Monitoring on-farm electrical power quality

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Licsko, Z.J., Leonard, J.J. and Koval, D.O. 1992. **Monitoring on farm electrical power quality**. Can. Agric. Eng. **34**: 239-245. A total of 23 farm sites across Alberta were monitored for two week periods to determine the frequency, severity and types of voltage disturbances occurring in their electrical power systems. Monitoring was carried out using a recording voltage monitor which was used to detect line-neutral disturbances on 120 volt circuits. Neutral-ground disturbances also were monitored at 10 sites. Sags, outages and undervoltages were recorded at 91% of sites; fast transients at 61% of the sites; surges and overvoltages at 30% of the sites; and frequency deviations at 26% of the sites.

Vingt-trois fermes situées en Alberta ont été étudiées durant des périodes de deux semaines pour déterminer la fréquence, la sévérité et la nature des perturbations de tension qui se produisent dans leurs systèmes électriques. Un moniteur-enregistreur de tension était installé pour détecter les perturbations de tensions entre les conducteurs neutre et sous tension des circuits 120 volts. Les perturbations entre le conducteur neutre et le conducteur de mise à la terre ont aussi été enregistrées dans 10 fermes. Des variations rapides de tension, pannes et baisses de tension ont été observées dans 91% des fermes, des tensions transitoires rapides dans 61% des fermes,des ondes de surtension et des surtensions dans 30% des fermes, et des variations de fréquence dans 26% des fermes.

INTRODUCTION

As in other fields, the use of computers and microelectronic devices in agriculture continues to expand. Agricultural applications of electronics include mobile electronics and farmstead electronics. The former group includes machinery monitors and control electronics, whereas the latter group covers environment control, dryer controls, feed milling and distribution control, monitoring systems, and data management computers. Depending on their power source, electronic controls for irrigation systems could be included in either group.

Farmstead systems generally are powered from AC circuits which may be shared with other farm equipment and which are supplied by a utility distribution line. These systems, and the quality of their power supplies, were the focus of this research.

Farm electronic systems may be threatened by power supply disruptions that arise from a number of sources. Firstly, there are usually numerous electric motors and other inductive loads on farms. The operation of this equipment may generate voltage disturbances great enough to damage electronic equipment. Secondly, as the distance from primary distribution transformers increases, there is greater likelihood of voltage sags and outages occurring. Finally, rural area supplies are generally more at risk than urban areas to the interruption of electrical power by lightning strikes.

This potential for damage to electronic equipment from the above problems is widely recognized. However, there is a lack of quantitative data on the severity and the extent of these problems. To date, this lack of data has not been felt in an acute manner because farmstead electronic systems have not been widespread. However, this situation is changing and information is required:

- To facilitate the rational design and specification of electronic systems for rural use.
- To identify problem areas in the design of farmstead electrical equipment and systems.
- To identify any problems in the electrical power distribution system at the farm level.
- To promote an understanding and awareness of the effects of power supply problems in farmstead electronics.
- To facilitate the selection and design of power supply protection devices for use with on-farm electronic equipment.

The objective of the work reported in this paper was to obtain general data on the nature and frequency of voltage disturbances.

SITE SELECTION

The project was designed to monitor power at a wide variety of sites. Not only were different types of farm enterprise sought, but also it was desirable to monitor at different times of the year due to the seasonality of some enterprises. Twenty three sites across Alberta were identified on the basis of information obtained from utility companies, Alberta Agriculture, and through responses from newspaper articles on the research project. Each of these sites was monitored for approximately two weeks. Details of site locations and monitoring dates are given by Licsko et al. (1990).

At each site, a preliminary evaluation was carried out to ascertain the nature of connected loads, their usage patterns, and the age and condition of wiring. Cooperating farmers were encouraged to keep logs of electrical equipment use to help identify causes of any disturbances recorded.

EQUIPMENT AND PROCEDURES

A recording voltage monitor (BMI 4800 Powerscope, Basic Measuring Instruments, Foster City, CA) with one channel was used for monitoring the line-neutral voltage on 120 V on-farm circuits. A second channel for monitoring neutral-ground voltage was added to the instrument for the last ten monitoring sites. The instrument was set to record disturbances when voltage or frequency levels on monitored circuits exceeded threshold values. Also, voltage waveshape disturbances were recorded if the voltage sine wave differed by more than 20% from a previous wave for a duration of 0.1 cycles. A line impedance value of 50 ohms was selected arbitrarily for estimating the energy levels of any impulses that were recorded. Normally, the limits were set at the following values:

Line-Neutral Thresholds

Surge voltage:	125.0 V_{rms}
Sag voltage:	108.0 V_{rms}
Impulse:	200 V_{peak}
High freq noise:	10.0 V_{peak}
High frequency:	60.6 Hz
Low frequency:	59.4 Hz

Neutral-Ground Thresholds (recorded at last ten sites)

Surge voltage:	10.0 V_{rms}
Impulse:	100 $V_{peak\text{-}to\text{-}peak}$
High freq noise:	10.0 $V_{peak\text{-}to\text{-}peak}$

Threshold values of 125 V_{rms} for surges and 108 V_{rms} for sags correspond to established standards (CSA 1983). These limits were used for most of the sites monitored. However, to accommodate site conditions, several sites required that either the surge or sag limits be changed.

The terminology used in this paper is consistent with that of McEachern (1988). Thus, in the above discussion, sags were considered to be low voltage disturbances lasting between 16 ms and 2s. Low voltage conditions that persisted for longer than 2s were termed undervoltages or outages. Similarly, surges were high voltage conditions lasting for l6ms to 2s and overvoltages persisted for longer than 2s. Disturbances lasting for less than 16ms were termed impulses or electrical fast transients.

SITE CHARACTERISTICS

Since the installed electrical equipment and its usage patterns were related to many of the voltage level disturbances recorded during this study, a brief discussion of the load profile for each type of enterprise monitored is useful in interpreting the monitoring results. In the description and tables that follow, sites are grouped according to the general type of enterprise and features of the load profiles are listed for each group.

All single-phase services provided 120/240V and, unless identified otherwise, three-phase services were "Y" (star) connected and provided 120/208V. Where three-phase services are identified as having a four-wire, open delta configuration, 120/240V were available in addition to a 208V single phase.

The first group consists of the hog farrow-to-finish operations for which the general site characteristics are presented in Table I. The load profile for these sites was as follows:

(a) electrical heating lamps in farrowing crates and sometimes in weaner rooms. Also, some electric floor heating in farrowing rooms and weaner rooms.

Table I: Hog farrow-to-finish sites

Site #	Size and type of operation	Service entrance
4	260 sows	50 kVA single phase
7	100 sows/grain	25 kVA single phase
15	50 sows/grain	25 kVA single phase
20	190 sows/grain	50 kVA single phase

(b) all four farms ground their own feed using mill motors ranging from 4 to 8 kW in size;

(c) other large loads (intermittent use) included: manure pumps (2 to 5 kW), feed blower (4 kW) and pressure washer (4 kW);

(d) numerous fractional kilowatt motors for feeding, watering, heating and ventilation systems;

(e) three of the hog farmers were also grain farmers (sites 7, 15 and 20). Therefore, large loads such as grain dryer fan motors (6 kW), aeration fan motors (3 kW) and augers (up to 8 kW) were added to the load during fall harvest.

The general characteristics of the beef feed lots that were monitored are given in Table II. The load profile of these sites was as follows:

(a) large single phase motors, 6 to 19 kW in size. Eight to 19 kW motors were supplied from a phase converter or from a three-phase service. Typical loads were elevator legs, silo unloaders, feed mills, augers, compressors and washers. One farmer (Site #16) was having three phase power installed to provide power for a grain handling system being built on the farm. Most motors were used intermittently.

(b) electrically heated stock waterers.

Table II: Beef feed lots

Site #	Size and type of operation	Service entrance
3	Feedlot/4000 head	Two 25kVA single-phase
12	Feedlot/1000 head	7.5, 27.5, & 35 kVA single-phase
16	Feedlot/1000-3000 head	15 kVA three-phase
23	Feedlot/1500 head	15, 15 & 5 kVA single-phase

Table III shows the characteristics of the poultry operations that were monitored. The load profile of these operations was as follows:

(a) large incandescent lighting loads (6 to 20 kW) on light dimmers operating up to 24 hours per day;

(b) large motors for washers, air compressors, augers and manure pumps (4 to 6 kW), were used only intermittently;

(c) numerous fractional kilowatt motors for feeding, watering, hotwater heating and ventilation;

(d) high voltage electric fences on feed chains.

Table III: Poultry operations: Broiler and layer

Site #	Size and type of operation	Service entrance
2	One turkey brooder barn (3000-5000 bird); one turkey grower barn (3000-5000); one broiler barn (12000) and grain	15 kVA single-phase
5	One layer barn (10000) and grain	25 kVA single-phase
9	Three broiler barns (10000/barn)	50 kVA single-phase
10	One broiler barn (8000); processing plant (7000/day custom killing)	50 kVA three-phase
11	One layer barn (10500); one pullet barn (6000); feed mill and egg packaging equipment	25 & 40 kVA three-phase, 4-wire, open delta
17	One broiler breeder barn; one pullet barn; two layer barns	25 kVA single-phase
21	Four broiler barns; one broiler breeder barn	25 kVA single-phase
22	Layer barn; pullet barn	25 kVA single-phase

The characteristics of the dairy sites monitored are summarised in Table IV and the load profile of these sites was as follows:

(a) several large motors (4 to 6 kW) in use in the morning and afternoon during milking, i.e. compressors and vacuum pumps;

(b) electric fence crowder used at one barn to move towards milking parlour;

(c) Computer-based data acquisition, record-keeping and management systems were installed in both barns. These used transponder collars for animal identification and included various solenoid valves, flow meters and electronic scales.

(d) a mix of incandescent and fluc:escent lighting.

(e) both were also grain farmers with a resulting large seasonal demand for electricity (site #4 had motors up to 19 kW in size as part of a grain handling system);

(f) several fractional kilowatt motors for ventilation, watering, and heating.

Table IV: Dairy farms

Site #	Size and type of operation	Service entrance
4	125 cows/grain	25 kVA three-phase
8	70 cows/grain	25 kVA single-phase

Calibration of the voltage monitor and weather conditions which delayed harvesting in the fall of 1989 resulted in only one grain farm with a grain dryer in use being monitored (Site #18). A second farm which had a large grain farming operation in addition to an 1100 pig feeder operation was monitored after the fall harvest. The characteristics of these sites are shown in Table V.

The load profile for the grain farms was as follows:

(a) large motors in use for grain drying and handling (6 to 11 kW) requiring either three-phase service or the use of a phase converter;

(b) a dryer drive which required an 11 kW motor and a phase converter at site #19. At site #18 an old tractor was used for this purpose.

(c) the load profile for the feeder barns (Site #19) was similar to that of the farrow-to-finish operations.

Table V: Grain farms

Site #	Type of operation	Service entrance
18	Grain	25 & 40 kVA three-phase, 4-wire, open delta
19	Grain/1100 feeder pigs	25 kVA single-phase

Both of the irrigation farms that were monitored had separate three-phase services supplying power for their irrigation pumps and drive motors. Since the monitoring equipment available for this study was incapable of monitoring three-phase power, power was monitored at the farmstead. In both cases, farmstead power was from a separate single-phase distribution line. Service sizes were 7.5 (Site #13) and 10 kVA (Site #14) respectively.

The load profile of these sites was as follows:

(a) air conditioning (Site #13);

(b) normal household loads.

RESULTS

The data obtained from the monitored sites were analyzed and classified using the terminology described earlier. The voltage levels of disturbances, their frequency, cause, and time of occurrence then were summarized. Some editing of the data occurred before an overall summary was completed. This was found to be necessary to prevent electrical problems of a chronic nature from skewing the overall monitoring results.

The chronic problems which appeared at some sites necessitated adjustments being made to the threshold limit values for the line-neutral RMS voltage. An adjustment of the upper limit to between 127-130 V was necessary at six of the farmsteads (Sites #8, #12, #13, #14, #17, and #21). Figure 1 shows a typical 24-hour voltage level summary from one of these sites. The lower voltage threshold limit had to be adjusted to 105 volts at only one of the sites monitored (Site #7). Figure 2 shows a typical 24-hour voltage level summary from this site. Two farmsteads (Sites #4 and #19) also had a chronic problem with impulses and these too, were excluded from the overall summary, unless otherwise noted.

In determining the source of disturbances, the following procedures, listed in order of importance, were used:

(1) a site investigation to determine the cause,

(2) analysis of the farmer's log of activities,

(3) review of the problem with the electrical utility,

(4) reference to published power "signatures" (McEachern 1988)

Sags, outages, and undervoltages

In terms of the number of sites at which they were recorded, sags to between 90 and 108 volts were the most frequently recorded voltage disturbance. The majority of the sags recorded were caused by the starting of large single-phase motors of 4 to 20 kW in size. Voltages would most frequently drop to levels in the 100 to 105 volt range.

Outages and undervoltages (longer than 2s in duration) had an occurrence and cause a pattern almost identical to that for sags. Figure 3 shows the frequency distribution for the voltage levels recorded for these disturbances.

The site (#7) with the largest number of momentary outages was also the site at which the sag threshold was set at 105 V.

On 24 of the 307 days monitored, the voltage dropped below 70 volts at least once during a 24-hour period. The

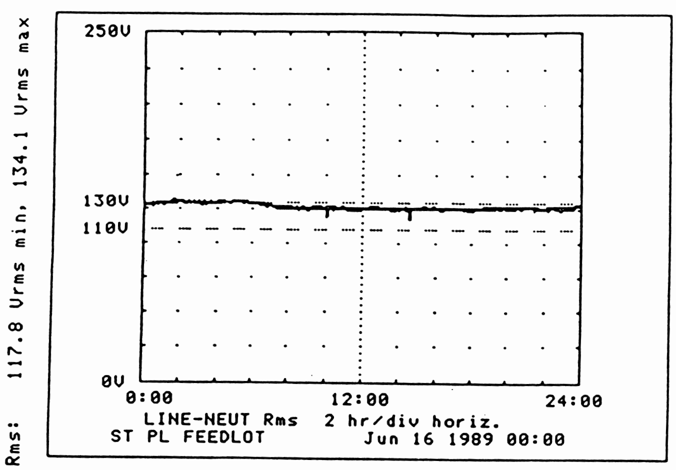

Fig. 1. A typical 24-hour voltage level summary from site #12.

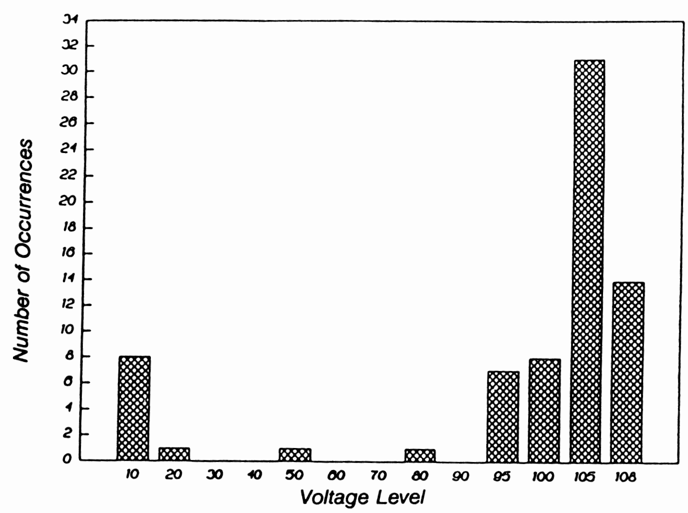

Fig. 3. Frequency distribution of outage and undervoltage levels.

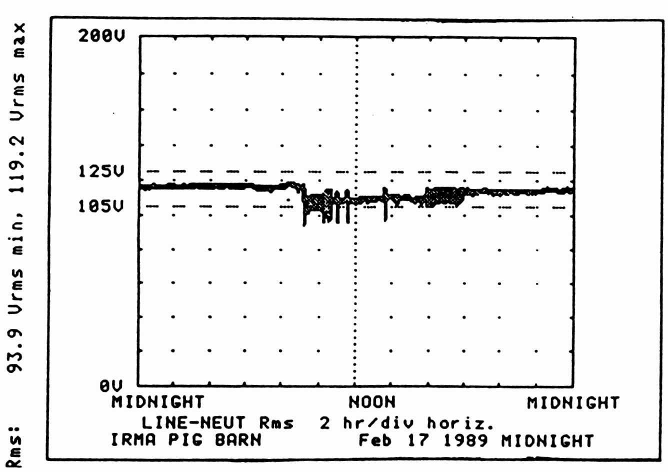

Fig. 2. A typical 24-hour voltage level summary from site #7.

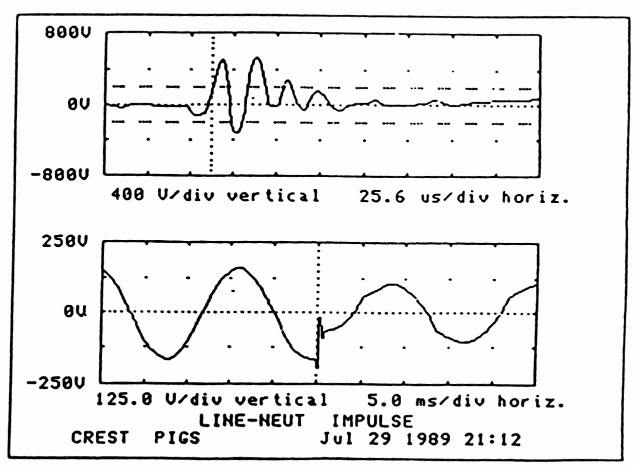

Fig. 4. Fast transient during a lightning storm at site #15. $546V_{peak}$, 299^{o} phase position, 10 µs rise time, 100MJ.

main causes for these low levels were the operation by the utility of circuit reclosers, while longer term outages were usually caused by lightning, maintenance shut-downs, and fuse blow-outs. In only two instances were the outages associated with abnormal voltage levels. One case resulted from lightning (Fig. 4) and another from the probable switching of a capacitor bank on the distribution line.

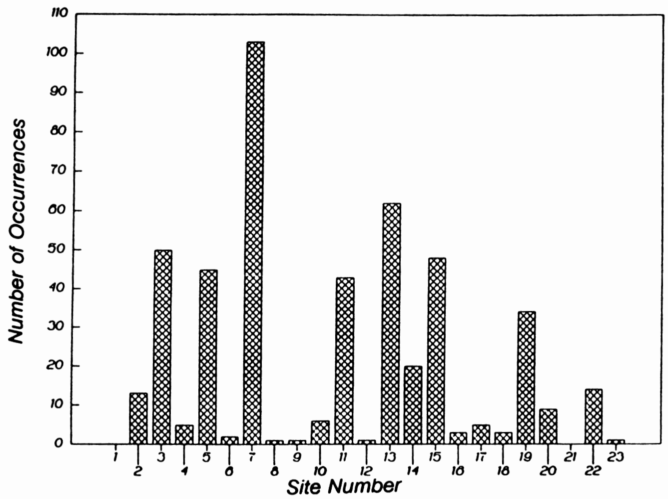

Fig. 5. Occurrence of sags outages and undervoltages by site.

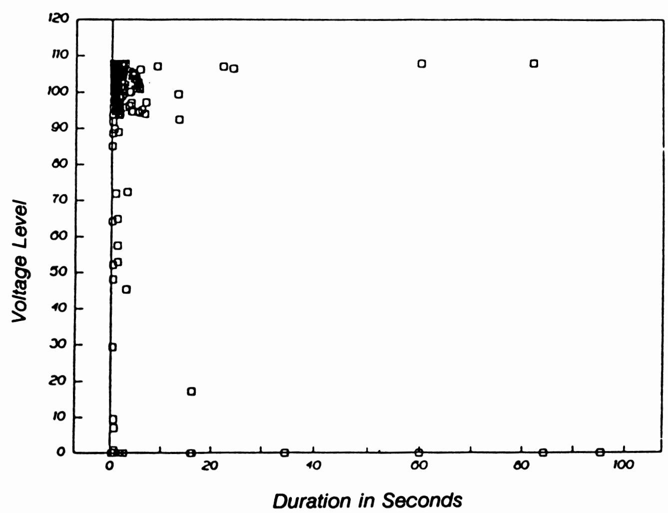

Fig. 6. Duration vs voltage level for sags, outages and undervoltages (Long term outages excluded).

Daily and hourly patterns of occurrence of sags due to causes both on the farm and in the utility distribution system followed a normal farm work pattern. Sags were most frequently recorded from about 8:00 am to about 7:00 pm with a slight decline at midday. Similarly, more sags were recorded during the week than on weekends. Sites with large, single-phase motors invariably had the most problems (Fig. 5). An overview of the duration and voltage levels for all the undervoltage disturbances recorded is shown in Fig. 6.

If accepted guidelines on susceptibility of sensitive electronic equipment to disturbances (Key and Martzloff 1986) are applied to the undervoltage data, 89 of the 436 incidents recorded (20%) had the potential to cause problems. Of these 89 incidents, 54 could be traced to on-farm sources while the remainder originated off the farm. The on-farm sources generally were associated with operation of large motors while the identifiable off-farm sources were due mainly to operation of reclosers by the utility company.

Surges and overvoltages

Voltage levels exceeded 127 V on 67 of the 307 days of monitoring. A voltage level of 135 V was exceeded on 6 of these days. The main cause for these voltage levels was attributed to utility regulation. However, some very short surges were attributable to rapid-start fluorescent lights.

In terms of occurrences, surges and overvoltages were recorded almost as frequently as were sags. Overvoltages between 125 to 131 V were frequent at several farm sites and usually were recorded sometime between midnight and 7:00 am. During daily operations on these farms, the voltage levels remained at a lower or normal level. Consequently, an adjustment to lower the voltage at the transformer might have resulted in too low a voltage level during daily operations, particularly for farms with large, single-phase motors.

A chronic overvoltage problem occurred at a broiler farm where large incandescent lighting loads were operated on a 24-hour basis. This tended to result in an abnormally-frequent light replacement schedule. A few similar farms had already mitigated the problem by using 130 V light bulbs. However, most were not aware of their availability. Although several farmers did complain to their utility company and utility service personnel did visit the farms, an appreciation of the diurnal nature of the problem was not apparent.

As already mentioned, overvoltages tended to occur more often early in the morning and, as would be expected, became less frequent later on in the day when sags and undervoltages were the most common. A pattern for the occurrence of surge voltage disturbances was not apparent. The largest surge recorded was 152 V for 1.9 seconds.

Maximum voltage levels and durations for the surges and overvoltages recorded are shown in Figs. 7 and 8, respectively. The longest overvoltage occurred at 3:00 am (Site #12) and lasted for 166 minutes. The maximum recorded rms

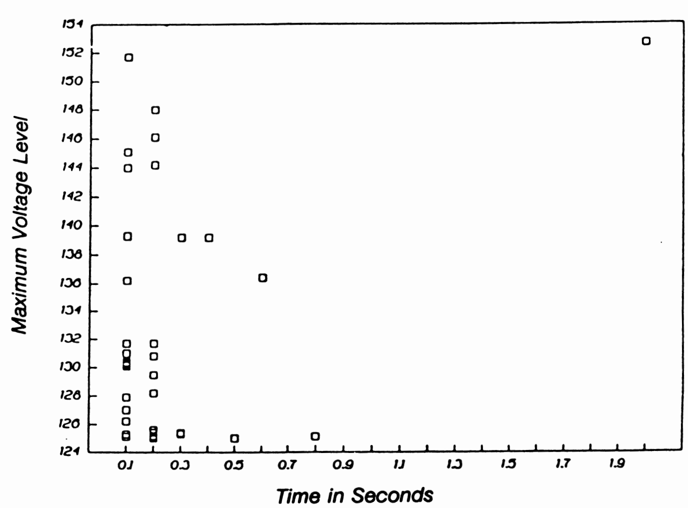

Fig. 7. Surge duration vs maximum voltage level.

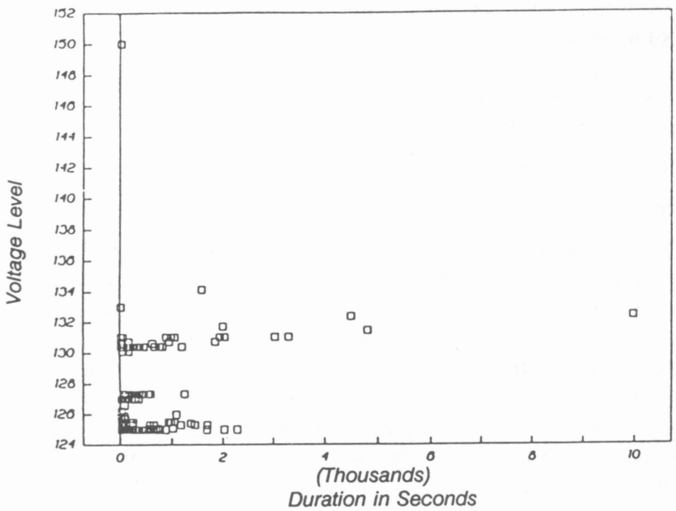

Fig. 8. Overvoltage duration vs maximum voltage level.

voltage level during the period was 132.3 V_{rms}.

A comparison of sites in terms of the occurrence of surges and overvoltages was not attempted because a common threshold value was not used.

A total of 501 surge and overvoltage incidents were recorded. According to established guidelines (Key and Martzloff 1986), 204 of these (41%) had the potential to cause problems with sensitive electronic equipment. Over 90% of these "problem" incidents were attributed to off-farm causes.

Electrical fast transients

In terms of the total number of disturbances recorded, transients were the most numerous; however, they tended to occur in groups. In some cases, several hundred occurred in just a few seconds. In fact, two of the monitoring sites (#4 and #19) generated 89% of the transients recorded. In total, transients were recorded during 56 of the 307 days of monitoring. Electrical fast transients were not recorded at nine of the 23 sites monitored.

Most of the transients were attributable to sources on the farmstead. Loads such as fluorescent lights or the shorting of connectors or equipment were the most common sources. Almost all the transients occurred in the 10 kHz to 500 kHz frequency range.

Transients due to the starting of a rapid-start fluorescent light accounted for the majority of transients recorded at site #19 and were in the 10 kHz range. An investigation of the effect that these transients might have on other circuits revealed that the transients did not effect any other circuits. A computer and printer shared the same circuit as the light but a surge suppressor/filter installed between the computer and the outlet prevented the impulses from reaching the computer.

The cause for the transients that occurred at site #4 could not be determined.

A summary of the rise times shows that all the transients recorded at sites other than #4 and #19 had a rise time of less than 60 ms (Fig. 9). Transients with a rise time of less than 10 ms accounted for 46% of all the transients recorded.

Another subcycle voltage variation disturbance recorded was voltage notching (Fig. 10). This type of disturbance was recorded at a number of sites, but mainly at poultry operations. Notching was usually the result of the use of light

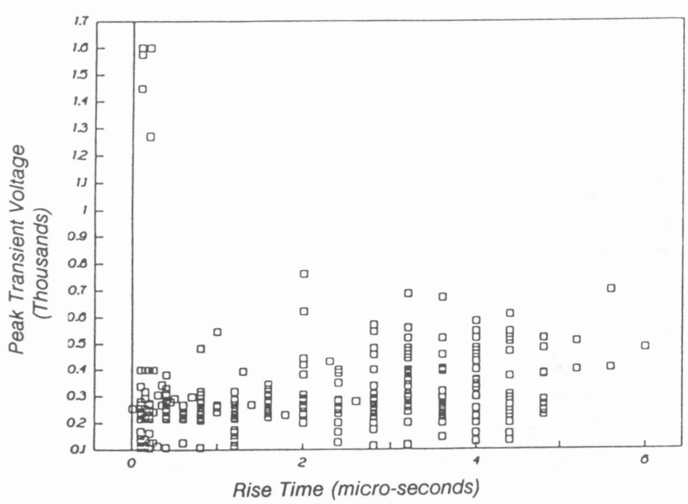

Fig. 9. Rise time vs peak transient voltage.

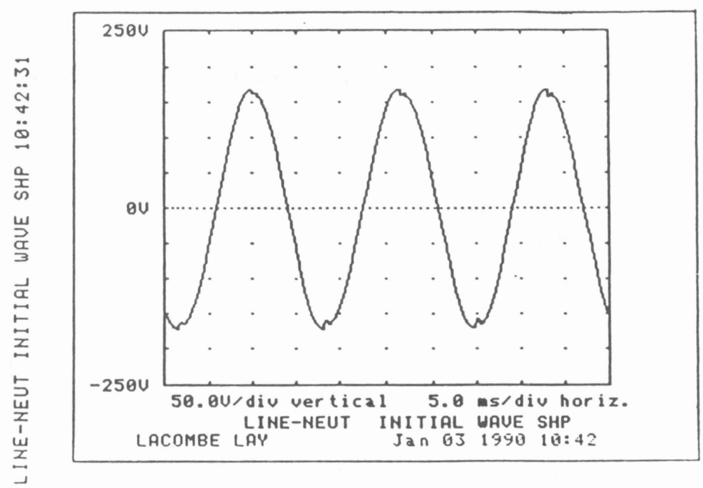

Fig. 10. Example of voltage notching by light dimmers.

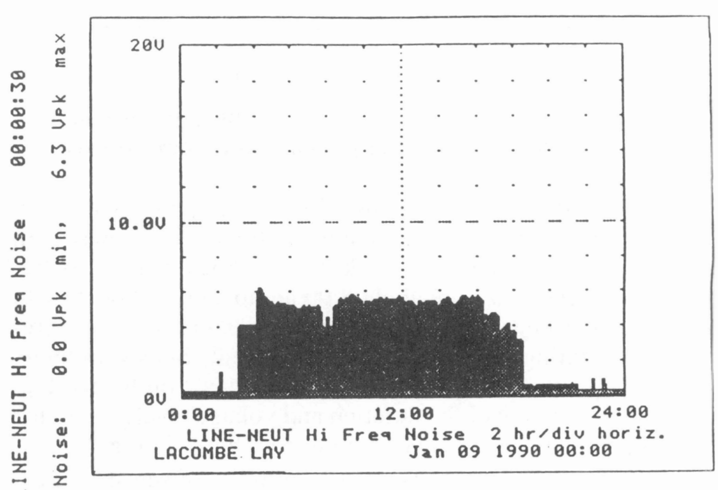

Fig. 11. Daily pattern of high frequency noise at site #22.

dimmers to control large banks of incandescent lights.

The use of light dimmers to control the lighting also resulted in more high frequency noise at these sites than at others. The lighting schedule required for laying hens was reflected clearly in the resulting daily high frequency noise patterns (Fig. 11).

High frequency noise and radio frequency noise also were generated by the use of triac-controlled, variable-speed fan motors. The extent of this noise would be expected to vary with the barns' ventilation requirements which, in turn, would vary both on a daily and on a seasonal basis. Radio frequency noise generated by fan controllers did cause problems with identification transponders in one of the dairy barns monitored. Radio frequency noise also interfered with radio broadcast reception.

Subcycle voltage disturbances as the result of utility servicing of equipment (Site #2) and the use of backup generators (Site #17) were also recorded.

Frequency

Frequency disturbances exceeding the threshold limits of 0.6 Hz were not very common. They were, however, recorded at six (26%) of the sites monitored. In terms of numbers, almost all of them (99%) occurred at site #4. This was one of the sites which had a chronic transient problem. However, very few of the transients occurred at the same time as did the frequency disturbances. At the remaining five sites, a total of only eight frequency disturbances were recorded. The largest disturbance was 61.9 Hz (Site #19) for three seconds, while the longest disturbance lasted for 15 seconds and had a maximum frequency of 60.9 Hz (Site #23).

EFFECTS ON ELECTRONIC EQUIPMENT

No direct damage to equipment occurred at any of the sites during the course of monitoring. When a computer performed a critical function, such as the automated feeding and milk production measurement systems on dairy farms, the need for an uninterruptable power supply (UPS) had been recognized. This was the case with the two dairy farms monitored, who reported no problems with their computers' reliability.

In addition to the computers dedicated to dairy record keeping, both dairy farmers and, in total, 64% of the sites monitored had home computers. The computers were used for accounting, word processing, spreadsheets, and games. Most of them had at least a surge protected MOV powerbar for their computer. A few farmers however thought they had surge protection, but in actuality only had an unprotected powerbar.

Most farmers also had microwave ovens, TVs, VCRs, and other consumer appliances with which they generally had no problems. However, several did complain about frequently having to reset the clocks on these appliances. This would appear to be a problem only with some equipment models, because ride-though capability or battery-backups are available for some electronics.

Farmers with better protection for their electronic equipment such as isolation transformers, filters, and UPS systems (site numbers #10, #12, and #18) were usually those farmers who had had electronic equipment damaged previously. In two of three cases the damaged equipment had been protected by a surge protector. Damaged equipment included a computer monitor and printer at one site (Site #10), an electronic scale (Site #12) and a satellite dish (Site #18). One farmer had damage occur to his television set (Site #11).

CONCLUSIONS

1. Voltage level disturbances were recorded at all 23 sites monitored, but none of the disturbances caused damage to electronic equipment.

2. Sags, outages and undervoltages were recorded at 91% of the sites monitored. The number recorded at a site ranged from 1 to 103. At 48% of the sites fewer than ten such disturbance were recorded.

3. Of the sags and undervoltages recorded, 20% had the potential to cause problems in the operation of electronic equipment. Most of these could be traced to on-farm sources, particularly the operation of large motors.

4. Electrical Fast Transients were recorded at 61% of the sites monitored. The number recorded at a site ranged from 1 to 441.

5. Surges and overvoltages were recorded at 30% of the monitoring sites. However, the surge and overvoltage threshold voltage level was set at 130 V_{rms} for four of the sites monitored and at 127 V_{rms} at another two sites.

6. Of the surge and overvoltage incidents recorded, 41% had the potential to cause problems with electronic equipment and most of these originated off the farm.

7. Frequency deviations occurred at six (26%) of the monitoring sites. The number recorded at a site ranged from 1 to 307. At five sites fewer than three were recorded.

ACKNOWLEDGEMENTS

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