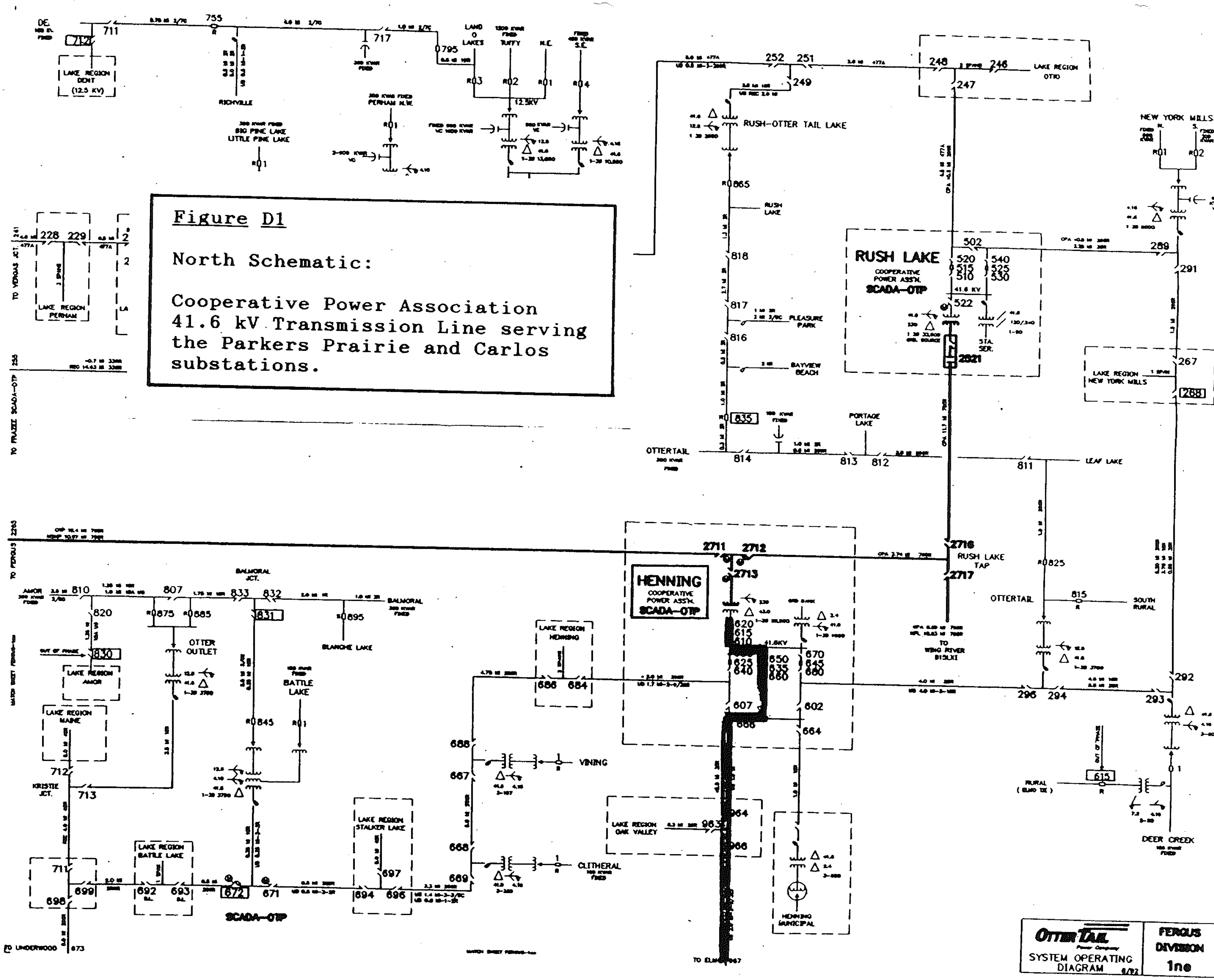


Figure D1

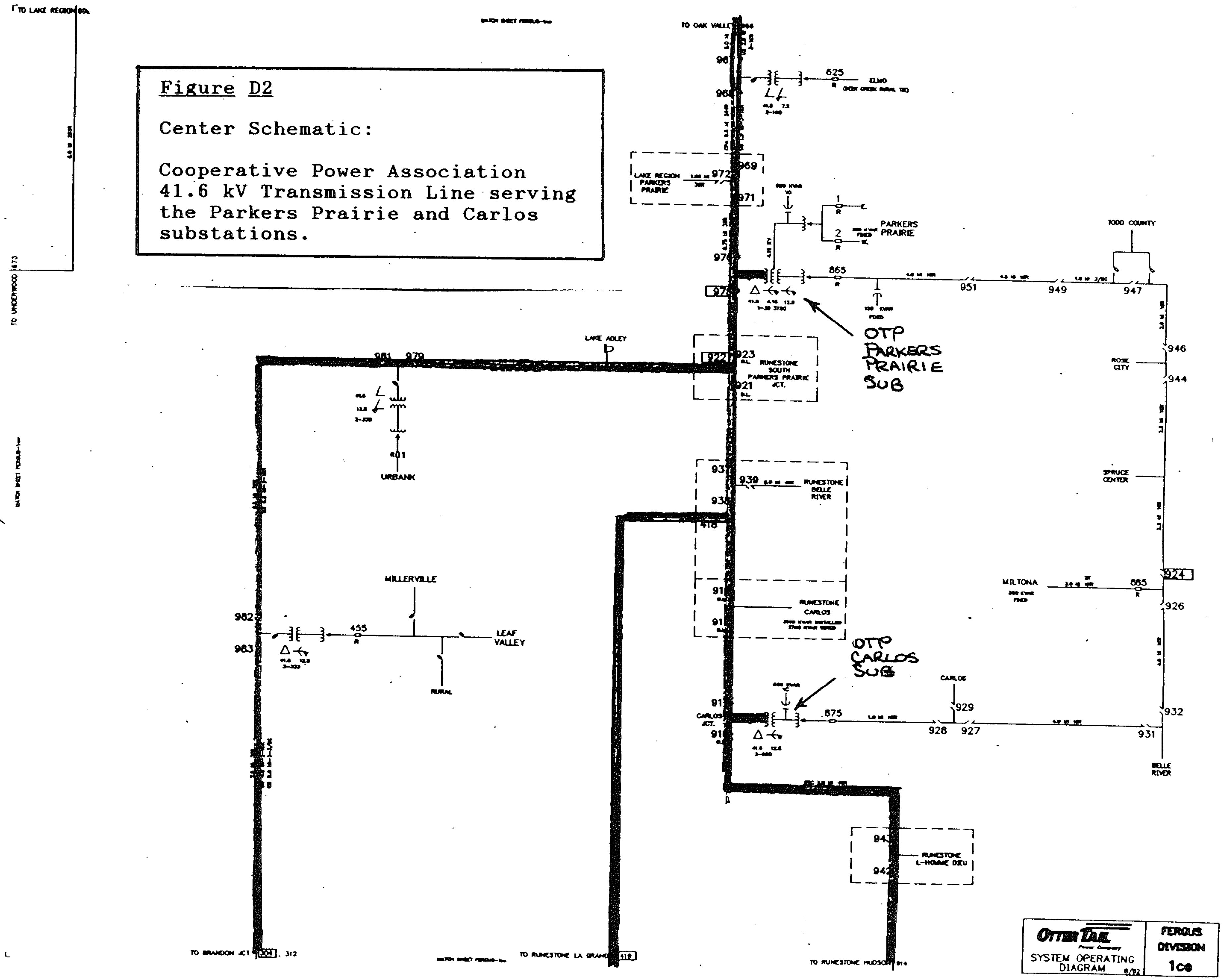
North Schematic:

Cooperative Power Association 41.6 kV Transmission Line serving the Parkers Prairie and Carlos substations.

Figure D2

Center Schematic:

Cooperative Power Association 41.6 kV Transmission Line serving the Parkers Prairie and Carlos substations.



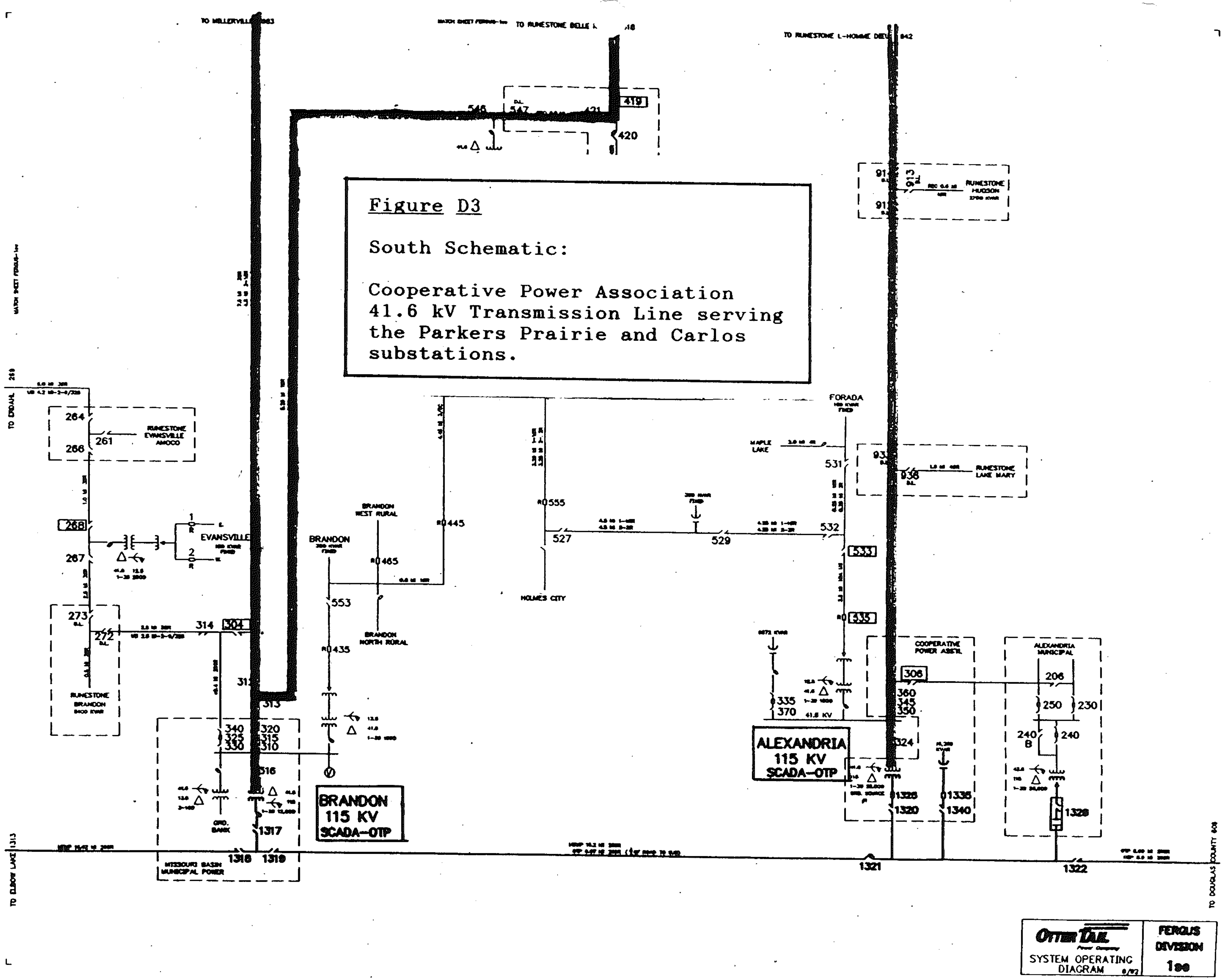


Figure D3

South Schematic:

Cooperative Power Association 41.6 kV Transmission Line serving the Parkers Prairie and Carlos substations.

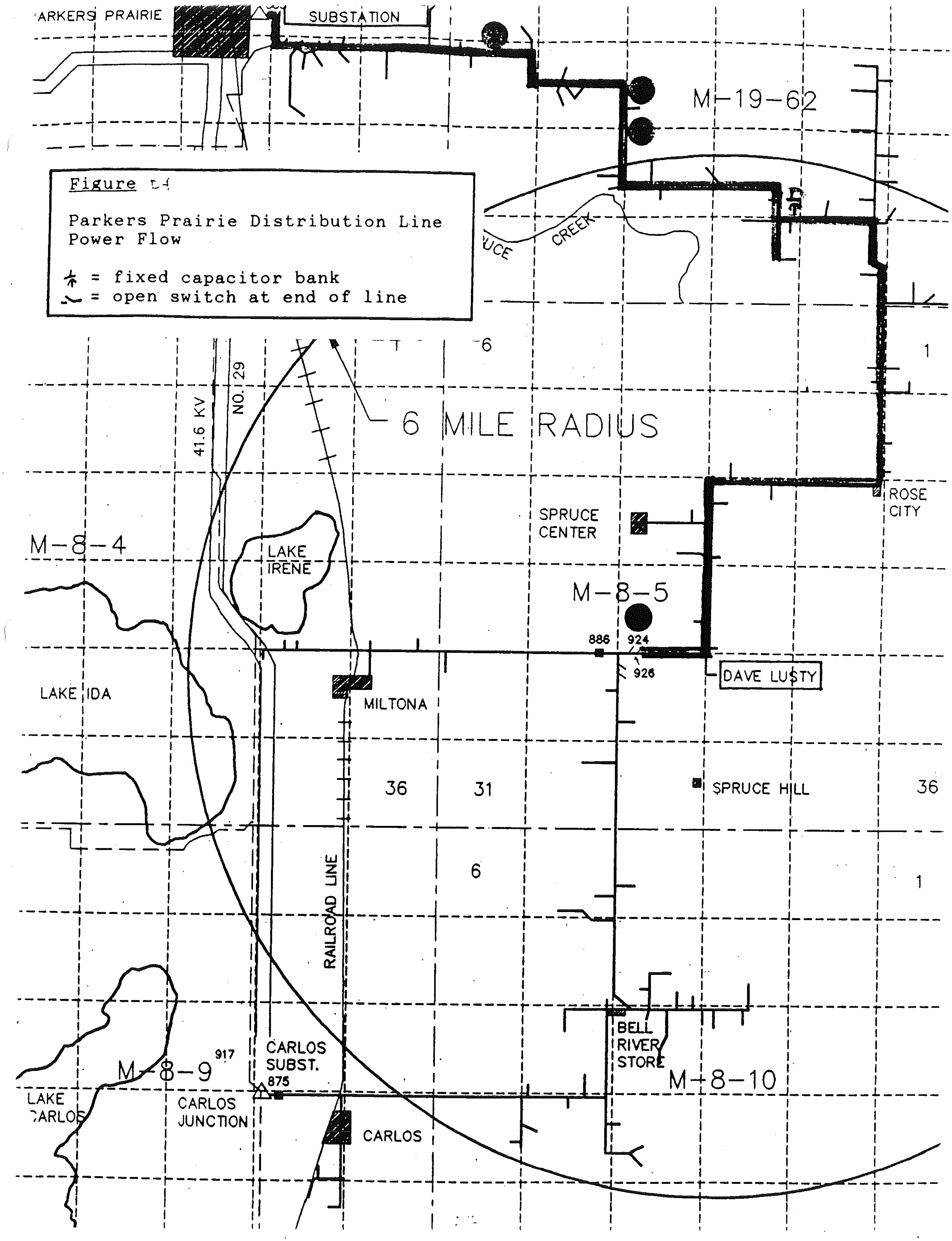


Figure D-4

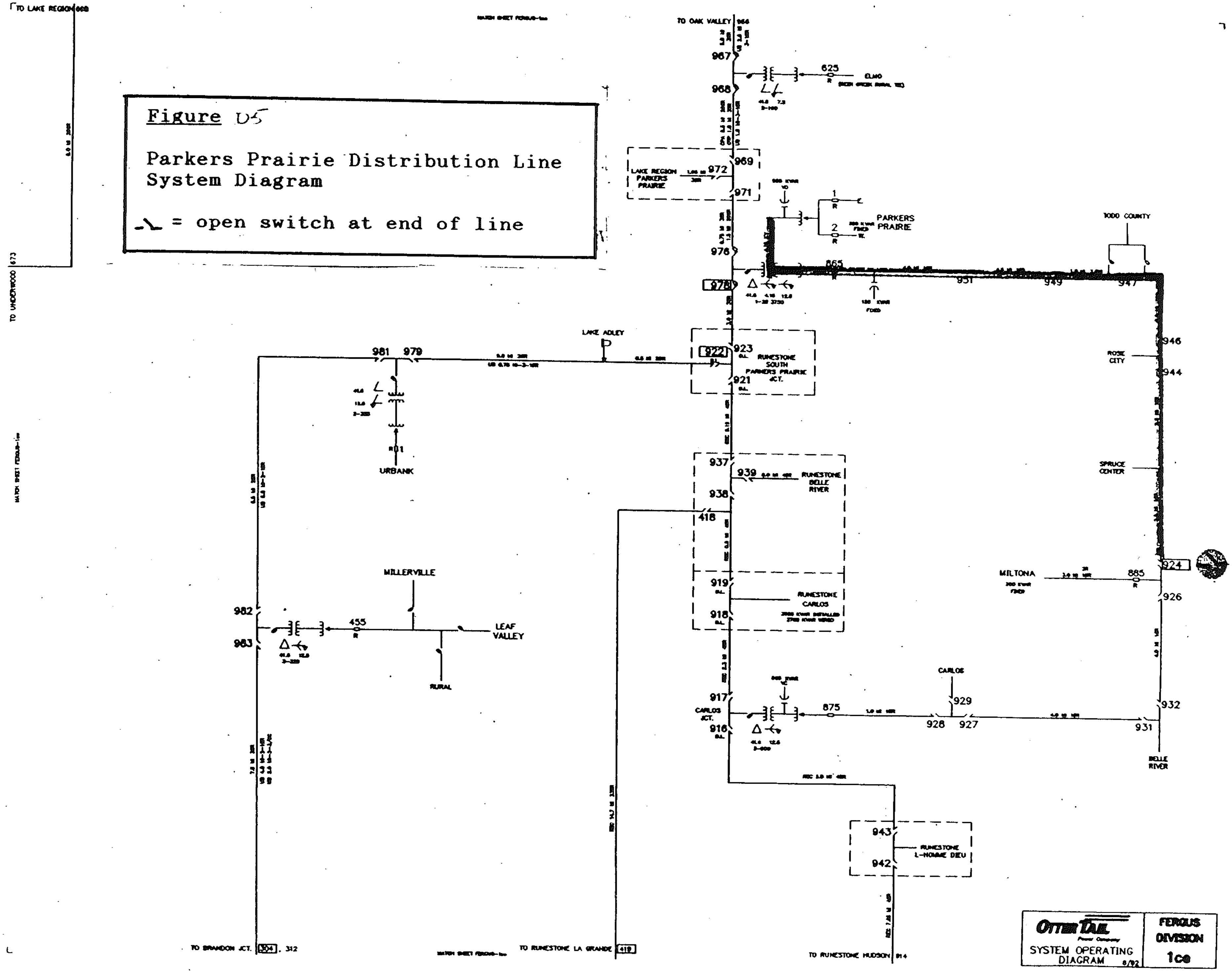
Parkers Prairie Distribution Line Power Flow

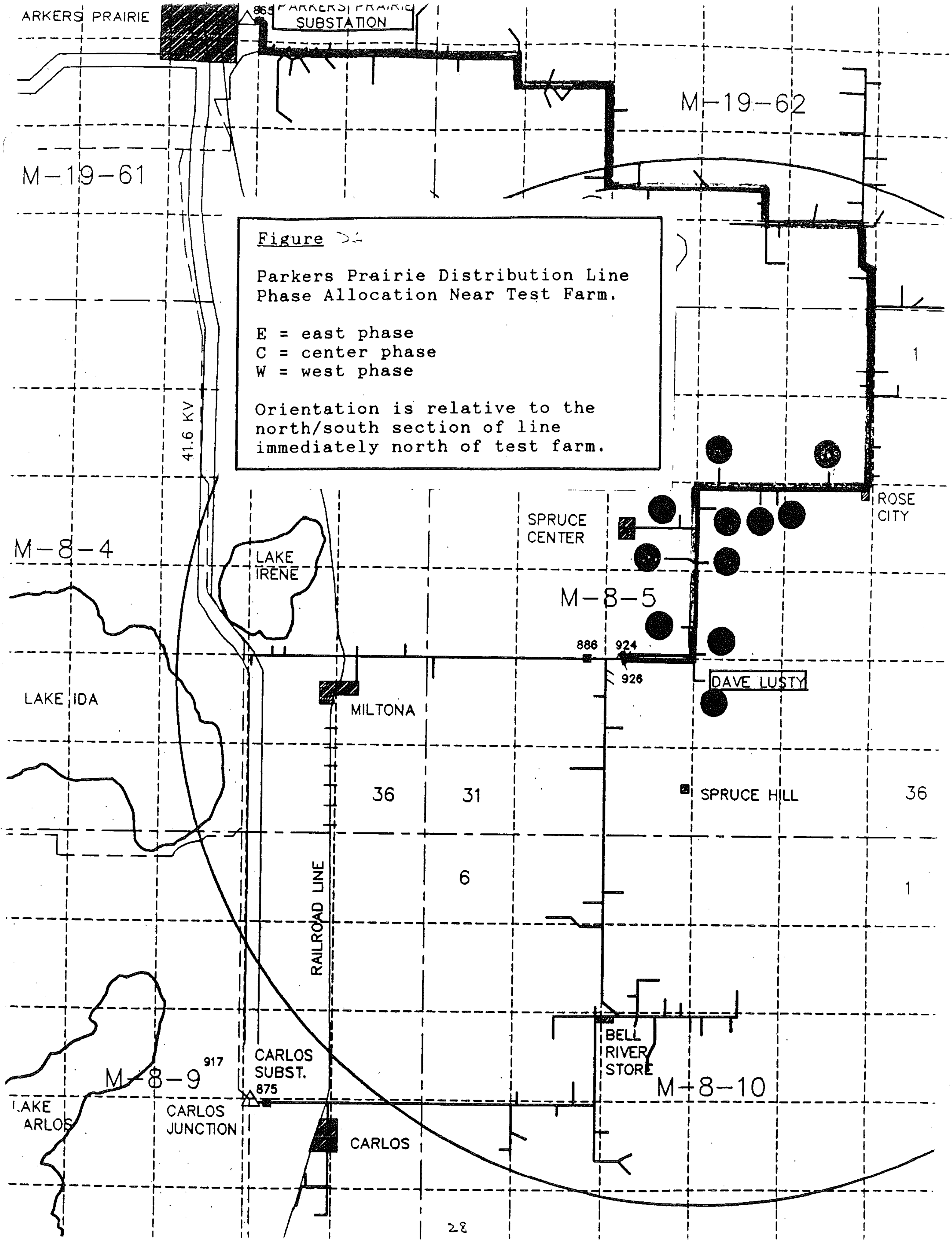
- = fixed capacitor bank
- = open switch at end of line

Figure D5

Parkers Prairie Distribution Line System Diagram

= open switch at end of line





Figure

Parkers Prairie Distribution Line Phase Allocation Near Test Farm.

E = east phase
C = center phase
W = west phase

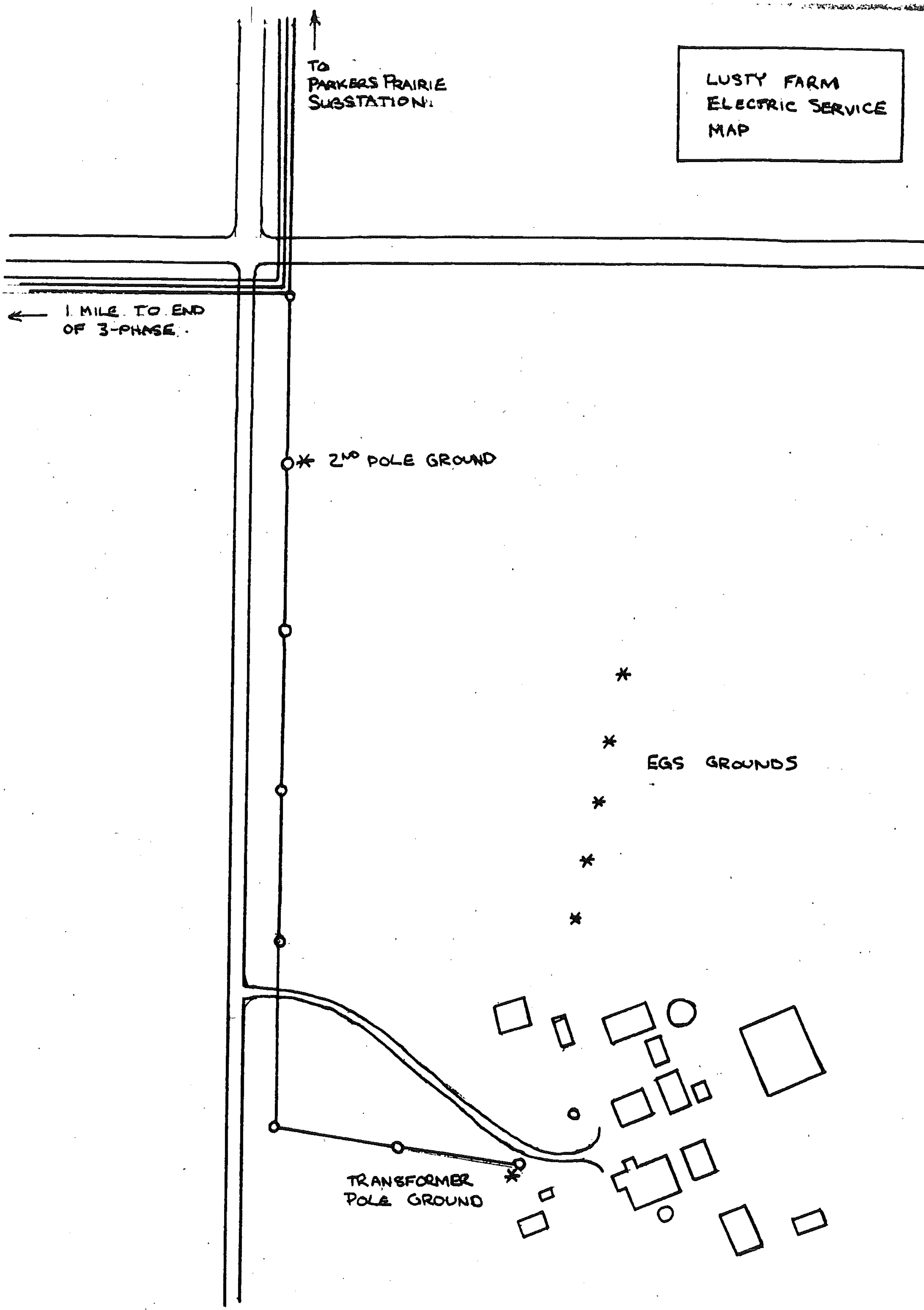
Orientation is relative to the north/south section of line immediately north of test farm.

Appendix

1. Diagram of Farm Yard Buildings, Ground Rods

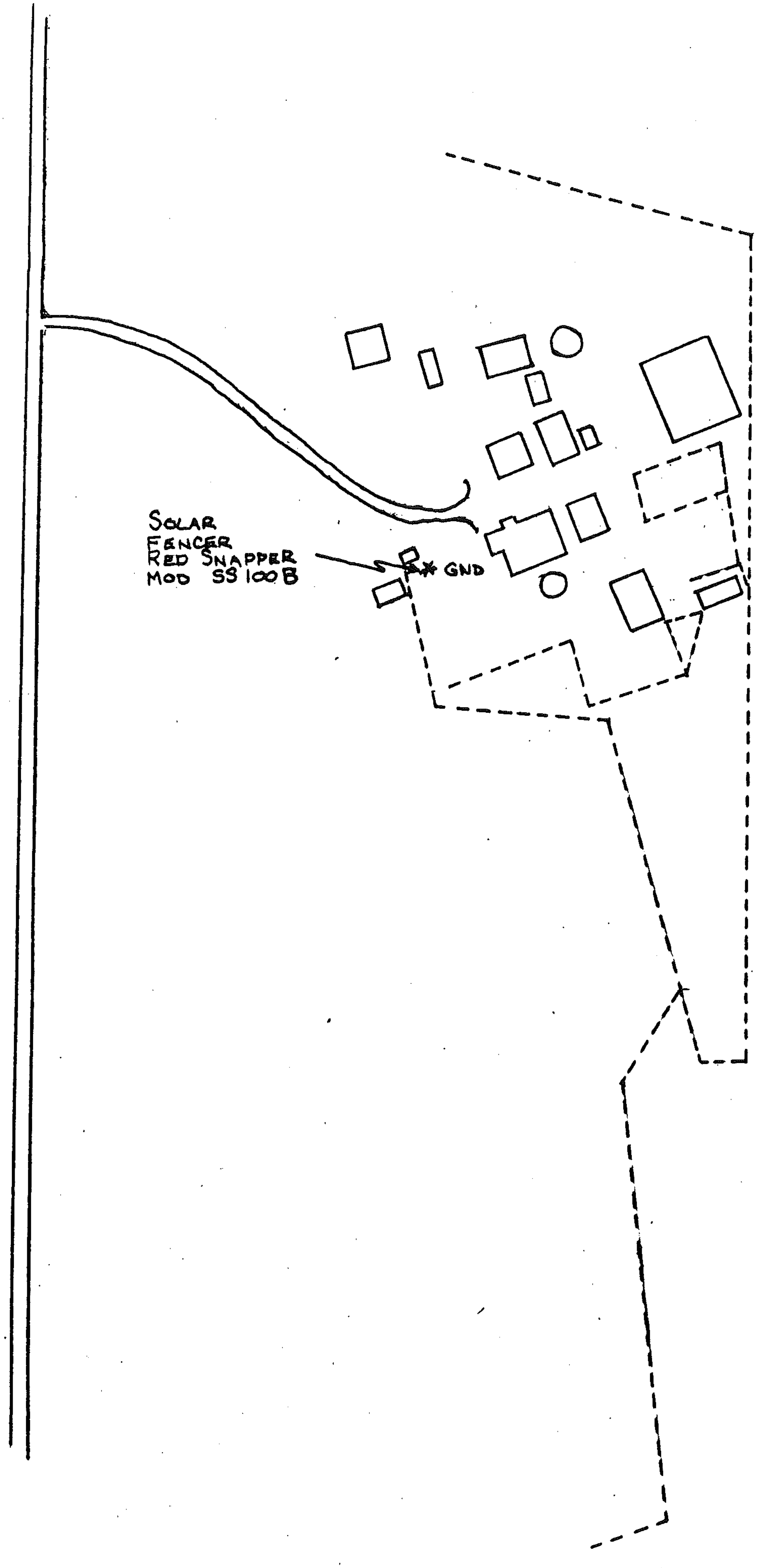
2. Diagram of Farm Distribution Feeder

3. Diagram of Farm Electric Fence



TO
PARKERS PRAIRIE
SUBSTATION
LUSTY FARM
ELECTRIC SERVICE
MAP
1 MILE TO END
OF 3-PHASE
2ND POLE GROUND
EGS GROUNDS
TRANSFORMER
POLE GROUND

LUSTY FARM: ELECTRIC FENCE MAP



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