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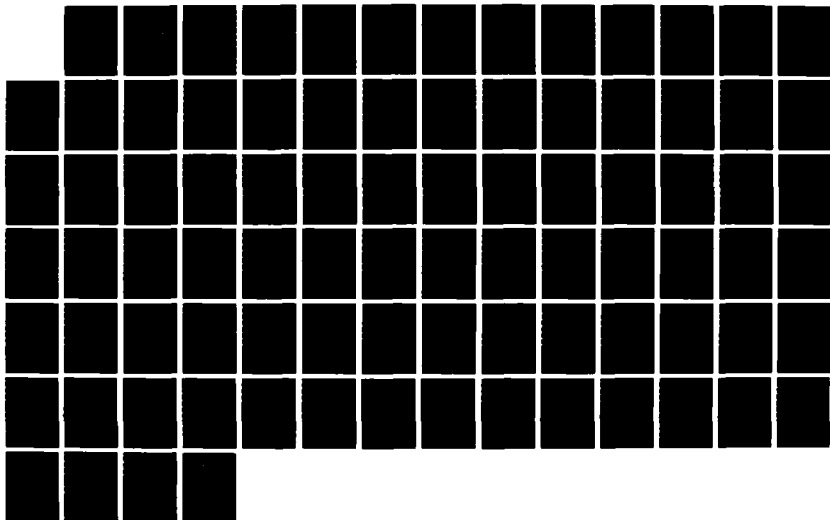
QUALITY OF ELECTRICAL POWER AND HIGH TECHNOLOGY
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AND
HIGH TECHNOLOGY EQUIPMENT

THESIS

Jonathan R. Decker
Captain, USAF

AFIT/GEM/LSR/87S-4

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QUALITY OF ELECTRICAL POWER
AND
HIGH TECHNOLOGY EQUIPMENT

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering Management

Jonathan R. Decker, B.S.

Captain, USAF

September 1987

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Preface

The purpose of this research was to determine if Air Force Bases within the Continental United States were receiving quality electrical power in accordance with ANSI C84.1. An investigation into factors that affect the quality of electrical power received and electrical Power Conditioning and Continuation Interface Equipment (PCCIE) was also conducted.

The proliferation of high technology equipment at all levels of the Air Force organization provides a unique challenge to the Civil Engineering community. The Civil Engineer is responsible for providing electrical power in accordance with ANSI C84.1, and trouble shooting electrical power problems that may be affecting the operation of high technology equipment.

Hopefully this research will provide the Civil Engineer with a base from which to begin to bring the problem of providing electrical power in accordance with ANSI C84.1 under control.

I would like to express my appreciation to Dr. Robert P. Steel, my thesis advisor, whose patient and enlightening explanations of statistical analysis eventually made sense. Another very important individual in this effort has been Major William J. Bierck, who provided guidance and support. Finally, my darling wife Theresa for her patience and support which words can not express.

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Abstract

The purpose of this research was to determine if Air Force Bases in the Continental United States were receiving quality electrical power in accordance with ANSI C84.1. An investigation into factors influencing quality electrical power and Power Conditioning and Continuation Interface Equipment was also conducted. There were four research objectives in this effort: (1) Determine if Air Force Bases in the Continental United States are receiving quality electrical power in accordance with ANSI C84.1. (2) Determine how grounding impacts the operation of high technology equipment. (3) Determine how power disturbances on the distribution grid affect the operation of high technology equipment. (4) Identify the different types of Power Conditioning and Continuation Interface Equipment (PCCIE) and determine how they help and when they are applicable.

This study was unable to determine if Air Force Bases in the Continental United States are receiving quality electrical power in accordance with ANSI C84.1 because over 60% of the individuals in the sample did not know if the electrical power they received met ANSI C84.1.

The most serious ground problem the Civil Engineer faces is the isolated grounding scheme. This is due to safety and operational factors.

It appears that electrical power disturbances cause less operational problems with high technology equipment than has traditionally been believed. Operational problems due to electrical power represent at most 10% of the total operational problems experienced by high technology equipment.

Several types of Power Conditioning and Continuation Interface Equipment were identified and concept of operations explained. ✓ The application is determined by mission criticality and the high technology equipment requirements.

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I. Introduction

General Issue

Are Air Force Bases receiving quality electric power from the local utilities in accordance with the American National Standards Institute (ANSI) standard C84.1? For this research effort quality electric power (quality power) is defined as electric power delivered at constant voltage and frequency in accordance with ANSI C84.1. ANSI C84.1 is the electrical utility industry standard for delivering electrical power. Additionally, there is no requirement or incentive for the utilities to provide a quality of electric power beyond that defined by ANSI C84.1. Poor quality power can cause operating anomalies in high technology equipment, and in some cases hardware and/or software destruction.

Electrical power quality is influenced by many factors, and equipment operating anomalies do not necessarily indicate that the electrical utility is providing power outside the range specified by ANSI C84.1. Years of experience and much research indicate that factors such as poor grounding and power disturbances caused by sources other than the utility can seriously degrade the quality of power received at a

specific site.

The electrical/electronics industry has developed a myriad of devices (Power Conditioning and Continuation Interfacing Equipment, PCCIE) to protect high technology equipment from poor quality power. These devices range from inexpensive surge suppressors to expensive solid state uninterruptible power supplies, designed to protect and/or isolate high technology equipment from the commercial power source.

Specific Problem

Several Air Force Major Commands have expressed concern about the increasing amount of down time their high technology equipment is experiencing. This problem is growing larger as the Air Force procures an increasing amount of this type of equipment, especially computers.

The days of Air Force Communications Command and the avionics section of operations controlling the vast majority of high technology equipment are rapidly coming to an end as a multitude of other organizations procure desk top computers and other types of high technology equipment to increase the speed and efficiency of their operations.

Civil Engineers, especially those in commands specializing in high technology equipment, feel they are coming under increasing pressure to correct high technology equipment problems attributed to the lack of quality power, and furthermore, they are being held responsible for supplying

whatever power/assistance is required to keep high technology equipment operational (3:2).

If the local utilities are supplying power in accordance with (IAW) ANSI C84.1, then why are we having problems with high technology equipment and what can civil engineers do within their area of responsibility and expertise to correct the problem?

When the requirement for PCCIE is identified by the user, the civil engineer must have the knowledge base of existing PCCIE to ensure he does not recommend more PCCIE capability than what is required to meet mission requirements. The cost gradient between different types of PCCIE can be measured in hundreds of thousands of dollars.

Research Objectives

The objectives of this research are to determine if Air Force Bases in the Continental United States are receiving quality electrical power from the local utilities IAW ANSI C84.1, to explore other factors that can degrade the quality of power received, and to provide a knowledge base of existing PCCIE.

Research Questions:

1. Is the Air Force receiving quality power from the local utilities IAW ANSI C84.1? If not, why not?
2. How does grounding of high technology equipment affect its operation?
3. How do power disturbances on the distribution system affect the quality of power? How are they generated?

4. What kinds of Power Conditioning and Continuation Interface Equipment (PCCIE) are there? How do they help the quality of power? In what type situations are they applicable.

II. Literature Review

ANSI C84.1

American National Standards Institute C84.1 establishes standards at which electric utilities in the United States must deliver electrical power. It sets ranges the utility must provide electrical power at to ensure steady state voltage and frequency is delivered to the service entrance or the point of utilization at standard voltages above 100 Volts through 230 Kilovolts (8:382). For example, a nonlighting circuit rated at 120/208 volts is allowed to have regular excursions of approximately -10% to +4% at the service entrance or point of utilization and infrequent excursions of -13% to +6% (8:382). The frequency at which these excursions occur conform to a normal distribution curve (8:382) (Figure 1.).

The majority of computers in use today can be expected to operate satisfactorily within the envelope of -10% to +4% if operating on a 120/208 nonlighting circuit. It is when the voltage deviates beyond these limits that operating anomalies begin to appear (8:382).

HQ USAF/LEE in their policy letter, Power Conditioning & Continuation Interfacing Equipment (PCCIE) dated August 1, 1984, outlined the Base Civil Engineer's (BCE) responsibilities in regards to electrical power:

The BCE is responsible and shall ensure the base electrical power distribution systems will meet the ANSI standard voltage ranges (ANSI C84.1) and the typical utility power profile.

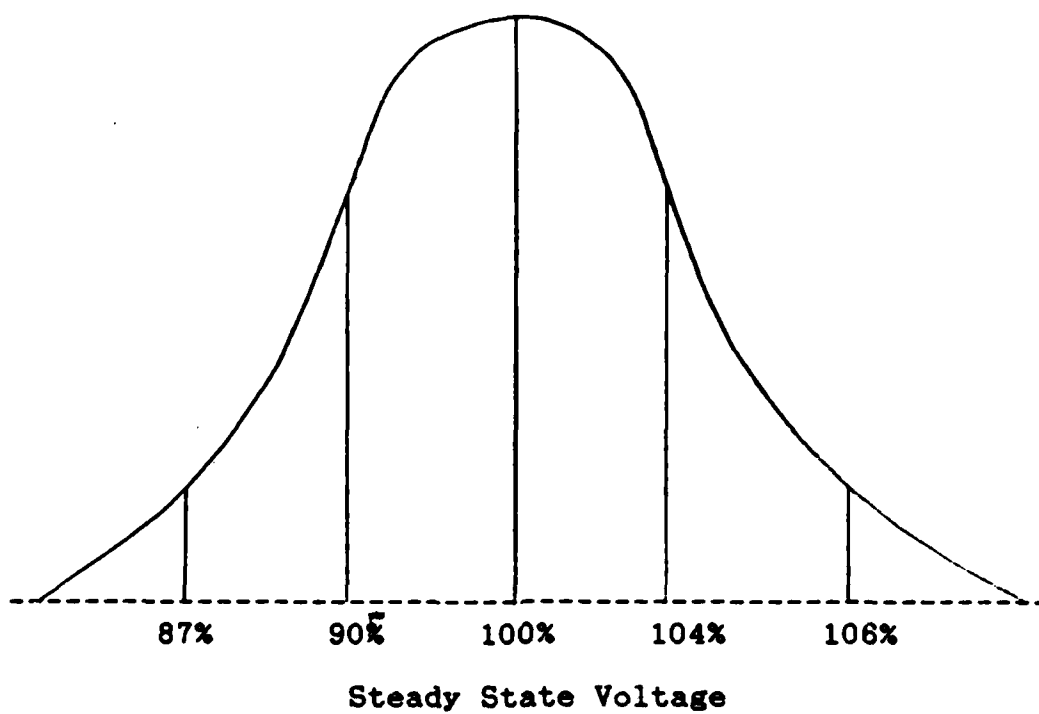


Figure 1.
ANSI Normal Curve (8:383)

This was reemphasized by HQ USAF/LEEE letter dated March 18, 1985, same subject:

The BCE is not responsible for the successful and reliable operation of sophisticated electronic equipment in excess of the parameters of ANSI C84.1 utility power profile.

As far as the utilities are concerned, if the utility provided electric power to the substation(s) of an Air Force base IAW ANSI C84.1, then the utility has met its contractual obligation because this is the utilization point of the customer. Most substations servicing Air Force Bases are owned by the Air Force. Once the electrical power is at the substation the responsibility for meeting the requirements of ANSI C84.1 are assumed by the Base Civil Engineer.

Grounding

Improper grounding can cause serious power problems for high technology equipment, and more importantly, can pose serious safety hazards. The main problems with improperly grounding the building, the high technology equipment, or the grounding scheme through which they are connected is that it creates voltage potential differences between the equipment and the power source. Improper grounding can cause voltage dips (under voltage condition) lasting up to 1/2 cycle (16:4). There is also evidence in the engineering community that improper grounding can make computers more susceptible to transients (momentary over or under voltages) (16:4). These voltage potential differences can drive currents through the

equipment, and in the electronics industry these currents are called ground noise (12:1). If sufficiently large, these ground noise currents can cause hardware or software operating anomalies, in some instances cause damage to the equipment, and in extreme cases present a serious electrical shock hazard to humans.

Compounding the problem for the Air Force is some of the high technology equipment was installed prior to a comprehensive understanding of grounding problems, and the civil engineering community has rehabilitated hundreds of older buildings (circa 1950, 1960) to house this high technology equipment without upgrading the building's wiring/grounding system. The grounding problem is further aggravated by the fact that the distinction between power grounding and signal grounding (signal referencing) is not universally understood or applied. Power grounding applies to the systems or circuits that supply electrical power usually at 60 cycles. Signal grounding applies to systems or circuits that transmit or receive electrical signals usually at frequencies other than 60 cycles. The NEC (National Electrical Code, ANSI/NFPA-70-1987) is clear on electrical power grounding requirements for high technology equipment. The NEC does not have jurisdiction over signal grounding and does not address signal grounding. AFR 88-15 (December 1985) doesn't specifically cover power or signal grounding of high technology equipment but defers to the NEC and references MIL-HDBK 419, Grounding, Bonding, and Shielding for Electronic

Equipments and Facilities, Volumes I & II, and AFM 88-4, CH 4, Data Processing Facilities.

In a paper written by Hewlett-Packard engineers, a part of their recommendation for detection of a noise problem on site is:

Check the wiring from the building's utility power connection back to the outlets in the computer room. Feedback from Hewlett-Packard systems specialist in the field indicates that improper site wiring is often the major cause of power line disturbance problems. With the help of an electrician who is aware of local codes, check the building's electrical layout, and look for load distributions that overload any circuits, or branch circuits that allow other electrical devices to use the same circuit breaker as the computer. Distribution and breaker panels must have solid electrical connections, and breakers and wire capacities must equal or exceed the computer's demand. Check equipment layout at the computer installation. All devices must be plugged into their own wall outlets. Extension cords with multiple outlet boxes must not be used. If possible avoid extension cords altogether. Check especially for grounding of all devices by having the electrician confirm that the ground wire is continuous back to the building service entrance. A computer system can pollute its own power if these procedures are not observed [5:29]. (emphasis added).

For many years there has been a difference of opinion between the electrical and electronics community on reconciling the proper installation of electronics equipment to comply with the NEC in general and grounding requirements in particular (11:11-13). A popular grounding technique with the electronics industry has been the "isolated grounding

electrode". This practice establishes an equipment power and signal ground separate from the building power ground and is considered the proper way to isolate the equipment from the building's "noisy" power grounding system (11:13). This practice has been responsible for a number of unsafe installations and NEC violations. Additional unwarranted expenses have been incurred to establish a "clean ground" far away from the building ground (17:37).

The problem with an isolated equipment ground is that two separate grounds are established within one system, and voltage potentials between the two grounds are established. This creates the ground noise the isolated system was designed to defeat, can damage or degrade the performance of equipment filtering devices, and can pass enough current to electrocute someone (12:13; 17:38).

Voltage Disturbances. Effect and Generation

The paper written by by Thomas Key, "Diagnosing Power Quality - Related Computer Problems" (8), defined power line disturbances as Type I, Type II, and Type III (Figure 2). Type I disturbances are oscillatory overvoltages and spikes that are usually 200-400 percent above or, in the case of negative spikes below, RMS voltage. These disturbances usually last less than 1/2 cycle (8.33 milliseconds). Type II disturbances are momentary over or under voltages. They exceed 110% of RMS voltage or fall below RMS by 80-85% and last 2 to 4 cycles.

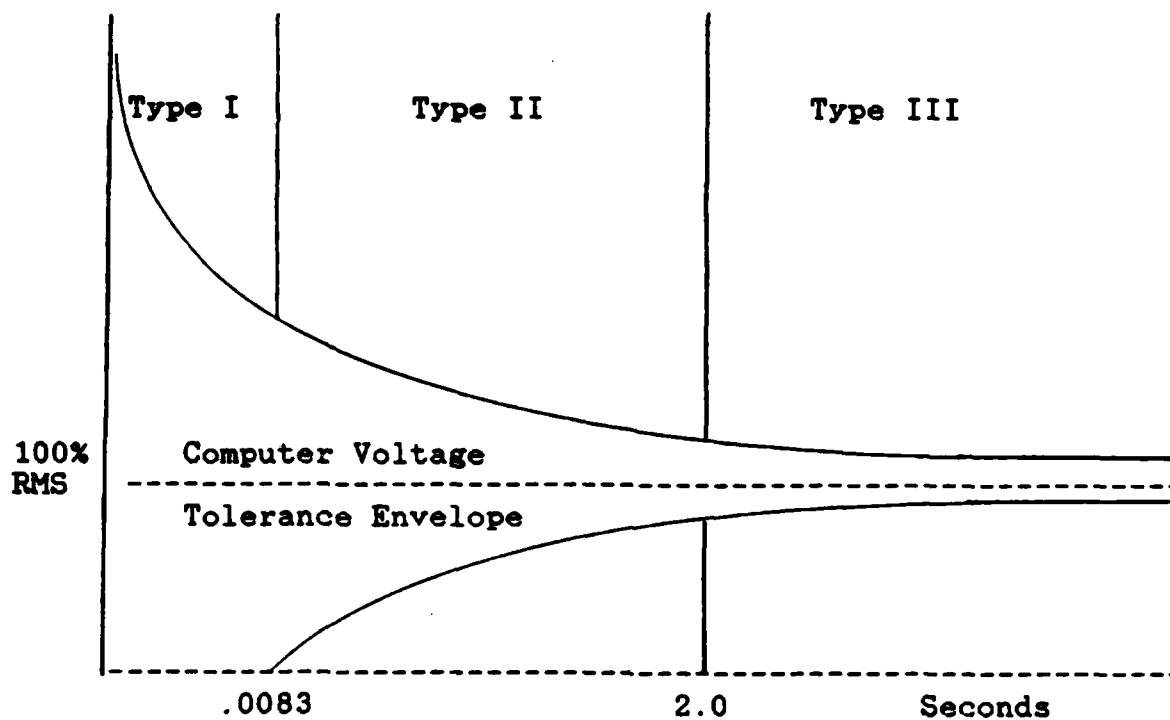


Figure 2.
Power Line Disturbances (8:387)

The Type II undervoltage disturbance is the most common cause of computer system failures. Type II overvoltages are rare in low voltage power systems and do not cause very many computer system failures. Type III disturbances are power outages that last from 2 seconds to whenever power is restored. Anytime voltage drops below 80-85% of RMS for more than 2 seconds it is classified as a Type III disturbance.

All three types of voltage disturbances can be generated in high technology equipment buildings by air-conditioning, heating, appliance/lighting loads, and lightning strikes.

For a simplified illustration of the problem, assume a 225 KVA transformer connected 208Y/120 at the secondary supplies power to a service panel in a building. Connected to this service panel is a high technology equipment load (assume computers) of 200 amps and an air-conditioning compressor rated at 100 amps full load and 600 amps locked rotor. The transformer can supply 208 volts at 625 amps indefinitely if loaded 100% or less. But if the computers are running full load at 200 amps and the air-conditioning compressor turns on, this represents a current requirement of at least 800 amps for usually less than a cycle. This condition reduces the voltage available at the service panel to 162 volts which is 22% less than RMS. Conversely, when the compressor turns off, it can cause a voltage surge (overvoltage condition) lasting from 1/2 cycle to less than 10 cycles (17:3; 9:388).

At one house in a study of residential voltage disturbances, voltage spikes of 1700 volts were recorded that

were caused by the start of an oil burner (14:1049-1055). Fluorescent lighting can cause transients (Type I disturbances) of 500 volts, 2 MHZ, lasting up to 20 microseconds (5:26). Lightning strikes have caused voltage spikes of over 5600 volts to be injected into power systems. These lightning induced voltage spikes can raise the potential at the point of impact, damage equipment, trip circuits, and cause power outages at the building (13:18; 14:1049; 8:388).

The power distribution system, usually overhead electrical lines, is the cause of voltage disturbances for many reasons. The distribution system within the boundaries of an Air Force base is owned and maintained by the Air Force, whereas those outside the base are owned and maintained by the local utility, but both are susceptible to the same problems. This is because the Air Force distribution system is a smaller version of the local utility's distribution system. The Air Force distribution system services industrial loads, residential loads, and office building complex loads. Additionally, the Air Force distribution system is tied into the local utility distribution system, which means that power disturbances can be transmitted between systems. Switching and motor starting of large utility/industrial loads connected to the power grid can cause voltage transients of Type I and Type II that affect high technology equipment (8:391; 5:28). Utility load switching to meet power requirements on the grid can cause voltage disturbances of Type I and Type II (5:26; 13:18; 16:2; 4:17). In some instances switching of power

factor correction capacitor banks have been identified as the source of overvoltages of 50 to 199 volts that were directly responsible for computer failures (8:389-391; 16:3).

Lightning can cause severe power disturbances on the distribution grid due to overvoltages and circuit breaker operation and can lead to equipment damage (8:388-392; 13:18; 14:1049; 16:2).

Allen and Segall monitored three phase 208 and 240 volt power sources supplying data processing equipment. They computed 90% confidence levels of the actual total mean occurrence for three types of electrical power disturbances. At 43 monitored locations, undervoltage conditions (i.e., voltage drops 10% or more of RMS) occurred 11.4 ± 5 times per month. Digital oscillatory disturbances are oscillatory decaying disturbances due to power factor correction capacitor switching and other network or load switching. The disturbances have a frequency of 400 cycles to 5000 cycles, with beginning amplitudes of 100% or more of RMS. They usually decay to zero within one cycle. Allen and Segall found these digital oscillatory disturbances occurred at 19 monitored sites 34.6 ± 14.7 times per month. The digital voltage spike (i.e. overvoltage of 50% or more of RMS due to lightning, power network switching that are of short duration, 10 to 100 nanoseconds) at 18 monitored sites occurred 17.1 ± 2.4 times per month (2:4).

One study was conducted using the distribution system as

the parameter of interest to determine if some types of systems were more susceptible to power line disturbances than others (1:1). In this study a power line disturbance was defined as one or more line-to-line voltages dropping to 80% of nominal or less. This 80% or more drop is greater than 10% of the range defined by Thomas Key (8:384) as tolerable for computer operations. With the exception of the overhead preferred alternate system (a secondary power line is provided to the site, if the primary power line fails then the secondary provides power) which had a power line disturbance per month rate of .9, the overhead distribution systems were almost twice as susceptible to power line disturbance than the comparable underground systems (1). The overhead systems had a disturbance rate of 2.61 to 4.03 per month while the underground systems had a disturbance rate of 1.11 to 1.30 per month. Not only is the underground system less susceptible to day-to-day operating disturbances, but a good argument may be made that the underground system would be less susceptible to peace time accidents or deliberate destruction. On the other hand, trends from Military Airlift Command indicate that directly buried underground power cable is being replaced every eight to ten years due to deterioration (15). Several studies established the existence of power line disturbances that can adversely affect high technology equipment, the missing data was the linkage between these disturbances and high technology equipment failures.

Voltage Disturbances and Computer Failures

There has been much debate about amount of computer downtime directly attributable to power disturbances. Some writings depict power disturbances as a very large cause of high technology equipment problems.

Operator mistakes, programmer errors, hardware failures, and systems software bugs will always cause some problems even in the most carefully run computer installation. However, of all the correctable problems that occur, 20% to 60% are informally estimated to be caused by power irregularities. Now and then a power problem can be identified as the culprit in a major or minor outage. In most instances power will not be an obvious cause [20:11].

Fortunately, systematic research has been conducted which links voltage disturbances to computer failures.

A study conducted at the University of Alberta over a ten year period examined the reliability performance of the school's AMDAHL 470/V8 computer system (9:367). The reliability base was divided into four bases: software failures, hardware failures, operator errors, and power system disturbances and outages (9:368). The study found that power disturbances and outages accounted for 3.1% of the computer failures over an eleven-year period (9:370). Some years reflected more power problems than others. The maximum number of power problems occurred in 1974 with 19 occurrences causing a computer failure which accounted for 3.4% of the total outages. An excerpt from their table for 1981, the most recent data provided, reveals the following information: 397

failures due to software errors, 407 failures due to hardware errors, 58 operator errors, and 11 failures due to power (9:370). In 1981 power accounted for 1.4% of the total computer failures experienced.

Key conducted an eighteen month investigation at the Naval Supply Center, Charleston, S.C., an area of high thunderstorm activity. Based on 80% productivity at the center with around the clock 7 days a week operation, he found that power related computer failures which included power outages and computer restart time accounted for 10% of the total computer hours available (8:382).

The Deputy Assistant Secretary of Defense (supply maintenance service) requested that the Defense Supply Agency Analysis Division conduct a study of the electric power being supplied to the logistics systems computers, and to determine the impact of power fluctuations and power outages on these systems (4). A survey of 44 sites, including Army, Air Force, Navy, Marines, and Defense Supply Agency (DSA) installations was conducted. There is a wide variety of computers throughout the logistics system including IBM, Univac, Burroughs, CDC Cyber, and RCA (4). The percent of total computer downtime attributed to power for each respective service is as follows; Army 8%, Air Force 10%, Navy 5%, Marines less than 1%, DSA 5% (4:7-28). These values are much smaller when compared to total computer time available; 32 sites are 1% or less, 10 sites are between 1% and 2%, while

there are two sites larger than 2%, (3.7% and 4.3%) (4:37-38). A portion of the summary of this report sent to the Deputy Assistant Secretary of Defense (Supply, Maintenance, Service) was:

Computer downtime because of power problems is a very small part of the total available computer hours, and downtime for other reasons far exceeds the downtime due to power problems. Available data does not support the existence of a causal relationship between power problems and increased computer down time for remedial maintenance [4:53].

The majority of research conducted concerning power disturbance effects on high technology equipment was initiated with the computer population explosion in the early 1970's. The variability of the computer compared to other high technology equipment with regards to susceptibility to power disturbances would appear to be small. That is, other types of high technology equipment do not appear to be any more susceptible to power disturbances than computers.

The above sources indicate that a 10% of total down time due to power disturbances is the worst case. The other 90% can be attributed to software/hardware problems or operator errors. Our distribution systems are susceptible to power disturbances that can affect high technology equipment adversely, and even if the power profile is within ANSI C84.1 standards, some of the more sensitive high technology equipment can be affected and caused to malfunction. It is doubtful that the utility industry will take steps to improve the quality of power beyond that required by ANSI C84.1 as

computer systems and other sensitive control loads represent less than .01% of the total utility load (5:26). Some manufacturers of computers have recognized this and designed accordingly to meet customer demands without excessively inflating cost (5:30). Hewlett Packard tests its units for input voltage, -10% to +5% of nominal, input frequency 47.5 to 66 HZ. A power fail test-outage of less than 20 milliseconds is conducted and should have no effect on the product (5:30). These procedures either meet or exceed ANSI C84.1.

Power Conditioning And Continuation Interface Equipment (PCCIE)

PCCIE comes in all shapes and sizes from simple line filters and surge arrestors to complex Uninterruptible Power Systems (UPS).

Current HQ USAF/LEE policy concerning UPS is:

Power Conditioning and Continuation Interfacing Equipment Policy Letter Dated August 1, 1984. Sophisticated electronic equipment acquisition documents such as purchase request, specifications, or request for proposals (RFP), as appropriate, shall be provided to ADP, C-E, etc., contracting personnel and the Engineering and Service electrical engineer at the proper level of authority (Base, MAJCOM, or Air Staff depending on the quantity & complexity of the acquisition). Prior to submission to procurement these documents shall be reviewed to ensure that a gap does not exist between the power supplied and the power requirements of the equipment. Review comments shall include recommendation by the electrical engineers at the Base, MAJCOM, or Air Staff on whether or not power conditioning/continuation and/or spike/surge transient protection should be included in the equipment acquisition. Equipment may be provided with either

integral or adjacent PCCIE interfacing devices, whichever provides the lowest life cycle cost. Regardless of whether the PCCIE is integral or adjacent, the appropriate budget activity funding the equipment requiring the PCCIE will also fund the PCCIE.

This policy was clarified for the BCE in the policy letter from HQ USAF/LEEUE dated March 18, 1985:

Power Conditioning and Continuation Interfacing Equipment (PCCIE) (Ref LEE ltr, August 1, 1984). The BCE is not required to provide PCCIE for users equipment. The BCE should provide assistance and advice, upon request, to aid or correct sophisticated electronic acquisitions to help ensure no gap exist between the quality of power supplied (ANSI C84.1) and the quality necessary. However, the BCE may make recommendations whether or not they believe PCCIE will be necessary for a specific application.

Even though the BCE is not responsible for PCCIE at this time, he/she must be able to aid in design requirements of PCCIE to meet power and mission demands of high technology equipment until he/she assumes responsibility for PCCIE.

The BCE may assume responsibility for maintenance of PCCIE in five years. HQUSAF/LEE letter dated 8 December 1986 seems to endorse this concept:

In a related area, we have also endorsed civil engineering taking maintenance responsibility for power conditioning continuation interfacing equipment (PCCIE) in the next five years. This time-frame is needed to implement the necessary career field, training, and logistics changes.

Filters are static devices designed to pass basic power frequency and reject noise and unwanted harmonics. The type of noise encountered in a system is of two types; common mode,

which occurs between line conductors, reference ground, the neutral, and sometimes the equipment ground, and normal mode, which occurs between line conductors and the line conductors and neutral (17:52). The low pass filter will pass 60 HZ power and lower order harmonics but will attenuate high frequencies which can interfere with the system's logic circuits (17:52). To operate properly the input and output impedances of the filter are matched to the impedances of the source and load. Since these are rarely constant, compromise is the only solution and the result is often unwanted ringing or line voltage disturbances at some other frequency other than the frequency the filter was intended to correct (17:53). Filters require application skill, are expensive, and can cause more problems than they solve (17:52). If filters are required, it is recommended that the supplier of the high technology equipment also supply and install the filters. The manufacturer has access to load impedances that government engineers may be unaware of or which may be proprietary.

Surge arrestors are of several basic types with different characteristics designed to limit overvoltage (17:61). There are two basic types of surge arrester operation. When the threshold voltage is exceeded, the type first conducts until current is reduced to zero, and the second type conducts until voltage is reduced to threshold and then returns to its natural state as an open circuit (17:61). The first type is usually a pellet or gas discharge device that can handle large currents, but it can be shorted by weak short-duration

impulses that can short circuit the line for 1/2 cycle. This transient may be larger than the impulse that originally triggered the device (17:61). The second type is usually made of a nonlinear insulation material that becomes more conductive as voltage increases (17:61). The point to remember is that these devices do not absorb the excess energy. They divert the energy, and it must be ensured that a path is provided for this diverted energy or they may cause problems or even equipment damage (17:61). These arrestors divert the excess energy to ground. The arrestor has a wire that is connected to a suitable ground within the system. If this ground is improperly connected (i.e., to an improper ground or a neutral), arcing, explosions, large transient voltage spikes, or even electrocution hazards may be generated.

Since these devices divert large amounts of energy, they must be mounted in suitable enclosures to prevent explosion hazards (17:61). Lightning arrestors provide excellent protection against lightning but are relatively slow reacting devices because they handle large amounts of energy (16:6). Because lightning arrestors are slow reacting, they may let the leading edge of a fast rise-time impulse pass through so a fast acting arrestor is often needed down stream to provide protection for sensitive equipment (16:6).

Surge arrestors should be considered in every design regardless of the presence of high technology equipment, because they provide excellent protection at relatively little cost. However beware of overpriced "energy saving" surge

arrestors (17:6).

Isolation transformers provide a clean ground and excellent common mode noise rejection. This is due to the low capacitance between the primary and secondary windings. It reduces capacitive coupling between windings, the only way common mode noise can be transmitted between windings (17:5). In accordance with the NEC, isolation transformers can be used as separately derived power sources. As separately derived power sources, the transformer can be the source of a separately derived ground. The "cleanliness" of this separately derived ground is dependent on proper installation and connection. Isolation transformers can limit fault currents to 20 times the rated current of the transformer, which may protect smaller downstream circuit breakers, and they are 95%-98% efficient (17:57). Transformers with a delta input windings and wye output windings are popular because of their ability to reduce apparent harmonic content of loads, improve power factor when harmonic currents make the power factor low, and balance input currents when individual output phase loads are unbalanced (17:57). Isolation transformers do not provide voltage regulation (17:57) and are generally ineffective in rejecting normal mode transients (16:6). They can add up to 2% to the air-conditioning load if installed in the computer room (17:58).

Voltage regulators can provide protection against voltage sags and surges, but prior to their specification, information on the high technology equipment's power supply should be

obtained. Newer computer power supplies may have operating voltage windows of 90 to 140 volts, older power supplies are usually limited to 108 to 125 volts (16:5). This may explain the higher frequency of problems encountered with older equipment. Voltage regulators can regulate voltages over a range of 36 volts on a 120 volt system (+10% to -20% or +15% to -15%) and are mechanically operated or operate on the principles of saturation of the transformer core (16:7-8; 17:53-57). The different types of voltage regulators all have advantages and disadvantages to their use. The main point to watch for in specifying a voltage regulator is whether the voltage regulator in the high technology equipment's power supply has the same response time as the external voltage regulator. If they both have the same response time, unstable interaction may occur (17:55; 16:7). This unstable interaction may occur when the external voltage regulator increases the output voltage. The computer power supply voltage regulator tries to reduce voltage. This reduces computer current which causes the external voltage regulator to reduce voltage. The computer power supply voltage regulator then tries to increase voltage. This "hunting" can go on indefinitely and can cause overheating of the power supply and equipment malfunctions (16:7).

Motor generators provide voltage regulation and a limited ride-through capability for serious voltage sags or voltage loss. Motor generators can provide ride-through protection for up to 333 milliseconds or about 20 cycles (8:391).

Motor generators come in different sizes and configurations but the better systems basically incorporate a synchronous motor (for better frequency output), a flywheel between the motor and generator to mechanically isolate the load from the electrical source, and a bypass switch for maintenance. The major disadvantage of the motor generator is its limited ride-through capability when compared to other systems. After long voltage sags or losses (i.e., greater than 1/3 second), some alternate means of bringing the synchronous motor up to speed may be required due to the motor's poor torque characteristics (17:60). Its main advantage is that it cost only 25%-35% of an uninterruptible power supply (18:10).

The uninterruptible power supply provides excellent voltage regulation and a ride through capability for voltage sags and losses only limited by the amount of battery time available. There are two basic types of uninterruptible power supplies, static and rotary. The static uninterruptible power supply is built exclusively with solid state electronics, whereas the rotary uninterruptible power supply uses a motor generator for the final power conversion device (6:29). The static uninterruptible power supply system can be operated in three different configurations, continuous, forward transfer, or reverse transfer (6:31). In continuous operation the uninterruptible power supply is the source of power for the load, and when commercial power is interrupted or falls below the threshold the battery bank comes on line and supplies power (6:31). Forward transfer operation only puts the

uninterruptible power supply system on line when voltage fails or falls below threshold (6:31). The reverse transfer operating scheme is similar to the continuous except that it can switch the load on to commercial power. The advantage of this is that if the uninterruptible power supply fails the commercial source will provide power. The commercial line can be used to clear faults downstream of the uninterruptible power supply (6:31). The uninterruptible power supply is the best power continuation interface equipment available, but it is also the most expensive (8:39; 18:13).

III. Method

Description of Populations and Samples

The fundamental question addressed by a telephone survey concerned the quality of electrical power received by active duty Air Force Bases in the Continental United States. After careful consideration it was decided that the individuals directly responsible for or directly affected by the quality of power would be surveyed. This list of individuals was further reduced to individuals in two organizations, Civil Engineering and the Communications Squadron.

Within the Civil Engineering Squadron the following individuals were contacted; Chief of Operations, Chief of Engineering, and the Electrical Superintendent. The Chief of Operations is a management level position responsible to the Base Civil Engineer for the day-to-day operation and maintenance of the base electrical distribution system and providing quality power in conformance with ANSI C84.1. He/She has operational control over the electrical technicians in civil engineering. The Chief of Engineering is a management level position responsible to the Base Civil Engineer for providing electrical engineering expertise for proposed electrical systems, solving electrical power problems and providing quality electrical designs. In meeting these responsibilities the Chief of Engineering must be aware of ANSI C84.1 requirements and further, he/she must be aware of the fact that electrical power does or does not conform to the

ANSI C84.1 standards. He/She has operational control over the electrical engineers in civil engineering. The Electrical Superintendent is a lower level management position filled by a senior technician and it will be henceforth referred to as the technician level. He/she is responsible to the Chief of Operations for electrical maintenance and the successful measurement of electrical power. He/she has all of the electrical technicians under his/her direct operational control.

Within the Communications Squadron the Deputy Commander for Maintenance was contacted. The Deputy Commander for Maintenance in the Communications Squadron is a management level position responsible to the Communications Squadron Commander for maintenance of all Communications Squadron controlled equipment; this includes computers, radar, navigation aids, and radios. He/She determines the cause of equipment failure and the requirements for equipment repair. While he/she is not responsible for providing quality electrical power or ensuring that electrical power meets the ANSI C84.1 standard, he/she is highly dependent on quality electric power for successful operations.

The four populations of interest were the Chief of Operations, the Chief of Engineering, the Electrical Superintendent (Civil Engineering) and the Deputy Commander for Maintenance (Communications Squadron) at active duty Air Force Bases within the Continental United States.

From among 108 active duty Air Force bases 35 were

randomly sampled. The bases were numbered from 1 to 108, and 35 random numbers were generated by computer. This provided for a 32% sample of all active duty Air Force bases. Table 1 lists the Air Force bases sampled. This sample provided a good cross section of all United States Air Force bases and of the different environments within which electrical power is delivered. In addition, a good representation of Air Force Major Commands was obtained.

Telephone Survey Instruments

For the telephone survey a structured set of questions was developed to try and determine if the base was receiving power in accordance with ANSI C84.1.

Management Level. Two questions were posed to management representatives to determine the quality of power received and intra/inter-organizational communications concerning this issue. Of course, the obvious question to ask was, "Does the local utility provide power in accordance with ANSI C84.1?" The problem is that there is no way to phrase this question so that it does not seem to automatically evoke a positive response. This is because most government employees seem to be conditioned to follow regulations and directives. If an unknown individual asks a government employee if he/she is complying with a specific standard, the gut reaction from the government employee might be, "Of course I am." Nevertheless the question was asked because it was fundamental to the research, and the point to keep in mind is that the Civil

Table 1
Air Force Bases Sampled

<u>Base</u>	<u>State</u>	<u>Command</u>
1. Altus	Oklahoma	MAC
2. Andrews	Maryland	MAC
3. Arnold	Tennessee	AFSC
4. Bergstrom	Texas	TAC
5. Blytheville	Arkansas	SAC
6. Brooks	Texas	AFSC
7. Carswell	Texas	SAC
8. Columbus	Mississippi	ATC
9. Davis Monthan	Arizona	TAC
10. Dyess	Texas	SAC
11. England	Louisiana	TAC
12. F.E. Warren	Wyoming	SAC
13. Grand Forks	North Dakota	SAC
14. George	California	TAC
15. Goodfellow	Texas	ATC
16. Grissom	Indiana	SAC
17. Holloman	New Mexico	TAC
18. Homestead	Florida	TAC
19. Kelly	Texas	AFLC
20. K. I. Sawyer	Michigan	SAC
21. Lackland	Texas	ATC
22. Little Rock	Arkansas	MAC
23. Lowery	Colorado	ATC

Table 1--Continued
Air Force Bases Sampled

<u>Base</u>	<u>State</u>	<u>Command</u>
24. Luke	Arizona	TAC
25. Macdill	Florida	TAC
26. March	California	SAC
27. Mather	California	ATC
28. McConnell	Kansas	SAC
29. Minot	North Dakota	SAC
30. Norton	California	MAC
31. Patrick	Florida	AFSC
32. Warner Robbins	Georgia	AFLC
33. Westover	Massachusetts	AFRES
34. Williams	Arizona	ATC
35. Wright-Patterson	Ohio	AFLC

Engineering representatives are responsible for this standard, the Communication Squadron representative is not. The problem of determining gut reaction responses was solved at the technician level. Additionally, a good indication of the quality of power received was to ask both organizations (i.e. Civil Engineering and the Communications Squadron), "Is the Communications Squadron currently experiencing problems with the operation of high technology equipment that the Communications Squadron attributes to electrical power?" This question served two purposes. It revealed perceived problems with the quality of electrical power by the Communications Squadron and the awareness of Civil Engineering to the Communications Squadron's concern. The major concern with this question was the fact that if there were problems with electrical power, it may not be the fault of the local utility. The problem may be somewhere within the confines of the base (i.e., grounding or some other electrical problem on base) as outlined in the literature review. Additionally, the Communications Squadron must communicate this concern for the Civil Engineer to be aware of it. Since the base's knowledge of the quality of electrical power is based on its ability to measure the quality of power, questioning about the availability of an electrical power analyzer was developed at the technician level.

The questions asked of the Chief of Operations, the Chief Of Engineering, and the Deputy Commander for Maintenance are consolidated in Appendix A.

Technician Level. There are two ways that management can determine the quality of electrical power received from the local utility. The first is by asking the local utility if they are providing power in accordance with ANSI C84.1. The second way is by direct measurement performed by individuals working for the Civil Engineer. Direct measurement by Civil Engineering is the most reliable way to determine the quality of electrical power received from the local utility. This is feasible due to the fact that each Base Civil Engineer has been authorized an electrical power analyzer on the organizational Table of Allowances for over 10 years (21). The Air Force Civil Engineering recommended power analyzer was the Dranetz Model 626 from 1981 to 1985 (21). Newer and better analyzers are available and the Air Force Civil Engineer is now encouraging Base Civil Engineers to procure these newer devices (21). The first question asked of the Electrical Superintendent was, "Do you have an electrical power analyzer listed on your table of allowances?" The only purpose of this question was to determine if the sample group knew that this was an authorized piece of equipment. The follow-up question, "What make and model electrical power analyzer is listed on your table of allowances?", was used to determine if the individuals sampled were aware of the specific piece of equipment they were authorized. Since the Dranetz Model 626 is probably the most widely recognized power analyzer in the Air Force (20), it was considered the correct answer in this research survey. It was determined that it was

more important that the base have some type of electrical power analyzer available rather than the possession of the specific Dranetz model recommended, so the question, "Do you have an electrical power analyzer available?", allowed for other types of electrical power analyzers, rentals or inter-command loans. It was felt that if a base had an electrical power analyzer, then its use would inform the base of the quality of power they were receiving. Additionally, if the base had an electrical power analyzer and had used it, then they would be able to isolate an electrical problem to the base or the local utility. Finally this question will provide a cross check on the questions asked of the Civil Engineering management representatives. For example if a Civil Engineering management representative answered that his/her base was receiving electrical power in accordance with the ANSI C84.1 standard, but the Electrical Superintendent did not have an electrical power analyzer available to directly measure electrical power, then the basis for management's affirmative answer may be called into question. This is due to management's apparent inability to get an accurate measurement of the electrical power it is receiving. However, the Civil Engineering manager may have obtained a measurement of electrical power from an outside source (i.e., the local utility). The point to remember is that the usefulness of the electrical power analyzer is not limited to power measurement only, but also the successful troubleshooting of electrical power problems. To determine if the electrical power analyzer

was a beneficial aid in solving electrical power problems two final questions were asked of the Electrical Superintendent. "Have you used an electrical power analyzer before?", and, "Did it help in determining the problem?" It was felt that the individual must have some type of firsthand knowledge of a tool to determine its usefulness and to determine if problems are limited to electrical power systems exclusively. Apparent electrical problems may include equipment problems rather than or in addition to an electrical power problem.

The questions asked of the Electrical Superintendents are consolidated in Appendix B.

Procedure

The telephone operator at each base in the sample was contacted and the phone numbers for the Chief of Operations, Chief of Engineering, Electrical Superintendent and Deputy Commander for Maintenance were obtained. Each individual was contacted, the research was explained, and voluntary help with the research was requested. Each individual was guaranteed anonymity. The format of the questioning was explained. The fact that the questions were technical in nature and could be answered by yes, no, or unknown was made clear. If the respondent wished to elaborate, he/she was encouraged to do so. The response rate for the telephone interview was 100%.

Analysis

The responses from the sample groups provided nominal level data because the responses were yes, no, and unknown.

This is true of all questions with the exception of the question asked of the Electrical Superintendent, "What make and model Electrical Power Analyzer is listed on your Table of Allowances?" In regard to this question, the power analyzer that had been recommended is the Dranetz Model 626. The percentage of Electrical Superintendents providing this response will be provided in Chapter Four. Each question will be analyzed by reporting the percentage response for each category by each sample group.

Since the same questions are being asked of the Chief of Operations, Chief of Engineering, and Deputy Commander for Maintenance and the responses are yes, no, or unknown, contingency tables were used. The chi-square statistic was used to determine if the responses were grouped, that is, if the responses were clustered in a non-random fashion. The problem was that contingency tables and the chi-square statistic do not provide any information on association between variables.

The Contingency Coefficient (C) can be used to provide a measure of association between variables. There are some considerations that limit the usefulness of this measure. First, C is always less than 1, even for perfect association. Second, C only provides an intuitive sense of association. Third, C's upper bound can only be determined for tables that have equal numbers of rows and columns (19:377).

Cramer's V provides a measure of association comparable to C. This is due to the fact that both measures are based on

the chi-square statistic. But Cramer's V can be used on contingency tables that have unequal rows and columns, and it has a maximum value of 1.0 for perfect association (19:379).

IV. Results

Management Item Responses

The first question asked of the Chief of Operations, the Chief of Engineering, and the Deputy Commander for Maintenance was, "Does the local utility provide electrical power in accordance with ANSI C84.1?". The results are displayed in Table 2. Two immediate observations may be made. First, there is a complete lack of negative responses, and second there is a large percentage of unknown responses. While examining the data in table 2, two points must be kept in mind. The first is that the Civil Engineering representatives (i.e., Chief of Operations, Chief of Engineering) are directly responsible for electrical power's conformance to the ANSI C84.1 standard and secondly the Communications Squadron representative is not (i.e., Deputy Commander for Maintenance). Even though the Communications Squadron representative is not responsible for electrical power's conformance to the ANSI C84.1 standard, he/she is highly dependent on the quality of electrical power and its conformance to the standard. Further the Communications Squadron representative would be very sensitive to any perceived electrical power problems. Evidently, at the majority of the bases surveyed there has not been an important enough power problem (i.e., mission critical) to draw attention and provide incentive to measure electrical power. This would explain the large percentage of unknown responses

Table 2

Electrical Power's Conformance to ANSI C84.1 Standards
(percentages and frequencies)

Sample Group	Yes	No	Unknown
Chief of Operations	40% 14	0% 0	60% 21
Chief of Engineering	22.9% 8	0% 0	77.1% 27
Deputy Commander for Maintenance	20% 6	0% 0	80% 29

(chi-square = 5.065, df = 2, p ≤ .10)

and the lack of negative responses. The most disturbing fact is the relatively low percentage of affirmative responses.

Table 2 displays the responses provided by both organizations (Civil Engineering and Communication Squadron) concerning electrical power's conformance to the ANSI C84.1 standard. The chi-square statistic for this table was marginally significant ($p \leq .10$) which implies a disproportionately high rate of unknown responses. The Cramer's V, a nonparametric associational statistic was significant but very low, $V = .22$. The maximum value for this statistic is 1.00. This may partially be explained by the fact that the Communications Squadron representative is not responsible for electrical power's conformance to the ANSI C84.1 standard, and it is reasonable to receive a large percentage of unknown responses from this group. Closer examination of Table 2 shows that the responses from the Civil Engineering representatives are distributed into proportions similar to the responses provided by the Communications Squadron representatives. It would appear from the response distribution in Table 2 that the management representatives agreed that power either conformed to the ANSI C84.1 standard or that they did not know if electrical power was in conformance. This is not the case, and in fact, the individuals surveyed from both organizations did not agree very often in responding to this question. This conclusion is highlighted in Table 3. Agreement in Table 3 means that the three individuals from the same base provided the same

Table 3

Agree/Disagree to
Electrical Power's Conformance to ANSI C84.1 Standards
Between the Chiefs of Operations, the Chiefs of Engineering
and the Deputy Commanders for Maintenance
(percentages and frequencies)

Agree	Disagree
31%	69%
11	24

response regardless of whether it was yes, no, or unknown. The 11 agreements in Table 3 in all cases reflected agreement that the conformance of electrical power to the ANSI C84.1 standard was unknown (i.e., 11 unknown agreements representing 31% of the total). This means that none of the managers at the bases surveyed agreed on the response yes or no. Sixty-nine percent of the time the respondents could not agree on the conformance of electrical power to the ANSI C84.1 standard. This apparent lack of interdepartmental communication was not wholly unexpected. Unless there had been some type of critical electrical power problem prior to the survey impacting Communications Squadron equipment, there would have been no reason for communications between the Civil Engineers and the Communications Squadron concerning electrical power's conformance or non-conformance to ANSI C84.1 requirements. The results seem to indicate that conformance of electrical power to the ANSI C84.1 standard is unknown, and further, there appears to be a lack of communication between the organizations concerning this issue. These results may be due to the lack of critical power problems at the bases surveyed. The lack of critical power problems at the bases surveyed may have also impacted the results obtained from the Civil Engineering organization.

Focusing on the answers from the representatives from the Civil Engineering organization summarized in Table 2, the Chief of Operations and the Chief of Engineering did not provide consistent answers when questioned about the base

receiving electrical power in conformance with the ANSI C84.1 standard. The chi-square statistic for Table 2 between the Chiefs of Operations and the Chiefs of Engineering was not significant. This is surprising because the Chief of Operations is directly responsible for providing electrical power in accordance with the ANSI C84.1 standard and the Chief of Engineering performs evaluations of electrical/electronic systems and development of electrical designs based partly on electrical power's conformance to the ANSI C84.1 standard. Additionally, the Chief of Engineering is tasked with providing engineering expertise in troubleshooting electrical system problems. An electrical system's performance is largely based on electrical power's conformance to the ANSI C84.1 standard. Also, these individuals belong to the same organization and in most cases are located in the same building. Additionally, these individuals meet weekly during the Base Civil Engineer's update briefing, and it would seem that any serious electrical power problems would be discussed at that time. The situation just described would seem to indicate adequate incentive and opportunity to communicate on the issue of electrical power's conformance to the ANSI C84.1 standard.

The results in Table 2 may indicate that there is little communication between The Chief Of Operations and The Chief of Engineering concerning electrical power's conformance to the ANSI C84.1 standard or that no serious power problems may have occurred at the bases surveyed to instigate such discussion.

This is highlighted in Table 4. Agreement in Table 4 means that both individuals from the same base provided the same response regardless of whether it was yes, no, or unknown. Of the 15 agreements in Table 4, 14 agreed that they did not know if electrical power conformed to the ANSI C84.1 standard. There was only one base that both the Chief of Operations and the Chief of Engineering agreed that power conformed to the ANSI C84.1 standard. Fifty-seven percent of the time the respondents could not agree on the conformance of electrical power to the ANSI C84.1 standard. This result provides more evidence on the apparent lack of communications between the Chief of Operations and the Chief of Engineering concerning this issue.

A final observation on Table 2 is that the Chiefs of Operations provided the largest number of positive responses to the question of electrical power's conformance to the ANSI C84.1 standard. This seems logical because the Electrical Superintendent who is responsible for the measurement of electrical power works for the Chief of Operations. However, only 57% of the Chiefs of Operations surveyed who said electrical power did conform to the ANSI C84.1 standard had the ability to directly measure electrical power. Table 5 shows a comparison between the Chiefs of Operations, who provided the largest number of positive responses to the question, and the Electrical Superintendents (works for the Chief of Operations), who said they had an electrical power analyzer available.

Table 4

Agree/Disagree to
Electrical Power's Conformance to ANSI C84.1 Standards
Between the Chiefs of Operations and the Chiefs of Engineering
(percentages and frequencies)

Agree	Disagree
43%	57%
15	20

Table 5
 Agreement Between Electrical Powers Conformance to ANSI C84.1
 According to the Chiefs of Operations and Possession of an
 Electrical Power Analyzer by the Electrical Superintendents
 (percentages and frequencies)

Electrical Superintendents		
	Have Analyzer	No Analyzer

"Electrical Power		
Conforms to	57%	43%
ANSI C84.1"		
Chief of Operations	8	6

A large percentage of the Chiefs of Operations (6 out of 14 representing 43%) who said that electrical power conformed to ANSI C84.1 standard had no direct capability of measuring electrical power. There may be three reasons for this apparent discrepancy. First, the question "Does the local utility provide electrical power in accordance with ANSI C84.1?" may have evoked a knee-jerk positive response. Second, a lack of electrical power problems on the base may imply that electrical power does conform to ANSI C84.1. Finally, the local utility may have told the Chief of Operations that electrical power provided to the base conformed to ANSI C84.1 standards.

The second question asked of the Chief of Operations, the Chief of Engineering and the Deputy Commander for Maintenance was, "Is the Communications Squadron currently having problems with the operation of high technology equipment that they attribute to electrical power?" The results are displayed in Table 6. The large proportion of responses fell in the negative category, which would seem to indicate that the majority of Communication Squadrons are not having problems with high technology equipment that they attribute to electrical power. Further, it would appear that Civil Engineering is aware of this and agrees with the Communications Squadron. The chi-square statistic for Table 6 was not significant. Apparently there was not a disproportionately higher yes, no, or unknown response given by any group concerning high technology equipment problems due

Table 6

High Technology Equipment Problems
Attributable to Electrical Power
(percentages and frequencies)

Sample Group	Yes	No	Unknown
Chief of Operations	17.14% 6	77.14 27	5.72% 2
Chief of Engineering	8.57% 3	82.86% 29	8.57% 3
Deputy Commander for Maintenance	22.86% 8	74.28% 26	2.86% 1

to electrical power problems. It must be remembered that the Civil Engineer must be made aware of the Communications Squadron's concern about equipment problems due to electrical power by the Communications Squadron. But the possibility does exist that the Deputy Commander for Maintenance may have contacted one of the Civil Engineering managers concerning equipment problems due to electrical power and there was no communication between the Civil Engineering managers concerning Communication Squadron equipment problems due to electrical power problems. This is highlighted in Table 7 which summarizes the agreements and disagreements between the organizations on this issue. Agreement in Table 7 means that the three individuals from the same base provided the same response regardless of whether it was yes, no, or unknown. In Table 7 all of the agreements were agreements on the absence of high technology equipment problems due to electrical power (i.e., 19 out of 35 representing 54%). However, 46% of the time the organizations could not agree on this issue. Taken together, Tables 6 and 7 do not indicate communication between the two organizations concerning high technology equipment problems attributable to electrical power but rather, indicate that since complaints concerning this issue have not surfaced between the organizations at the management level investigated there may not be a problem.

Technician Item Responses. The first question asked of the Electrical Superintendent was, "Do you have an Electrical Power Analyzer listed on your Table of Allowances?" Table 8

Table 7

Agree/Disagree to
High Technology Equipment Problems
Attributable to Electrical Power
Between the Chiefs of Operations, the Chiefs of Engineering
and the Deputy Commanders for Maintenance
(percentages and frequencies)

Agree	Disagree

54%	46%
19	16

displays the responses. Over 74% of the Electrical Superintendents knew that they they were authorized such a device. Actually, this percentage is quite low considering the fact that an electrical power analyzer has been authorized for over 10 years (21). Since 1984 it has been Air Force Civil Engineering policy that the Base Civil Engineer shall be able to provide electrical power readings for inclusion in acquisition documents for high technology equipment to the single point manager for acquisition of high technology equipment.

The second question asked of the Electrical Superintendent was, "What make and model Electrical Power Analyzer is listed on your Table of Allowances?" The results are displayed in Table 9. A little over 37% of the respondents were aware that the Dranetz Model 626 is the electrical power analyzer that had been recommended. This result may be attributable to the fact that the Electrical Superintendent manages the technicians that use this instrument rather than actually using it himself/herself. This percentage is still rather low considering the recommendation of this particular power analyzer and Air Force Civil Engineering policy.

The third question asked of the Electrical Superintendent was, "Do you have an Electrical Power Analyzer available?" Table 10 presents the results. Fifty-seven percent of the bases surveyed have some type of electrical power analyzer available. Without this device the quality of electrical

Table 8

Electrical Power Analyzer Listed on
the Table of Allowances

Sample Group	Yes	No	Unknown
Electrical Superintendent	74.28%	14.29%	11.43%

Table 9

Make and Model Electrical Power Analyzer
Listed on the Table of Allowances?

Sample Group	Dranetz Model 626	Unknown
Electrical Superintendent	37.14%	45.71%

Table 10

Electrical Power Analyzer Available?

Sample Group	Yes	No	Unknown
Electrical Superintendent	57.14%	42.86%	0%

power can not be directly determined, and, if a problem does surface, it is difficult to locate the source of the problem without an electrical power analyzer. This percentage is low due to the considerations mentioned above. A mitigating circumstance may be that the Base Civil Engineer must pay for this device from his/her organizational funds. This means that the electrical power analyzer must compete with other procurement needs for space on the organization's budget. Depending on the model, costs run several thousands of dollars. Unless the quality of power is an important issue at the base, the priority for procurement of the electrical power analyzer may be quite low.

The fourth question asked of the Electrical Superintendent was, "Have you used an Electrical Power Analyzer?" The results are displayed in Table 11. Over 68% of the Electrical Superintendents had used an electrical power analyzer before, which tends to indicate that these individuals were familiar with this instrument.

The last question asked of the Electrical Superintendent was, "Did the Electrical Power Analyzer help in determining the problem?" The results are displayed in Table 12. Of the Electrical Superintendents that had used this instrument, 100% felt that it had helped them in solving the problem. They articulated the problem as either solving an actual electrical power problem or convincing a customer that the equipment problem was not due to electrical power. This seems to indicate that an electrical power analyzer is a necessary and

Table 11

Have you used an Electrical Power Analyzer?

Sample Group	Yes	No	Unknown
Electrical Superintendent	68.57%	31.43%	0%

Table 12

Help Determine the Problem?

Sample Group	Yes	No	Unknown
Electrical Superintendent	100%	0%	0%

useful instrument.

Based on the results in Tables 8 through 12, it is not clear that the typical Civil Engineer has the ability to measure electrical power or troubleshoot electrical power problems. It does appear that the electrical power analyzer is useful in solving electrical power problems according to the Electrical Superintendents surveyed who have used the device.

V. Analysis and Discussion

Research Question 1

Is the Air Force receiving quality power from the local utilities in accordance with ANSI C84.1? If not, why not?

Asking the question, "Does the local utility provide electrical power in accordance with ANSI C84.1?", provided inconclusive results. Table 2 shows that the overwhelming proportion of responses to this question were "unknown". Even though no one in the three sample groups (the Chief of Operations, the Chief of Engineering, and the Deputy Commander for Maintenance) responded negatively to the question, the positive response rate was too small to make a firm statement concerning the quality of power received at the sampled bases.

The responses by representatives of both organizations (Civil Engineering and Communications Squadron) to this item produced a marginally significant chi-square statistic (at $p < .10$) due to the high ratio of unknown responses. This is highlighted by the fact that all the agreements on this issue were on the response "unknown". This disproportionately high use of the "unknown" response category is most likely based on a lack of communication and/or a lack of serious power problems, rather than on some type of informed concurrence between the two organizations.

Within the Civil Engineering organization there were no significant clusterings of responses into yes, no, or unknown categories in response to the question dealing with electrical

power's conformance to the ANSI C84.1 standard. This may indicate a lack of communication concerning this issue within the organization or the absence of serious power problems. This is reinforced by the responses in Table 4. This table lists the agreements/disagreements to the question of electrical power's conformance to the ANSI C84.1 criteria from officials in the same Civil Engineering organization. Of 35 bases surveyed, 15 pairs of respondents agreed, but 14 agreements reflected "unknown" responses to the question.

Finally, of the 14 Chiefs of Operations that said electrical power met the ANSI C84.1 criteria, 6 had no organizational capability to measure electrical power.

An indication of the quality of power received at a base was assessed by asking the question, "Is the Communications Squadron having problems with the operation of high technology equipment that they attribute to electrical power?" Table 6 shows that over 74% of the sample groups responded that the Communications Squadron was not having problems with the operation of high technology equipment that they attributed to electrical power. Evidently, electrical power problems with high technology equipment were not prevalent at the sites investigated. Additionally, the chi-square statistic was not significant, indicating that no response was given at a disproportionately higher rate than any other possible answer. Another purpose of the research question was to see if the three sample groups representing the two organizations were in communication concerning electrical power problems.

It appears that there is little communication between the two organizations concerning electrical power problems. This was accentuated by the fact that 46% of the time the organizations could not agree if there were equipment problems due to electrical power.

A Civil Engineer's knowledge of the quality of electrical power he/she is receiving is based on his/her ability to measure electrical power. The electrical power analyzer provides this capability, and the study's questions concerning the availability of this instrument do not provide support for the typical Civil Engineer's ability to measure power or his/her ability to locate electrical power problems. Tables 8 through 12 provide a summary of the responses by the Electrical Superintendents concerning the electrical power analyzer. A little over 74% of the Electrical Superintendents sampled knew that they had an electrical power analyzer authorized on their table of allowances. The Dranetz Model 626 electrical power analyzer had been recommended on the table of allowances and 13 (37.14%) of the 35 Electrical Superintendents were aware of this. Of the Electrical Superintendents surveyed over 57% had an electrical power analyzer of some kind available. Over 68% of the Electrical Superintendents had used an electrical power analyzer before, and of those that had used the instrument 100% said that it had helped in solving electrical problems. Based on the results at the bases surveyed, I conclude that about half have the means to accurately measure electrical power.

What can be said is that the electrical power analyzer does help in locating electrical power problems according to the Electrical Superintendents surveyed.

My conclusion is: (1) There is a lack of consensus on this issue. (2) There is little evidence of severe manifest electrical power problems. (3) A lot of guesswork and implicit faith exist because many bases can not measure electrical power quality. (4) Within the bases sampled there appears to be a consensus among Electrical Superintendents that have used the electrical power analyzer that it is a useful instrument in solving electrical power problems.

Research Question 2

How does grounding of high technology equipment affect its operation?

When high technology equipment experiences operating failures, electrical power is the first suspect. The actual problem may be due to improper grounding. Improper grounding not only causes problems with the operation of this equipment through differing potentials but also poses serious shock hazards to the operators and technicians. The biggest grounding problem appears to be the use of isolated grounding schemes by the high technology equipment community. Not only does this grounding scheme provide opportunity for creating potential differences in equipment, there is concern for the possible loss of life due to electrical shock.

Research Question 3

How do power disturbances on the distribution system affect the quality of power? How are they generated?

Disturbances on the power distribution system can either increase or decrease the quantity of electrical power received. This increase or decrease represents a distortion of the quality of electrical power received by the high technology equipment. When the quality of power is outside the electrical operating limits of the equipment, then operating failures and/or equipment/software damage may occur.

There are many causes of power line disturbances. The major problems seem to be confined to weather and the switching of large utility/industrial loads and motors. The interesting thing is that at most about 10% of high technology equipment failures can be directly attributed to poor quality power. The other 90% can be attributed to other sources such as software/hardware errors, operator errors, and improper grounding. Of course this is not all conclusive, but it appears that the probability of the quality of electrical power causing a high technology equipment failure is about .10. Finally, the underground distribution system appears to be less susceptible to power disturbances than the overhead system.

Research Question 4

What kinds of Power Conditioning and Continuation Interface Equipment (PCCIE) are there? How do they help the

quality of electrical power? In what types of situations are they applicable?

There are really three types of equipment within this arena. Equipment that conditions power, equipment that provides power continuation, and equipment that does both. Suppressor devices condition power in the sense that they protect the equipment from excessive power surges that could damage the equipment. Voltage regulator devices condition power to meet the operating limits of the high technology equipment. But voltage regulators are limited because electrical power must meet a certain quality for them to operate properly. Power generators provide power continuation when electrical power drops below a certain limit or when the electrical power source fails. Finally motor generators and uninterruptible power supplies provide both electrical power conditioning and continuation.

These devices are designed to keep the quality of power within the operating limits of the high technology equipment. In the case of power conditioning, these devices may be designed to condition the power beyond the limits of ANSI C84.1 to meet the operating requirements of high technology equipment.

The situation determines the type of device required. This is important because power continuation costs more than power conditioning. The cost differential may be by a factor of 100%. The costs of supplying power conditioning and continuation cost more than conditioning or continuation

separately. The criticality of the mission should be the determining factor in justifying procurement of these devices.

VI. Summary and Recommendations

Summary

As noted in chapters one and two, the quality of electrical power is an important issue in meeting Air Force mission requirements. There is not a facet of Air Force operations that high technology equipment does not touch. This is extremely important to the Civil Engineer because he/she is responsible for ensuring that electrical power meets the standards established by ANSI C84.1. Although no inferences about the populations as a whole were made, the summaries that follow provide an interesting insight into the problems faced by the bases sampled.

1. It cannot be determined from this research if the Air Force Bases in the sample are receiving electrical power from the local utility in accordance with ANSI C84.1 because the overwhelming response was "unknown". There is a lack of consensus within the Civil Engineering organization between the Chief of Operations and the Chief of Engineering concerning the quality of electrical power received from the local utility. This may be due to the fact that no serious electrical power problems occurred prior to the interviews. There appears to be a lack of communication between the Civil Engineering organization and the Communications Squadron concerning equipment problems due to electrical power problems that the Communications Squadron may be having. This may be due to a lack of serious electrical power problems

prior to the research survey. Finally the electrical power analyzer is useful in helping to locate electrical power problems, according to the Electrical Superintendents who have used the device.

2. The most serious grounding problem faced by the Civil Engineer is the isolated grounding scheme used by the high technology equipment community. High technology equipment operational problems blamed on the quality of power may actually be due to grounding.

3. Electrical power disturbances on the distribution system appear to cause about 10% of the operating problems encountered with high technology equipment. It also appears that underground distribution systems are less susceptible to power disturbances than overhead systems.

4. Mission criticality should be the determining factor in the procurement of power conditioning and continuation interface equipment because of the costs involved. In other words, if a facility's mission was not mission or life critical, power conditioning may be justified but power continuation would not be.

Recommendations

The following recommendations based on this research are offered for consideration

1. Air Force should consider making ANSI C84.1 a required reference in the Civil Engineer's technical library
2. Air Force should ensure that Civil Engineers are

aware of the requirements of ANSI C84.1 and their responsibilities in meeting these requirements.

3. Air Force should ensure that Civil Engineers are aware of the authorization of electrical power analyzers on their Table of Allowances. Further, some type of program for accelerated procurement and financial assistance or possibly a loan system within Major Command bases may be established.

4. Emphasis on communications within the Civil Engineering organization between the Chief of Operations and the Chief of Engineering concerning the quality of electrical power and possible problems outside organizations may be having with electrical power should be stressed.

5. Air Force should ensure that all procured high technology equipment will operate within the standards established by ANSI C84.1. This can be done by an integral equipment power supply.

6. Air Force should prohibit the use of the isolated grounding scheme based on safety and operational factors.

Limitations and Recommendations for Further Research

The author is aware of limitations in this research effort that should be considered by researchers considering a follow on research effort.

1. The most significant limitation is sample size which precluded making inferences to the population as a whole. A census of Air Force bases should be considered.

2. Rather than conduct a telephone survey, a

questionnaire should be considered. A request for electrical power readings would provide documentation on the quality of power received at an Air Force base and raise the level of data from nominal to ratio. The only problem may be the limited number of bases that possess an electrical power analyzer, that is, if the sample in this research is indicative of the population. About 57% of the population would probably have electrical power analyzers.

3. Since this research effort focused on Air Force bases in the Continental United States, overseas bases should be considered. The thing to remember is that ANSI C84.1 does not apply outside the United States and the respective standards for each country would be applicable.

4. A case study on one electrical power problem at one particular Air Force base should be considered. The objective would be to develop a set of guidelines for Civil Engineers to troubleshoot electrical power problems.

Appendix A: Questions Asked of
the Chief of Operations, the Chief of Engineering
(Civil Engineering)
and the Deputy Commander for Maintenance
(Communications Squadron)

- A. Does the local utility provide electrical power in accordance with ANSI C84.1?
- B. Is the Communications Squadron currently having problems with the operation of high technology equipment that they attribute to electrical power?

Appendix B: Questions Asked of the
Electrical Superintendent (Civil Engineering)

- A. Do you have an Electrical Power Analyzer listed on your TA-489?
- B. What make and model Electrical Power Analyzer is listed on your Table of Allowances?
- C. Do you have an Electrical Power Analyzer available?
- D. Have you used an Electrical Power Analyzer?
- E. Did the Electrical Power Analyzer help in determining the problem?

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Abstract

The purpose of this research was to determine if Air Force Bases in the Continental United States were receiving quality electrical power in accordance with ANSI C84.1. An investigation into factors influencing quality electrical power and Power Conditioning and Continuation Interface Equipment was also conducted. There were four research objectives in this effort: (1) Determine if Air Force Bases in the Continental United States are receiving quality electrical power in accordance with ANSI C84.1. (2) Determine how grounding impacts the operation of high technology equipment. (3) Determine how power disturbances on the distribution grid affect the operation of high technology equipment. (4) Identify the different types of Power Conditioning and Continuation Interface Equipment (PCCIE) and determine how they help and when they are applicable.

This study was unable to determine if Air Force Bases in the Continental United States are receiving quality electrical power in accordance with ANSI C84.1 because over 60% of the individuals in the sample did not know if the electrical power they received met ANSI C84.1.

The most serious ground problem the Civil Engineer faces is the isolated grounding scheme. This is due to safety and operational factors.

It appears that electrical power disturbances cause less operational problems with high technology equipment than has traditionally been believed. Operational problems due to electrical power represent at most 10% of the total operational problems experienced by high technology equipment.

Several types of Power Conditioning and Continuation Interface Equipment was identified and concept of operations explained. The application is determined by mission criticality and high technology equipment requirements.

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