RURAL ALASKA ELECTRIC POWER QUALITY

FINAL REPORT

by

J.D. Aspnes, R.P. Merritt and B.W. Evans
Engineering Experiment Station
School of Engineering
University of Alaska
Fairbanks, Alaska 99701

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DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
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2301 Peger Road
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ABSTRACT

Poor quality electric power has traditionally been blamed for electrical and electronic equipment malfunctions and failures in rural Alaskan communities. This report presents results of a recently completed project in which power system disturbance analyzers provide the first comprehensive power quality data from Alaskan villages.

Power systems of four widely separated communities were studied for a total of 1,010 days. These results are important because of the trend in rural Alaska toward more sophisticated equipment that is sensitive to power system disturbances. These data represent a first step in developing appropriate countermeasures to protect electrical systems connected to isolated rural 60 Hz power generator facilities.

INTRODUCTION

Increasingly sophisticated electrical and electronic equipment are being utilized in small Alaskan villages at state owned and operated public facilities. They range from communications satellite earth stations, computers and office equipment to controllers and circulating pump motors. The isolated electric power systems which serve these communities may be owned and/or operated by public or private entities but they are almost universally supplied by diesel engine-driven generators in the 100 to 1,000 kVA range and are often characterized by small distribution transformers with long secondaries.

The failures and maintenance problems now being experienced by operators of public facilities of various types is not a new phenomenon. For many years the communications users in Alaska's isolated villages complained about the quality and availability of electric power. Whenever a radio system would fail the usual comment was "the electric power system caused the failure." In many cases, the power system did cause the problem with power surges followed by long periods of operation at below normal voltage and wide variations in operating frequency. Vacuum tube equipment, used for many years, could stand some variation in power quality. New solid state electronic components, now used in so many more applications than just radio communication, cannot

survive in the presence of power surges and are especially sensitive to short pulse high voltage transients. Because of the history of problems in the communications area most of the data on rural power quality results from experience with communications equipment. It seems reasonable therefore to use these data as a foundation on which to build a database for other types of equipment.

In 1975, the State of Alaska purchased 120 satellite earth stations for use in the most remote villages. The complete station consisted of a 4.5 meter antenna and the electronics for at least two channels of "single channel per carrier" transmitting and receiving equipment. The only vacuum tube was the traveling-wave tube in the 40 watt high power amplifier. The remainder of the electronics were solid state transistors and integrated circuits.

The satellite system equipment was purchased by the State and, at the directive of the Federal Communication Commission (FCC), installed and operated by RCA Alascom. In order to protect the electronics system and provide emergency operation of the satellite earth stations during short power outages, a battery capable of operating the system for six to eight hours was installed. The battery was trickle-charged from the village power system. Even with this large battery acting as a huge filter, the village power system was identified as the cause of most of the system failures and the unavailability of the two-way communications system.

The Governor's Office of Telecommunications was concerned by the frequent equipment failures and inadequate maintenance provided for the system. The manufacturers were required to improve the reliability of their components and RCA Alascom was required to increase technicians' training and improve their maintenance practices. System operation was monitored and detailed failure records were tabulated. As component and subsystem reliability was improved, and maintenance and response time following a failure were brought to reasonable levels, the village power system became the limiting factor in providing reliable communication for a village. Detailed records maintained by Alascom for several years clearly show that in a village with good quality, reliable power, the availability of the satellite communication system is 98% or better. In villages with less reliable power, availability of communications cannot

reach the minimum agreed value of 95% for remote villages. At the present time, Alascom records do not readily provide a separate tabulation for power-related failures. Alascom has provided a tabulation of the 1981 calendar year trouble ticket data at our request.

We would like to express our appreciation to Alascom and Mr. Gary Christopherson, Network Coordinator, for the data listed in reference [28]. The tabulated data list Alaska villages and the percent of time satellite earth stations were unavailable for communication due to power-related failures. Included in this list are villages such as Akhoik where the power was turned off because money was unavailable for buying fuel and Chalkysik where the power was turned off when the school shut down in the spring and was not turned on again until the fall semester began in September.

Much of the electronics in the earth stations are computer-like integrated circuits as are most of the modern data and control system devices in common use. Personal computers and word processors appearing in nearly every school and office use the same type of semiconductor chips. All these devices are most vulnerable to short duration, high voltage transient pulses. These impulse signals are detected by the Dranetz power line analyzer monitors used on this project. The pulses are measured in height and the time of occurrence is recorded.

Most electronic systems do not have adequate filtering in the power supply to remove these high voltage pulses. The pulses travel along the power line and pass through the power transformers directly into the regulated DC supply in the system. An example of this problem will be presented from the earth station records. Even though the earth station was operating from a battery, the following problem still required a solution.

In one of the switching circuits an integrated circuit chip with four NAND gate circuits was used to perform several functions. It is standard practice to use a NAND gate as an inverter by connecting one of the two input gates to the +5V power bus. Dozens of these devices failed in the system and the manufacturer took the failed chips to a special laboratory where the integrated circuits were cut open and inspected under a microscope. All of the units failed at the gate connected to the +5V bus. The voltage on the 5 volt bus was measured by

using a special high speed oscilloscope. Short high-voltage transients were observed. This particular failure mode was totally eliminated by the addition of a 1000 ohm resistor between the NAND input gate and the 5 volt bus. The 1000 ohm resistor and the gate input capacitance of 20pF constituted a low-pass filter that dissipated the pulse energy and protected the integrated circuit.

This example shows that problems can be documented, analyzed, and a solution found in a specific case. However, when the myriad of electrical and electronic equipment and applications used in modern rural facilities is considered, electric power-related problems and their solutions can be very complex. This is particularly true when assessing the real economic impact of these problems to the state.

All commercial electronic devices should be designed to be as immune as possible to the usually occasional impulses found on power systems. Reduction or elimination of excessive power surges, outages and high voltage pulses are often considered the responsibility of the power supplier. However, some of these problems can be caused by equipment owned and operated by the electric power consumer. It is unrealistic to expect electronic equipment manufacturers to provide a special product line for use with Alaska rural power systems. The market would be too small and the expense too great. Transient suppression equipment that can provide some protection to sensitive equipment is commercially available.

This study is intended to investigate the severity of alleged power quality problems at specific locations. With these data we can perhaps begin to estimate the magnitude of this problem for state facilities and be in a better position to identify appropriate solutions.

SITE IDENTIFICATION

The process of choosing villages was determined by several considerations: (a) reviewing power availability for small earth stations [2]; (b) Public Health Service (PHS) circuit availability; (c) Federal Aviation Administration (FAA) facility and service outage reports; (d) accessibility to candidate villages; and (e) state

facilities availability for placement of equipment. The power availability for earth stations and PHS circuit availability were categorized into four breakdown causes: (1) outages caused by power; (2) environmental; (3) equipment; and (4) unknown. Two separate lists of candidate villages were made; one from the earth station data and the other from PHS circuit availability.

The resulting lists included villages that reported the most outages. All four breakdown categories were weighted equally in the process of selection. Hence, a village with a high number of outages in one category and low numbers in the other three would not lend itself to candidacy. Finally, a single list was made by choosing villages from each list that matched in data reported from the two sources, thereby reducing the possibility of erroneous data. The FAA reports were coded as follows: (1) scheduled maintenance; (2) line outages; (3) improvements; (4) power failure; (5) power failure standby; (6) propagation conditions; (7) weather effects; (8) software; (9) unknown; and (10) other.

The list of candidate villages resulting from FAA reports was determined in a similar fashion as that used for the earth station and PHS circuit availability list. The final selection of Ambler, Fort Yukon, Kotzebue and St. Marys utilized data from all above sources.

This study was primarily concerned with measuring electric power quality at user locations likely to receive sensitive office automation and computer equipment. Therefore, in three of the four villages the data collecting site was an office in a public building. In the fourth site, Ambler, data were recorded at the service entrance of the public school. In all cases a single phase 120V line to neutral, 60 Hz source was monitored, supplied by a four wire grounded wye system. All four data collecting sites were in relatively modern buildings following National Electrical Code requirements for wire size and distribution. Overvoltage protection was not present at any site. The power generating plants and data collecting sites were centrally located in all communities.

Type and character of electrical loads at each site were standard office equipment, fluorescent and incandescent lighting, small refrigerators and freezers, circulating pumps and air handling

equipment. The probable maximum individual motor rating at any location was less than 10 hp.

DESCRIPTION OF DISTURBANCE ANALYZER MEASUREMENT CAPABILITIES

The power line disturbance analyzers utilized in all cases for data collecting were Dranetz Model 606-3 units with option 101 (over/under frequency monitoring). They provided the following information [24].

1. Over/under frequency monitoring to 0.25 Hz accuracy.
2. RMS voltage level based on a 10 second moving average of the measured voltage to an accuracy of $\pm 1\%$ of reading $\pm 1\%$ of nominal input at 60 Hz. This is also referred to as slow-average voltage in the heading of Table II.
3. RMS value of each AC cycle compared with the 10 second moving average of measured voltage to an accuracy of $\pm 1\%$ of reading $\pm 1\%$ of nominal input at 60 Hz. A single-cycle measurement lower than the slow average is a sag. A higher single-cycle measurement is a surge.
4. Transient impulses with duration between 0.5 and 800 microseconds are recorded to an accuracy of $\pm 5\%$ of reading $\pm 1\%$ of nominal input ± 6 dB over the entire range of impulse width.
5. Outages, defined as loss of line voltage for periods greater than 0.5 second, are recorded. The disturbance analyzer returns to normal operating mode 10 seconds after line voltage is restored.

Sag/surge duration and timing of all events including power outages are also recorded.

The Dranetz 606-3 power line disturbance analyzer has isolated circuits for three individual phase inputs. These inputs are isolated from each other, the internal power supply and ground. In all but one

of the data sites the only power source available was a single phase branch circuit feeding a single duplex outlet. For uniformity, the disturbance analyzers were in all cases powered by the same single-phase circuit that was being monitored.

There has been concern that the disturbance analyzer power supply might affect impulse measurements. The units which provided data for this report have power supplies which present a 0.01 μ F capacitance across the power line regardless of whether the unit is turned on or off. This low-pass filter type of input circuit is common in household and office appliances. For microsecond pulses (1 MHz), this capacitance represents 16 Ω reactive impedance. This impedance would have a small effect on transients generated in low impedance sources such as a power system having 100 kVA or greater capacity as determined by our own laboratory measurements.

POWER SYSTEM DISTURBANCE DATA SUMMARY

The following tables and figures present data taken during a total of 1,010 days in four remote Alaskan communities. The data categories are: frequency deviations from 60 Hz, 10 second moving average, surge/sag, impulses and known outages.

Table I shows the number and percentage of days in which the maximum power system frequency deviation occurred within various ranges for each village and for the overall project. A ± 0.5 Hz threshold for frequency monitoring was used at all sites except at Kotzebue where the threshold was set at ± 1.0 Hz. In an effort to be consistent with computer manufacturers' power system performance specifications, we have reported only worst-case frequency deviation data when line voltage was within a useable range. Precise frequency excursion duration information is not available.

Table II gives the number and percentage of days in which the smallest and largest 10 second moving average rms system voltage occurred within specified ranges for each village and for the total project. Reference value is taken to be 120V rms. Thus, the +6% to +10% range corresponds with 127V to 132V; the -13% to +6% range

Table I. Number and Percentage of Days With Worst-case Frequency Deviation Within Specified Ranges
(60 Hz reference)

Location (total days)	Deviation range Δf (hz)				
	$\Delta f \leq 0.5$	$0.5 < \Delta f \leq 1.0$	$1.0 < \Delta f \leq 2.0$	$2 < \Delta f \leq 10$	$\Delta f > 10$
Ambler (147)	13 days 8.8%	100 68.0%	23 15.7%	7 4.8%	4 2.7%
Fort Yukon (310)	271 days 87.4%	7 2.3%	12 3.9%	19 6.1%	1 0.3%
Kotzebue (222)	31 days 14.0%	146 65.8%	20 9.0%	10 4.5%	15 6.8%
St. Marys (331)	187 days 56.5%	89 26.9%	12 3.6%	25 7.6%	18 5.4%
Project Total (1,010)	502 days 49.7%	342 33.9%	67 6.6%	61 6.0%	38 3.8%

Table II. Number and Percentage of Days with Worst-Case Slow Average Voltages Within Specified Ranges in Percent Above and Below 120V Reference.

Location	(total days)	Voltage Ranges (%)				
		-100% → -40.1%	-40% → -20.1%	-20% → -13.1%	-13% → +6%	+6.1% → +10%
Ambler	(147)	0 0%	8 5.4%	16 10.9%	113 76.9%	10 days 6.8%
Fort Yukon	(310)	5 1.6%	11 3.6%	32 10.3%	262 84.5%	0 days 0%
Kotzebue	(222)	1 0.5%	3 1.4%	5 2.3%	0 1.4%	221 days 99.5%
St. Marys	(331)	1 0.3%	54 16.3%	180 54.4%	93 28.1%	3 days 0.9%
Project Total	(1,010)	7 0.7%	76 7.5%	233 23.1%	468 46.3%	234 days 23.2%

corresponds with 104V to 127V; the -20% to -13% range corresponds with 96V to 104V; the -40% to -20% range corresponds with 72V to 96V; and the final -100% to -40% category corresponds with 0V to 72V. The slow average threshold voltage setting for all disturbance analyzers was 3V except for the unit at Ambler, for which the threshold was set at 5V. In the case of Kotzebue, there were days in which the 10 second moving average both rose into the 6.1% to 10% range above 120V and dropped below the -13% threshold. Both events were counted independently, giving percentages that do not total 100% and days which do not sum to the total number of measurement days at that site. This was done to provide a clearer picture of system disturbances. Duration of slow average deviations are not reported here in detail but typically range between one and ten minutes.

Table III provides number and percentage of days in which the worst case sag and surge occurred within specified ranges. These ranges are: 6% to 10%, 10% to 20% and >20% above a 120V reference and -20% to -13%, -40% to -20% and -100% to -40% below the 120V reference. Sag/surge threshold settings were as follows. Ambler: 10V; Fort Yukon: 3V for 40 days, then 5V for the project duration; Kotzebue: 5V; St. Marys: 3V for the first 146 days, then 5V for the remainder. The maximum surge duration measured during the entire project for a daily worst-case surge was 231 cycles. Maximum sag duration measured for a daily worst-case sag was 115 cycles. Typical sag/surge duration was observed to be less than 40 cycles.

Table IV shows the number and percentage of days in which the maximum impulse occurred within a 50V to 99V range or had an amplitude greater than 99V. The number of impulses in each category is given as well as the average of the monthly maximum impulse magnitudes recorded at each location. The maximum impulse measured at each site is also included. Impulse voltage threshold at all sites was 50V.

Table V gives a summary of outage data. Included is the total number of known duration outages at each data collection site, total number of outages, total known duration outage time, average outage duration and average number of days between outages.

Figures 1 through 41 on pages 29 to 69 provide more detailed information than is possible to show in Tables I through V. The

Table III. Number and Percentage of Days with Worst-Case Sag/Surge Voltages Within Specified Ranges in Percent Above and Below 120V reference.

Location	(total days)	Voltage Ranges %					
		-100% → -40.1%	-40% → -20.1%	-20% → -13.1%	6% → 9.9%	10% → 20%	>20%
Ambler	(147)	0 0%	1 0.7%	69 46.9%	13 8.8%	4 2.7%	1 day 0.7%
Fort Yukon	(310)	14 4.5%	35 11.3%	248 80.0%	0 0%	0 0%	0 day 0%
Kotzebue	(222)	2 0.9%	4 1.8%	25 11.3%	36 16.2%	50 22.5%	2 days 0.9%
St. Marys	(331)	5 1.5%	32 9.7%	247 74.6%	2 0.6%	2 0.6%	0 day 0%
Project Total	(1,010)	21 2.1%	72 7.1%	589 58.3%	51 5.0%	56 5.5%	3 days 0.3%

Table IV. Impulse Disturbance Data Summary

Location (total days)	Number of days with maximum impulse between 50V and 99V	Number of days with maximum impulse greater than 99V	Number of impulses during days with 50V to 99V magnitude range	Number of impulses during days with maximum magnitude greater than 99V	Average of monthly maximum impulse magnitudes	Maximum impulse recorded
Ambler (147)	66 days 44.9%	81 days 55.1%	4,489 68 per day average	5,210 64 per day average	120V	188V
Fort Yukon (310)	106 days 34.2%	200 64.5%	755 7.1 per day average	2442 12.2 per day average	143V	168V
Kotzebue (222)	122 days 55.0%	98 44.1%	12,098 99 per day average	10,533 107 per day average	163V	168V
St. Marys (331)	66 days 19.9%	264 79.8%	5,796 88 per day average	28,278 107 per day average	262V	368V
Project Total (1,010)	360 35.6%	643 63.7%	23,138 64 per day average	46,463 72 per day average	172V	368V

Table V. Outage Summary

Location	(total days)	Known duration outages	Total outages	Total known duration outage time (hours)	Average outage duration (minutes)	Average number of days between outages
Ambler	(147)	13	35	2.39	11.0	4.2
Fort Yukon	(310)	15	17	45.8	183.0	18.2
Kotzebue	(222)	12	13	1.15	5.8	17.1
St. Marys	(331)	95	99	11.4	7.2	3.3
Project Total	(1,010)	135	164	60.7	51.8	6.2

following data are shown on a daily basis for each community included in the study: maximum and minimum frequency, maximum and minimum average voltage, maximum sag and surge voltages, maximum impulse voltage and total number of impulses (50V threshold), number of sags and sag duration and number of surges and surge duration (3 to 5V threshold).

ESTABLISHED LIMITS OF ACCEPTABLE POWER QUALITY

Several references define acceptable power quality limits for computer systems [14, 19, 20, 22 for example] and at least one addresses communications systems [22]. General agreements exist that +6% and -13% rated voltage steady-state limits are necessary, although at least one computer manufacturer is reported to require $\pm 4\%$ tolerance [20]. Opinions about acceptable power quality differ for transients lasting less than 2 seconds. The American National Standards Institute (ANSI) Standard C84.1 requires +15% and -20% voltage tolerance for transients between 0.05s and 0.5s duration and +20% and -30% voltage tolerance for transients between 0.008s and 0.05s duration as reported in [20]. A different tolerance envelope is suggested in [19] resulting from U.S. Navy tests and computer manufacturer's information. It is generally more restrictive than the C84.1 standard for voltage surges and impulses with the tolerance boundary rising smoothly from +6% rated voltage for a 2s disturbance to +30% for 8.33 ms, +100% for 1 ms and +200% rated voltage limit on a 100 μ s disturbance. The undervoltage limits of this tolerance envelope include -13% rated voltage for a 2s disturbance, -30% for 0.5s, -42% for 0.1s, -70% for 16.7ms and -100% for an 8.33ms disturbance.

Frequency tolerance for a 60 Hz source is reported to be ± 0.5 Hz in some instances [20], although at least one major computer company specifies ± 1.0 Hz.

Voltage and frequency fluctuations are known to cause detrimental effects in electric motors, but the authors have not found an electric motor manufacturer or supplier who is willing or able to provide information relating such power anomalies to motor damage or reduced

service life. Some users of motors in small communities have devised protective schemes utilizing voltage and frequency relays.

METHODS OF IMPROVING POWER QUALITY

Electric power in remote Alaskan villages is almost a luxury with energy costs from 50 cents to 90 cents per kilowatt hour. On the other hand, most consumer products such as calculators, typewriters, word processors, and modern telephones are dependent on computer technology-based microcircuit digital devices. Building services such as heating, ventilating and lighting control are becoming totally dependent on solid state microcircuit electronics. Operation of these systems will require that village power quality be greatly improved. This will require a complete reevaluation of the present power generation and distribution services in rural Alaskan villages. More modern power generating units can provide improved voltage regulation and frequency control at the power station. Upgrading of power distribution facilities will be required before users receive satisfactory service. Observers familiar with rural power systems report that undersized transformers and long secondary conductors contribute to unsatisfactory power delivered to customers' premises. Inadequate wiring by the consumer can also degrade power quality at the point of end use.

Selection of electric motor type and size can seriously affect power quality on the user's premises and also for a number of other consumers in the surrounding area. A motor starting controller to reduce surge may greatly improve the stability of voltage on the feeder circuit.

Substantial system improvement may be obtained by increased training of plant operators and maintenance personnel. Preventative maintenance can reduce power outages and extended down time. Attention to detail such as oil temperature and proper lubrication can save money and improve power quality. A program of improved training, perhaps through the community college system, should be instituted. First the supervisor of the power system must be made aware of the extent of the power quality problem. The dependence of the modern electronic control

and operation systems on a stable and reliable power system should be made clear. In addition to education of utility supervisors, the general public needs to know how important the power system is to the operation of most modern consumer products. Operator training is a critical factor in good power system quality. The position of power plant operator needs to be upgraded in the eyes of the community. Additional training and rewards for excellence must be provided. Investment in better generation, transmission and distribution facilities will greatly improve the quality of power delivered. The reduction of long, inadequate, secondary conductors has been mentioned elsewhere as a way to reduce voltage sag and transient problems.

A radio paging system with coded signaling can be connected to the generating system to monitor such critical items as load limit, oil temperature, fuel level and cooling water. An alarm condition results in a radio transmission with a tone code received by the operator on duty and the supervisor indicates the type of emergency condition that may exist. See report by Strandberg and Merritt [26].

EFFECT OF LOW VOLTAGE ON MOTOR OPERATION

It has been difficult to obtain definitive data from manufacturers of electric motors concerning the economic impact of changing motor voltage and power system frequency. Many years ago it was considered "good engineering practice" to operate motors over a voltage range not to exceed 5% lower and 10% higher than the nameplate stated voltage.

In reference [27], relationships are derived for power, torque and current as a function of line voltage. If we use these relationships, assuming for the moment that the torque output is constant, we may use Eq. 5.73, pg. 399, to derive induction motor slip(s) as a function of line voltage and other parameters.

$$T \approx \frac{3}{\omega_s} \frac{(P)}{2} \frac{s}{R_r} V_a^2 \quad (\text{Eq. 5.73})$$

where

ω_s = power system angular frequency ($2\pi f_s$), i.e., at $f_s = 60$ Hz, $\omega_s = 377$ radians/sec.

P = number of poles in the motor, i.e., 2, 4, 6, etc.

s = slip of the induction motor, i.e., 0.03

R'_r = equivalent rotor resistance in ohms

V_a = applied line voltage to neutral

T = motor output torque (Newton-meters)

so that

$$s = \frac{T \omega_s}{3} \frac{2}{P} \frac{R'_r}{V_a^2}$$

This equation shows that reduced line voltage, V_a , will result in greatly increased slip (s). The increase in slip by a fraction proportional to $(1/V_a^2)$ lends support to the practice of not operating motors at less than 95% of rated voltage. It may be shown that

$$I'_A = \frac{S}{R'_r} V_a \quad \text{amperes}$$

If we solve for the component of this line current (I'_A) that provides torque and substitute the equation for slip, we obtain:

$$I'_A = \frac{T \omega_s}{3} \frac{2}{P} = \frac{T \omega_s}{3} \frac{2}{P} \frac{1}{V_a} \quad \text{amperes}$$

From this equation we see the major component of line current is proportion to $1/V_a$ if we maintain a constant torque. The resistive (heat) loss at any speed are given by

$$P_{res} = 3(R_s + R'_r)(I'_A)^2 \quad \text{watts}$$

If we substitute in the equation for I_A' above we see the heat loss in the motor will be proportional to $1/V_a^2$.

$$P_{res} = 3(R_s + R_r') \frac{T^2 \omega_s^2}{3} \left(\frac{2}{P}\right)^2 \left(\frac{1}{V_a}\right)^2 \text{ watts}$$

where R_s is the motor stator winding resistance.

The above equations are based on the assumption that the magnetic circuit is relatively linear and not operating close to magnetic saturation. Within this linear region, increasing the line voltage V_a results in a reduction of both I_A' and hence the heat loss P_{res} . This condition no longer holds as magnetic saturation begins. Under saturation conditions, the input current to the motor shoots up during the saturation peaks and results in a very nonlinear increase in energy losses. This value refers to the upper limit of allowed line voltage suggested earlier as 110% above the nameplate rated value.

EFFECT OF LOW FREQUENCY ON MOTOR OPERATION

Momentary changes in the power line frequency will not change the speed of large motors due to the energy storage in the large moment of inertia. The current and voltage, however, will make substantial rapid changes as line frequency varies. If frequency rapidly decreases, energy will flow out of the rotating machine and into the power system causing a voltage surge on the customer's premises and back into the distribution system. If the reduced frequency condition persists for a longer time, Eq. 5.73 given on page 16 indicates that reducing the line frequency f_s ($\omega_s = 2\pi f_s$) will result in an increase in torque required to maintain power output and an increase in line current (I_A'). A motor equivalent circuit is often considered as a transformer with a rotating secondary winding. A similar relation can be derived relating to operation at lower than normal frequency. To utilize the iron efficiently, frequency, the number of winding turns on the stator coils and other factors such as maximum flux and the area of the magnetic

circuit must be related appropriately. As frequency is decreased, excitation current will also increase resulting in further heating of the motor windings. Again, manufacturers are reluctant to provide data about their products relating to operation at lower than normal frequencies. Textbooks and technical papers also ignore the low frequency problem, apparently assuming everyone is receiving their power from a gigawatt-size interconnected system operating at precisely 60.0 Hz.

CONCLUSIONS

The following conclusions may be drawn from data presented in this report.

1. As shown in Table I, power system frequency deviations measured in four isolated Alaskan locations for a total of 1,010 days exceeded ± 0.5 Hz during 50.3% of those days, exceeded ± 1.0 Hz during 16.4% of the days, exceeded ± 2.0 Hz during 9.8% of the days and exceeded ± 10 Hz during 3.8% of the total project days. This particular type of power system anomaly is not usually considered a problem in large interconnected systems. In fact, a very extensive monitoring program reported in 1974 did not even mention frequency deviations [1]. Clearly, users of frequency sensitive equipment cannot assume the continuous availability of 60 Hz electric power frequency in isolated systems.
2. The data given in Table II show that the 10 second moving average voltage monitored throughout the project stayed within -13% to +6% of nominal 120V limits for only 44.3% of the 1,010 days. The worst case daily average voltage variations were within the +6% to +10% range for 23.2% of total days, within -20% to -13% below 120V for 23.1% of total days and fell below -20% of 120V 8.2% of the total days during which data were taken. Results were strongly site dependent. One community had a consistent overvoltage problem; another a persistent undervoltage condition.

3. Worst case sag/surge data presented in Table III show that, during 78.3% of the total monitor days, per cycle rms voltage exceeded the +6% and -13% of 120V limits. Daily worst case sags between -20% and -13% occurred 58.3% of days monitored. Sags below -20% and/or surges above +10% of nominal 120V occurred during 15.0% of all days monitored.
4. As Table IV indicates, 0.5 to 800 μ s duration impulses greater than 50V magnitude occurred during 1,003 out of 1,010 days of system monitoring. Impulses with magnitude greater than 99V occurred during 643 days or 63.7% of the total. 23,138 impulses in the 50V to 99V range were recorded during 360 days for an average of 64 impulses per day. 46,463 impulses were recorded during 643 days for an average of 72 impulses per day during those days in which the daily maximum impulse exceeded 99V. For comparison, reference [1] recorded an average of 50.7 voltage spikes per month at a 25% (30V) threshold during a total of 109 monitor months at 29 locations in the contiguous United States. Table IV shows 69,601 impulses recorded in 1,010 days for 68.9 impulses per day or 2097 impulses per month at a 41.7% (50V) threshold. In spite of a 67% higher threshold, the number of impulses recorded in the Alaskan communities is 41.4 times that recorded in reference [1] study. The maximum impulses recorded at the four Alaskan sites ranged from 168V to 368V. The average of monthly maximum impulse magnitudes over the entire project was 172V.
5. The project outage summary in Table V shows 164 known outages recorded during 1,010 days with 135 of them having a known duration totalling 60.7 hours or an average outage duration of 51.8 minutes. However, two of the outages account for 36.5 hours. Neglecting these reduces the average outage duration to 10.9 minutes. The average number of days between known outages is 6.2. This is equivalent to an average of 4.9 outages per month. In comparison, reference [1] reported 0.6 outages per month with a 1.0 minute mean outage time.

Data in Tables I through V and in Figures 1 through 41 make comprehensive electric power quality information available on isolated Alaskan generation and distribution systems. For the first time, a comparison of such data has become possible with that from much larger, interconnected systems. These results, coupled with power quality requirements specified by electrical and electronic equipment manufacturers, will aid in the design or specification of appropriate power conditions to protect equipment connected to isolated 60 Hz power generation facilities.

It should be noted that some of the disturbance listed may be user generated. For example, impulses may be produced by local load switching over which the utility has no control. Of course, a high system impedance would accentuate these problems.

An agency charged with the responsibility of design, construction and utilization of equipment in remote Alaskan villages, and in some urban areas as well, must be aware of the difficulties that will arise with unreliable electric power service. Motors and controls have for many years been subjected to excessive voltage and frequency deviation from the prescribed values. These devices have on occasion failed even though they are very rugged and relatively insensitive to these excesses. With the introduction of computers and computer-like digital microcircuit devices in an ever increasing number of consumer products and control systems, an order-of-magnitude increase in component sensitivity to power disturbances has occurred in the last several years. Where the agency has control over the design of a system or can write specifications to require manufacturers to meet certain standards, protective steps can be incorporated into the circuit devices and systems. As an example, electronic components can be selected to be most reliable and insensitive to voltage transients. Circuits can be designed to provide increased protection to the microcircuit devices. Systems that utilize volatile memory can be operated from storage batteries so that power failures from several seconds to several hours will not result in a loss of data, instructions to perform tasks or internal clock time. If specialized equipment and system design such as the Satellite Earth Station electronics are not affordable, special efforts can be applied to a separate power circuit in a building

reserved for sensitive electronic loads. If large local electrical loads are switched off and on many times during the day, it may be necessary to install separate distribution transformers as well as separate feeder and power panels to reduce local effects on the protected service.

Power conditioning may require only the installation of transient suppressors or may include shielded isolation transformers. Additional improvement may require voltage regulation in addition to shielding and transient protection. Motor-generator sets and magnetic synthesizers provide further isolation and improvement. The ultimate power conditioning is provided by what is called the Uninterruptable Power Supply (UPS). In this system the local utility power is rectified, filtered and used to charge a large bank of storage batteries. The DC from the batteries is then converted into single phase AC power for small loads or three-phase AC power for large loads. Two types of AC generation are available using highly reliable solid state devices. In one system the inverter (DC to AC) uses pulse width modulation techniques to obtain a close approximation of a regulated sine wave output. The second system, usually employed in very large protected three-phase power systems (i.e., greater than 100kVA) uses a synthesized or stepped waveform [20, 22].

In writing the specification for a UPS system, one must stipulate the amount of radio interference that can be tolerated in the output and radiated from the inverter due to fast rise time pulses inherent in this type of generator. Selection of the proper power conditioning equipment for a specific application will require an analysis of the local power service and the specific requirements of the electronic equipment to be used. The cost of outages must be compared with cost of the power conditioning installation and the power loss in the conditioning equipment.

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IMPLEMENTATION STATEMENT

It was beyond the scope of this project to determine a quantitative figure that poor power quality is now costing the State. In fact, it could also be argued that four isolated power systems is a minuscule data base on which to base conclusions about the hundreds of isolated diesel-electric systems which are out there in use and right now supplying power. It could also be said that the variation in power quality parameters shown in the data would produce enormous standard deviations if any attempt to derive statistical significance from the findings was made. So what have we proven and what is the significance to DOTPF?

This project has been a beginning step, the first attempt to document a problem which for years has been a complaint of maintenance personnel from several State agencies. Perhaps there was a time when the physical plants at State facilities were simple enough that concern over power quality was not warranted. But today, with almost every device which consumes electricity becoming integrated with solid state electronics and with the high degree of sophistication in the physical plants of our rural facilities, we can only expect the potential for excessive repair and operation costs to increase. After all the cost of a service call to replace an integrated circuit chip in a copy machine at Fairbanks or Anchorage might be less than fifty dollars. But the same call to Kiana might cost fifteen hundred when travel, per diem, and personnel costs are added in.

At this stage in the research effort no specific recommendation can be made to implement the findings of this project. The Research Section will continue to investigate the problem in more quantitative terms. We will also work with the Division of Standards and Technical Services to plan a strategy with which to deal with the problem for future

construction. We will also discuss the implications of this project with staff from the Maintenance and Operations Division concerning existing facilities.

Leroy E. Leonard
Facilities Research Manager

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FIGURE CAPTIONS

FIGURE

- 1 September 1982 disturbance data taken at Ambler, Alaska.
- 2 October 1982 disturbance data taken at Ambler, Alaska.
- 3 November 1982 disturbance data taken at Ambler, Alaska.
- 4 December 1982 disturbance data taken at Ambler, Alaska.
- 5 January 1983 disturbance data taken at Ambler, Alaska.
- 6 February 1983 disturbance data taken at Ambler, Alaska.
- 7 October 1982 disturbance data taken at Fort Yukon, Alaska.
- 8 December 1982 disturbance data taken at Fort Yukon, Alaska.
- 9 January 1983 disturbance data taken at Fort Yukon, Alaska.
- 10 February 1983 disturbance data taken at Fort Yukon, Alaska.
- 11 March 1983 disturbance data taken at Fort Yukon, Alaska.
- 12 April 1983 disturbance data taken at Fort Yukon, Alaska.
- 13 May 1983 disturbance data taken at Fort Yukon, Alaska.
- 14 June 1983 disturbance data taken at Fort Yukon, Alaska.
- 15 July 1983 disturbance data taken at Fort Yukon, Alaska.
- 16 August 1983 disturbance data taken at Fort Yukon, Alaska.
- 17 September 1983 disturbance data taken at Fort Yukon, Alaska.
- 18 October 1983 disturbance data taken at Fort Yukon, Alaska.
- 19 November 1982 disturbance data taken at Kotzebue, Alaska.
- 20 December 1982 disturbance data taken at Kotzebue, Alaska.
- 21 January 1983 disturbance data taken at Kotzebue, Alaska.
- 22 February 1983 disturbance data taken at Kotzebue, Alaska.
- 23 March 1983 disturbance data taken at Kotzebue, Alaska.
- 24 April 1983 disturbance data taken at Kotzebue, Alaska.
- 25 May 1983 disturbance data taken at Kotzebue, Alaska.
- 26 June 1983 disturbance data taken at Kotzebue, Alaska.
- 27 July 1983 disturbance data taken at Kotzebue, Alaska.
- 28 August 1983 disturbance data taken at Kotzebue, Alaska.
- 29 August 1982 disturbance data taken at St. Marys, Alaska.
- 30 September 1982 disturbance data taken at St. Marys, Alaska.
- 31 October 1982 disturbance data taken at St. Marys, Alaska.
- 32 November 1982 disturbance data taken at St. Marys, Alaska.

FIGURE CAPTIONS (Continued)

FIGURE

- 33 December 1982 disturbance data taken at St. Marys, Alaska.
- 34 January 1983 disturbance data taken at St. Marys, Alaska.
- 35 February 1983 disturbance data taken at St. Marys, Alaska.
- 36 March 1983 disturbance data taken at St. Marys, Alaska.
- 37 April 1983 disturbance data taken at St. Marys, Alaska.
- 38 May 1983 disturbance data taken at St. Marys, Alaska.
- 39 June 1983 disturbance data taken at St. Marys, Alaska.
- 40 July 1983 disturbance data taken at St. Marys, Alaska.
- 41 August 1983 disturbance data taken at St. Marys, Alaska.

FIGURE 1

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