Discussion of "Rural Alaska Electric Power Quality"

Excerpts of paper by **J.D. Aspnes, B.W. Evans and R.P. Merrit**
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Discussion by F.D. Martzloff, submitted August 1984

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Significance:
Part 3 – Recorded surge occurrences and surveys
Part 5 – Monitoring instruments

The paper reports an extensive project of monitoring power quality performed with typical instruments available in the mid-eighties. Note that during the period of monitoring, the proliferation of low-voltage metal-oxide varistors had probably not yet involved all the sites covered by the monitoring. Nevertheless, the results indicated that the maximum surges ever recorded in this project had only a 368 V peak. This somewhat surprising result needed an explanation.

The discussion offers such an explanation: the monitors that were used for the survey had a built-in varistor in their power supply input, a reasonable precaution from the designers of the instrument. With hindsight – too late for the researchers – it was realized that the power supply of the monitor was plugged in the same receptacle from which the monitored voltage was acquired: small wonder then, that the maximum surge voltage that could be observed was simply the let-through voltage of the varistor.

For the purposes of this discussion, only the most relevant pages concerned with surge occurrences have been reproduced. The full copyrighted paper is a rich source of data on other disturbances.

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RURAL ALASKA ELECTRIC POWER QUALITY

J. D. Aspnes, Senior Member, IEEE
B. W. Evans, Student Member, IEEE
R. P. Merritt, Member IEEE

Electrical Engineering Department
University of Alaska
Fairbanks, Alaska 99701

Abstract - Poor quality electric power has traditionally been blamed for electrical and electronic equipment malfunctions and failures in rural Alaskan communities. This paper reports results of a recently completed project in which 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 is being utilized in small Alaskan villages. This ranges from communications satellite earth stations, computers and office equipment to controllers and circulating pump motors. The isolated electric power systems of these communities 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.

Poor electric power quality has repeatedly been blamed for electrical equipment malfunction and failures, even though data to substantiate this viewpoint were lacking. A project undertaken to remedy this lack of data was recently completed and the results are reported in this paper. Although extensive studies monitoring power line disturbances have been completed more than a decade ago [1], the authors believe that this paper represents the first comprehensive electric power quality data from isolated rural Alaskan villages to appear in the open literature. Data were collected from four communities for a total of 1,010 days. These data help identify the scope of the power quality problem in rural Alaska and help approach the larger question of what equipment is necessary and appropriate to protect in a cost-effective way the electrical and electronic systems used in remote Alaskan locations.

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 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. Page limitations preclude a more detailed power system description. 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].

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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 ±1% of reading ±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 ±1% of reading ±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 ±5% of reading ±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 paper have power supplies which present a 0.01 μF 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 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 4 provide one representative month of power system disturbance data for each community included in the study. Included on a daily basis are 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). Thus these figures give more detailed information than is possible to show in Tables I through V.

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 agreement exists that +6% and -13% rated voltage steady-state limits are necessary, although at least one computer manufacturer is reported to require ±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

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

Discussion

G. T. Heydt (Purdue University, West Lafayette, IN): This is a fascinating glimpse into an area which few power engineers in the United States see. The problems of rural electric power systems are frequently multifarious, including voltage support, frequency control, surge surpression, conductor sizing, and economic operation. The authors have focused on a few areas which relate to siting of specialized, high technology installations. Their remarks nonetheless apply to a wide range of rural electrification settings.

I would like to ask the authors whether problems of reconductoring and upgrading of components were also considered. Perhaps a table of peak load and MWh served annually would be helpful for the reader to assess the impact of added loads in the four towns included in the study. This question comes to mind since many rural sites have little generation margin for expansion. Sites in Latin America, for example, often have distribution conductor limitations which would preclude expansion without considerable expenditure for upgrading capacity. Is this also the case in rural Alaska?

A second area which I would like to discuss concerns the presence of harmonics in rural power systems. In many isolated systems of limited capacity, loads such as fluorescent lighting and motors with solid state controllers cause a significant harmonic distortion. Were tests also made in this area? The total harmonic distortion should be considered in rural electric systems for which computer loads are planned. In our experience, a total harmonic distortion greater than 10% (bus voltage) has the potential of interfering with computer timing signals. This has been observed at sites in the continental United States and Latin America.

I would certainly encourage the authors of this paper and others to report on other findings relating to rural electric power systems. The specialized procedures of design and operation of these systems have been neglected in the literature.

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Francois D. Martzloff (General Electric Co., Schenedtady, NY): This paper is indeed a very useful contribution to the data base on the occurrences of power system disturbances. However, the section dealing with the results obtained on the occurrence and levels of "impulses" might still be misleading even though the authors make a passing reference to the question on the effect of the built-in surge suppressor of the Dranetz Analyzers used the measurements.

The problem arises from a characteristic of the Dranetz equipment, which exists for both Models 606 and 626, and which was not recognized at the time the measurements were made but is now pointed out in more recent Dranetz instruction manuals.

In order to protect the electronics of the Disturbance Analyzer from damage by overvoltages in the power supply to these internal electronics, a surge suppressor has been provided in the input to the power supply—not to the monitoring input of course. However, if the ac power system being monitored is the same as the power system in which the instrument power supply cord is plugged—a likely possibility in the general case, and which is precisely situation of the measurements reported in the paper—then the observations of surge occurrences on that power system are those of a system whose transients have been suppressed!

To support this claim, Fig. 1 shows an oscillogram recorded at the output of a surge generator which provides both 120 V ac power and the IEEE/ANSI C62.41 (formerly IEEE 587) ringwave, Category B. The oscillogram shows the surge without the Dranetz analyzer plugged in the test system output, and, superimposed, the effect of plugging the POWER CORD ONLY of the Dranetz analyzer in the test system output. Without the analyzer, the open-circuit voltage is 3 kV; with the analyzer plugged in, the output voltage is reduced to 1.1 kV.

The Category B characteristics are 6 kV open-circuit voltage, 500 A short-circuit current, therefore a source impedance of 6000 : 500 = 12 ohms. From the circuit values of Fig. 2, the unknown effective impedance of the analyzer, Z, can be computed to be only 7 ohms. The authors cite a 16-ohm impedance at 1 MHz; assimilating the first loop of the test wave to a half sine wave with a duration of 2.5 microseconds, the equivalent frequency in Fig. 1 would be 200 kHz (a period of 5 microseconds) for which the impedance resulting solely from a capacitor would be higher than the 16 ohms at 1 MHz. Thus, it appears that there is additional parallel impedance on the line cord input, since the simplified computation of Fig. 2 yields only 7 ohms. That low impedance, when connected in parallel with the voltage measurement leads, will load the source of the transient and yield lower voltage recordings than the actual occurrence would have been without the analyzer connected. This situation makes my facetious remark in the 1970 paper [1] come true ("the best surge suppressor is a surge monitor!").

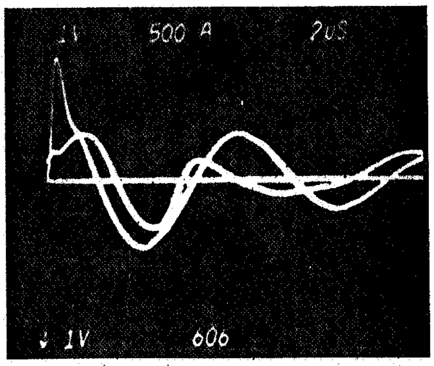

Fig. 1. Open-circuit voltage output of KeyTek Surge Generator Model 711 with P1 Plug-in and Voltage with Dranetz 606 power cord connected at output of generator.
Vertical : 1 kV/div
Sweep : μs/div

The authors make the statement that, according to their own laboratory measurements, this effect should be negligible on a 100 kVA power system. That statement seems to imply that there is a correlation between the 60 Hz impedance of a system (which indeed decreases as the kVA rating increases) and the effective impedance at the equivalent frequency of the impulse; I have some difficulty in accepting that implication. It would be interesting to know the details of the measurements cited by the authors, and compare them to other references, such as the Bull paper [2] from which Fig. 3 is excerpted. If we accept the value cited by Bull, 50 ohms at 100 kHz, then the 7 ohms effective impedance of the analyzer will reduce the voltage recordings in a 8 : 1 ratio (7/57 = 8), regardless of the low 60 Hz impedance of the 100 kVA system.

While it is too late for data already recorded, there is a very simple solution to the problem. Ferroresonant line conditioners not only provide surge isolation at their output, but also decoupling of the input form the output [3]. Fig. 4 shows the open-circuit output of the surge generator at 6 kV (upper trace) and the output with the line conditioner feeding the analyzer plugged in (lower trace). There is no detectable effect on the impinging surge. Thus, by merely inserting the line conditioner in the power cord of the analyzer, the issue disappears, and measurements can be obtained without the present ambiquity which can cause a sense of false security in the relatively low levels of impulse cited.

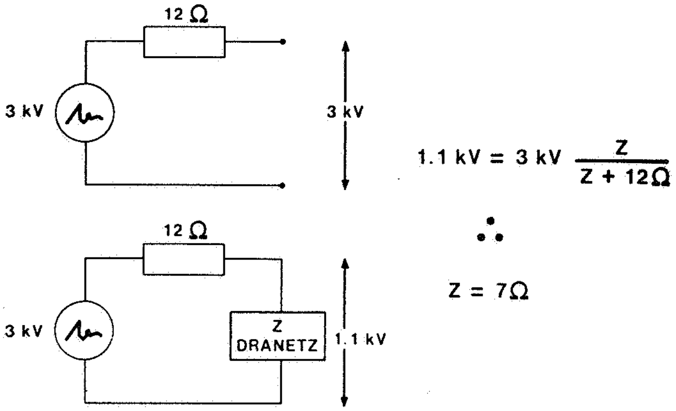

Fig. 2. Computation of effective input impedance of the disturbance analyzer power supply.

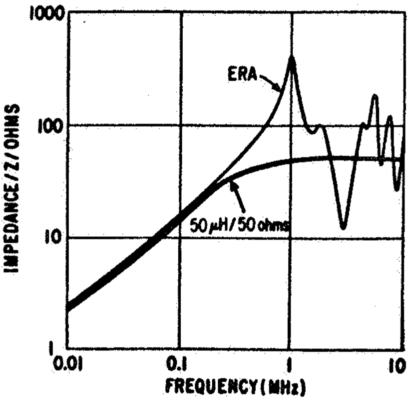

Fig. 3. Impedance of "Power Mains" as a function of frequency, compared to 50-ohm, 50-uH series combination. (From Ref. [2].)

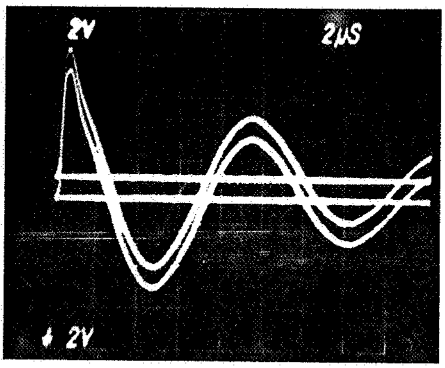

Fig. 4. Output voltage of KeyTek 711/P1 surge generator.

Top trace: no connected load
Lower trace: Line conditioner
GE Cat 9T91L130G3
Plugged in output

Vertical: 2 kV/div
Sweep: 2μs/div

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3. F. D. Martzloff, "The Propagation and Attenuation of Surge Voltages and Surge Currents in Low-Voltage AC Circuits" *Trans. on Power Apparatus and Systems PAS-102,* pp. 1163-1170, May 1983.

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J. D. Aspnes, B. W. Evans and R. P. Merritt: We thank the discussers for their thoughtful and detailed comments.

With reference to the questions posed by Dr. Heydt, we recognize the problems of reconductoring and upgrading rural systems and the impact of such system modifications on electric power quality. This was, however, outside the scope of the project discussed in this paper. A study of economic costs and potential power quality benefits of various system upgrades would certainly be a useful follow-up to our initial work.

Peak load and annual megawatt-hour generation data for the four isolated electrical systems are included in Table 1 [1].

Tests to determine presence of harmonics were not done. This would also be a valuable addition to future investigations.

TABLE 1—Utility data

Location	Utility installed nameplate capacity (kW)	Net generation (MWH)	Peak demand (MW)
Ambler	420	348	0.1
Ft. Yukon	1,050	2,013	0.5 (estimated)
Kotzebue	4,825	11,531	2.2
St. Marys	1,500	1,599	0.4

We turn next to the interesting points raised by Mr. Martzloff. A power system impedance function characterized by a parallel 50 ohm, 50 μH, RL network is provided in Fig. 3 of his closure. If this is a true representation of the power systems tested, and if the Dranetz Model 606 analyzer may be represented by a 7 ohm impedance, then we agree with Mr. Martzloff's conclusions. However, the resulting 8:1 impulse attenuation would imply measured averages of monthly maximum impulse magnitudes ranging between 906V and 2944V. Intuitively, these numbers seem excessively large.

To gain some idea of actual impulse attenuation caused by the Model 606 analyzers used in this project, a Dranetz Disturbance Simulator (Model 604A) was used as an impulse generator. We found that the unerengized Model 606 power supply attenuated these impulses approximately the same as a 0.01 microfarad capacitor connected across the disturbance simulator terminals. A higher energy, lower impedance impulse generator was assembled and a correspondingly lower attenuation was noted.

It would be very interesting to repeat our impulse measurements at the original data-gathering sites using a suitably isolated surge monitor. However, we have not yet had the opportunity to do so.

We again wish to express our appreciation of the discussions which have added to the value of our paper.

REFERENCE

[1] U. S. Dept. of Energy, Alaska Power Administration, *Alaska Electric Power Statistics, 1960-1981,* Seventh Edition, August 1982.

Manuscript received October 25, 1984