FIPS PUB 94

FEDERAL INFORMATION PROCESSING STANDARDS PUBLICATION

1983 SEPTEMBER 21

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

GUIDELINE ON ELECTRICAL POWER FOR ADP INSTALLATIONS

CATEGORY: HARDWARE
SUBCATEGORY: POWER, GROUNDING, AND LIFE-SAFETY

FIPS PUB 94

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Foreword

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Abstract

This recommended Guideline for Federal agencies identifies and describes the electrical environment for safe, reliable operation of automatic data processing (ADP) systems. The electrical environment in and immediately outside the computer room is considered. The Guideline describes the fundamentals which underlie the power, grounding, and life-safety requirements, and provides a guide and checklist for specifying and preparing ADP sites, and evaluating their suitability.

An annotated bibliography is provided.

Key words: computer; electrical power; Federal Information Processing Standards Publication; grounding; isolating transformers; life-safety; lightning protection; motor-generator sets; power conditioning; shielding; signal reference grids; surge arrestors; uninterruptible power source.

Natl. Bur. Stand. (U.S.) Fed. Info. Process. Stand. Publ. (FIPS PUB) 94, 98 pages
(1983)
CODEN:FIPPAT

For sale by the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

Federal Information Processing Standards Publication 94

1983 September 21

ANNOUNCING THE

GUIDELINE ON ELECTRICAL POWER FOR ADP INSTALLATIONS

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Name of Guideline: Guideline on Electrical Power for ADP Installations (FIPS PUB 94).

Category of Guideline: Hardware; Power, Grounding, and Life-Safety.

Explanation: This recommended Guideline for Federal agencies identifies and describes the electrical environment for safe, reliable operation of automatic data processing (ADP) systems. The electrical environment in and immediately outside the computer room is considered. The Guideline describes the fundamentals which underlie the power, grounding, and life-safety requirements, and provides a guide and checklist for specifying and preparing ADP sites, and evaluating their suitability.

Approving Authority: U.S. Department of Commerce, National Bureau of Standards (Institute for Computer Sciences and Technology).

Maintenance Agency: U.S. Department of Commerce, National Bureau of Standards (Institute for Computer Sciences and Technology).

Cross Index: See bibliography.

Applicability: This Guideline is intended as a basic reference document for general use by Federal departments and agencies on electrical power, grounding, and life-safety for ADP installations. Its use is encouraged, but is not mandatory.

Implementation: The use of this Guideline should be considered whenever ADP sites are to be prepared or evaluated for suitability relative to electrical power, grounding, or life-safety.

Specifications: Federal Information Processing Standards Publication 94 (FIPS PUB 94), Guideline on Electrical Power for ADP Installations.

Where to Obtain Copies of the Guideline: Copies of this publication are for sale by the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161. When ordering, refer to Federal Information Processing Standards Publication 94 (FIPS PUB 94) and title. When microfiche is desired, this should be specified. Payment may be made by check, money order, or NTIS Deposit Account.

ACKNOWLEDGMENTS

Contributions have come from many sources, many of which are listed in the annotated bibliography. The University of Wisconsin–Extension has been responsible for organizing and conducting professional "continuing education" seminars on Computer Room Design, Surge Protection of Computers, and Uninterruptible Power Sources. Much of the material presented in this Guideline has been discussed at these seminars. Particular acknowledgment is made of the contributions of J. F. Kalbach, Consultant, and Warren H. Lewis, Computer Power Systems Corporation, for many of the examples and illustrations presented at these seminars and used in this Guideline. This document was reviewed by computer site planning engineers of several Government agencies and by the Power Interface Subcommittee, ESC-SC3, of the Computer and Business Equipment Manufacturers Association.

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Specifications for

GUIDELINE ON ELECTRICAL POWER FOR ADP INSTALLATIONS

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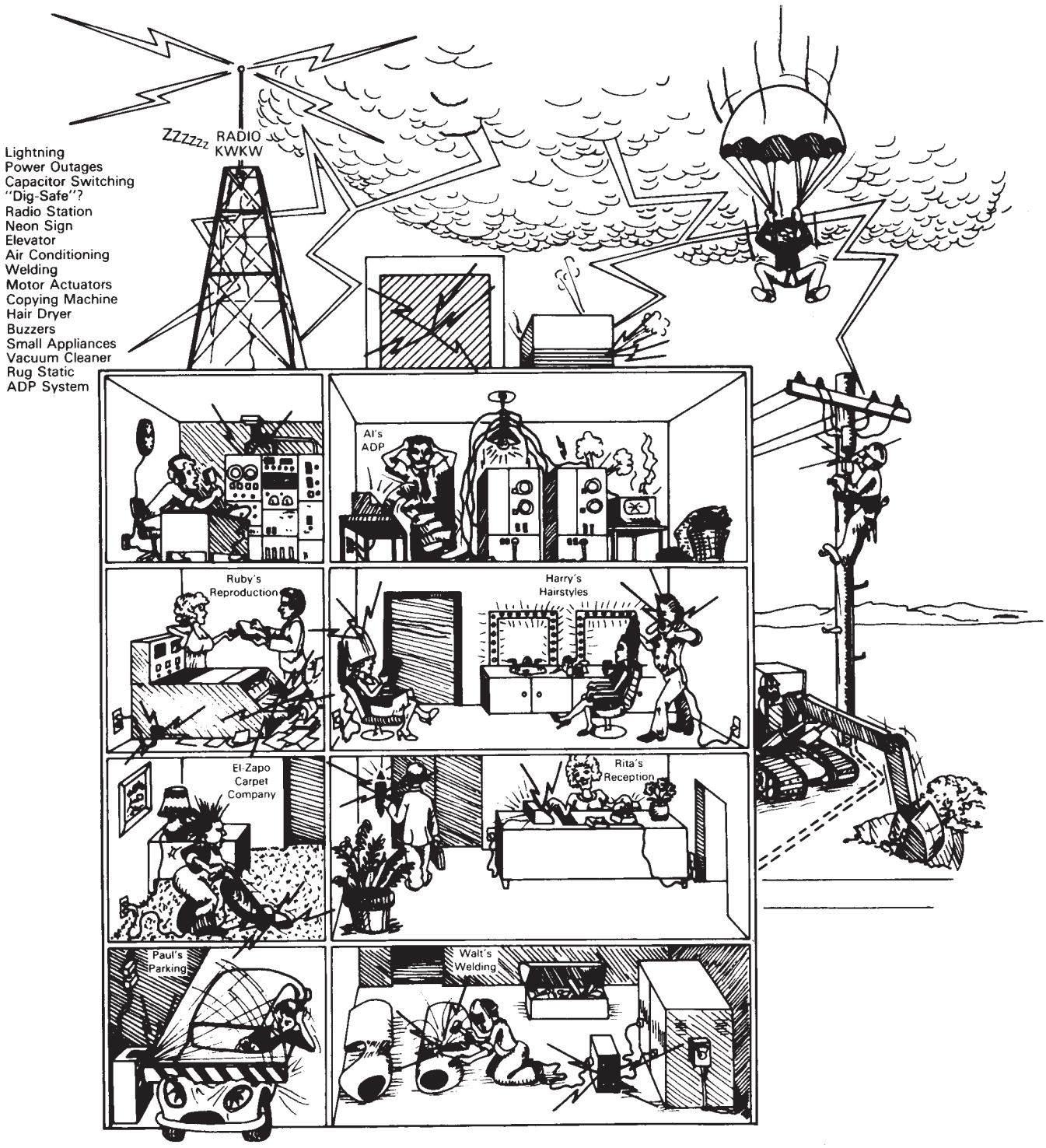
EXECUTIVE SUMMARY

This Guideline describes means for resolving typical electric power and related grounding problems frequently encountered with the installation and operation of large- and medium-scale automatic data processing (ADP) systems.

In addition to power continuity, power quality, and proper electrical grounding, ADP systems are susceptible to malfunctions created by power source aberrations, environmentally induced disturbances, and electrical noise. The severity and frequency of occurrence of these problems can vary greatly from one ADP installation to another, just as ADP hardware susceptibility to power problems varies among the products of different ADP manufacturers.

Surveys may show significant differences in power quality among nearby sites—even within the same building. The reasons for these differences are not always clear. Often, however, they can be determined by studying disturbance records and analyzing power source and circuit loading configurations. Grounding techniques can also create or solve performance problems. In general, there is no "average" power or grounding problem; there is no universal solution. The issues can be highly technical, requiring specialized knowledge for resolution, and are often outside the training and experience of most ADP managers and many ADP field service engineers.

The ADP manager is often responsible for taking corrective action to ensure reliable ADP operations. Such action may initially involve working with engineering personnel from the electric utility and telephone company, building superintendent's engineers, and ADP maintenance personnel. This may result in decisions leading to extensive rewiring of the ADP site as well as the acquisition of expensive power conditioning facilities. This Guideline is intended to provide ADP managers with a perspective and basis for selecting an optimal (cost/benefit) course of action from among the range of possible alternatives.



The electrical environment.

1. INTRODUCTION

This Guideline identifies and describes the electrical environment recommended for safe, reliable operation of automatic data processing (ADP) systems. It describes the fundamentals which underlie the power, grounding, and life-safety requirements, and provides a guide and checklist for specifying and preparing ADP sites, and evaluating their suitability.

1.1 Importance of the Electrical Environment

The electrical environment for computers includes their power sources, grounding and electrical interfaces with communications lines, air conditioning, and life-safety systems. It also includes lighting and other noncomputer electrically operated equipment in and about the computer room, plus the electrical characteristics of the computer room floors, furnishings, and even the footwear and clothing of human occupants which may generate static electricity discharges.

The electrical environment immediately outside the computer room must also be considered, since electrical disturbances propagate through conductors, pipes, metal ducts and conductive structural members, or by radiation as radio waves. External sources of electrical disturbances range from lightning to nearby radio transmitters and electrical loads which generate electrical noise when operated or switched on and off. Internal sources of electrical disturbances within the computer room may be generated by the ADP equipment itself [5].

No ADP hardware is completely immune to electrical disturbances. However, sensitivity may vary from one ADP unit to another, and from one type of disturbance to another. Disturbances of high energy content can result in catastrophic failure or impairment of circuit components. Smaller disturbances may not damage components, but may corrupt the logic signals and cause intermittent errors in data or control. Figure 1 lists some possible consequences of a poor electrical environment.

- **Recovery action activated automatically to correct errors**
  - — Event logging and throughput reduction
- **Malfunctions and data corruption**
  - — Halts, checks, hangs, loops, need to reload and restart
  - — Units with lowest signal energy levels usually affected first
  - — Computer hardware and program "bugs" cause similar symptoms
- **Protective device operation**
  - — Self-contained detectors and indicators are activated
  - — Automatic power shutdown
  - — Loss of cooling causes overtemperature shutdown
  - — Overcurrent tripping of circuit breakers and fuse interruption
  - — Undervoltage dropout of contactors
  - — Lost phase, phase reversal, under-frequency/overvoltage
  - — Shaft tachometer and phase-lock loop in disc packs off normal
  - — Operation of ground fault current interruptors (GFCIs)
- **Permanent damage**
  - — Degraded performance margins
  - — High component failure rate
  - — May be intermittent or solid failure
- **Total power outage**
  - — All lights out except emergency and equipment on Uninterrruptible Power Systems (UPS)
  - — Ventilation blowers and water circulation off
  - — No power to computer if not on UPS
  - — Prospect of lengthy restart, data recovery, re-runs, memory purge
  - — Prospect of possible damage

Figure 1. *The possible consequences of a poor electrical environment.*

Many power problem symptoms are difficult to distinguish from software problems. They may vary from a noticeable decrease in throughput rate or an increase in response delays to a variety of operational malfunctions. These range from self-correcting parity errors to events which require manual intervention. Recovery may require a variety of techniques ranging from simple restart to time consuming reruns (starting with earlier copies of a database and a fresh copy of the control program, then updating the work with audit trail data).

When both power disturbances and programming errors are suspected as causing an observed malfunction, diagnosis becomes much more difficult. ADP service engineers typically report "no fault found" in more than 90% of their calls for unscheduled maintenance. In other words, no detectable component failure or weakness could be found which would justify replacing any particular component or circuit board. This may result in repeated maintenance calls, blindly replacing suspected components without any real evidence of defects, or a combination of the two. Either is expensive and not totally effective.

A more positive approach is to prepare comprehensive specifications in requests for proposal and in purchase orders for ADP hardware. An objective is to obtain reliable hardware which is not overly sensitive to slow line voltage variations, surges, sags, harmonics, impulse spikes, noise (normal and common mode), and other power quality disparities. Purchase, lease, and maintenance agreements should include an understanding of the power conditioning equipment and special grounding conductors to be installed, if any. Do not be misled by salesmen without technical credentials who claim ADP equipment will work in any office environment without modification.

1.2 Power Conditioning Apparatus

Power conditioning can improve the electrical environment if applied properly.

There is no single solution to all problems which can be caused by electrical disturbances. However, there are several approaches which are often effective, particularly when used in combination. These include:

(a) Select an adequately "stiff" (low impedance) undisturbed power source.
(b) Reduce or eliminate disturbance sources (some ADP loads may cause disturbances as implied in fig. 2).
(c) Reduce the coupling between disturbance sources and disturbed circuits.
(d) Select ADP hardware which is not easily disturbed by power abnormalities.
(e) Provide software and operating procedures which enhance the ADP system's ability to detect, correct, and recover from errors and unscheduled halts.
(f) Install power disturbance recorders and a computer malfunction log which will simplify correlation of events in time and provide diagnostic clues.

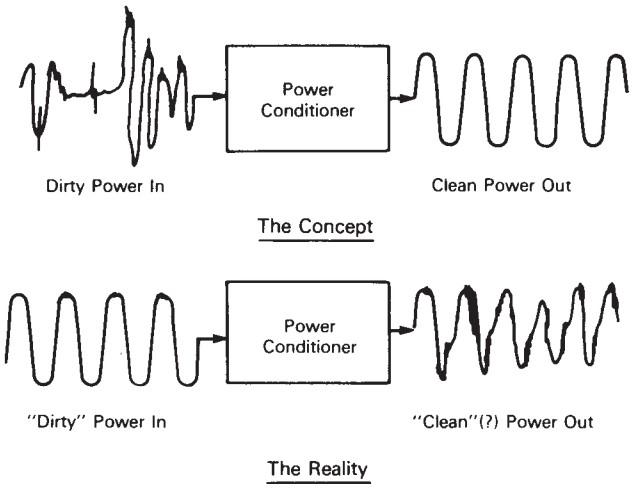


Figure 2. *Interaction between ADP units and power sources* must be considered when selecting power conditioning equipment. A distorted ADP load current can disturb a "clean" power conditioner's output.

Of the above, items (a), (b), and (c) fall into the category of power conditioning. The various conditioning devices and installation techniques are most effective when their selection is appropriate to the specific ADP units and the types of disturbances or aberrations which may be present. Interaction between load and power source can be a problem (see fig. 2).

Like any other form of insurance, total protection against every possible type of power quality problem is very expensive if not impractical to achieve. It is prudent to evaluate both the existing and potential power and electrical noise problems before selecting power conditioners and other improvement projects. Select those which are appropriate to the specific site and hardware to be protected. Of course, one should compare their cost with the probable consequences of selecting other measures or taking no corrective action at all.

1.3 Evolutionary Trends in ADP Hardware and Its Power Sources

Increasing dependency on computers:

A trend in ADP applications is toward ever-increasing dependency upon ADP systems. In public service such as air traffic control, computer-aided emergency vehicle dispatch, hospital management, and control of essential communications, the safety of the public can be affected by power-related ADP problems (see fig. 3).

In some Government agencies, loss of data and delays in processing can have a severe adverse impact upon society and the economy. For example, delays in the receipt of social security and welfare checks create real hardship for the recipients. The daily interest on repayment of loans and tax rebates to be paid in the event of unnecessary processing delays can be significant.

Some examples of ADP applications which require or justify considerable effort to achieve uninterrupted, error-free performance:

HOSPITALS
- Life support systems
- Patient history files
- Treatment schedules
- Logistics in keeping needed materials, medicines, supplies on hand
- Hospital management

ESSENTIAL PUBLIC SERVICES
- Police and Armed Services
- Ambulance
- Paramedics and fire department
- Public utilities; electric power, gas, water, sewage, garbage, transit
- Air traffic control
- Street traffic control and lighting
- Communications; telephones, radio, TV, telegraph, special controls
- Social Security, Department of Motor Vehicles, Department of Internal Revenue, etc.

IMPORTANT BUSINESSES where ADP interruptions can be costly:
- Banks, financial institutions, brokers, stock market, commodities
- Electronic funds transfer
- Shipping and warehousing
- Inventory control
- Shop load scheduling

Figure 3. *Critical load examples.*

Circuit performance improvements have not included immunity to electrical noise:

Vast improvements have been made in the logic circuit design of ADP as well as office machine hardware. A major breakthrough has been large-scale integration (LSI) and very large scale integration (VLSI) of thousands of semiconductors and their interconnections on silicon chips which are typically 1/4 inch$\times$1/2 inch or less in area. The result is faster, more powerful and complex logic, plus vastly greater capacity memory in small packages. The power of office machines has been enhanced by these circuit elements; at the same time, the physical size of ADP logic and memory units for a given capacity and power has been shrinking. The means for distinguishing between ADP systems and office machines appear to be disappearing.

The electrical power and the logic voltages associated with these new logic and memory circuits have been decreasing while the upper limit of circuit speed (short response time) has been vastly improved. This results in a great decrease in the power consumption and cooling requirements of individual logic circuits, and makes larger, more complex arrays feasible. These advances are most welcome, but these lower energy level circuits are easier to disturb than many of their predecessors. Unfortunately, the electrical noise and disturbances associated with unconditioned commercial power have not been reduced. If anything, the quality of commercial power has become worse with time. Significantly, the faster response time of newer, higher performance logic circuits makes them susceptible to fast noise pulses which have always existed, but which failed to disturb the older, slower logic circuits. This implies that electrical environments which were suitable for older generations of ADP and office machine hardware may need to be improved to be acceptable for some of the newer systems.

Power source disturbances are greater than ever:[30]

A trend in ac power sources is toward more highly loaded public utility systems. The comfortable margins between peak loads and peak generating and transmission capacities have been eroding as new power source construction fails to keep pace with load demand growth. Although conservation measures, education of the public, and higher prices have slowed load growth below earlier predictions, the trend is still toward periods when demand will exceed capacity. When this occurs and noncritical loads are switched off and on, or if line voltage is deliberately reduced in the form of "brownouts," the resulting line voltage disturbances and aberrations will be particularly bad for ADP operation. (At one time, brownouts threatened to become a regular occurrence, but few, if any, have occurred in the past few years. In the future, brownouts may again be necessary.)

Trends in power consuming appliances and electrical apparatus are toward the use of solid state controls, even for loads of many kilowatts. Some of these are capable of being switched on and off every cycle (60 times per second) to give a continuously variable control of motor speed or temperature of heating devices. Others turn large loads on and off less frequently. Either scheme creates electrical noise and transients which can adversely affect ADP system circuits if they are not properly designed, properly installed, and properly operated.

Neighbors who share a common utility distribution line can create disturbances or controlled signals on one site which will interfere with ADP equipment operation on another site. Large step loads, arc welders, spark igniters, and tone burst signals superimposed upon the 60-Hz power frequency to reset clocks or control water heaters and air conditioners can be transmitted through switchgear and transformers to permeate the power wiring of all who share the same power distribution system.

Government regulation cannot solve the problem:

The Federal Communications Commission (FCC) regulations on line-conducted and radiated electromagnetic interference (EMI) may help enforce abatement of major sources of excessive continuous interference. However, it is unlikely that the FCC can police all noise sources, especially those which only occasionally exceed legal limits or which are intermittent in nature. Whether the disturbances are virtually continuous or in the form of random, single, or bursts of impulses, ADP hardware can be adversely affected.

Self-induced disturbances:

It is popularly assumed that sources of unwanted electrical noise are external to ADP systems, and that power conditioners placed between the external power source and the ADP equipment will prevent excessive disturbance from reaching it. In fact, it is not uncommon for ADP units to be major sources of disturbances, especially when the ADP systems are operated from small, limited power sources such as diesel driven generators, motor-generators, regulators, and uninterruptible power systems (UPS). In such cases, devices intended to prevent the transmission of electrical noise while passing the desired power can make the ADP load more susceptible to its own noise rather than less susceptible. **Before selecting power conditioning equipment, it is important to determine which side of the noise barrier the noise source will be.**

Monitor the environment:

The net result of varying conditions and trends is a need to monitor the changing electrical environment and the changing needs of ADP systems in the face of new applications. Otherwise a problem of gradual or rapid ADP deterioration of performance could become most difficult to solve when overly sensitive ADP equipment is operated in an overly disturbed environment. A log can easily be kept of power disturbances and aberrations, including the consequences and impact upon ADP performance. In large, important ADP centers, a Power Line Disturbance Monitor may be justified by the amount of diagnostic detail it can provide in the event of power quality changes.

What to do about power quality:

The problems of power quality and ADP sensitivity are not trivial. Mere compliance with codes will not solve them, although it may provide a safe system. Within the scope of allowable installation techniques permitted by codes, however, there are usually some which simultaneously meet those requirements and provide the desired electrical disturbance and noise control over a broad frequency spectrum extending as high as 30 MHz or more. These will be described later.

There are two basic objectives and problem areas. First is to maintain a relatively constant line voltage at or near its nominal rating to ensure energy flow when it is needed. The second is to prevent the unwanted coupling of electrical noise and transients from all sources into low power level digital circuits where signal corruption and component damage can result. Short duration power interruptions create transients and interfere with energy flow. These effects on ADP systems and their "ride-through" capabilities need to be analyzed.

2. ADP POWER REQUIREMENTS VS POWER SOURCE CHARACTERISTICS

2.1 The Power Profile of an ADP System Electrical Load

In order to install ADP equipment, its power requirements and characteristics of available power must be matched. Technical terminology and concepts may be difficult for those without electrical training, but the subject deserves the attention and basic understanding of ADP management personnel. Specification of details which affect the capacity and quality of the power source can affect the ADP system's performance, initial installation cost, and continuing operating expense. Figure 4 is an example of an ADP Power Profile.

ADP unit power requirements are supplied by their manufacturer. The information should include the following for each ADP unit:

Line frequency limits and maximum rate of frequency change
Line voltage or voltages and phase requirements (upper and lower limits)
Load current; average steady-state rms (root mean square) amperes per line
Apparent power in volt-amperes (VA) or kilovolt-amperes (kVA)
Real or active power in watts or kilowatts (kW)
Power factor (ratio of kW/kVA)
Average steady-state peak amperes per line
Inrush current in rms amperes and inrush duration
Maximum peak half-cycle amperes
Acceptable limits for line voltage surges, sags, impulse spikes, noise (in volts)

Line voltage and frequency options may be provided on some ADP units, enabling them to be powered from a variety of domestic and international power systems. In these units, there may be appropriate terminal, switch, or tap positions for selecting the available power source. To compensate for the different motor speeds when they are operated at 50 or 60 Hz, there may also be a stepped pulley. Adapting the ADP unit to the available power source requires the proper selection of connections and belt position where applicable.

If there are multiple line voltages to which the ADP unit can be adapted, the choice of the higher of the alternative voltages is generally preferred. When line voltage is doubled, it requires half the line current to transmit the same amount of power. This results in savings in the amount of copper required in conductors and switching hardware, reduces power loss, and improves performance.

Combined power requirements of an ADP system is often referred to as a "power profile." The total load currents will depend partly upon the currents of the ADP units and partly upon how they are connected to the power source. Typically there will be small ADP units which require 120 V and very little current. Larger loads may require a higher voltage of single phase or three phase. Where ADP systems present a variety of voltage and phase requirements, most ADP systems adapt easily to 208Y/120-V power. This power source provides three-phase 208 V to three-phase loads while simultaneously providing three single-phase 120-V circuits from each line to a common neutral. Additionally, 208-V single-phase power can be supplied from any two of the three-phase conductors.

To avoid a possible safety hazard, overcurrent sensing and tripping are required in every line conductor except the neutral. Single-phase equipment manufactured for the international market often has only one circuit breaker pole or fuse in a "hot" line which typically operates at 220 V or 240 V from line to grounded neutral. If such equipment should find its way into the domestic market, the single-pole circuit breaker must be replaced with a two-pole circuit breaker for safety on typical 120/240-V or 208Y-V systems. Equipment designed for ungrounded systems will have two-pole breakers.

It is important to note that just because the ADP system will operate from a 208Y/120-V power source, a feeder or branch circuit from the building service equipment and distribution center does not have to be 208Y/120 V. In fact, there are further performance and economic advantages to a building wiring arrangement in which three-phase 480-V power is delivered to the computer room via dedicated feeders and branch circuits. Near or in the computer room, it is transformed by a shielded transformer to 208Y/120 V as close to the ADP system center as feasible. The transformer can be installed as part of the premises electrical installation with 208-V and 120-V branch circuits on the secondary. However, the transformer can also be supplied as a power peripheral module which operates from 208-V, 240-V, or 480-V branch circuits.

SYSTEM POWER PROFILE

DOUGLAS COUNTY
3/28/80 14:46

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	3148- J	INCL 3047, ISC FTR, 1 IOC
1	3037- 1	
1	3125-HG2	INCLUDES FTR 4505
1	3411- 3	
2	3410- 3	
3	3340- A2	
3	3340- B2	
2	3344- B2	POWERED FROM 3340-A2
1	3504- A1	
1	3525- P1	
1	3803- 2	
3	3420- 6	
1	2501- B1	
1	3704- A2	
1	3274- 1B	

SYSTEM DATA

SYSTEM VOLTAGE LINE TO LINE..... = 208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE = 142.3 AMPS
AVG. STEADY STATE PEAK CURRENT PER LINE = 227.2 AMPS
POWER FACTOR..... = 0.87
REAL POWER..... = 44.497 KW
REACTIVE POWER..... = 25.35 KVARS
APPARENT POWER..... = 51.211 KVA
AIR HEAT DISSIPATION PER HOUR..... = 151.868 KBTU/HR

SYSTEM NOTES

1) PROFILE VALUES SHOWN ARE POWER RQMT AT LAST CUSTOMER CKT BREAKER PANEL(S) CONNECTING EDP/MG TO PWR SOURC. LOSSES IN CABLE(S) TO XFMR/UPS AND IN XFMR/UPS ARE NOT INCLUDED.
2) PROFILE ASSUMES WORST CASE USAGE, IE ALL DISK DRIVES RUNNING AND ALL TAPES MOUNTED.
3) IF THE CPU REQUIRES A MOTOR-GENERATOR, THE PRIME POWER REQUIREMENT FOR THE M/G IS INCLUDED IN THE CPU CALLOUT. THE HEAT DISSIPATION SHOWN INCLUDES THE HEAT DISSIPATION IN THE M/G SET.

INRUSH DATA

THE 10 HIGHEST (PEAK) INRUSH CURRENTS ARE:

(3148- J) = 780 AMPS 2 SEC (3125-HG2) = 210 AMPS
(3803- 2) = 170 AMPS DCAYS-60 MILSEC (3420- 6) = 130 AMPS
(3704- A2) = 100 AMPS (3411- 3) = 29 AMPS
(3525- P1) = 26 AMPS (3504- A1) = 25 AMPS
(3340- A2) = 20 AMPS DCAY IN 8 SEC (3274- 1B) = 20 AMPS

INRUSH NOTES

1) INRUSH VALUE GIVEN IS WORST CASE PEAK VALUE FOR 1 UNIT OF THE TYPE SHOWN.
2) INRUSH CURRENTS FOR VARIOUS UNITS DO NOT OCCUR SIMULTANEOUSLY SINCE UNITS ARE NORMALLY SEQUENCED ON.
3) ALL INRUSH CURRENTS UNLESS OTHERWISE STATED ARE FOR HALF CYCLE OR LESS.
4) INRUSH FOR THE 3145, 304/ ON A 3145 VERSION 2 OR 3148, AND THE 3046 ON A 3135, 3138 OR 3345, IS FOR THE M/G SET ON A 208 VOLT, 60 HZ SYSTEM, EXCLUDING HALF CYCLE INRUSH. HALF CYCLE INRUSH IS SHOWN IN THE TABLE BELOW. 3138=3135 DATA, 3148=3145V2 DATA

HARD START -208V, 60 HZ

M/G ENCLOSURE	USED ON	PEAK INRUSH AMPS	RMS INRUSH AMPS	START TIME SECS	PEAK 1/2 CYCL AMPS
16KW	3145	780	550	<2	1000
3047	3145V2	780	550	<2	1000
3046	3135	495	350	<2	750
3046	3345	495	350	<2	750

THANK YOU

Figure 4. *Typical ADP system power requirement profile:* In addition to this summary, amperes and voltages of each ADP unit will be needed for load balancing, wire sizes, and connection schedules.

These power modules are designed to be a part of the ADP system. More will be said later about the advantages of having them on the computer room floor.

To combine the ADP unit loads, a schedule of connections of individual ADP units to the power source must distribute single-phase loads among the phases so that when all units are operating, phase currents will be nearly equal or reasonably well balanced. It is desirable, but not imperative that ADP units used rarely or intermittently should be distributed among the phases rather than connected to one phase so that the total phase currents will not become and remain greatly unbalanced for long periods of time.

Starting with an ADP equipment list, power requirement specifications, and a schedule of power connections, the calculation of the total kVA and line currents of the combined system can be tedious if it is to be done accurately. Such a calculation can be done by ADP systems with the appropriate programs and characteristics of units. Such programs can even take into consideration the effects of load current harmonics and combine them. Some ADP manufacturers provide this as a service or as part of their sales effort. If such a calculation service is not available or if the necessary performance data of some units are missing from the program's data bank, some rough approximations can be made.

Individual kW's (kilowatts) listed for each unit of the ADP system are usually for fully loaded conditions. When added, these may give a higher total power requirement and heat load for air conditioning than needed, sometimes by as much as 50–100% more than actual measurements may show. Calculation of the apparent power or kVA's (kilovolt-amperes) is not so simple. However, a crude estimate can be made by assuming a typical power factor of, say, 0.8 as a ratio between active power (kW) and apparent power (kVA). The estimated kVA will therefore be approximately 125% of the kW.

The total kW load and the operating time determines the cumulative kilowatt-hours which are the basis for the monthly power bill. KVA load determines the power source capacity which is needed. In some cases, the maximum demand charge is based upon kVA rather than kW.

Additional loads supporting the ADP system must be considered in addition to the power consumed by the ADP units. The largest of these is often air conditioning, although lighting, general building utilities, and ADP accessory equipment such as printers, collators, bursters, and office copiers can add significantly to the total load. If power should be interrupted to the air conditioning but not to the ADP units, their temperature could rise in minutes to the overtemperature limit. If equipped with a safety overtemperature shut-off, the ADP equipment might automatically shut down. If not, there could be great risk of permanent, widespread ADP component damage. Continued air flow will reduce rate of rise after chillers stop.

Air conditioning is essential to most ADP systems. Each kilowatt used by ADP equipment releases 3412 Btu per hour of heat to be removed from the room. Approximately 3 tons of additional refrigeration is needed for each 10 kW of ADP load. This is in addition to air conditioning energy which removes or adds water to the computer room air for humidity control.

The power required to operate the air conditioning and the extra capacity of the power source needed will depend upon temperature differences between the computer room air as a heat source and the heat sink's highest anticipated temperature. The use of insulation, vapor barriers, thermal storage of prechilled water, and other related techniques can be very effective in saving energy, but further description is outside the scope of this Guideline.

The design of ADP temperature and humidity control should be handled by competent engineers with experience in process cooling rather than following the usual published guidelines for comfort cooling.

Power conditioning may be an additional requirement in some ADP installations where the quality of power or its continuity has not been satisfactory. Such conditioning ranges from fairly simple filters, capacitors, and surge suppressors to isolating transformers, motor-generator sets, voltage regulators, and complete uninterruptible power systems (UPS). The efficiencies of these will vary. Some require negligible power; others may be 50% efficient or less. All add to the consumption of power in support of the ADP system.

Those power conditioners which provide some form of energy storage to help the ADP system ride through momentary interruptions in the public utility power may include motor-generators or uninterruptible power systems (UPS). The ability to ride through tenths of seconds of power interruption in the case of a motor-generator or tenths of hours in the case of UPS installations is an asset. However, when public utility power returns following an interruption, the lost energy which had been stored must be replaced while the ADP system is still operating. The motor-generator must be reaccelerated to its full speed,synchronous state, or the UPS batteries must be recharged. These can add to the peak load required by the ADP system and the power source capacity and protection needs.

Margins must be added to all other factors which establish the maximum total electrical load. First, electrical codes require the ampacity (current carrying capacity) of branch circuit conductors between each ADP unit load and its power source to be no less than 125% of its rated connected ADP load (see NFPA 70-1981 National Electrical Code, article 645-2a). Second, provision must be allowed for future load growth. Third, calculated load currents and their added margins must be rounded upward to the next higher standard ratings of circuit protection devices, conductor sizes, transformer ratings, and capacities of wiring devices. Diversity results in total load being less than their sum.

Differences between calculated and measured loads are to be expected for several reasons. A common source of difference is measurement error. Many commonly used clip-on ammeters may give repeatable readings with third decimal accuracy but can be in error by as much as a factor of 2 or more. These instruments sense the ac field around a conductor, induce an ac voltage, and convert it to a dc voltage, calibrated in terms of rms (root mean square) amperes of sine wave current. This is known as an "average actuated, rms calibrated" instrument. It is accurate only when the measured current is sinusoidal. To the extent that the load current of most ADP units is a distorted wave and not sinusoidal, the ammeter indication can have considerable error, as mentioned earlier. Fortunately there are clip-on ammeters which read true rms values. Some of these would miss a direct component of current if it is present. A combination of true rms ammeter readings and readings from an ammeter which responds to the dc component may be needed to measure total load current. At least one popular volt-ohm-milliammeter combines ac and dc rms readings. The types of ammeters which give incorrect readings almost always err on the side of showing a lower line current than actually exists.

Another source of difference between calculated (or specified) and measured load current sometimes comes from the ADP unit's provision for field installable options which upgrade the ADP unit's capability. This is often accomplished by merely plugging in additional printed circuit boards or exchanging pluggable components. The rated line current for the product is often based upon all options installed, even though some of them may not have been designed or available when the ADP unit was first installed.

Complete ADP systems rarely operate continuously with all units turned on and operating in a mode which causes each unit to draw its maximum rated line current. For example, it would be rare for all magnetic tape units to rewind simultaneously or for all disk moving heads to seek a remote track at the same instant. However, if the system can be programmed to do this, it will happen. Good design dictates that such an event should not cause a malfunction or any damage, even if this results in more capability than would normally be used.

Effects of low line voltage on load current may use some of the margin by which the design load current exceeds the true measured current. Because ADP units normally incorporate internal regulation circuits for unvarying logic power, input power will also be essentially constant as line voltage rises and falls. This dictates that line current will rise as line voltage falls. The product remains a constant. During a brownout where line voltage may be 5–8% below the normal low voltage excursion, input line voltage could be as low as 8–13% below nominal. Load currents would then rise a corresponding amount. Selected circuit breaker ratings should be adequate to avoid premature tripping due to low line voltage, but still provide true overload and fault protection.

Susceptibility to line voltage disturbances is one of the most difficult product characteristics to define and measure. There is an entire spectrum of disturbance magnitudes and durations. The most simple to describe are simple over- and under-voltages. If sustained, they are known as slow-average rms voltages. If of short duration (as short as a half cyle), they are known as surges and sags. Very short duration spikes which add to or subtract from the instantaneous line voltage (1 ms or less) are known as impulses. These can all be measured by Line Disturbance Monitors. Some monitors detect impulses but are unable to indicate their amplitude (volts), strength (volt-seconds), polarity (additive or subtractive), or probable origin (power source or load). These measurements may be useful in problem diagnosis and should be considered when selecting a monitor. Figure 5 is a commonly used power line disturbance duration profile. It is used to illustrate the capabilities of typical ADP units to survive line disturbance events. It implies tolerance of ADP units to slow variations from −13 to +5.8%. However, greater amplitude overvoltage surges and undervoltage sags can be tolerated as their time durations become shorter. This is not to be used as an ADP performance specification, but does illustrate how these disturbances can interfere with energy transfer from a power source to an ADP product. The ability of some ADP units to ride through severe line disturbances depends upon internal energy storage in filter elements and in rotating motors which can reconvert rotational energy back into electrical energy in the event of momentary line voltage sag.

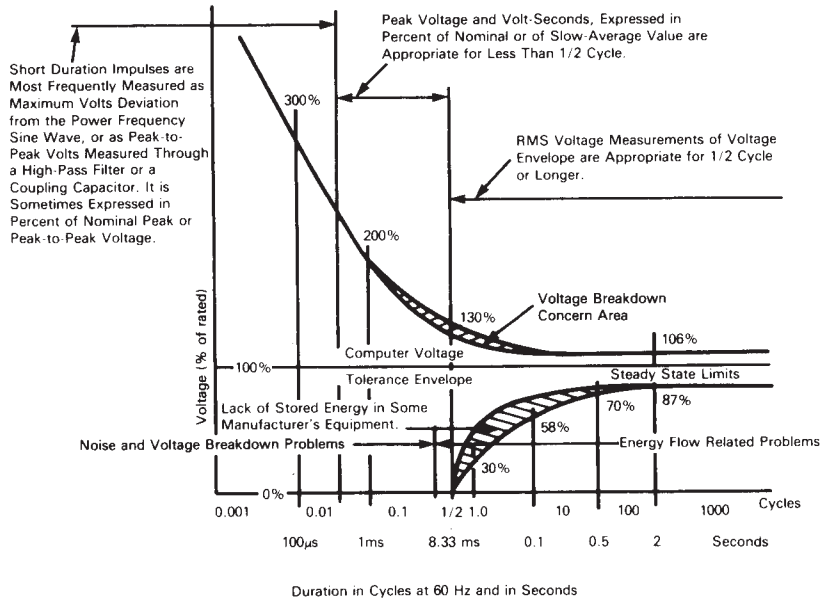


Figure 5. *ADP susceptibility profile to line voltage variations and disturbances* is not an industry standard, but can be considered to be a typical design objective of power conscious computer hardware designers [11].

Large sudden voltage changes can interfere with energy transfer and also create malfunctions or failure of regulator and converter circuits. The electrical noise associated with these events may enter the ADP unit by paths other than the power connection and cause malfunctions through signal corruption whether or not the event interfered with energy transfer needed for an undisturbed logic supply voltage.

The 400-Hz requirement for some of the ADP units produced by some manufacturers is an intermediate step in providing regulated dc for logic and memory. When required, the 400-Hz voltage must be derived from the basic 60-Hz power (50 Hz abroad) through motor-generator (m-g) sets or UPS conversion equipment. Small 400-Hz m-g sets are often installed in the computer room as part of the ADP system. Larger m-g sets or 400-Hz UPS units are usually installed as accessory equipment in a nearby utility room. The distance it can be transmitted efficiently is limited.

When conversion equipment is installed as part of the ADP equipment in the computer room, its input power includes heat generated due to inefficiency. This power requirement is usually listed with the power for the central processing unit (cpu) or other units which receive and use the 400-Hz output, usually at 208 V, three phase, three wire.

Conductors which carry 400-Hz power cannot be run in ferrous metal conduit, but can be run in aluminum conduit. The high-frequency magnetic fields around the conductors carrying 400-Hz power induce heating in ferrous metals. This would create excessive temperature rise of the conductors leading to serious power problems. Multiple parallel conductors in separate conduits (all phases in each conduit) are superior to three large-phase conductors in a single conduit when the objective is to minimize voltage drop in a 400-Hz feeder. However, even with multiple parallel paths in aluminum conduit, line-drop-compensators may have to be added in the event that the conduit run is greater than approximately 100 ft. The conclusion is that wiring methods commonly used for 60-Hz power cannot be used for 400 Hz.

2.2 Characteristics of Available Power (see Table I, appendix)

Public power can be made available in numerous voltage and phase arrangements. Preferred arrangements and logical choices often depend upon the size of the ADP load and its supporting equipment, and upon existing power facilities outside and inside the ADP site. Rather than to try to adapt ADP equipment to an existing obsolete building power source, it is often better to install dedicated wiring to be used only by the ADP equipment at the most favorable voltage and with minimum interaction with other building functions.

Frequency of public power in the United States, Canada, and most of Mexico is virtually standard at 60 Hz. Most of the rest of the world is predominantly 50 Hz. Public power in the United States is generally interconnected into large networks with many power sources and many loads. The line frequency is so closely regulated that frequency variations are seldom a cause of ADP problems. In any interconnected system, regardless of voltage transformations, or line voltage variations with load, overloads, and even faults, frequency will be the same at any one time throughout the system.

Small independent power sources such as generators driven by diesel, turbine, or electric motor will generally lack the frequency stability found in power networks. An exception might be a synchronous motor driven alternator when the synchronous motor is powered from a power network. With this exception, increasing loads generally cause line frequency to drop in small independent systems. The result may be poor performance or malfunctions in those ADP units which rely on constant driven shaft speed (disk packs, for example). Even though the average frequency may be acceptable, short duration variations can create problems.

Even with precision governors which maintain an accurate average line frequency, small independent power systems characteristically have momentary line frequency excursions whenever there are substantial load changes unless paralleled with a large power network. If this is not always feasible, the stable frequency needed by some of the ADP disk units can be derived through use of a double conversion apparatus. The unstable frequency power is first rectified and then reconverted back to ac with frequency and voltage regulated as accurately as desired. With storage batteries floating on the dc bus, this is known as UPS. However, if line frequency variation is a problem, the circuit which synchronizes the UPS output with the ac line input must be disabled except prior to bypass transfers.

Standards for voltages, phase configurations and grounding points are treated in an American National Standard on Voltage Ratings for Power Systems and Equipment (60 Hz) (ANSI C84.1–1970 with later dated supplements [3]). This standard describes the commonly used nominal voltages and anticipated ranges of normal variation at the service point (where utility's and user's conductors meet) and at the utilization point (where connections are made to ADP units).

The limits over which the supply voltage may be expected to vary without special treatment are roughly −13.3 to +5.8%. Although this range has been adopted as a standard for office machines (ANSI X4.11–1973), it is somewhat severe for large computer systems where efforts are being made to enhance their reliability through some control over the electrical environment and by other means. With a little care and with help by power companies line voltage should not vary beyond −10 to +5%. With much more care and power conditioning, it should be possible to maintain the ADP input line voltage within −3 to +3% of nominal. Added benefits of greater reliability or improved system performance would not be expected with tighter regulation limits.

Nominal voltage of a line is simply a convenient designation for its voltage class. Measured line voltages may vary from one location to another and by time of day as loads change. When someone mentions 110-V, 115-V, or 117-V power, they are referring to 120-V nominal voltages which fall within the limits prescribed in ANSI X4.11 and C84.1 with supplements [2,3]. Many ADP manufacturers request power with more tightly controlled limits than for office machines (fig. 6).

Nominal Voltage	Phases	Office Machine Range	Typical ADP Range**
120 V	1	104–127 V	110–125 V
120/240 V	1	104–127/208–254 V	110–125/220–250 V
208Y/120 V	3	180–220Y/104–127 V	190–217Y/110–125 V
240 V	3	208–254 V	220–250 V
480 V*	3	—	440–500 V*
600 V*	3	—	550–625 V*

*480 V and 600 V three-phase power sources are used primarily for input to power peripherals, motor-generators, and UPS installations at ADP systems.
**IBM and some other ADP manufacturers use the office machine range for both office machines and their ADP products.

Figure 6. *Supply voltages for ADP and office machines* [2,3].

Single- vs three-phase power. Almost without exception, commercial power is generated and distributed as three-phase power because of performance and economic advantages. Three-phase motors have better starting torque, run more quietly, have better efficiency, and are smaller than single-phase motors of the same horsepower (hp) rating. In ratings of several hp or more, they are also less expensive. The few applications for which single-phase power sources are preferred are generally limited to lighting, electric heating, small appliances, and small electronic instruments such as radios, televisions, calculators, and clocks. Single-phase wiring devices are less expensive than three-phase devices where the load is small.

For these considerations, single-phase power is typically installed in residences, small commercial shops and offices, and other locations where there are no substantial loads or large motors. Some typical phase connections and grounding points are shown in figure 7. If the connected load includes at least one 3-hp motor or larger, many public utilities will supply three-phase power in one form or another. If it is supplied in the form of balanced three-phase service from transformers connected (fig. 7D), the phase voltages are likely to be nearly equal (balanced), both line-to-line and line-to-neutral and to ground. This is a preferred power source for ADP installations.

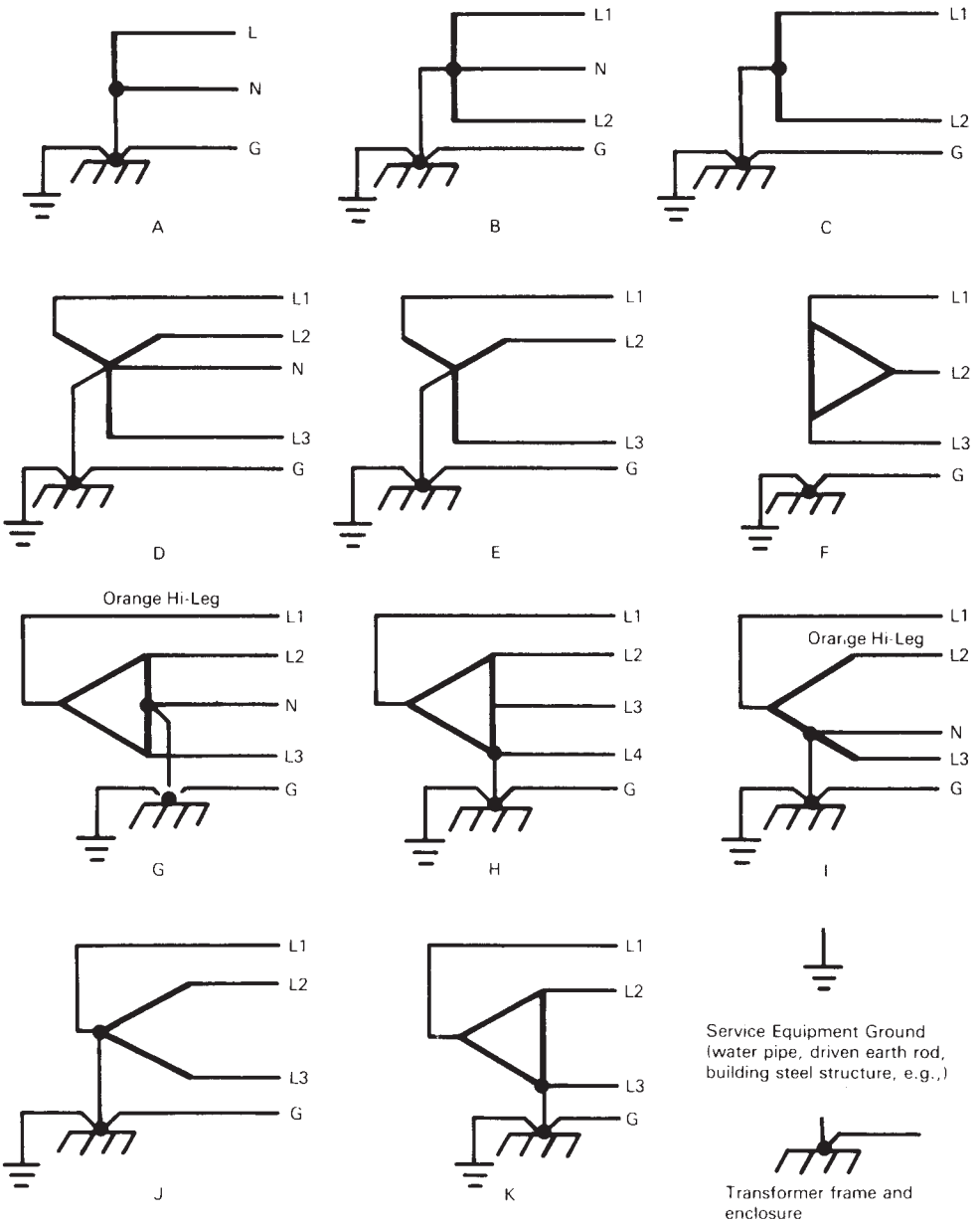


Figure 7. *Principal transformer connections* used for output to utilization circuits will determine phase relationships, voltages between power conductors, and voltages to ground [3].

Large ADP system owners can generally have the type of service they request. To accommodate small system owners in residential or small commercial buildings, the public utility may elect to supply a three-phase service for motor operation from a transformer connection as indicated in figure 7G or 7I. In these circuit arrangements, the normal residential type 120/240-V single-phase service is supplemented by a "high leg" from another phase. This conductor is commonly color coded orange for identification. Together with the 240 single-phase line conductors, this provides 240-V, three-phase power suitable for operating three-phase motors. In this form of three-phase power, the voltages from line-to-neutral and to ground are not all equal. Moreover, the line-to-line voltages are often unbalanced by single-phase loading, especially the arrangement of figure 7I which uses only two transformers in an open delta configuration to provide the third phase.

This unbalanced form of three-phase power source is not directly suitable for ADP systems which require three-phase power and which are disturbed by line voltage unbalance with unequal voltages to neutral and to ground. It should be avoided if possible. However, if the line voltage unbalance is not excessive, this type of power source can be converted to a balanced system with a three-phase isolating transformer with delta input and wye connected output. It is interposed between the power source and ADP system so that its power appears to come from a transformer connection shown in figure 7D. Such an installation should include a protective "loss of phase" sensor to trip the input circuit breaker for lack of voltage balance, typically 3–6% continued unbalance.

Power source impedance creates line voltage drop at the load as load current is increased. During step load changes such as when starting a disk drive or turning on a major ADP unit, the line voltage drop is immediate. Voltage regulators cannot anticipate the drop and can only correct it after it has occurred and been detected. Low internal impedance of the power source will limit the line voltage drop which occurs before any regulator can respond to correct it.

A transformer with a typical internal impedance of 5% implies that an increment of load current equal to the transformer's full load rating will create a 5% voltage drop at the transformer output terminals. This is under worst case load power factor of zero, lagging. Loads with high power factors approaching unity (100%) will create insignificant line voltage drop at the transformer output, but the voltage absorbed by the internal impedance will create some phase shift. Low power factors where the current is leading instead of lagging will create a voltage rise at the load instead of a voltage drop.

The internal impedance of a power source can be reduced by using a unit which is specially designed for low impedance, or by simply using a unit with a higher capacity rating. Using a transformer with 5% impedance but double the rating will produce only a 2.5% output voltage drop if the load current increment is only half the transformer rating. However, attempts to make the impedance of the power source very low can prove to be expensive and hazardous. Momentary voltage changes of 5% or less are generally acceptable to ADP units, so very low impedance "stiff" power sources are unnecessary. If their short circuit current output is very high, the circuit breakers and other protective measures can become more costly. A 5% impedance transformer will deliver no more than 20 times its full load current rating with output short circuited.

High source impedance problems are sometimes encountered when voltage regulators, motor-generators, or other power conditioning devices are installed between the public utility network power and the ADP system. Often this is done in an attempt to correct varying line voltage, which may become marginally low during periods of heavy power usage such as for air conditioning during hot weather. If the regulating device or generator has a high internal impedance, this may correct the steady state line voltage, but make the ADP system unacceptably disturbed by sudden load changes created by operation of the ADP system. It may also enable the regulated power source to become distorted by voltage wave harmonics if the load current is highly distorted.

The internal impedance of some regulators and generators is typically 15–30% as seen by its effect on load induced transients. This is 3 to 10 times greater than that of an isolating transformer which may also be in the circuit. The increase in transient voltages from less than 5% to values as high as 15–50% is unlikely to be tolerated by some ADP units. To prevent this from becoming a problem, attention should be given to selection of a type and capacity of regulator which will not become the source of excessive load induced transients. There are regulator types and ratings which should not create problems.

Other power source attributes which are sometimes important to reliable operation of ADP units include the following:

Load currents and voltage unbalance among phases should not be excessive, typically 25% or less for current, and 5% or less for voltage. Phase voltage unbalance is the difference between the lowest and highest line-to-line or line-to-neutral voltages. It is usually expressed as a percentage of the average of the phase voltages.

Phase angle unbalance is similar to voltage unbalance, but is the difference between the greatest and smallest of the phase angles between phases which should normally be 120°. This is expressed as a percentage of the normal 120°. Voltage or phase angle unbalance causes uneven stress on rectifier components, and creates extra ripple in rectifier output. It also causes unnecessary extra loss in some three-phase units such as transformers and motors.

Tolerance to low power factor may be needed if the ADP system has low power factor loads such as some motors when they are being started. As discussed under power source impedance, low values of lagging power factor cause excessive voltage drops. Low power factor causes extra loss in power sources and taxes voltage regulation capabilities. As an incentive to avoid low power factor loads, some utility companies collect extra fees as low power factor penalties or as kVA demand charges.

Harmonics in the power source voltage can interfere with the proper operation of some ADP unit's internal regulators, creating extra losses, excessive ground leakage current in line filters, and coupling unwanted signals into low signal level conductors (see fig. 8). Some types of voltage wave distortion reduce the convertible energy and increase susceptibility to sags. A common specified limit for harmonics which originate at the power source is 5% total harmonic distortion, and 3% for any one harmonic. These are unwanted frequencies in the power source, and are exact multiples of the fundamental power frequency (60 or 50 Hz). On an oscilloscope, they are viewed as distortion in the voltage wave rather than as individual frequencies which would appear on a spectrum analyzer display screen.

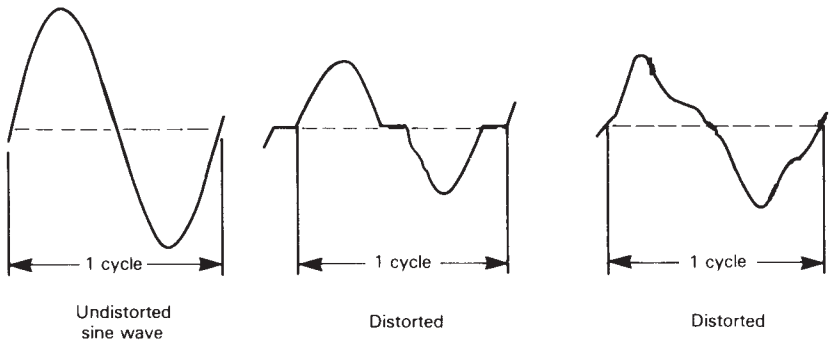


Figure 8. *Harmonic distortion* in ac voltage and current waves. Harmonics can distort the appearance and characteristics of a sine wave in many ways.

When the load current of ADP units is distorted and contains harmonics, they interact with the power source impedance to create voltage drops at the harmonic frequencies which may be present. Line voltage distortion from this cause is the result of ADP load characteristic interacting with power source impedance. It is not correctable at the power source except to the extent that the source impedance can be reduced at each harmonic frequency by filters. Capacitors in parallel with the load may help, but may cause unwanted resonances at specific frequencies.

dc load component in an ac load can appear through unwanted half-wave rectification. This could be the result of very poor product design or of component failure. Some power sources cannot tolerate appreciably any dc without saturating the iron in inductive elements such as transformers. This could induce overheating, premature operation of overcurrent protection, and significant voltage waveshape harmonic distortion. Some transformers, constructed on a three-legged core and which have a delta-connected primary in a three-phase configuration, are able to handle much more dc load component than three single-phase transformers with separate cores. If there is substantial direct current in the ADP load, this should be isolated from the power source by a transformer which is capable of handling it.

Ordinarily, the available power sources are not designed to handle large harmonic currents or dc. When these are encountered, it is possible for the neutral current to be substantially larger than the phase currents, as much as 175%. This can occur when line currents contain high percentages of third and multiples of the third harmonic (9, 15, etc.). These are zero-sequence currents where phase currents in the neutral add arithmetically rather than cancel each other. It would be 0% when neutral power frequency components of current cancel as ordinarily expected.

Combined effects require ADP three-phase power source neutral conductors to have an ampacity at least equal to the line conductors, and preferably 175% to double the normal cross-section of neutral conductor or busbar as a precautionary measure.

Voltage deviation factor of the power source is merely its departure of the actual voltage wave from the equivalent ideal sine wave, expressed as a percentage of the ideal sine wave. It is sometimes used instead of harmonic distortion to describe or specify the power source voltage.

Voltage modulation is commonly observed as a periodic increase and decrease of amplitude as though a voltage regulator might be hunting or some periodic load such as a pump might be causing voltage to vary and lights to flicker.

Transient surges and sags have already been discussed as part of the characteristics of ADP loads and their capability of surviving these events. The Line Disturbance/Duration Profile of ADP Susceptibility previously shown in figure 5 is intended to portray the susceptibility of ADP equipment to these transients [16]. What is often needed but is not readily available for a specific intended site is a similar portrayal of the types of disturbances which have been encountered and which may be expected to recur.

This information is best developed over a period of time with the use of a Power Line Disturbance Monitor connected to the intended power source or, if the intended power source has not yet been installed, to another neighboring source on the same public utility circuit. At least one computer manufacturer and one extensive user have measured the disturbances at representative sites and published reports on the results [4,6]. One conclusion is that there is too much variation between sites to assume that any one is an "average" or a "worst case" site.

A line voltage variation profile is also needed. Information can be gathered from the same Power Line Disturbance Monitor or from a simple recording voltmeter. Line voltage variations with the time of day or time of year will indicate whether or not it may be necessary to install voltage adjusting apparatus. If it is not feasible to shut down the ADP system to make line voltage adjustments, the voltage adjusting means will have to be capable of being switched or adjusted without power interruption, and without creating an excessively large disturbance.

In most cases, the initial selection of the proper voltage tap will be sufficient to keep the maximum and minimum line voltages within the capability of the ADP's own regulating system.

Large power networks vs small. In general, large power networks have more power sources and more loads than small networks. As a result, the loss or addition of any single source or load creates less of a disturbance on the total system. Frequency stability and reliability of large networks are typically better than small networks. Yet much depends upon the spinning reserve of peak generating capacity which exceeds load, and its management. If that reserve becomes too small and the protective load shedding thresholds are too close to the point of overloading, a major system fault could cause the total system to become disconnected and major, widespread power outages can result. Smaller power networks which may tie into the larger networks can have some of the advantages of large system stability as well as a better chance of survival in event of large-scale system problems.

Small independent power sources such as those used in large buildings and shopping malls are often part of a "cogeneration" system in which electrical power is generated as a virtual by-product of the energy needed for heating, cooling, and ventilation. In small industrial factories, a similar arrangement may produce process steam with electric power as a by-product. In such cases, the cost of electric power is generally substantially less than if it was purchased from public utility networks.

Another advantage of such a system is its relative independence from the power network which is exposed to many sources of disturbance and interruption by natural causes and other subscribers who share the power. A disadvantage is that individual loads are likely to represent a much larger portion of the total generating capacity. When such loads are turned on or off, the changes in line voltage and frequency can be much greater than when such loads are supplied from a stiffer public utility power network.

By separating the steady loads from the variable loads, and the critical loads from the noncritical loads, it is often possible to supply some of the power from the utility without serious disturbances to an ADP

system. At the expense of additional equipment and some reduction in efficiency, it is possible for an independent power source to be superior to public power for ADP purposes. If the public power can be wired to the system for use when the independent power equipment fails or must be serviced, the result can provide highly dependable power at high quality and at costs which can be partly supported by the energy savings.

Voltages at ADP input terminals will vary more than voltages at the building entrance, primarily because of voltage drop in the conductors when they are loaded. This drop can be reduced by the following techniques:

(a) Use one or more dedicated feeders and/or branch circuits for the exclusive use of ADP units.
(b) Put non-ADP loads and those ADP loads which are constantly switched on and off on separate branch circuits. The voltage changes at the variable loads will then affect only those units and will have much less effect upon line voltage at the ADP units with steady loads.
(c) Operate the feeders (and branch circuits to power centers) at an intermediate higher voltage (480 or 600 V) to lower the branch circuit current and percentage voltage drop.
(d) Put the stepdown transformer which provides the final utilization voltage as near to the load as possible, preferably in the ADP room.
(e) Avoid low power factor (lagging) loads to reduce the reactance voltage drop in transformers and generators.
(f) Use oversize feeders and/or branch circuit conductors.

2.3 Matching ADP Requirements to Power Source Characteristics

How much kVA and kW capacity is needed? What margins should be allowed? And what voltages should be available to the ADP room? Many of these points have been discussed, but will be summarized here for convenience:

(1) Obtain an ADP equipment list. Show each unit's power requirements.
(2) Select a common voltage and phase arrangement for the utilization voltages.
(3) If the ADP system is to have multiple processors for duplex or triplex operation because of a need for dependability, group the ADP units into subsystems which can each be independently powered. In this manner, it should be possible to interrupt the power to one subsystem group without destroying the viability of the other groups.
(4) Prepare a connection schedule for the ADP units in each group, distributing the single-phase units, the stand-by units and the intermittent units so that the phase currents will be balanced at full and partial loads, as far as is practically feasible. Conductor sizes are to be rated for no less than 125% of total connected load. (NFPA-70 Article 645-2).
(5) Compute the total electrical load power profile for each subsystem and include diversity factor.
(6) Add allowances for addition of anticipated additional equipment.
(7) Add 10% to the calculated total connected load to be expected.
(8) Round upward the largest combined load to the rating of the next larger isolating transformer where required by the ADP manufacturer and pick a transformer kVA. If this is more than 50 kVA, one should consider the advantages of further subdividing the load for ease of installation and for diversity and flexibility. Transformers are available in much larger sizes (500 kVA or larger), but one failure would affect more ADP equipment, the connections of some ADP equipment to it would become very long, and it is unlikely that it could or should be put in the computer room.
(9) If future needs are unknown, it is unnecessary to add significant margin when specifying and procuring an isolating transformer. Additional transformers can be installed as necessary to support ADP system growth.
(10) Plan to energize each isolating transformer from a separate feeder (or branch circuit) operating at typically 480 V, three phase. Plan to put these transformers near or in the computer room where the 208Y/120-V output is to be used.
(11) For future growth, put the greatest additional unused capacity into the feeders to the branch circuit distribution panels, and provide ample panel capacity pole positions for future additional circuit breakers and loads.

(12) Review the plan with the ADP system supplier's installation planning personnel, with the building site engineer, and/or an architect-engineer. If future addition of power conditioning or UPS are contemplated, the peak connected load on the utility may increase substantially, sometimes double.

Effect of Power Factor on ADP systems and their power sources can be substantial. Power factor is a characteristic of each ADP load, but power sources are rated on their ability to handle loads with various power factor ranges based upon the interaction which will occur between load and power source.

Power factor is merely the ratio of real power consumed in watts to the apparent power in voltamperes measured by ammeter and voltmeter (volts×amperes=voltamperes). At unity power factor (1.0 or 100%), the two are equal and all the voltamperes are consumed by the load as watts of energy. At power factors less than unity, some of the energy circulates between the load and the power source without being released permanently to the load. This is often due to inductive or capacitive elements in the load which alternately store and return energy from and back to the power source. In computer systems with rectifier loads, it is also due to the rectifiers and SCR solid state switching elements which interrupt the load current every cycle or half cycle for a portion of the ac cycle.

These effects increase the load current without corresponding net energy transfer which remains to be dissipated in the load. As a result, larger power source unit capacities and larger conductors to the load are needed for low power factor loads than are needed for high power factor loads which use the same net energy.

In addition, low power factor inductive loads (with lagging current) tend to drop line voltage. Low power factor capacitive loads (with leading current) tend to raise line voltage. Where only inductive and capacitive reactance are involved, one will cancel the effects of the other. Capacitors for power factor correction are commonly added for correcting (raising) low power factors caused by magnetically inductive loads. At the same time, this often helps raise sagging line voltages and reduce load currents. Electrical engineers use vector diagrams such as in figure 9 to estimate the magnitude of these effects.

Where rectifier loads creating harmonic load current are the cause of low power factor, the addition of power factor correcting capacitors will not necessarily provide the desired correction. The capacitors, in some cases, may actually raise the line current and fail to improve the power factor. Harmonic currents generally are most apparent in the neutral of three-phase circuits. Conductors supplying three-phase rectifiers using a neutral conductor need a neutral conductor as large as the phase conductors. A reduced neutral should not be permitted. In some cases, the neutral will need to be increased as previously discussed under *combined effects,* section 2.2.

When adding capacitors for any purpose, caution must be exercised to avoid any unwanted voltage resonances which may be excited by harmonic load currents.

If a delta/wye connected power transformer is installed between the power source and the load, the power factor at the transformer input will generally reflect the average power factor of the loads on the secondary if low power factor has been caused by inductive and capacitive reactance in the loads. However, if the load current is rich in harmonics from rectifiers and switching regulators, some of the harmonic currents will flow no further toward the power source than the transformer's delta winding. The third harmonics and multiples of three will flow in the delta winding and will be greatly reduced in the current input to the transformer. By this means, the transformer will create some improvement in the power factor of the total load.

An economic evaluation of cost vs benefits plus a review of any mandatory limits which must be observed for power factor correction will determine how much power factor correction, if any, may be required. It can be anticipated that power factor will vary with load, so let the correction through use of capacitors be optimum for a typical load rather than the maximum connected load. Correction to 0.85 power factor will satisfy most requirements. No economic advantage is likely in correcting to 0.95 or greater. Note that overcorrection (too many capacitors) can reduce the power factor after reaching unity, and can cause uncontrollable overvoltage in low kVA capacity power sources.

The power factor-correcting capacitors may offer some substantial benefits in absorbing line voltage impulse type noise spikes, but if they are switched on and off, they can create substantial impulses of their own. The switching may be accomplished with acceptably low disturbance through use of soft-start or pre-insertion resistors. These are momentarily connected in series with the capacitors before shorting the resistors prior to connecting the capacitors directly across the line. Capacitor load variation can also be

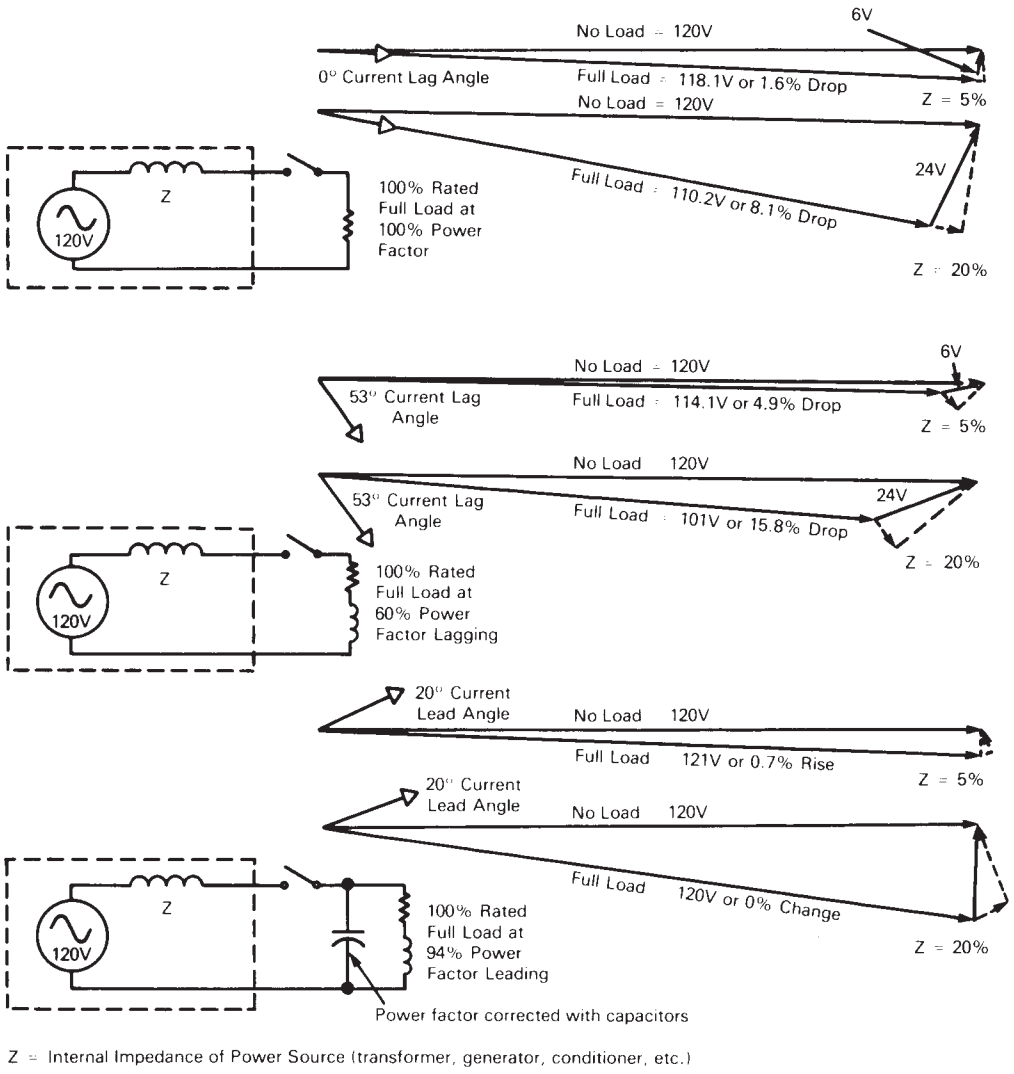


Figure 9. *Vector diagrams* show effects of load power factor and source internal impedance on line voltage at normal load currents. Low lagging power factor of a load and high inductive internal impedance of the power source combine to create large variations in line voltage with load change.

accomplished through use of a variable voltage ratio transformer which avoids large step voltage changes. It will also vary the natural resonance frequency.

Transformers, where to locate them? (fig. 10)

Power available in many buildings suitable for ADP sites is often from transformers located in a basement utility room. In large buildings, the power available to each floor or to each of several widely separated areas may be supplied by dry type transformers closer to the loads which they serve. Some transformers supply 120/240-V single-phase. More frequently they will supply 208Y/120-V three-phase to panel boards (circuit breaker enclosures) from which single- or three-phase power may be distributed to branch circuits. Most fluorescent lighting circuits in newer buildings operate at 277 V which is supplied by 480Y/277-V transformer outputs via separate panel boards.

Where the ADP installation is expected to be a significant load, these dry type transformers which service local areas may not be large enough in capacity to serve the additional ADP load. Even if they were, however, unwanted coupling of other load disturbances into the ADP system is reduced if it is powered from its own transformers and feeders which are dedicated to the ADP system only (see fig. 11). This reduces unwanted coupling with other load circuits.

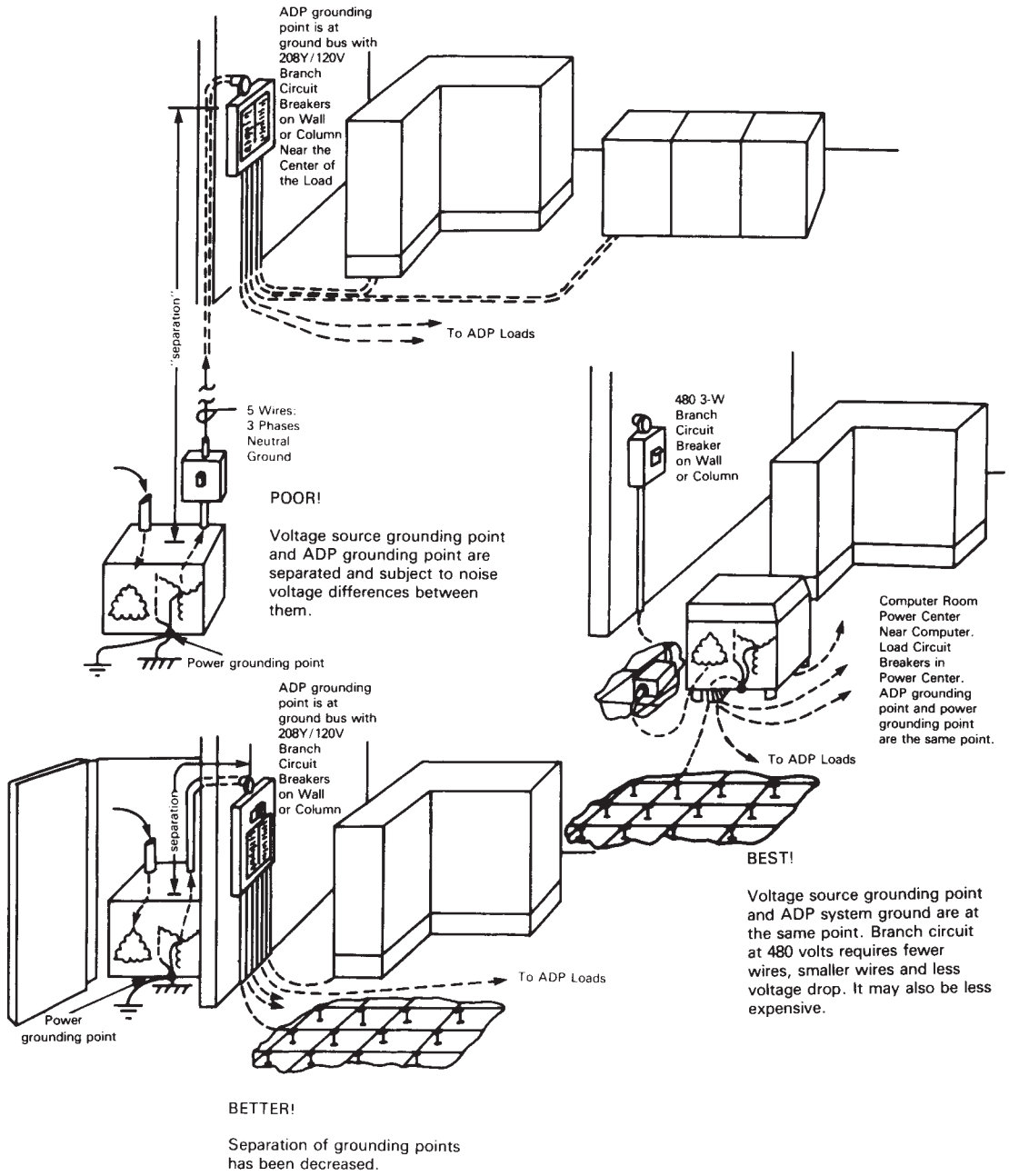


Figure 10. *Isolating transformers* for effective common mode noise control should be located near ADP equipment and its system central grounding point or signal reference grid.

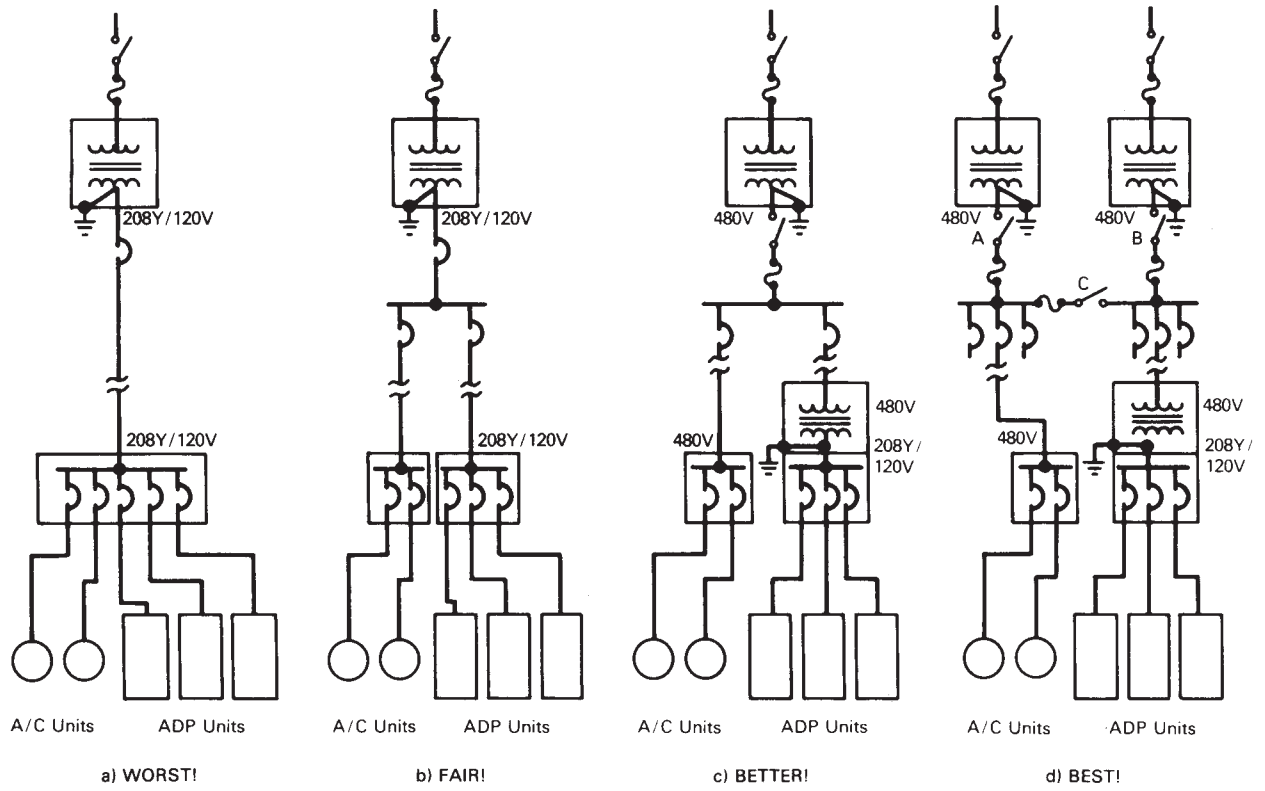


Figure 11. *Common vs. separate feeders:* Arrangements "c" and "d" enable the power source ground to be close to the ADP load. Arrangement "d" greatly reduces common voltage drop by using separate transformers while switch #C is open. If either transformer #A or #B or their power source fails, each is large enough to carry all important loads when switch #C is closed and #A or #B open.

Installing long feeders to carry the 208Y/120-V final utilization voltage over any significant distance, say, 150 ft or more, to an ADP room is not the best arrangement. Installing one or more feeders (and also, where applicable, branch circuits) at a higher voltage such as three-phase 480 V to the ADP room and to specific load devices rated for 480 V for large installations will be far more effective in performance and lower installation cost. At 480 V, the line current will be 43% of a 208-V system for the same transmitted power, and will require three power carrying conductors rather than four. The resulting losses will be less and voltage regulation improved. Lower installation cost will also help offset the cost of the transformer in the ADP room which can be justified for reasons other than cost.

In general, transformers which provide power at the final utilization voltage to an ADP installation should be as close to the load as possible. As described later, under grounding and power conditioning headings, there are advantages to putting the transformers directly in ADP rooms. Their effectiveness in isolating noise can be further strengthened by using transformers with interwinding Faraday shields.

Other upstream transformers will have some advantage in achieving ground circuit noise reduction if they can be placed at some distance from the computer room transformers.

2.4 Minimizing Electrical Disturbances

Some of these issues have been discussed, but will be summarized:

(1) Use separate feeders and branch circuits for ADP units so that no sudden common voltage drop will be created by noncomputer equipment sharing the same circuits.

(2) Not only is it permissible, but it can also be advantageous for small (say 1 hp), constantly-running three-phase motors such as used in air handlers to share a common power source transformer, feeder, and even branch circuits with ADP units. Each motor acts as a stabilizing circuit element in absorbing surges, storing rotating-mass energy electromechanically, and even returning

electrical energy to the line and computer load during momentary severe voltage dips. Such motors also help correct phase voltage unbalance and reduce harmonic content in line voltage. Blower motors and fans within ADP units also help in this respect, especially if they are three-phase units. Single phase motors are less effective.

(3) Larger motors which drive air conditioning compressors and which are regularly started and stopped are sources of electrical disturbance. They should not be powered from the same feeders or isolating transformers which supply ADP power.

(4) Operation of ADP units from high impedance power sources such as some voltage regulators, motor-generator sets, diesel or gas turbine driven generators, and UPS which typically have 15 to 25% dynamic impedance can result in large transient voltage variations. These can occur even though these units regulate the voltage within narrow limits under steady state conditions.

(5) If there are harmonics in the load current (typical of ADP unit loads), the large inductive internal impedance in these devices can also create substantial harmonic distortion of the line voltage wave.

(6) Prevent excessive disturbances and wave shape distortion by selecting power sources and conditioners with low internal impedance, larger kVA sizes than needed to carry the load, or a combination of both.

(7) Avoid apparatus with regulators which are susceptible to overshooting or to oscillatory interaction with loads which contain their own regulators. Without suitable damping, such units can amplify line voltage variations or even cause uncontrolled oscillation which will be described in item (9). Regulators of ferroresonant design and some UPS often have self-protecting current limiting features in which the load current cannot typically exceed 125% of full load rated current. Compared to an isolating transformer which can handle typically 2000% of rated full load current when output is short-circuited, ferroresonant products can cause system malfunctions if momentary current should exceed the current limiting threshold. If this should occur, the line voltage at the ADP system input would drop and might create a worse disturbance than without the regulator. Use of adequate regulator capacity can avoid this problem.

(8) Some 50 and 60 Hz UPS units incorporate static transfer switches. Upon sensing the loss of UPS inverter output, these switches transfer the load within a few ms to the bypass circuit. Normally, the public utility serves as the bypass power source when the normal UPS output is from the dc powered ac inverter. The quality of bypass power may be inadequate and may require some conditioning such as regulation, filtering, and noise suppression. The same conditioning may be more effective in the UPS/static switch output.

Successful application of high impedance power sources requires careful consideration of the ADP peak load current (1/2 cycle peak amperes) and the power source's capability to handle it without activating automatic bypass.

(9) Some caution must be exercised when voltage regulators are connected in cascade; that is, one regulator output connected to the input of another (fig. 12). Many ADP units incorporate their own internal voltage regulators. Many types and operating principles are used. If the two regulators in series both have similar response times, they can interact and become unstable. They can become a virtual "flip-flop" under some load conditions.

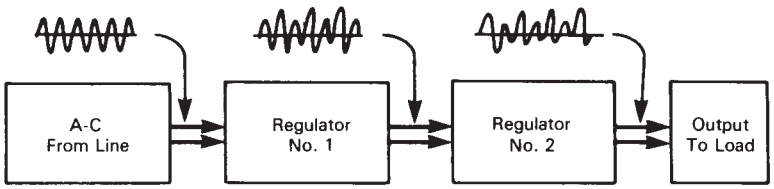


Figure 12. *Regulator stability problems:* Regulators incorporated into ADP products may react with upstream line voltage regulators. If they have similar time constants, high gain and phase shift characteristics, interaction can create oscillatory response ranging from damped oscillation to a disasterous "flip-flop" instability.

Similar precautions must be exercised when voltage regulators of single-phase design are connected in a three-phase wye configuration and with single-phase loads connected line-to-line. Severe voltage regulator instabilities can result in line voltage fluctuations worse than with no regulators at all.

(10) Avoid large step load changes. Block loading and unloading (turning numerous loads on or off simultaneously) should be avoided as an operating practice. The line disturbances and the transient energy are proportional to the current which is switched. Such transients can damage components or weaken them to produce early failure. ADP loads should be turned on or off in small increments, often one unit at a time. Block unloading should be an emergency procedure only.

3. GROUNDING

(General references include [1,3,7–15,17,19–24,26–29,31])

3.1 Purposes of Grounding

Grounding accomplishes multiple functions, all of which must be considered in the design and installation of an ADP system. Persons concerned with only one or two of these functions may violate the others in ignorance or because they are not his or her responsibility. Grounding is required both for safety reasons and because of the need for highly sensitive computer circuits to operate reliably. Safety takes top priority, but the ADP system must be simultaneously safe and operationally reliable. There must be no compromise.

For more than 100 years of attention to lightning protection and power transmission fault control, electricians and electrical engineers have been exhorted to create and use low resistance ground connections to earth. This is appropriate for lightning and transmission line ground faults since part of their paths is through earth. However, this is not the rationale for applying grounding principles to 120-, 240-, and 208-V utilization circuits. At these voltages, a system of interconnected or bonded conductors acting as a voltage reference network can equalize voltage differences throughout the network much more effectively than multiple low impedance earth contacts.

Such an interconnected, bonded network can serve as both a power and signal reference, regardless of its voltage with respect to earth ground. However, to avoid shock hazards in a building structure and to minimize voltage differences between individual reference networks, it is not only accepted practice but mandatory for safety purposes that these networks be connected to earth ground. Since the connection to earth is never expected to carry load or fault current, the National Electrical Code permits this conductor to be smaller than the equipment ground conductors in the network (Article 250-94 of NFPA 70-1981)[21].

If there are ground currents in a driven earth ground electrode from any source, a low resistance between earth and ground conductor with its attached electrode will help prevent generation of electrical noise which sometimes appears in coincidence with a high-voltage gradient in dried-out soil. If ground currents appear to be excessively high (more than an ampere or two in a residence to more than 20 amperes in a large building), it is advisable to determine the source of such currents and reduce its magnitude if at all feasible to do so. High currents can cause deterioration of the electrode and become an increasing source of electrical noise.

For ADP systems, minicomputers, microprocessors, and office machines, a copper rod driven into moist soil is not a magic cure-all for grounding problems, or is it necessarily a requirement. Computers aboard aircraft work well without being connected to "earth." However, when the aircraft lands and someone is about to disembark, a ground conductor between the airframe and earth (bypassing the rubber tires) may be needed to avoid a nasty shock. In the event the aircraft had picked up an electrostatic charge with respect to earth, a grounding conductor would quickly equalize the voltage difference.

Various functions and details of ADP system grounding may be summarized as follows:

(1) Touch voltage differences must be limited by bonding and grounding to avoid shock hazard.
(2) Ground fault current return path to power source must be low enough impedance to enable it to actuate overcurrent protection and disconnect the source.
(3) Ground potential differences in the ADP area must be reduced to essentially a constant potential reference.
(4) Grounded conducting enclosures serve as electromagnetic shielding for sensitive circuits.
(5) Grounding in compliance with safety codes is mandatory.
(6) ADP manufacturer's recommendations should be followed to the extent that they are consistent with item (5). Inconsistencies must be resolved.

Touch voltage (fig. 13) is the voltage between any two conductive surfaces which can be simultaneously touched by an individual. The earth may at times be one of these surfaces. There should be no "floating" panels or enclosures in the vicinity of electric circuits. In the event of insulation failure or inadvertent application of moisture, any electric charge which appears on a panel, enclosure, or raceway must be drained to "ground" or to an object which is reliably grounded. A "safe" touch voltage of 30-V rms or less will not necessarily satisfy system requirements for low noise signal differences (0.5 V or less) between parts of an ADP ground system.

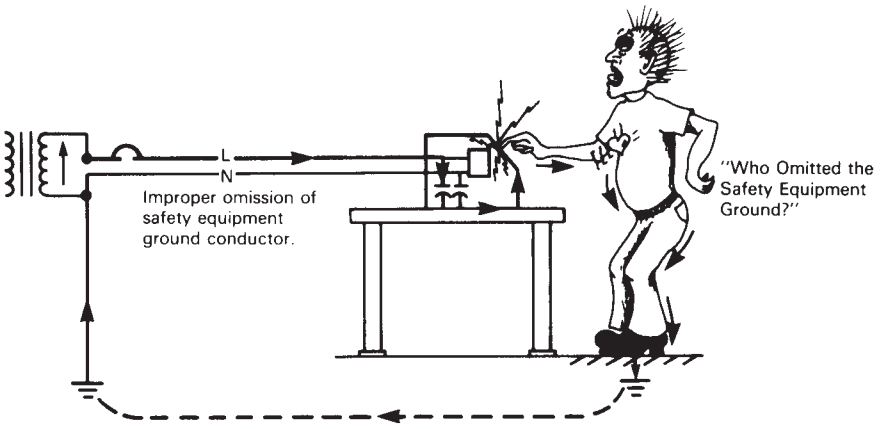


Figure 13. *Touch voltage shock hazards:* Although voltages of 30-V ac rms or more are classed as electric shock hazards, it is the current, not the voltage, that kills. Commonly accepted "safe" limits are 3.5 mA (0.5 for portable devices), but these are both above the threshold of feeling.

A ground fault return path to the point where the power source neutral conductor is grounded is an essential safety feature. The National Electrical Code and some local wiring codes permit electrically continuous conduit and wiring device enclosures to serve as this ground fault return path. Some codes require the conduit to be supplemented with a bare or insulated conductor included with the other power conductors. In either case, the conduit, grounding conductor (if used), and the power source's neutral conductor are bonded together at the power source if it is in the building, or at the building entrance if the power source is outside the building. If it is part of the premise's wiring, a transformer secondary winding which is isolated from the primary winding can be considered to be a separately derived power source and one of its conductors (neutral) must be grounded.

As indicated in figure 14, an insulation failure or other fault which allows a phase wire to make contact with the enclosure will find a low impedance path back to the power source neutral. This will be virtually a short circuit. The resulting overcurrent will cause the circuit breaker or fuse to disconnect the faulted circuit promptly. Driven ground rods are not part of this path [27].

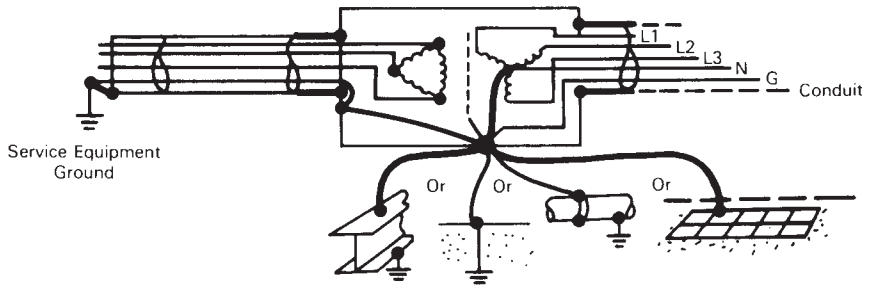


Figure 14. *Grounding of separately derived ac systems* such as the isolated output of transformers and generators is a safety requirement per Article 250-26 in the National Electric Code [20].

Ground voltage equalization of voltage differences commonly found between parts of an ADP grounding system is accomplished in part when the equipment grounding conductors are connected to the grounding point of a single power source. If the equipment grounding conductors are long, and if the ground currents are significant, the impedance of the grounding conductors may be too high to achieve a constant potential throughout the grounding system. Supplementary conductors which may be needed must be in addition to the equipment ground conductors which are required for safety, and not a replacement for them, as indicated in figure 15.

Shielding may consist of metal barriers, enclosures, or wrappings around one, the other, or both circuits. Such shielding, between sensitive circuits and sources of disturbance, must be connected to a signal referençe such as ground in order to be effective [19]. A floating shield can be worse than no shield at all. A long ground conductor to a shield (fig. 16A) reduces the shield's effectiveness at high frequency since the

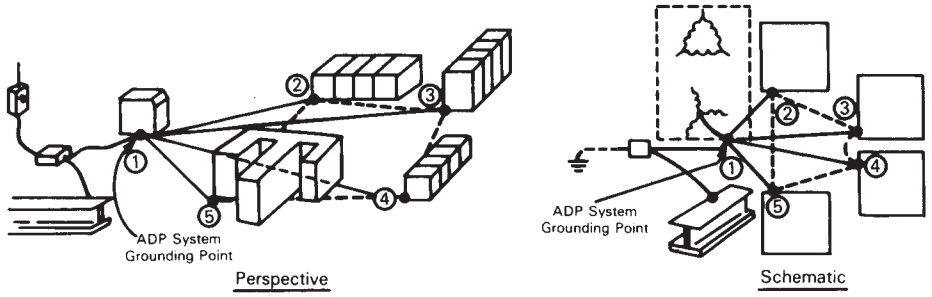


Figure 15. *Supplementary ground potential equalizing conductors* may be added to reduce high-frequency electrical noise. Connections required for safety are 1-2, 1-3, 1-4, 1-5. Connections to reduce electrical ground voltage differences are 2-3, 3-4, 4-5, and 5-2.

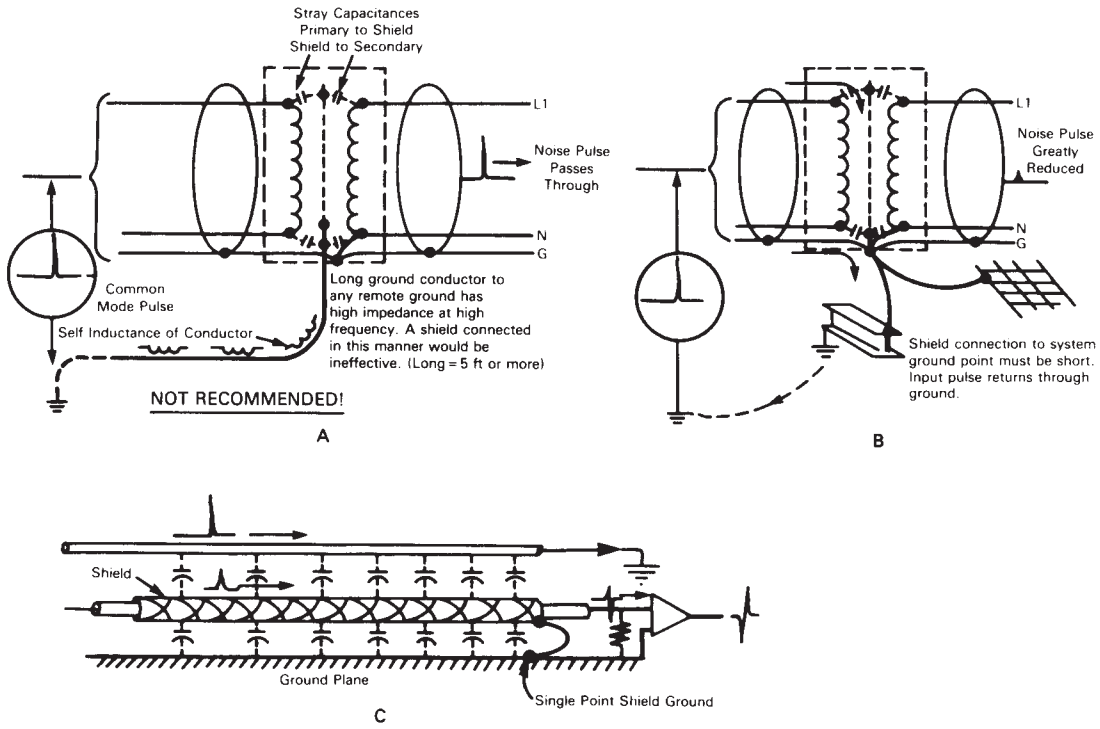


Figure 16. *Grounding of shields:* (a) A long shield return path makes an interwinding shield ineffective; (b) A short shield path to the system ground reference reduces pulse noise at the output; (c) Where a single point ground on one end of a shield may be ineffective above 1-10 MHz, multipoint grounding of an outer shield may be required.

inductance of the conductor obstructs the flow of current to the shield. To be effective at high frequencies above 10 MHz, the shield must be grounded with short connections at multiple locations (fig. 16C). As indicated in figure 16C, single point grounding at one end of a shield does not equalize the voltage along the length of the shield at high frequencies or during a pulse of noise current. Shield voltage at the ungrounded end will couple to the inner conductor and will be partly converted to normal mode signal as it reaches the grounded end.

Compliance with safety codes is important, but it is also important to understand the basis for specific code requirements. Codes are often misinterpreted by individuals who lack understanding, but may be installing wiring, inspecting the job, or interpreting specifications. A little knowledge of basic principles can help one identify and resolve these problems before any harm is done [1,20-21,31].

3.2 Techniques of Grounding

ADP manufacturer's grounding instructions and recommendations are important and should be followed. Occasionally, however, the grounding techniques specified for various units are inconsistent, especially if they have been supplied by different manufacturers. Sometimes they are inconsistent with the interpretations of wiring codes by contractors, electricians, and inspectors. When there is doubt, there must be no compromise with safety. The system must be safe and must be capable of operating reliably without compromise.

Where the grounding instructions appear to conflict with safety code requirements, the manufacturer who prepared the instructions should be consulted and asked to resolve the problem. Any arbitrary independent departure from the installation instructions or electrical codes can result in taking the responsibility and accepting part of the liability for safety hazards or failure of the ADP equipment to perform reliably.

Electrical safety inspectors and code requirements must always be given serious attention. Compliance is always recommended whenever it is possible to do so, especially if it removes a safety hazard. Occasionally, interpretations of codes and their applicability have to be questioned when they are believed to be wrong or unnecessarily restrictive. Codes are constantly being changed, amended, or expanded because new situations are constantly arising which were not anticipated when the codes were first written.

Sometimes an interpretation will depend upon whether the governing safety standard applies to building wiring or to a factory assembled product to be installed in a building. Underwriters Laboratories (UL) and other qualified testing laboratories examine products at the request and expense of manufacturers or purchasers, and will list products if the examination reveals that the product presents no significant safety hazard when properly installed.

Municipal and county safety inspectors generally accept UL and other qualified testing laboratories certification "listings" as evidence that a product is safe to install. Without a listing, a test, or examination by the safety department's own laboratory (if there is one), it may not be possible to obtain wiring permits and inspection sign-offs for connecting power to the loads. Most ADP equipment manufacturers routinely seek and obtain UL listing of their products. Without it, there can be installation delays.

On-site wiring must generally comply with local wiring codes. Most of these are based upon the National Electrical Code (NFPA 70). In addition there is NFPA 75 which is the Standard for the Protection of Electronic Computer/Data Processing Equipment. These codes specify wiring materials, wiring devices, circuit protection, and wiring methods. There are sections devoted specifically to ADP installations. Both codes are primarily directed toward prevention of electrical shock and smoke or fire-related hazards, and to minimize loss of property.

Some communities, particularly large cities, will require site construction features which are considerably more restrictive and expensive to install than those specified by the National Electrical Code. In some instances, these features have been a factor for picking ADP sites outside of these areas. It is not sufficient that the product to be installed and the wiring devices and methods are UL listed and covered by code. The cooperation and objective technical judgment of good electrical inspectors, electrical contractors, and electricians can result in safe, reliable ADP installation without arbitrary unnecessary restrictions and expense.

The Central Grounding Point (fig. 17) of an ADP system should be readily identifiable. It should be the *point* where the interconnected parts of the computer's grounding system are connected to other ground conductors which extend beyond and outside the ADP room. If there are two such points, each being interconnected to each other and to separate external grounds, the noise voltage difference between those separate grounds will cause noise current to flow through the ADP ground system via the ground loop which is formed.

Within very large systems, there may be subsystems, each with a central grounding point for connection to other central grounding points. However, separate connections to separated external grounds would create unwanted external ground loops. By such means, impulse ground currents can find paths in the grounded shields and grounded conductors of signal pairs and coaxial cables. Intercoupling with digital circuits and signal corruption can be the unwanted results.

The frequency of noise signals (any signal other than the desired signal) can vary from dc to MHz and even GHz frequencies. Few detectors will respond to the entire spectrum and fortunately the digital circuits will not either. However, the trend in devices used in ADP circuits, as mentioned before, is toward ever

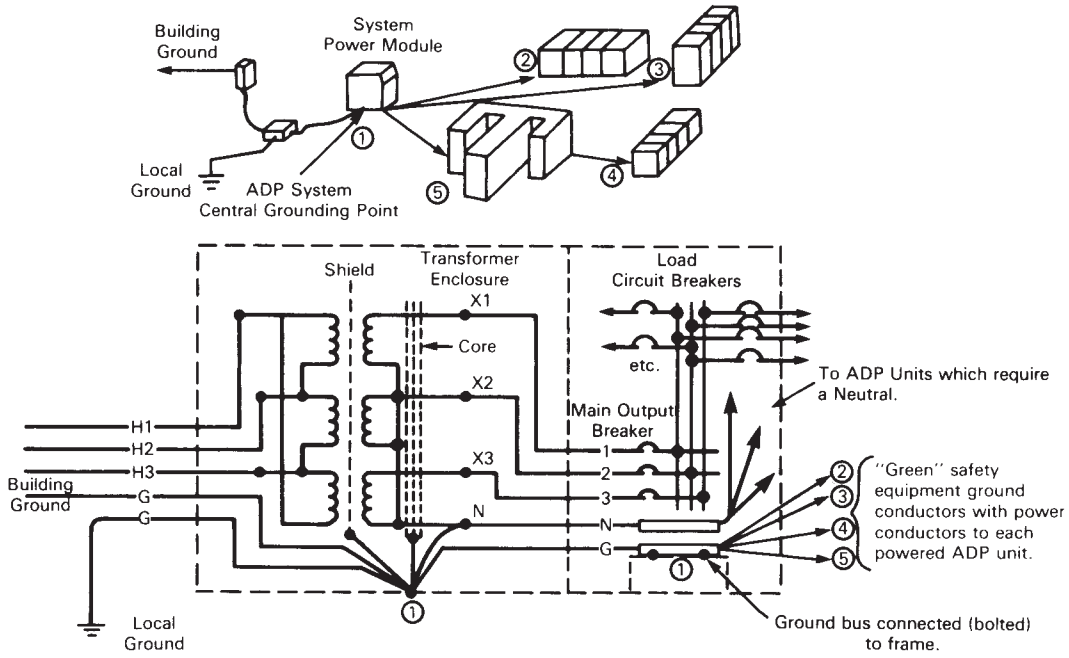


Figure 17. *A "single point ground"* in an ADP system prevents unwanted ground loops by providing only one conducting path between it and all external grounds. Point "1" or several closely interconnected ground terminals "1-1" illustrate a single point ground.

increasing bandwidth and lower signal levels. Moreover, the interference sources still range from dc to frequencies as high as can be measured.

As signal frequencies reach and exceed approximately 10 MHz, radiation of the signals and coupling to adjacent circuits become increasingly troublesome problems. It requires more costly wiring techniques such as twin lead, twisted pair, strip lines with ground planes, or coaxial conductor construction to contain the electromagnetic fields associated with signals and noise. At frequencies above 30 MHz, concern over line conducted signals and noise becomes overshadowed in importance by radiated signals and noise.

Future computers with higher frequency performance circuits will most likely require careful shielding of all circuits longer than a few inches. Coaxial conductors and waveguides become appropriate for higher frequencies. However, these are prime candidates for replacement with fiber optic signal transmission which is already being put into communications service to carry digital signals at 90 to 400 megabits per second. Research indicates this transmission media may be suitable for bit rates as high as 2 to 10 gigabits per second (1 gigabit = 10^9 bits). The tradeoffs between cost and usable performance will determine the direction of future development and rate of progress in that direction.

Fiber optics will solve some of the common mode noise problems that bother today's computer circuits, but other limitations will take their place. The signal energies may continue to decrease as noise is reduced, but there are theoretical limits which will ultimately be approached.

In today's technologies with digital data and control signals, any dc and low ac frequency (100 KHz or less), signal currents will follow the lowest resistance paths where conductors may be the largest and shortest. At high radio frequencies (above 100 kHz), stray capacitance and electromagnetic coupling become significant circuit paths. The path taken by dc currents could be tortuous and have too high an impedance to be a good high frequency path. At low frequencies where currents follow conductors, single point grounding is generally preferred. As signal frequencies exceed approximately 10 MHz and greater, the noise currents and voltage signals cannot easily be confined to conductors. In this realm, multipoint grounding becomes necessary if it is to be effective.

If the desired signal must be protected against both high and low frequency interference, a solid metallic galvanic grounding connection is needed for a single point ground, while at high frequencies one can use multiple ground paths via deliberate use of stray or discrete capacitors. A very effective technique is to have multipoint ground connections to an outer shield over an inner insulated shield which has a single point ground.

The single point of entry wiring strategy for ADP rooms (fig. 18) is a practical approach to establishing a virtual single point ground for the ADP system, the communication system, the power source, and the life-safety system. If all external conductors penetrating the ADP room were to enter at a single point rather than at multiple points around the room, their respective ground conductors could all be interconnected at the point of penetration.

The expected benefit is that noisy ground currents flowing between the power, communication, and other ground conductors can flow through the short ground interconnections at the entry point rather than going through the grounding conductors within and among ADP system units. The remaining question is, "How short is short?" The answer depends upon signal frequency. The measuring yardstick is often related to wavelength of electrical signals. (Wavelength is approximately the speed of light divided by the frequency of a signal.)

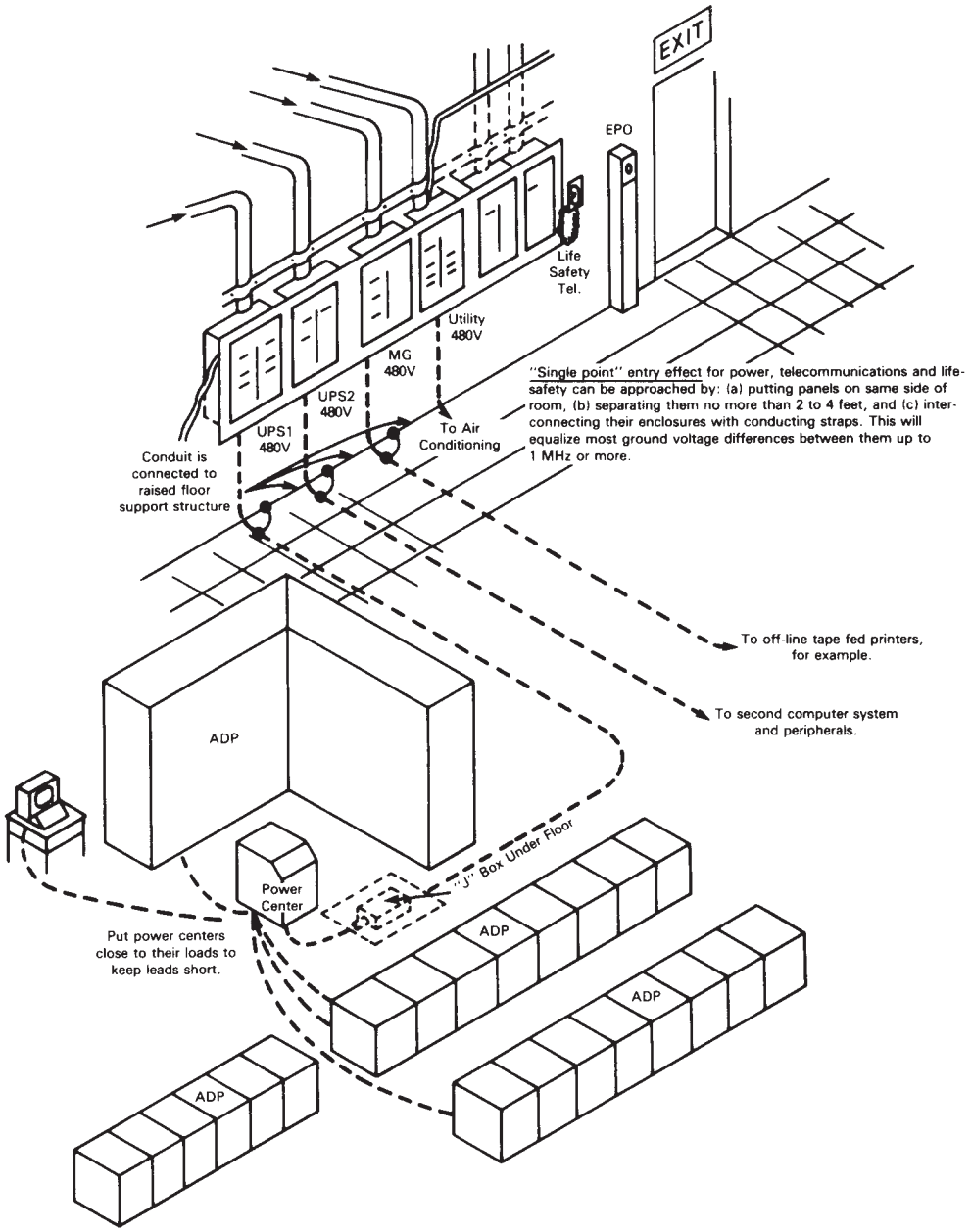


Figure 18. *Electrical interface location:* Entry of power, communications, and life-safety in one place rather than opposite sides of the room permit use of short interconnections to equalize ground voltage differences without passing equalizing currents through the ADP room.

Very short grounding conductors and interconnections are needed if they are to be effective at high frequencies. Not only does the typical conductor have inductance distributed along its length, but with the distributed capacitance there will be frequencies at which the conductor can become resonant with the high frequency noise or desired signal. As will be discussed later, resonance considerations dictate that unless the interconnections can be shorter than 1/20th of a wavelength of the signal to be bypassed, its ability to conduct current will be impaired by partial or full resonance [24].

If not for the need to separate groups of power, communications, and life safety conductors to prevent propagation of fire damage from one group to another, and to prevent unwanted electromagnetic coupling of noise from the power conductors into communications and other low level signal conductors, the ground voltage differences would be most completely equalized if the ground equalizing strap conductors were no more than several inches long.

With flame barriers and separate metal conduits, raceways, or cable troughs for the separate services, approximately 1–2 ft separation can be sufficient for this purpose. However, if any voltage equalizing strap is to be effective for equalizing noise signals up to 10 MHz, it should be no longer than about 4.5 ft (1.4 m). As equalizing conductor lengths exceed this, their effectiveness in providing a single point of entry with a common ground voltage is reduced.

Placement of isolating transformers to achieve short connections to the loads they serve re-establishes a new ground reference point for the power source close to the ADP units they serve. If the isolation transformer is in an adjacent utility room, the ground reference point for that power source and its connection to the computer system ground will be outside the computer room. If it is on another floor or in the basement of a building, the ADP units which are served by that transformer will be connected to a remote grounding point. There may be considerable noise voltage difference between that remote grounding point and the ADP central grounding point within the computer room.

If the primary circuit is 480 or 600 V rather than 208Y/120 V, the feeder to the isolating transformer and wiring devices will cost less to install, will have lower losses, and will provide better regulation. These are not insignificant for distances over 100 ft.

As shown in figure 19, the voltage differences between the ground conductors of various services entering the single point of entry may be equalized at that point. However, any voltage difference between that equalizing point and the remotely located transformer's grounding point will be superimposed upon the line voltages as common mode noise. The power delivered to the ADP units with superimposed noise will be divested of the noise by the filters which will deliver clean power to the logic circuits within the ADP unit. However, the filters will shunt the noise current to the ADP frame and return to the source via the safety equipment ground conductors and any conduit or raceway which parallels that path.

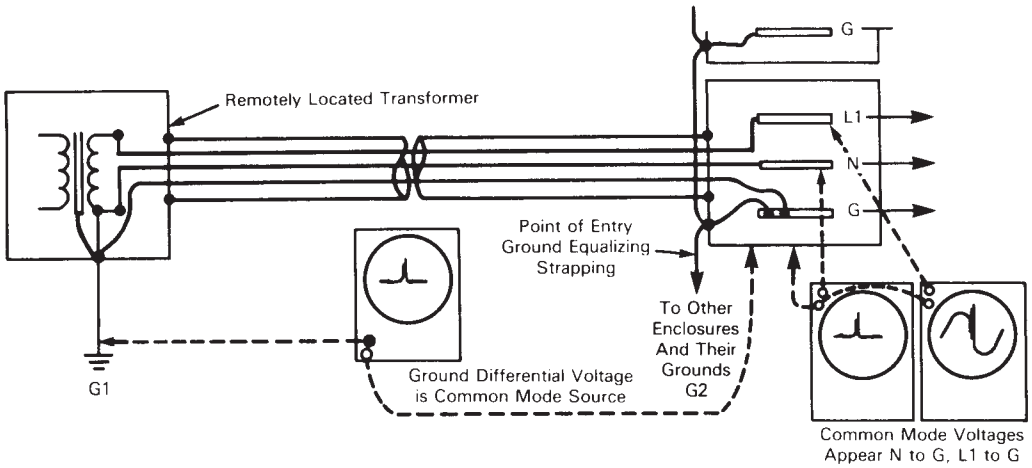


Figure 19. *Common mode voltages:* Without an isolating transformer at the ADP room, the voltage between the upstream neutral grounding point (G1) and the ADP system's central grounding point (G2) will appear as common mode voltage at all ADP units.

The noise currents flowing through these return paths create voltage drops in them, particularly at high frequencies or during impulses with fast rates of voltage change. The result is the creation of impulse noise voltage differences between various units of the ADP system, followed by equalizing currents flowing

in the grounded conductors of the digital circuit cables between ADP units. This is not a desirable condition. Typical noise impulses of up to 170-V peak may occur regularly as a result of switching 120-V ac circuits at random. This can result in ground current impulses of typically 1–4-A peak which must be steered away from signal cables, since fractions of a volt and a few milliamperes or less can corrupt a data signal.

Putting the isolating transformer within the ADP room eliminates one source of ground noise voltage. Putting the transformer close to the loads which it serves reduces the impedance of the return path for any residual noise, including that created by some of the ADP loads. This is the desired path for the noise currents to flow, and because it is short, the noise voltage between ADP unit frames will be greatly reduced compared to installations with longer return paths to the transformer's neutral grounding point.

There are techniques for increasing the impedance of the interconnecting digital cables to common mode noise currents which will be described under the topic of "avoiding ground loops." If putting the transformer close to the load does not provide sufficient reduction of noise interference, some of these techniques can offer additional attenuation of noise which would otherwise be transferred to sensitive digital signal circuit cables.

The "Earth Ground Connection" can be important to reliable performance of electronic circuits in ADP systems, minicomputers, and word processors, but its role is frequently misunderstood. As a result, much effort and sometimes needless expense is incurred in achieving a "quiet, isolated ground" with a very low ground resistance. The quiet, low-resistance attributes are always desirable, but a misunderstanding of the term "isolated" can lead to dangerous grounding practices which violate safety codes and will not necessarily solve noise problems.

Stand-alone word processors, minicomputers, their peripherals, and other electronic office machines are typically powered and grounded solely by their three-prong grounding type 120-V plugs on their power cords. If a minisystem requires more than one separately powered unit, it is common practice to use a grounding type duplex receptacle, cube tap, or portable receptacle strip provided that the total load does not exceed 80% of the 15- or 20-A circuit protection rating for that circuit.

In many instances, such an arrangement has been used successfully. In its favor are having all minisystem grounds connected together at a common point as well as limited noise voltage differences appearing between this minisystem central grounding point and the grounding point for the power source's neutral or any conducting structural member or surface in the vicinity of the load.

Unfortunately, there are often reasons why this may be marginally successful or not work at all:

(1) The ground pin at the receptacle, the neutral grounding point at the building entrance service equipment, and the transformer power source's secondary output winding ground point are separated and may be grounded at two or three separate locations. This could permit noise voltages to develop between them and appear as common mode noise.

(2) Older buildings may contain wiring without an equipment ground conductor, and may even lack electrically continuous conduit to serve in its stead. If the outlet receptacle enclosure is grounded to a local water pipe, driven earth electrode, or building structural steel and there is no provision for an electrical return path such as as an equipment ground conductor or continous conducting path provided by conduit back to the power source grounding point, such an installation could be unsafe. It also may inject excessive electrical common mode noise current. This is described later and is illustrated in figure 20.

(3) The equipment ground conductor in the receptacle may be permanently connected to the conducting enclosure in which it is mounted. A connection which is integrally built into the receptacle normally creates this ground path. Noise currents originating from a load plugged into an adjacent or nearby receptacle could reach the sensitive equipment via this path.

One solution is to install an "isolated ground" receptacle (sometimes identified by orange color) in which the ground terminal is isolated from the mounting strap (fig. 22). An insulated equipment ground conductor is then connected from the grounding terminal of the receptacle in accordance with National Electrical Code Article 250-74 Exception No. 4 (NFPA 70-1981), and is passed through one or more panel boards without connecting to their grounding terminals (Article 384-27, Exception No. 1) for direct connection to the applicable derived system or service grounding terminal.

Contrary to illustrations in some catalogs which show examples of the equipment ground connected to an independent earth electrode without any other connections to the building ground, the equipment grounding conductor from the receptacle with the isolated ground must be connected directly to the neutral

grounding point for the building. This is necessary for safety, compliance with code, and for low electrical noise at an ADP unit.

An alternative to rewiring the building to install a proper ground conductor is to use an isolating transformer with its own local ground near the load. An isolating transformer has separate primary and secondary windings and an interwinding shield. The secondary and shield can be referenced to the load's equipment grounding conductors simply by connecting short bonding straps between the shield, the secondary output neutral, and the transformer frame which in turn is connected to a local ground (driven earth electrode, building steel, water pipe, raised floor structure, etc.). For safety in event of a primary circuit ground fault, an equipment ground conductor is also run with the input power to the service equipment ground or separately derived source ground.

The term "isolating transformer" may be confusing when used to describe this arrangement because it implies that no connection exists between primary and secondary, but this is not true. Primary and secondary are each connected to grounds or circuits which are grounded. However, these are not the same ground. Even though a grounding conductor may interconnect the two grounds, noise voltage can appear between them. Without the isolating transformer, this voltage difference would be superimposed upon the line voltage and delivered to the load. More will be said about isolating transformers later, with or without other power conditioning features.

Grounding myths:

One myth about earth grounds makes them appear to be analogous to cesspools, allowing unwanted noise current to be drained into the earth and dissipated. If the ground current is small, one rod will do. If it is large, one must install a very long ground rod, install multiple interconnected rods, or create a buried grid of conductors over a large area like a leach field for sewage effluent. Treatment of the soil with water and chemical salts further decreases the ground resistance and enables the ground connection to earth to carry more current with less voltage drop.

This information on how to create a low resistance earth connection is not myth. However, the myth is that all noise current can be drained away and dissipated into the earth. This can be true for lightning induced noise where the earth is one of the terminals of the lightning current path. In most other instances, the earth is not or should not be one of the terminals of a noise source. Electricity flows in circuits. It follows Kirchhoff's laws (what current goes in must come out, and generated voltages equal the voltage drops). If instruments indicate that an ampere of noise is flowing into the driven earth rod, it must be returning from some other earth connection. If the ADP system is part of that circuit, it is important to identify where it is entering as well as where it is leaving.

The appropriate solutions are either to eliminate the source of the ground current or to provide short, low impedance paths where that current can flow safely without creating significant voltage drops or unwanted coupling into signal circuits. A low impedance connection to earth is difficult and sometimes expensive to achieve. A solution which requires two such grounds to provide a low impedance path through earth cannot be expected to be better than a lower impedance conductor directly between the source and destination of that noise current.

Another myth is that a computer requires a "clean, dedicated, isolated ground" with no electrical connection whatsoever between it and the "dirty ground." The term "dirty" is often used to describe the ground rod used for the utility power neutral ground where it enters the building, or a downstream isolating or stepdown transformer within the building. This myth has been responsible for a number of unsafe installations and code violations, plus needless expense for additional grounding rods and long, heavy guage copper grounding conductors to "clean ground" locations placed far away from the "dirty grounds."

If one were to believe this misinformation and act upon it, the power source conduit to the ADP enclosure could be broken at point "X" of figure 20 and replaced with an insulating bushing (a safety violation). Additionally, any grounding conductor within that conduit would not connect the ADP enclosure back to the power source grounding point, but instead would be connected to a "dedicated, isolated, clean ground" (another safety violation).

Figure 20 illustrates the fault current path in the event of a short circuit between a line conductor and the ADP unit's frame or a line-to-frame fault resulting from a line filter capacitor failing in a short-circuited mode. The return path of the fault current back to the neutral must flow through two driven earthing rods, the resistance of which is likely to be at least 5 ohms or more each. From a 120-V power source, the maximum fault current could not exceed 12 A. This is not enough to open circuit breakers which may range

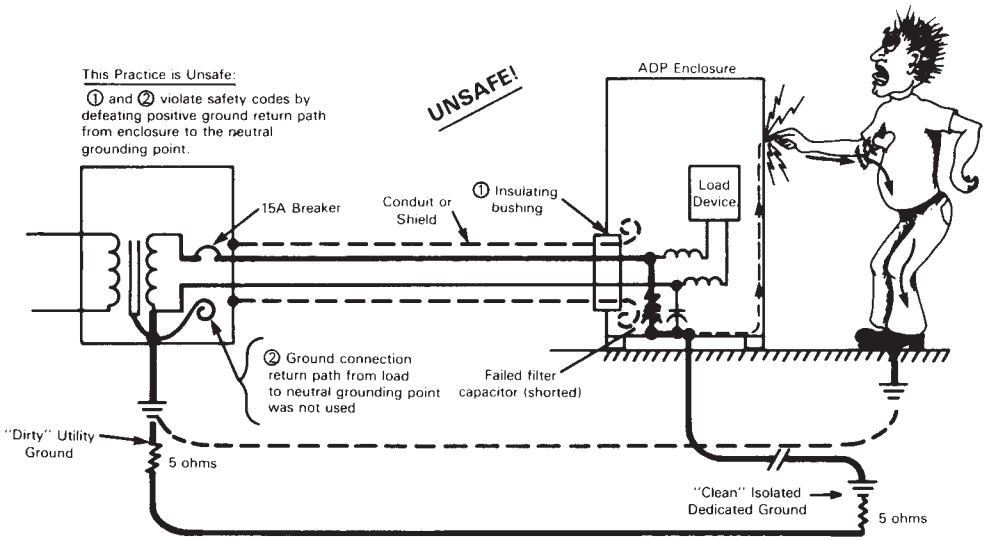


Figure 20. *Electric shock hazard of isolated grounds:* Using an illegal insulating bushing in the power source conduit and replacing the prescribed equipment grounding conductor with one to an "Isolated Dedicated Computer Ground" is dangerous, violates codes and is unlikely to solve noise problems. With two 5-ohm earth grounds in the fault path, ground faults will pass more than enough current to electrocute someone and burn up small wires, but not enough current to trip a 15-A breaker.

from 15–80 A or more. A 15-A rated circuit breaker needs 75–150 A or more to cause it to open without delay. Larger circuit breaker ratings take proportionately more current.

If the circuit breaker does not remove the power promptly upon a fault, people could be hurt or electrocuted, and small wire gauge conductors for signals together with electronic interface components could be literally fried and create a risk of fire. Ground fault interrupters are available which, if operational, would trip the power source circuit breaker with fault or leakage currents typically as low as 5 mA. However, safety codes in the United States do not permit this to be a substitute for an equipment ground conductor to the power source neutral grounding point.

Figures 21 through 23 show methods of grounding which comply with the codes, are safe, and reduce the voltage differences between ADP enclosures and surrounding grounded objects. All of these, including the isolated ground receptacle, have equipment ground paths to neutral. This general arrangement minimizes the noise currents which will flow in grounded signal circuits as well as in the safety equipment ground conductors to each powered ADP enclosure. It complies with code requirements and has none of the hazards of the "isolated earth electrode ground" connection. It recognizes that two earth rods in soil cannot be isolated from each other.

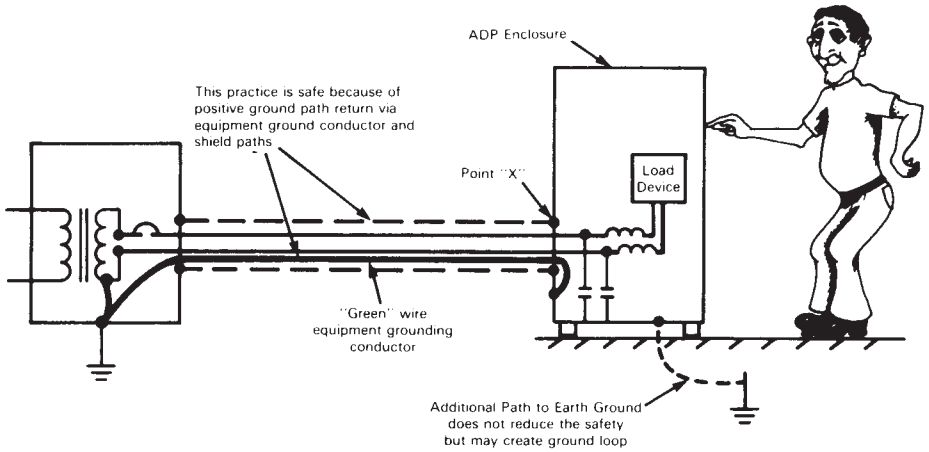


Figure 21. *Safe grounding practice:* Codes require enclosures to be directly connected to the power source's neutral grounding point via equipment grounding conductor (green wire), via conduit through point "X," or both. Without a connection at point "X," the system may be safely grounded by the green wire, but may violate code interpretations.

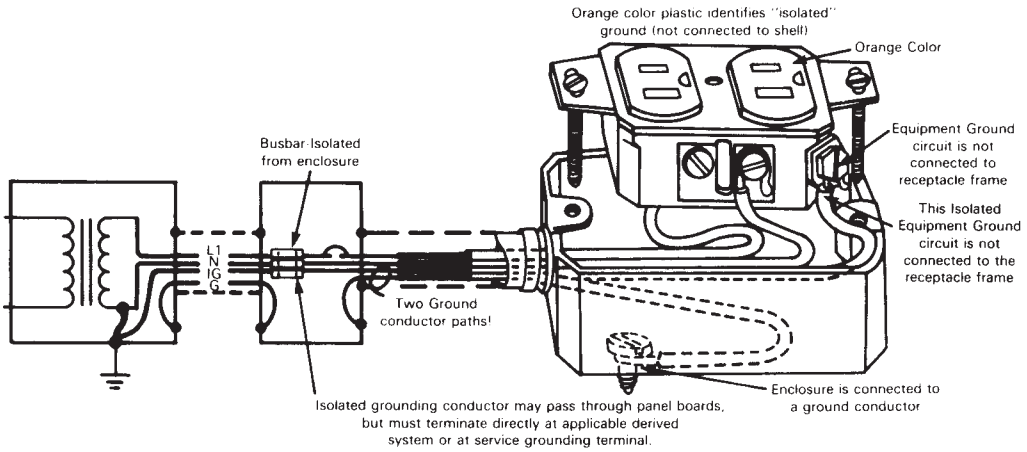


Figure 22. *Isolated ground receptacles:* When installed per National Electric Code Article 250–74, Exception 4, at least two ground conductor paths are required; one for the receptacle ground pin and the other for the receptacle enclosure.

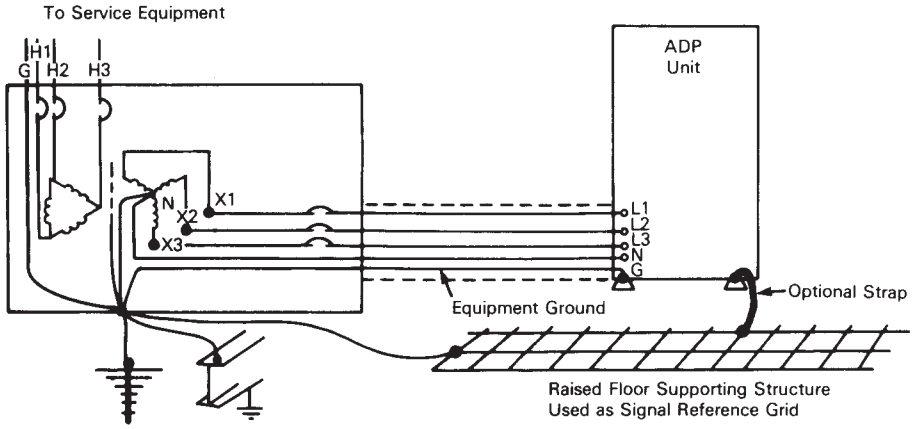


Figure 23. *Grounding ADP units to a grounded reference grid* with optional ground straps can supplement but must never replace equipment ground conductors. Optional ground straps to a suitable signal reference grid are recommended to reduce impulse noise currents in ADP system ground conductors.

It has been stressed that earth electrodes should not be normal paths for ground fault currents in ADP load utilization circuits. However, there may be some sources of ground current in driven earth electrodes associated with the power source. Lightning and switching transients have already been mentioned. In addition, there may be fault sensing and relaying, plus the ground current resulting from multiple ground connections along a current-carrying neutral. Driven earth rods at various points along the neutral will have potential differences between them, thereby providing a source of ground current in these grounds and other grounds which are interconnected with them.

Depending upon the amount of current flowing in a grounding rod, the need for low rod-to-earth effective resistance will vary. If only a few milliamperes are flowing, a 25-ohm ground would most likely be low enough. If many amperes are flowing, it would be important that the heat loss about the grounding rod would not be so great as to dry out the soil and cause the ground resistance to rise. If this occurs or if too much current causes a high voltage drop in the soil around the rod, the back voltage is often rich in electrical noise which is unwanted in ADP sites. The solution is to find and reduce the source of the ground current, if feasible, or add more parallel grounding rods. These should be at least 6 ft from the original driven earthing rod and from each other.

Instrumentation specially designed for measuring the effective resistance of driven earthing rods and buried or concrete-encased conducting grids is available. It should be used rather than ohmmeters or

multimeters for measuring ground resistance of rods and other electrodes in soil or concrete. Where performance is dependent upon good, noise-free ground connections, the grounding rods and the connections to them must be inspected and maintained frequently, typically at no less than 3-month intervals. If there is any dc component to the ground current, deterioration can appear rapidly. The deterioration rate with ac ground current is far less rapid.

Ground interconnections between separately grounded systems (fig. 24) create ground loops. These are undesirable if loops create a path for noise currents to flow where they can enter signal cables in which a grounded conductor is one of the signal conductors as well. This situation often exists in ADP installations where data terminals and remotely located printers are located outside the ADP room.

Even if the remote terminals are located in the same building, they will not be likely to be operated from the same power circuits as those supplying the ADP units. Each of those terminals will be connected to power outlet receptacles on other branch circuits. Each of their equipment ground connections will most likely be attached to the metal enclosure into which each is mounted. The enclosures are connected to conduits which will be attached to building steel and other conduits all along the path to the branch circuit breaker cabinet and to the power source within the building.

Unless the terminal has been designed with double insulation so that its frame need not be grounded with the third "green" wire via the grounding pin, safety considerations demand that the frame of the terminal must be grounded to the same point as that circuit's neutral grounding point. The fact that the terminal and the ADP system are each grounded to separated, but interconnected, grounding points does not prevent noise voltage differences from appearing between them. The installation of a direct interconnection of signal cable, usually a twisted pair with a wrapped foil shield and drain wire, completes a ground loop path. Through the path, differences in ground potential will let noise current flow and intercouple with data signals.

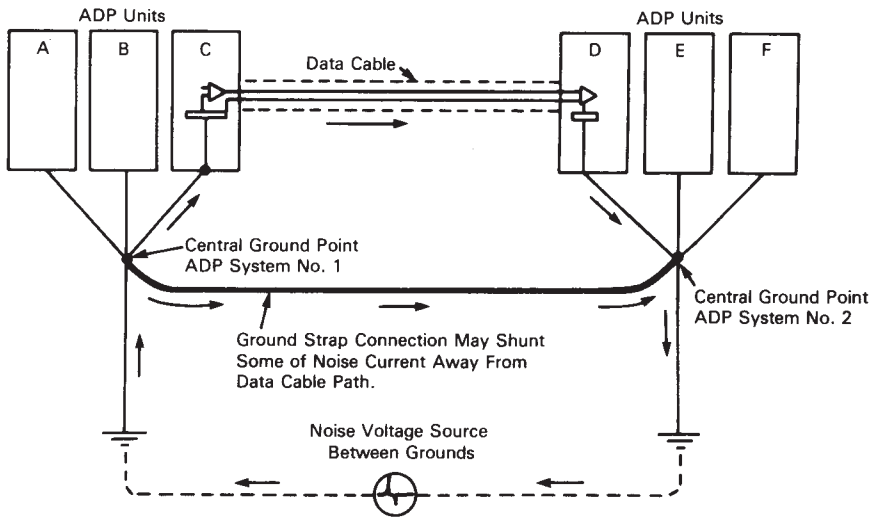


Figure 24. *Multiple separated grounds* can create unwanted ground loops through data cables. Supplementary low impedance ground strap interconnections or a signal reference grid may shunt noise current away from data cable paths C–D as well as C–A and C–B, and D–E, and D–F.

Figure 25 illustrates an example where noise signals between a computer and a remote terminal caused so much corruption of the desired signal that the terminal could not be used. The ground loop is illustrated by the arrows.

Figure 26 illustrates a temporary but effective remedy. An extension cord was used to permit the terminal to obtain its power and ground reference from the same point. This resulted in the creation of what amounts to a single point ground. The terminal performed properly in this configuration.

Figure 27 illustrates a computer user's happy but accidental discovery of one means to reduce the noise current in the ground loop without reducing the signal. The extension cord was wound into a coil and placed under the terminal's table to get it out of the way. When the power was fed through the coiled extension cord, the common mode inductance of the coil reduced the flow of current which went in one

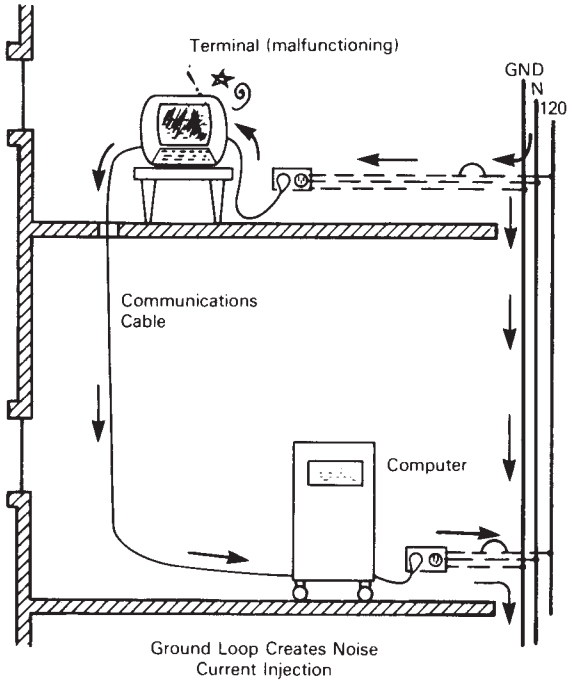


Figure 25. *An unwanted ground loop* is created by grounding two ADP units to separated points on a bus duct ground conductor. The resulting noise current in the data cable creates errors and malfunctions.

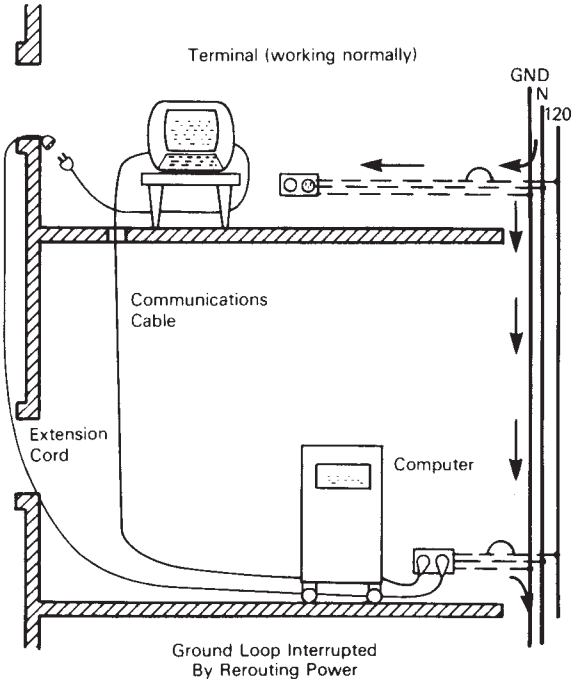


Figure 26. *A temporary solution:* An extension cord provides total system power from one duplex receptacle and avoids creation of a ground loop.

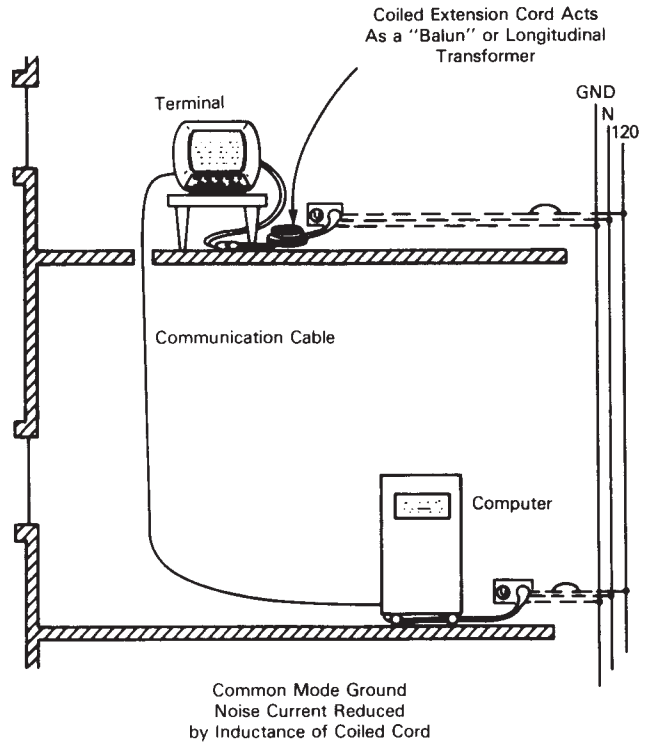


Figure 27. *Increasing ground loop impedance* with a coiled extension cord "Balun" reduces noise current flow.

direction only through the coil, but had a return path elsewhere. As for the power flowing in the extension cord to supply the terminal, the current through the phase conductor and the return current through the neutral conductor were equal and in opposite directions at all times. Their inductive effects cancelled each other and had no adverse effect upon the flow of power through the extension cord. Yet the common mode noise ground loop path was sufficiently restricted that it allowed the terminal to operate in spite of the ground noise voltage differences which were present.

A similar result could have been achieved by using a longitudinal coil called a "balun" in the data signal circuit (fig. 28). It serves the same function as the coiled extension cord, but requires less space and need only pass milliamperes of signal current rather than amperes of line current. A small inductor of this type can be built into the power and communications interfaces of terminals which may be used at remote locations. Similarly, the data communications ports of the ADP system may need common mode suppression by this or other means which achieve the same end result.

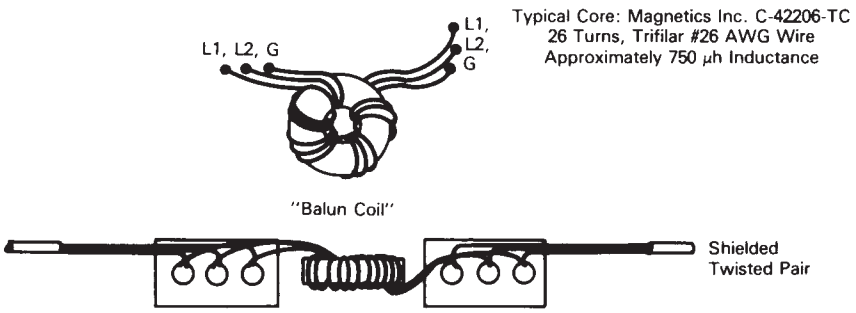


Figure 28. *A data line balun* may be a more practical way to reduce common mode ground loop noise current than the coiled power cord shown in figure 27.

Known techniques which address this problem of breaking up ground loop current paths include the following:

*(a) Single point ground (not feasible at very high frequencies or large distances).
*(b) Baluns (described above and effective only in some frequency ranges).
*(c) Modems (normally used as interfaces with telephone circuits).
*(d) Fiber optic transmission over completely nonconducting paths (new technology).
(e) Optical isolators (requires skill in shielding input from output circuits).
(f) Differential amplifiers with high impedance inputs (technically complex).
(g) Isolating transformers in signal circuit (will not pass dc levels).
*(h) Isolating transformers in power circuits (safety ground reestablishes loop).
*(i) Interface devices which limit surge voltages and currents due to lightning or switching surges in addition to providing some common mode isolation.

*(Note: The techniques designated by an asterisk can be incorporated as original installation or site improvement projects. The others require incorporation into products.)

3.3 High-Frequency Effects on Grounding Conductors

Avoiding resonances at radio frequencies has become increasingly important as the frequencies of digital signal circuits have increased beyond the 3–10-MHz clock pulse repetition rate.

Resonance in electrically conducting members is related to the velocity of propagation of electric signals in the conductors and the repetition rate of a series of signals. Electric disturbances travel at 186,000 miles per second in vacuum, slightly slower in conductors. While this is very impressive, a voltage wave will travel a far less impressive distance of 98 ft in free space during one cycle of a 10-MHz clock signal in a modern computer. In a grounding conductor, it may travel only 88 ft in 1/10th of a microsecond.

If a conductor is continuous for only 88 ft, the voltage wave will reflect from the open end and arrive back at the beginning at the same instant that another cycle arrives. If the arriving new wave and the reflected wave are in phase, resonance will occur and line oscillations will be greatly magnified. This is the principle of tuning a radio transmitting tower or antenna for maximum resonance and maximum radiation. This example is at 10 MHz.

Figure 29 illustrates the effect on the impedance of conductors at resonant and antiresonant frequencies. Antiresonance is where the reflected wave is out of phase with the arriving new wave. If one end of the conductor is grounded, the first resonance at 10 MHz occurs when the conductor is only 22 ft long or 1/4 wave length. The grounded end is at maximum current flow while the open end is at maximum voltage and zero current. At this frequency, such a ground conductor appears to be virtually an open circuit or at least a very high impedance. It is incapable of equalizing the voltages appearing between its ends.

At frequencies slightly below and above resonance, the partial resonance still increases the impedance so that it is ineffective as a constant potential conductor such as needed as a ground reference. Good engineering practice decrees that a conductor any longer than 1/20th of a wavelength cannot be counted upon to equalize voltages between its ends. This amounts to only 4.4 ft at 10 MHz.

The significance of this is that unless conductors can be limited to less than 4–5 ft in length, conventional grounding techniques with single point grounds may not be effective for signal and noise frequencies up to 10 MHz. At higher frequencies and longer length of conductors, other techniques are needed to avoid resonances.

At high frequencies, signal lines are often terminated in their characteristic surge impedance to kill most of the reflection and resonance. However, single ground conductors can no longer provide a virtual short circuit between one end and the other at the high frequency portion of a broad frequency range.

The use of multipoint grounding and short conductors appear to be the most reliable and simple methods for coping with signals over 10 MHz in frequency. With bypass capacitors instead of bonded straps to "ground" placed at strategic points, it is possible to make a conductor shield appear to be grounded at frequencies where those capacitors appear to have very low impedance. At low frequencies, they carry negligible current, so the same system may have the characteristics of a single point ground at power frequencies and other low frequencies. This raises the question of what should be used for the "ground" to which bonding straps or bypass capacitors should be connected?

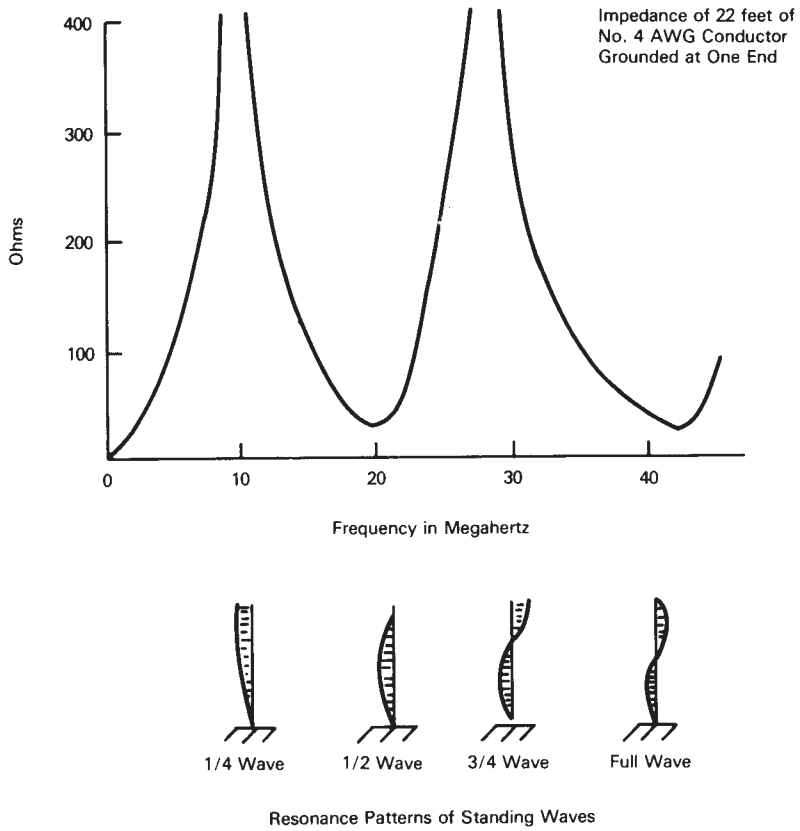


Figure 29. *Resonance characteristics of conductors:* These are typical of grounding conductors used in ADP systems, although lengths and natural frequencies will vary.

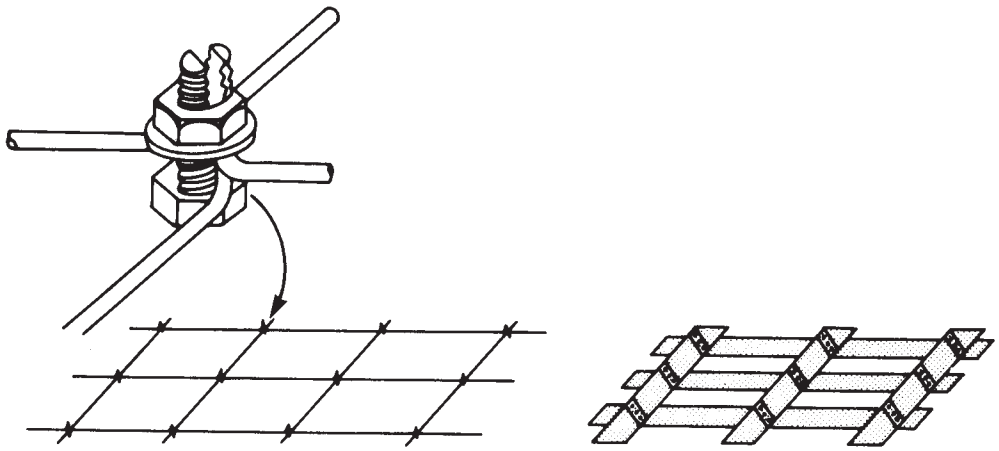
Signal reference grids can be to ADP rooms what the metal chassis is to a radio or television set. Both serve as signal reference planes of constant potential over a very broad band of frequencies. A grid provides multiple parallel conducting paths between its parts. If one path is a high impedance path because of full or partial resonance, other paths of different lengths will be able to provide a lower impedance path.

A signal reference grid could be constructed of continuous sheet copper or aluminum, zinc-plated steel, or any number of pure or composite metals with good surface conductivity. However, this type of construction would not only be expensive but also difficult to install in a computer room where other services have already been or are about to be installed.

Experience has demonstrated that a grid of conductors on approximately 2-ft centers provides a satisfactory constant potential reference network over a very broad range of frequencies from dc to well above 30 MHz [13,15,23,29]. Typically these have been formed of #4 AWG copper or aluminum conductors, which have been electrically joined at their intersections, or by copper straps some 0.010 in thick by 3–4 in wide, also joined at their intersections. These grids typically lie directly upon the subfloor under the ADP room raised floor. Cables and conduits under the floor would normally lie below the raised floor but above the grid. Figure 30 shows a grid consisting of discrete conductors.

An alternative which appears to be equally effective and less expensive to install is the use of the raised floor supporting structure to serve as a signal reference grid. The two essential requirements are (1) bolted-down stringers (the lateral supporting braces installed between supporting pedestals), and (2) suitably plated (tin or zinc) members so that low resistance pressure connections can be made. (See fig. 31.)

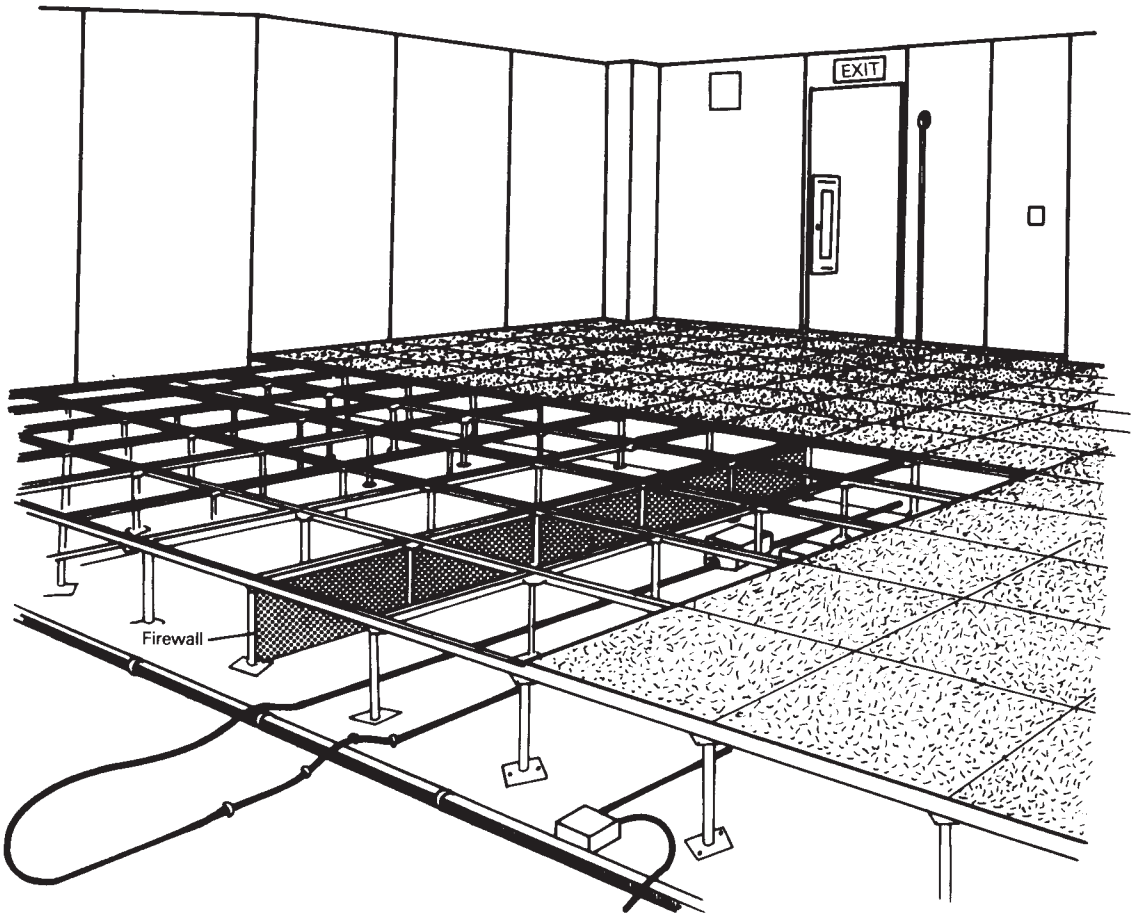
There are some stringerless supporting structures marketed in which the removable floor tiles lock onto the supports by gravity, but it has not been demonstrated that the contact has a low enough resistance and is free from intermittent contact as people or loads are moved across the floor. The bolted down horizontal stringers (braces) with pressure type spring washers or spring in the assembly have been shown to be highly suitable for this purpose.



No. 4 AWG Copper Conductors.
Intersections Clamped with Connectors
GOOD

0.010" x 4" Copper Straps
Bolted or Soldered Together
BETTER

Figure 30. *Signal reference grid:* Installed under a raised floor, the grid typically lies on the subfloor. One popular option is conductors on 2-ft centers, one under each row of removable floor panels of a raised floor.



Raised Floor Supporting Structure as a Signal Reference Grid

1. Bolted Down Stringers (struts between supporting posts) assure low electrical resistance joints.
2. Isolation from building steel except via computer system grounding conductors, conductor to computer systems central grounding point and to power source ground.
3. Ideal floor height for crawling access is 30 inches. Less than 18" restricts air flow. For large computer rooms, install firewall separation barriers to confine fire and Halon extinguishing gas.

Figure 31. *Raised floor as a signal reference grid.*

Experience shows it unnecessary that the lift-out floor panels make a low resistance contact with the supporting network of stringers. It is sufficient that the plastic or synthetic rubber cushions or molded edging upon which the panel resets be sufficiently conducting to drain static electricity from the panel if any should accumulate. A resistance as high as 20,000 megohms under 20% relative humidity will satisfy this requirement.

The removable panels may be of metal or may have a plywood core; however, the lower surface of each panel must have metal cladding to satisfy flammability resistance requirements. When these metal or metal clad panels are placed into the raised floor openings to form a raised floor, their presence supplies damping to the electrical resonances which would otherwise occur at the radio frequency where the 2-ft-long members enter their lowest frequency resonance mode.

Once a signal reference grid has been established in an ADP room as indicated in figures 32 a and b, the various ADP units can each be connected to that grid by flexible flat braided copper straps. The connection should be made from each ADP unit, preferably at a point near its identified safety ground connection, to the nearest intersection of the reference grid. The strap should be no longer than necessary, and should have few bends and very little loop or sag to minimize the impedance at high frequency. Typical reduction in overall grounding impedance by use of a signal reference grid is illustrated in figure 32 c.

If the computer hardware manufacturer does not subscribe to the notion that ADP units should have these multiple connections to a reference grid, the stray capacitance between each ADP cabinet and the raised floor reference grid will still help reduce voltage differences between grounded parts of the ADP system.

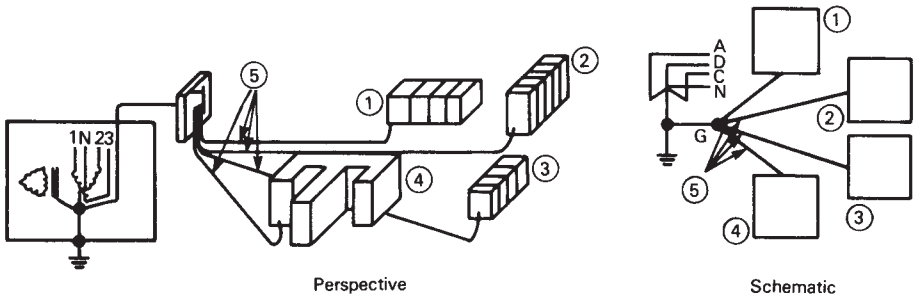
The effectiveness of the reference grid is further enhanced if it is connected solidly to the ADP system's central grounding point by a very short strap. This can be accomplished by installing one or more isolating transformers or modular power center peripherals in the computer room, each being placed conveniently close to the loads which are to be served, particularly those ADP loads which transmit or receive the highest frequency data signals. Loads consisting primarily of small motors and no high performance digital circuitry (computer room air handlers, for example) need not be close nor have short leads. The isolating transformer in each load center will have a secondary output winding that is grounded to the signal reference grid as well as to all other ground points required by electrical safety codes. The ac voltage output to the ADP units will thereby be isolated from outside sources of disturbance, and closely connected to the reference grid and to the loads by conductors too short to cause any resonance problems or to pick up other disturbances by induction.

If more than one power transformer or modular power center is used in the ADP room, the signal reference grid will be a sufficiently low impedance broadband interconnection to intertie their respective output circuit grounding conductors. The supporting structure for the floor with its multiple electrical paths prevents significant voltage differences from arising between them. Typical construction is illustrated in figure 33.

It is important, however, to adhere to the principle that the signal reference grid is not a substitute for any safety ground prescribed by code. It is used in addition as an overlay upon the safety conductors and their required routings and connections. The term "grounding grid" was used until someone pointed out that all ground conductors (safety grounds required by code) were required to be put in conduits. The term "signal reference grid" is a more appropriate description of its function. The grid should be grounded for safety, just as all other conducting members near electrical conductors should be grounded. The conductor which grounds the grid at some convenient point to a ground bus in a branch circuit distribution circuit breaker cabinet should be a green wire, enclosed in conduit and be of a conductor size appropriate to the largest phase conductor ampacity (ampere capacity) to be brought into the ADP room.

Transient suppression plates, often called transient traps, have been used to control and limit the appearance of noise voltage differences between the ADP system ground and the reinforcing within concrete which may underlie the subfloor. If the reinforcing should be energized with high frequency electrical noise voltages or currents, the ADP data and power cables lying upon the subfloor would be subjected to coupling by capacitive and magnetic means. The transient suppression plate provides a controlled bypass between the reinforcing steel and the electrical ground conductors at or near the point or points of power entry into the computer room. This is illustrated in figures 34 and 36.

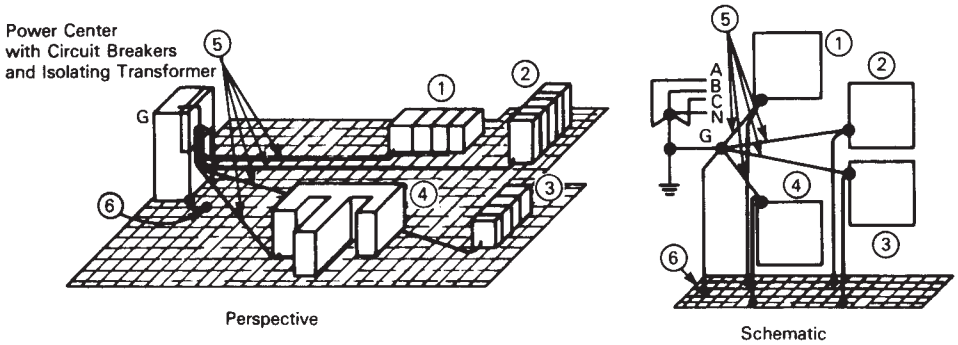
Single point vs multipoint grounding has been discussed in theory. However, grounding practice is seldom like the theory. Many unintentional ground connections not discussed in theory do appear in practice. The symbols in figure 35 will be used in diagrams to identify these often overlooked ground paths.



Perspective Schematic

Computer Conductors Subject to High Frequency Resonance with RF Signals

A



Perspective Schematic

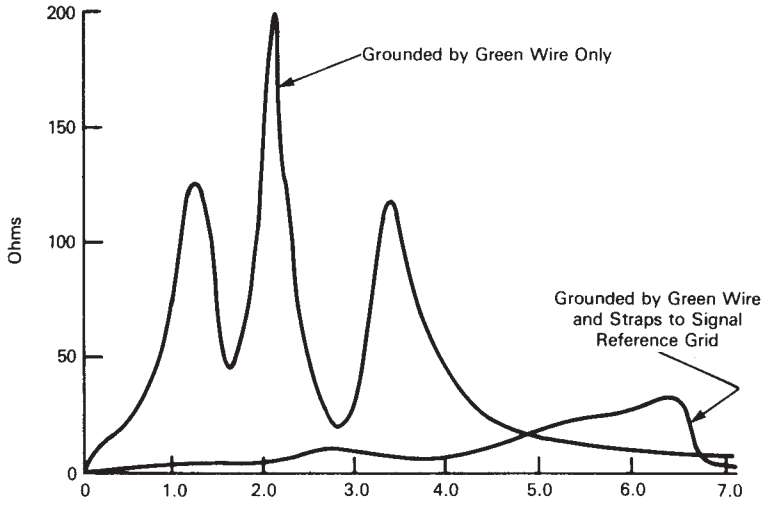
Computer Units Connected to Signal Reference Grid and to A-C Ground

(1) through (4) are typical computer system modules.

(5) is the "Green Wire" safety equipment ground conductor.

(6) is safety ground for raised floor structure.

B



Resonance of Power Equipment Ground Conductors in Typical Site

C

Figure 32. *Signal reference grids reduce resonances:* (a) computer conductors subject to high-frequency resonance with RF signals; (b) computer units connected to signal reference ground and ac power source ground; (c) resonance of power equipment ground conductors in typical site.

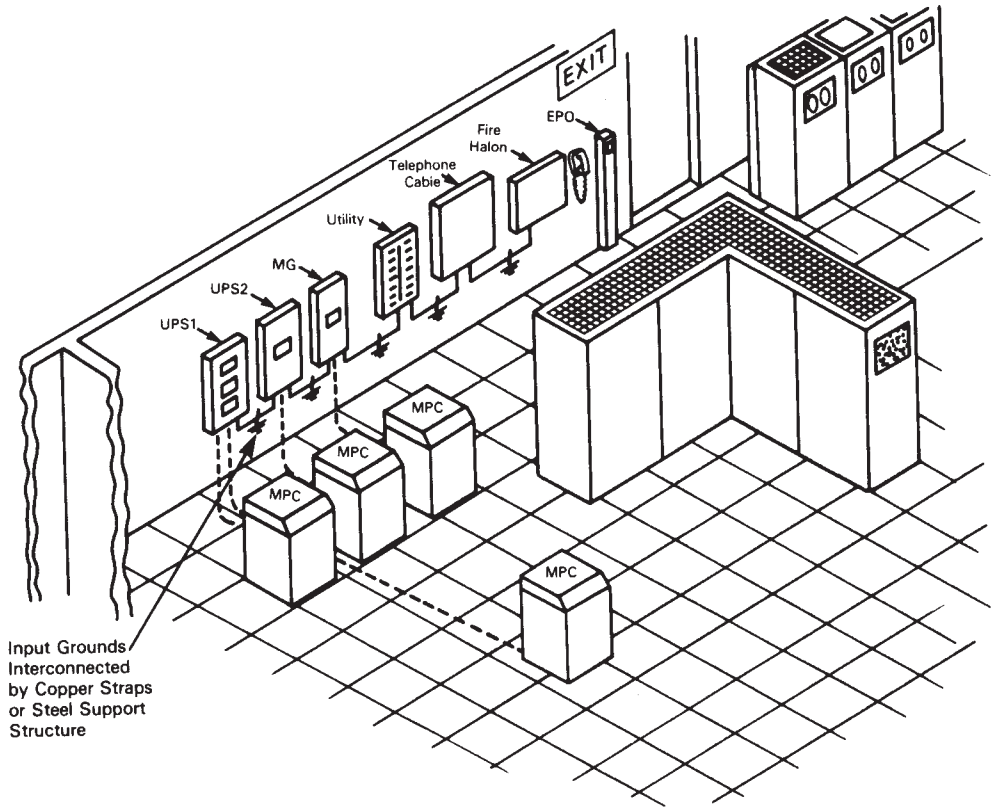


Figure 33. *Multiple modular power centers (MPC's):* Output grounding points may be interconnected via short interconnecting cables or by straps to the same signal reference grid. This maintains low-voltage differences between their ground reference points and approaches a single grounding potential for all ADP loads regardless of upstream power source grounding points (utility, m-g set, diesel generator, regulator or UPS).

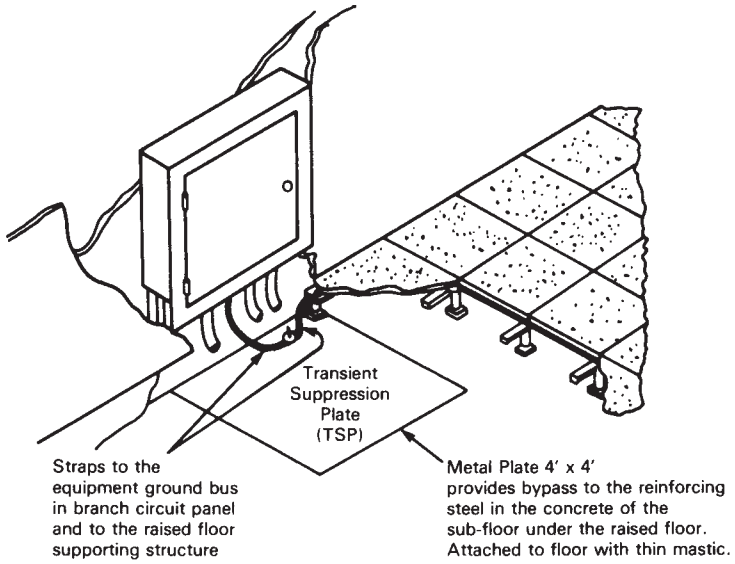


Figure 34. *A transient suppression plate* reduces noise currents which might otherwise be coupled into underfloor data cables from subfloor reinforcing steel.

(a) Connection (Intentional) to "Earthed" Electrode, Metal Mass, etc.

(b) Connection (Intentional) to Electrically Conductive Conduit, Raceway, Enclosure, etc.

(c) Connection (Unintentional) to Both "Earthed" Items and to Electrically Conductive Conduit, Raceway, Enclosures, etc. Along Their Associated Lengths, Perimiters, etc.

(d) Conduit (Metallic) Containing Multiple Conductors (2 to 5, typ.) and Showing Unintentional Connection(s) at Random Points Throughout its Length, to Other Enclosures, Conduits and "Earthed" Items.

Figure 35. *Symbols* which appear in schematic and pictorial diagrams.

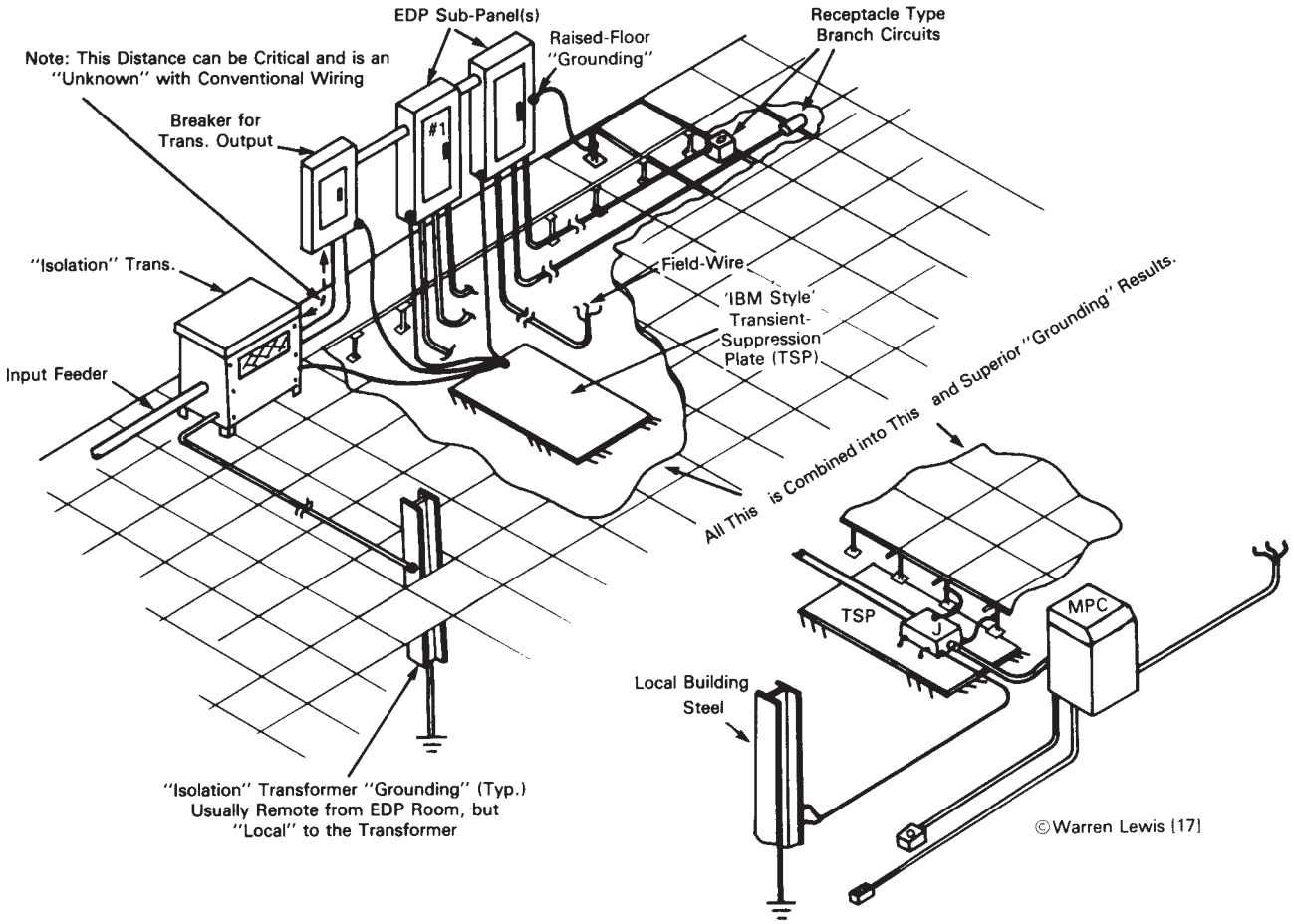


Figure 36. *Transient Suppression Plate (TSP) installation details.*

As shown in figures 37 and 38, the wiring system in a building with a large ADP installation will have many conductors and circuits, all of which will be in conduits, wireways, or in some cases in cable troughs. There may be freon pipes, chilled water pipes, sprinkler pipes, Halon systems, compressed air tubing for thermostat controls, and others in addition to air ducts and building steel structural members.

These may be hung by wire or straps from the ceiling, sometimes above a drop room ceiling. Others may rest upon or be propped up slightly above the subfloor. They often penetrate the computer room and may be in walls and partitions around the ADP room. Many of these conductive conduits, pipes, ducts, and structural members will be electrically interconnected at multiple points where they share the same hangers and clamp tie-down strips.

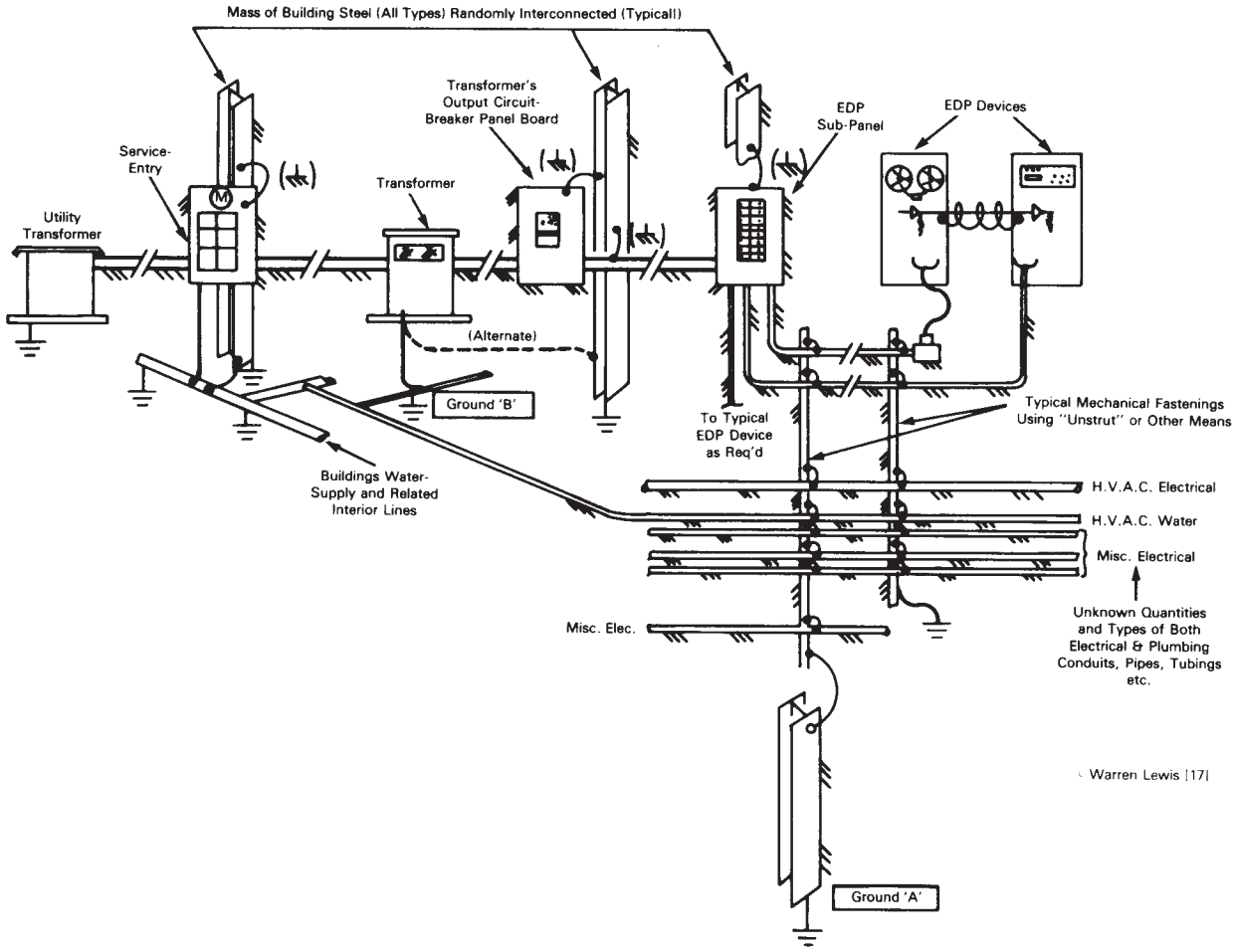


Figure 37. *Ground loops* are impractical to prevent in normal electrical construction.

With these conditions, it is difficult to claim that the computer room has been designed as a "Faraday cage" (shielded room) because of the many foreign conductive members which penetrate it. Refrigerant cooling pipes or copper tubes are often connected to roof mounted condensers or heat exchangers. Another name for this arrangement might be "lightning rod" with conductors directly to the ADP room.

It is virtually impossible to enclose power, communications, and other conductors in a conduit and have electrical noise voltages and currents on that conduit without coupling to the conductors contained within it. For this reason, it is possible to make a great improvement if some control can be exercised over all conducting members which penetrate the ADP room or which are run nearby. A single point of entry (previously illustrated in fig. 18) makes it possible to equalize the voltage differences without having the resulting current conducted throughout the ADP room.

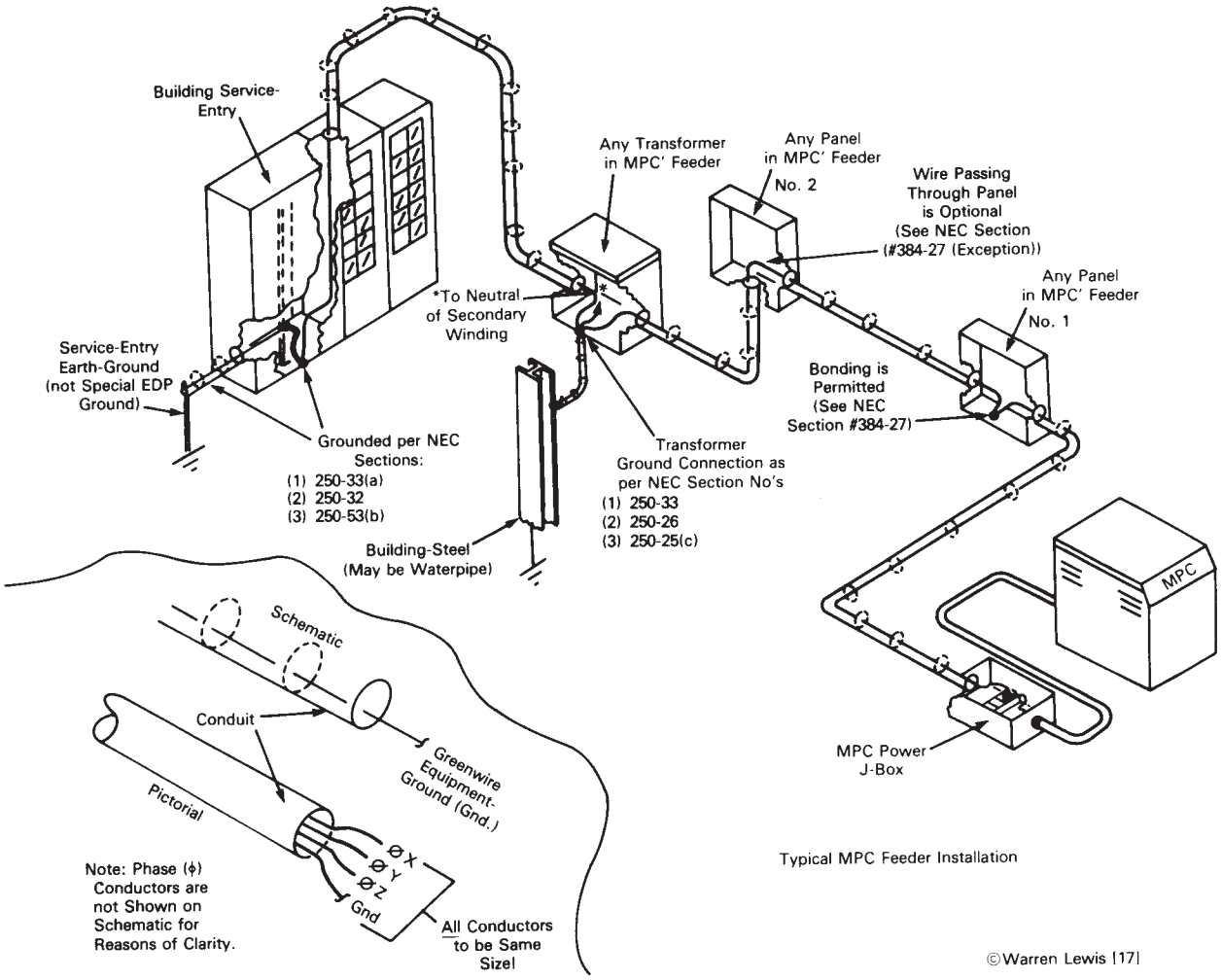


Figure 38. *A typical modular power center (MCP) feeder installation.*

Finally, it is easier to isolate the incoming power if the isolating transformer is on the load side of the single entry point. Tests have shown that the signal reference grids of proper design are capable of equalizing voltage differences and handling considerable noise currents without injecting excessive noise into digital circuits of the ADP systems. However, this may be asking too much of the reference grid and should not be practiced as a planned approach.

If single ground point strategy is to be followed, this may be possible within the ADP room, but as soon as circuits leave the room, they must be considered to be grounded at multiple points and be sources of ground loop noise currents.

It may be possible to retain the characteristics of a single point ground for the shielded conductors by using double shielded signal conductors or by running shielded cable with an outside insulating jacket through conduit. However, the outer shield or conduit may become a multipoint ground, whether or not it is desired.

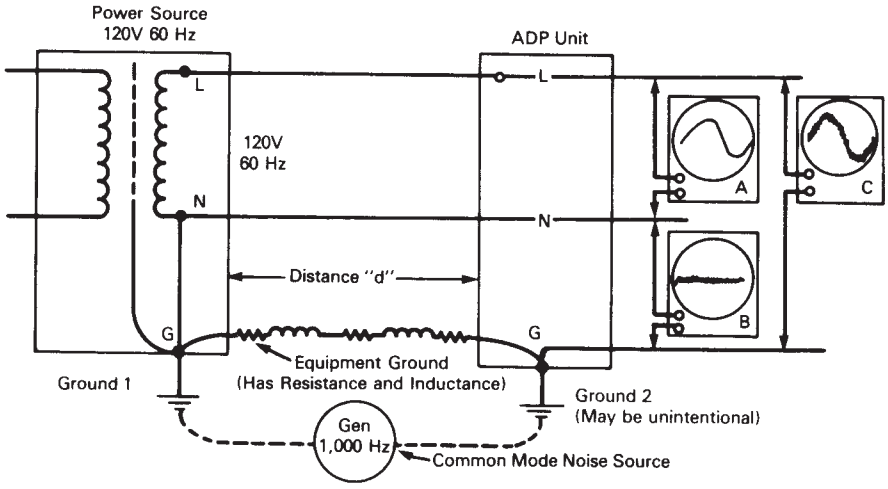
4. POWER CONDITIONERS: WHAT THEY DO; WHEN AND WHERE TO USE THEM

4.1 Filters

Filters which pass basic power frequency and reject electrical noise and unwanted harmonics in the line voltage are feasible, but are not particularly popular. This may be because of their expense and because of the many opportunities for them to create more problems than they solve. They require applicational skill.

Noise and unwanted harmonics appear in the form of line-to-line and line-to-neutral voltage signals (normal mode), and also as noise voltages between the local ground reference point and each of the power conductors including neutral and sometimes equipment ground (common mode) as illustrated in figure 39. Typically, the unwanted noise includes radio frequency signals and fast rise-time impulses. A low-pass filter will therefore pass the 60-Hz power and its low order harmonics needed to operate an ADP unit's power conversion equipment, but will attenuate the high frequencies which interfere with logic circuits and do little if anything to provide power. Such filters typically have individual inductors in series with each power wire and shunt capacitors between power conductors and from each power conductor (including neutral) and the ADP unit's conducting enclosure.

The conducting enclosure is required to be grounded, using an equipment ground conductor for reasons of safety. However, this conductor often creates a path for common noise currents to flow in a loop circuit, starting with the equipment ground conductor's connection to a grounded conduit which becomes a source or a sink for noise currents which may be generated in the total electrical premises wiring or in the ADP load. Part of that ground loop may be the shield or the grounded wire of a conductor pair used for digital signals. Any noise current flowing in that ground loop can create noise in logic signal conductors by electromagnetic coupling or direct connection and stray capacitance. Such noise voltages and currents are associated with the voltage differences which appear throughout a large interconnected system of grounding conductors.



Equipment Ground Conductors are typically in conduit with power conductors.
Separate Ground Conductors (Ground 1 and possibly 2) are typically in steel conduit which is bonded at both ends to the ground conductor to provide lowest impedance.

Example with 1,000 Hz Noise with Equipment Ground Removed:
Oscilloscope A = Normal Mode at 120V 60 Hz.
Oscilloscope B = Commom Mode Noise at 1,000 Hz.
Oscilloscope C = Normal and Common Mode Added Together.

To Reduce Common Mode Voltage at ADP Unit:
1) Disconnect One of the Grounds (Safety Rule Prevents Disconnecting #1).
2) Lower Impedance of Equipment Ground Conductor (Make it larger).
3) Shorten Distance "d".
4) Find and Eliminate Noise Source.
5) Add a Common Mode Filter Section to ADP Input Filter.

Figure 39. *Common mode noise:* This is the noise signal which appears equally and in phase from each conductor to the ADP system's "ground reference point."

It may be impossible to eliminate the common mode noise voltages, but it is possible to exert some control on where they will occur and the noise current paths which might result. Figure 40 illustrates a form of common mode filter, also known as a "balun." It passes the flow of normal mode current without significant voltage drop because the power conductors, wound on a common core, are wound in opposition. Load current does not saturate the core.

On the other hand, any high frequency noise or impulse appearing between the equipment ground conductor on the left of figure 40 and the ADP enclosure or frame on the right would find the connection through the filter to be a high impedance connection. The ground voltage offset would appear across this coil where it would do no harm. Almost identical voltages would also appear across the neutral and line conductor coils, thereby offsetting their voltage to equipment ground by the same amount as the frame to ground offset.

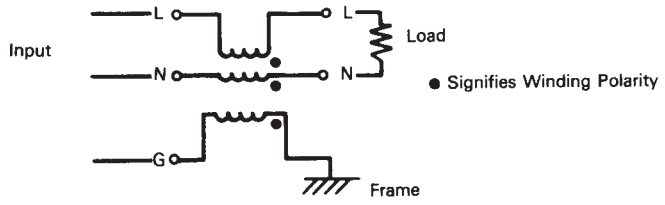


Figure 40. *Common mode filter:* Some ADP units contain one or more common mode line filter sections. The grounding conductor winding must pass sufficient current to operate circuit breakers or fuses for reasons of safety. All coils are wound on a common core.

The total inductance in the ground path is typically less than 750 microhenrys which at 60 Hz is less than 0.3 ohms. This offers no shock hazard if it has sufficient ampacity (ampere capacity) to pass fault current safely until overcurrent devices can disconnect the power source. At 10 MHz, the series impedance is greater than 40,000 ohms which effectively attenuates any ground loop current which might try to flow through that path.

ADP units susceptible to electrical noise or which create it almost always contain line filters. When the ADP unit must have direct connected digital signal cable connections with other units, it is sometimes supplied with a composite line filter which will attenuate both normal and common mode noise voltages and currents. When users of ADP attempt to assemble and interconnect units supplied by different manufacturers and operate them as an interconnected system, they may find that none of the units have the total amount of filtering needed to prevent common mode ground loop current problems. In such cases, supplementary filters may be needed.

To operate properly without interaction, filters are typically designed to operate effectively when the input and output impedances are matched to the respective impedances of the power source and the load. These are not always constant, so practical filters must often be a compromise. The result is often unwanted "ringing" or line voltage distortion at some frequency other than the disturbance frequency which the filter is intended to correct.

Filters are sometimes necessary to correct severe harmonic distortion from a small power source such as an uninterruptible power source inverter circuit. The more usual and generally effective filters are low-pass filters which remove high frequency normal mode electrical noise. However, equally effective in most cases is the use of a transformer having suitable leakage reactance and capacitors across output windings to perform several functions simultaneously. These are voltage transformation, tap adjustment, common mode isolation, and substantial high frequency noise attenuation. This is described under transformers.

4.2 Line Voltage Regulators

Line voltage regulators are a solution to line voltage regulation exceeding the capability of the self-contained voltage regulators in most ADP units. They are available in units which use various operating principles, each having some advantages and disadvantages. Unless combined with a transformer with separate input and output windings, many regulators do not establish a new output voltage with its own ground reference. Instead, most regulators act as autotransformers to buck or boost the input line voltage, but the ground reference of the output is to the same input neutral and its upstream grounding point.

The motor operated variable ratio transformer (fig. 41) is a slow but generally reliable regulator. It is excellent for keeping ADP input voltages generally within their optimum operating voltage input range so their regulators can best handle faster voltage variations. They are generally able to follow the steady rise and fall of line voltages which vary as public use increases or decreases the drain over daily and seasonal use.

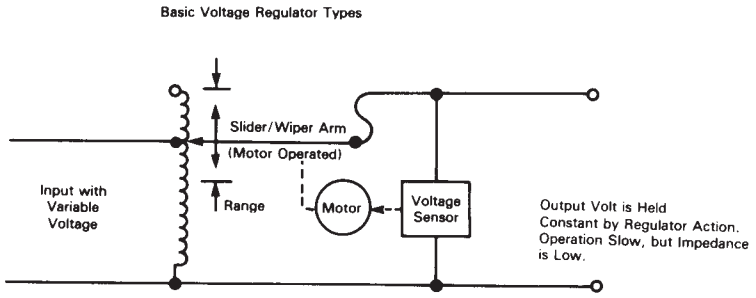


Figure 41. *Line voltage regulators:* The variable ratio motor-operated auto-transformer.

There is little chance that the slow rate of change will create an instability through interaction with the faster regulators in the ADP load units. When regulators are used to supply power to other regulators having similar response times, the combination can become unstable and the two sets can behave as a "flip-flop," with one going high while the other goes low. Severe variations may occur in the final regulated voltage if any exceed their regulating range.

Efficiency is normally very good, approaching that of a good transformer. The internal impedance can also be low, resulting in excellent capability to supply sudden increases or decreases in load current without creating excessive momentary under and over voltages. Because of low internal impedance, the need for fast response may not be required.

Disadvantages are mostly related to the maximum current ratings which are feasible with moving brushes, the losses and heating at the brushes, and the possibility of some maintenance. At least one vendor uses copper-to-copper wiping contacts and absorbs voltage differences by semiconductor diodes in order to reduce brush power loss and heating, and to enable products to be made in larger kVA ratings.

Rototrol or induction regulators (fig. 42) are constructed like a three-phase induction motor with a three-phase wound rotor winding. The rotor is not permitted to rotate as a motor, but its position may be rotated by a hand or motor operated worm gear. The induced voltage in the rotor windings shift their phase as the shaft is turned, adding to or subtracting from the line voltage as required.

Like the variable ratio transformer it is slow, but it has no brushes and requires little maintenance. The induction regulator has higher inductive reactance and is slightly less efficient than the variable ratio transformer; otherwise it is similar.

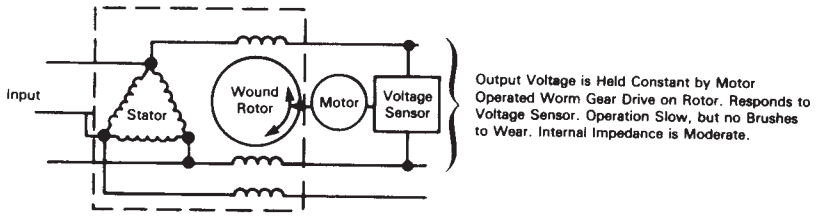


Figure 42. *Line voltage regulators:* The induction regulator contains a wound rotor, the angular position of which is varied inside of a wound stator by a motor-operated worm gear drive for stepless buck-boost voltage control.

Ferroresonant transformers (fig. 43) have the characteristics of a transformer in that output windings can be separated from input windings for common mode isolation and there can be transformation from one voltage to another. In its basic form, it is essentially a single-phase device. Voltage output is fixed by the size of the core which saturates each half cycle and by the number of turns. It is determined at the time of manufacture and cannot be adjusted. The secondary circuit resonance depends upon capacitors to work with the saturating inductance of the device to keep the resonance active.

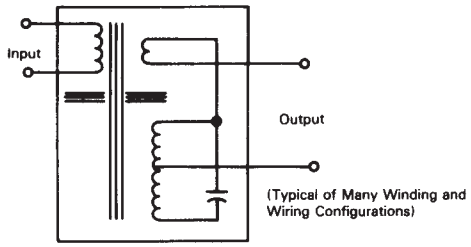


Figure 43. *Line voltage regulators:* The ferroresonant transformer is self-regulating, using only saturating magnetic and nonsaturating capacitive elements to control output voltage. It is uncomplicated, but somewhat limited in momentary and steady overload output current capability. It is sensitive to line frequency variations, and creates a variable phase shift as it regulates.

Load currents tend to demagnetize the core, so output current is limited automatically. Typically a "ferro" cannot put out more than 125–150% of its full load rated output without going into a current limiting mode. Such transformers cannot support normal starting loads of motors without a drastic dip in output voltage. If more than 150% of rated output current is needed to start the motor, it may never start.

When the output is at no load, full load, or at overload, there is little change in input current. At light loads, the ferro will have very poor efficiency, so they are usually designed and selected to operate at no less than 80% of full load; at the same time, they cannot supply significant overloads without voltage dips and the risk of voltage collapse.

The advantages of the ferro are simplicity, lack of moving parts, lack of solid state semiconductors to fail, high reliability, and the ability to regulate output over a wide range of input voltages, but limited range of output load currents. There are no adjustments to be made or changed. Output can be square wave or sine wave voltage, depending upon design.

The ferro also has disadvantages. Among these are high losses at partial loads, moderate losses at rated load, and a limited overload capability. Fuse protection is ineffective because currents under no load, full load, and short-circuited output do not vary enough to cause protection to operate selectively. Some have excessive heat and audible noise.

Three-phase versions consisting of single-phase units connected in delta-delta, delta-wye, or wye-wye can be unstable under many conditions, especially with unbalance loads on the phases. Some three-phase configurations have been demonstrated to be stable with zigzag and other special winding configurations.

Ferroresonant transformers have been used extensively in the past in ADP units, but are generally being replaced in newer products by switching type regulated power supplies. If a ferroresonant line voltage regulator were to be placed ahead of another similar unit within an ADP product, the combination of the external and internal regulators could become unstable and oscillate.

Some ferroresonant transformers produce transients during momentary start-up, momentary line voltage interruption, and significant drop in load current. Unless the characteristics are well known, surge protection on load devices may be advisable. Response times to line and load changes can be variable.

If the ferroresonant transformer is not supplied with an input having a constant frequency, the regulated output will usually vary, typically 1.5% for each 1% of line frequency change. This applies only to a range of about ±3%.

Although the above characteristics are typical of ferroresonant transformers as a class, individual designs can vary significantly.

Magnetic coupling controlled voltage regulators (fig. 44) are available in which a direct current control winding controls the saturation in parts of a special transformer structure. This, in turn, controls the ac flux paths through boost or buck coils to raise or lower output voltage in response to an electronic regulator circuit's dc output current.

Since the regulators are all solid state, there is no mechanical maintenance. Changes are smooth. Although the typical response time of 5–10 cycles is too slow to prevent surges and sags from reaching the load, it is much faster than electromechanical regulators. As with any other regulator placed ahead of another regulator, there is the danger of unstable interaction if the regulator in the load and the regulator in the line have comparable response time delays.

The internal inpedance of these regulators is greater than isolating transformers which are commonly used.

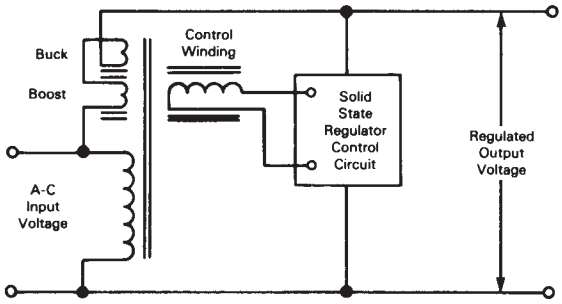


Figure 44. *Line voltage regulators:* The electronic magnetic regulator uses electronic circuits to sense output voltage and to control buck-boost action through magnetic saturation control windings. Dynamic internal impedance is typically high and response time may be 3–6 cycles duration or longer.

Tap switching regulators (fig. 45) are available which dynamically select a transformer voltage tap on a cycle-by-cycle basis in response to the changes in load as well as line voltage. This is accomplished by silicon-controlled switches which are timed to switch at the moment alternating line voltage or current passes through zero. Steps can be course or fine, but are typically 2–3%, well within the capability of the load's internal regulator to complete the regulation process if needed. However, these steps are sufficiently close together that loads will need no further regulation.

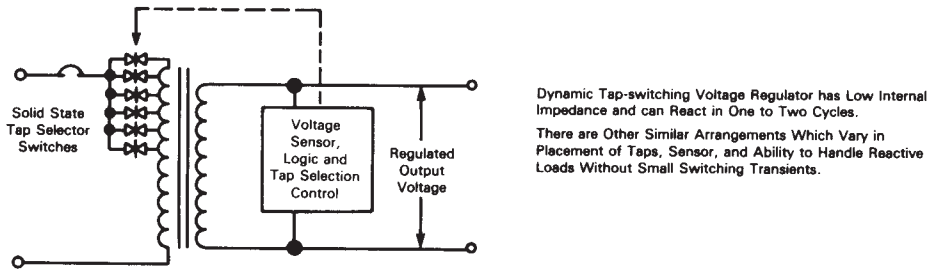


Figure 45. *Line voltage adjusters:* Dynamic tap-selecting electronic switch changes taps to keep output voltage within an acceptable range. It has the high efficiency, low internal impedance and overload capability of a good transformer. Some units are supplemented with surge limiters and filters.

These tap switching regulators create no objectionable switching transients in unity power factor loads where the current and voltage are in phase. For low power factor loads where the load current is not in phase with the voltage, some regulators of this type which switch at zero voltage create a small but observable transient in the output voltage wave at the moment the current is switched. This does not normally affect most loads adversely, but it is worth checking before installing this type of regulator. Switching at zero current avoids this problem.

These regulators offer the advantages of low internal impedance (similar to a transformer), high efficiency from full load to 25% or less, rapid response time (one to three cycles), and low acoustic noise levels. However, among their disadvantages, changes occur in steps rather than appearing to be continuously variable, vulnerability to SCR breakdown under exposure to large surge voltages, and a small switching transient under some low power factor load conditions (in zero voltage switching).

Capacitor bank switching for voltage control (fig. 46) is sometimes commonly used by public utilities at or near the end of long distribution lines to compensate for line drop during heavy loads. This practice creates large voltage transients when they are switched onto or off the line, giving very fast rise-time impulses. These are notorious for the ADP system problems which they cause.

As described under power factor and its control, the capacitors will draw leading phase angle load current and counteract the lagging currents from inductive loads which cause line voltage to drop under

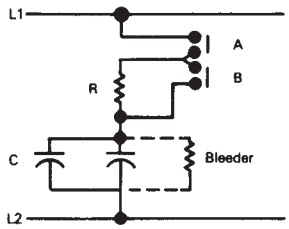


Figure 46. *Power factor capacitor switching:* This is usually done by public utilities to control line voltage. Switching operations create severe line transients if preinsertion resistors are not used by the utility when capacitor banks are turned on.

load. Such capacitor banks can be beneficial in other ways such as improving power factor of inductive loads, helping to filter out high frequency harmonics and noise, and lowering impedance of the line to accommodate high inrush current demands of very short duration.

These can be a worthwhile line conditioning element if the capacitors can be left on the ac line at all times. However, this advantage can become a liability if the operating procedures permit or require them to be switched by time clock, in response to line voltage or any other criterion. The use of "soft-start" resistors allows the capacitors to charge slowly in milliseconds rather than rapidly in microseconds before being connected solidly to the line. This can be installed by the utility company through use of appropriate switchgear if someone is sufficiently insistent. It is slightly more complex and more expensive than the normal brute force switching, but can greatly reduce the severe disturbances which so often adversely affect ADP systems.

4.3 Isolating Transformers (fig.17)

These have two basic functions: (1) transformation of voltage to the final utilization voltage and (2) provision of common mode shielding between separated primary and secondary circuits. Among secondary benefits, they limit output fault current to approximately 20 times the transformer's rated output current to protect smaller downstream circuit breakers from excessive fault current without the need for additional current limiting fuses. Three-phase delta-wye connected transformers also improve power factor when they supply power to rectifier loads because third harmonics and their multiples are not passed on to the upstream power source.

While isolating transformers do not provide any voltage regulation, they do not create a significant internal voltage drop which would make it necessary to have an output voltage regulator in most applications. No useful energy is stored in an isolating transformer, so no extension of ride through is provided by a transformer during a power input interruption. Ride-through energy storage requires supplementary apparatus.

Transformers are among the more efficient of power conditioning devices, typically in the 95–98% range, even at partial loads of 25% or less. With no moving parts, they rank among the most reliable of electrical apparatus. Giving off little heat and creating little acoustic noise, isolating transformers in suitably packaged UL-listed enclosures are completely suitable for installing in ADP rooms.

Transformers are available as single- or three-phase units. For all but the smallest ADP systems, however, three-phase 208Y/120-V output is almost an industry standard in the United States and Canada. Transformers with a delta input winding configuration and a wye output configuration are preferred for their ability to reduce the apparent harmonic content of loads, improve power factor when the harmonic current content makes it low, and help balance the input currents when the individual output phase loads are unbalanced. Using a transformer with three-phase legs on one core will enable it to withstand some dc component and even harmonics in the load current. Three single-phase transformers on three separate cores with windings connected in delta on the primary and wye on the secondary would most likely saturate under similar load conditions and cause power source fuses to blow.

Conventionally, the input winding is tapped at 2.5% intervals to provide rated output voltage with average input voltages running high or low. The total tap adjustment range is typically for input voltages from 5% above nominal to 10% below nominal. For three-phase, typical input voltage nominal ratings are 600-, 480-, 240-, and 208-V line-to-line for 15 kVA and larger.

Single-phase transformers are used mostly in small kVA ratings of 10 kVA to 500 VA and sometimes less. In sizes up to about 1.2 kVA, 120-V input is common. In larger sizes, input voltages of 208, 240, 277, 480, and 600 V are also commonly found. They are available with or without voltage adjusting taps.

With a shield between windings, the attenuation which it supplies is often specified in decibels (dB) or an equivalent voltage attenuation ratio. For a 1 to 1 ratio transformer, the dB attenuation is equal to 20 times the log to the base 10 of the voltage attenuation ratio. A voltage ratio of 30 becomes 29.5 dB, 100:1 becomes 40 dB, 1000:1 becomes 60 dB, etc. Super-isolation transformers with multiple shields are offered with claims of 140 dB or more, or a voltage attenuation ratio exceeding 10,000,000:1. If these cost more than those in the 40–60-dB range, it may be a waste of money to purchase and install one unless equivalent shielding were applied to all other paths by which external electrical noise could reach the ADP equipment, and the noise which the ADP equipment itself generates could be reduced as well.

Most transformers without shields will provide some common mode isolation, especially at low frequencies, primarily because of the electrical separation of primary and secondary windings. Adding an interwinding shield and connecting it to the secondary ground reference point with a short, direct conductor will improve the isolation. The ratio of the attenuation with the shield grounded to the attenuation with the shield floating with a 20-kHz signal is sometimes quoted as a shield effectiveness ratio, but is not directly comparable with the voltage attenuation ratio. Typical quoted values range from 20 to 30 or more. A second shield between primary and the grounded shield will reduce the conversion of common mode input to normal mode output noise voltage.

The impedance of the transformer has been discussed previously under the heading of power source characteristics. To prevent load faults from drawing currents which would exceed the interrupting capacity (not the trip current rating) of circuit breakers, transformers with excessively low internal impedance are not desired. Typical impedance values are a compromise between a desire for good regulation (low impedance indicated) and fault current limiting (high impedance indicated). Dry type transformers with internal impedances between 3 and 6% are usually acceptable. A 5% value is very common. In a fault on the 208Y/120-V output of a 100-kVA transformer, the symmetrical RMS value would not exceed 5500 A if the transformer impedance were 5%. This is within the capability of a standard 10,000 A interrupting capacity circuit breaker, even though the fully offset peak transient fault current could be as much as 15,700 A.

Isolating transformers are not always listed as a "requirement" by ADP manufacturers. There are circumstances where existing electrical systems may be adequate. Additionally, some ADP users are more tolerant of occasional computer malfunctions than others. However, ADP manufacturers who do not insist upon isolating transformers generally recommend their use. Some ADP manufacturers offer them as optional "power peripherals" as part of their ADP systems, contained in enclosures which harmonize with the rest of the system and listed by Underwriters Laboratories under UL 478, "Standard for Electronic Data-Processing Units and Systems" [31].

Whether isolating transformers are installed as part of the building wiring or as a power peripheral, they can perform the same functions. If in the form of modular power center peripherals, they are easier to position near the loads which they serve, are infinitely easier to move, and make it possible to reconfigure the output circuits in accordance with needed additions or changes to the ADP system. Having these transformers in the computer room typically adds about 2% to the air conditioning load in the computer room, but putting them in a nearby utility closet does not entirely eliminate the need to cool them. As part of the computer system, the power centers can be moved with the system if a move is required. As part of the building wiring, this becomes more difficult. The financial treatment may also be affected, depending upon whether the isolating transformer is part of the computer system or a leasehold improvement to the building wiring.

The definitions of "branch circuit" and "feeder" in NFPA 70-1981 [20], and UL 478 [31], affect the names applied to an isolating transformer's input and output circuits. If the transformer is installed as part of the site's "premises" wiring, its input and output circuits are "feeders" and the individual circuits from the circuit breaker panel which distribute 208- and 120-V power to individual ADP units are the "branch circuits."

If a power peripheral is used, the final overcurrent protective device and premises wiring to the outlet receptacle or permanent connection terminal block becomes a "branch circuit," even if it is 480 V and is not the final utilization voltage in the ADP system. The circuits between the power peripheral and other ADP system units become "interconnecting cables" rather than "branch circuits" since they are not the circuit

conductors between the final (site wiring) overcurrent protecting device and the output(s). These definitions can affect what is subject to inspection, who inspects, and inspection fees.

Ordinarily the premise's wiring is subject to electrical codes. The appliances to be connected to the premise's wiring by pluggable or permanent connection are also subject to examination for safety if they have not been found acceptable by a recognized testing laboratory such as UL. In most municipalities, electrical safety inspectors accept UL and other recognized testing laboratory "listings" as evidence of suitability for safe connection to premise's electrical wiring. ADP users should be aware, however, that any modification to a product which has been UL listed voids that listing until the product has been reexamined and found safe. The modification may be trivial and entirely safe, but the implications of liability and the trouble, effort, and expense of reexamination should discourage ADP users from modifying any UL-listed equipment without being prepared to go all the way in reinspection.

4.4 Motor-Generator Sets

Motor-generator (m-g) sets (fig. 47) are much more versatile than transformers, but they also have limitations. Among their intended functions are: (1) they provide an independently generated source of voltage which can be regulated without interaction with any line voltage changes on the power source which drives the motor, (2) the rotational speed and inertial momentum of the rotational mass are responsible for a substantial amount of stored rotational energy, preventing sudden changes in voltage output when the input is momentarily interrupted, and (3) the input and output windings are electrically separated, and are at least as effective as an isolation transformer in preventing the transmission of common mode noise voltage.

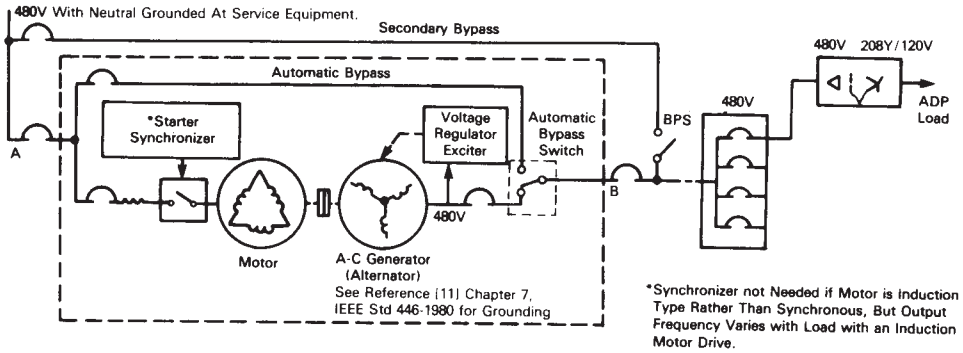


Figure 47. *Motor-generators:* Typical installation one-line diagram, showing automatically sequenced bypass controls to put m-g set in and out of service, plus secondary manual bypass to allow servicing of automatic controllers or unit replacement.

There are a number of types of motor-generator sets, each having its own characteristics, advantages, and disadvantages. One important characterization which affects output frequency depends upon the type of electric motor which drives the m-g set. Direct current motor drives can be controlled in speed independently of the frequency of the ac power source from which the dc may be derived, thereby giving the m-g set the capability to produce power at the desired frequency regardless of variations in input frequency. The requirement for rectifier conversion equipment, control equipment, and commutator maintenance have all been listed as reasons why this type of m-g set has not become more popular.

The most simple and least expensive motor is the induction motor. Unfortunately, its rotor turns slower than the rotating field produced by the power source. This results in the generator unable to produce 60 Hz if the motor is operated at 60 Hz and the units are directly coupled end-to-end at their shafts or are belted with cog belts in a one-to-one ratio. Furthermore, the shaft speed and output frequency of the generator is decreased as load on the generator is increased. The varying output frequency may be acceptable where it is to be used merely as input to a power supply in which input power is rectified and converted to dc before further conversion. However, there are loads such as disk memory drives which cannot tolerate frequency changes greater than typically 1 Hz/s and frequency deviations of more than 0.5 Hz from the nominal 60-Hz value.

Low slip induction motor-driven generators will reduce output frequency from the generator to 59.7 Hz at full load, assuming 60-Hz input. During power interruptions, the output frequency will drop further depending upon the length of time until input power is restored. Ability of the induction to restart after a momentary power interruption is valuable.

Various systems of variable speed belts have been tried. Magnetically-controlled slipping clutches have been found to be unsatisfactory and other means to make the induction motor drive the load at constant speed have produced no generally acceptable product.

Using a synchronous motor with direct coupling or cogged 1:1 ratio belt drive guarantees that the output frequency will be equal to the motor input frequency. Although the synchronous motor is more expensive, it is more efficient and can be adjusted to be a unity power factor load on the power source.

The starting characteristics and the disturbance following a short duration line voltage interruption depends to a large extent on motor design. As previously mentioned, induction motors are good in this respect. Many synchronous motors not required to start under load have very weak starting torque and may use a "pony motor" (fig. 48) to aid starting. Those designed to start with a load have starting pole face windings which provide starting torque comparable to that of an induction motor. Such motors can be brought into synchronism while under load with proper motor and automatic starter selection. Typical ridethrough times during which an ADP load can be sustained through a momentary line voltage interruption are generally at least 6 cycles (0.1 s). Depending upon design, size, and flywheel, it can be as much as 0.5 s or more. The generator will continue to produce output power for a longer duration, but its frequency and rate of frequency change will most likely fall outside of the acceptable range for most ADP units.

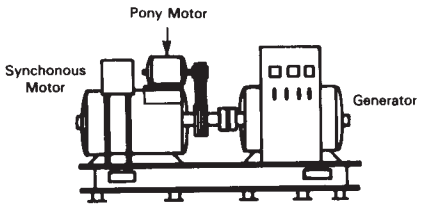


Figure 48. *Motor-generator pony motor:* This is sometimes used to limit starting currents of large m-g sets to a value not exceeding the full load input current.

If input power is interrupted and does not return before the output voltage and frequency fall outside of acceptable limits, the generator output control can be adjusted to disconnect the load. Prior to this event, a signal to the ADP system can warn of impending shutdown and initiate an orderly interruption of any active programs prior to shutdown of power. This facilitates restart of the computer.

It is important not only to estimate the length of time that the m-g set will continue to deliver power without input to the motor, but also to ensure that it can handle the return of power without operating overcurrent protection due to the inrush of current to reaccelerate and synchronize the motor with the line frequency. This requires a "smart" synchronous motor controller which knows when to disconnect and reconnect the field current supply. It could be worthwhile to delay an impending shutdown for 100 ms. This could give the computer time to prepare for the event by orderly interruption. It would also be useful if the computer were able to resume without shutdown should power return within the ride-through period. Signals from the motor-generator controller can be supplied to identify these conditions and events to the computer. However, few ADP systems are designed to act upon this information.

Since m-g sets do require some maintenance requiring shutdown, most m-g set installations also have bypass capability so these operations can be undertaken without having to take the computer out of service. If the automatic bypass contactors, solid state switches, and controls are in the same cabinet as other controls and also need to be deenergized, a secondary bypass is highly recommended as shown in figure 47. Once the automatic bypass path has been established, transfer switching to secondary bypass can be enabled, taking the m-g set and its automatic bypass out of the circuit completely.

Some automatic bypass control arrangements are designed to transfer the load of the generator to the bypass with minimum disturbance. This requires the generator output to be synchronized with the bypass power before closing the switch and opening the generator output breaker. However, with the load off the generator, bypass power will no longer be synchronized with it. Consequently the retransfer of load back to

generator output will not be without some disturbance. Adjustments for minimum disturbance in either direction require a compromise in phase setting or means to shift the phase prior to and after transfer.

Generators, as previously mentioned, have substantially higher internal impedance than equivalent kVA rated transformers. Because of this, m-g sets are sometimes supplied with an oversize generator which will be lightly loaded at most, and a smaller motor which is adequate to drive the actual load. This saves initial cost and reduces losses in the motor.

Motor generators, particularly those with flywheels (fig. 49), have been demonstrated in many installations to enable ADP systems to ride through a majority of line voltage disturbances and interruptions of very short duration. Upon power restoration, the input circuits must be able to accelerate the flywheel without overcurrent protection tripping. The few longer duration disturbances which the m-g set did not ride through would not have justified purchasing much more expensive uninterruptible power systems. Of course, this is a value judgment of those users. Not every computer user would necessarily come to the same conclusion.

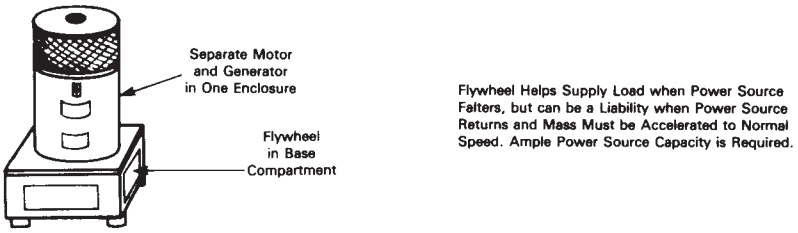


Figure 49. *Vertical m–g set with flywheel:* Such a device with induction motor drive provides ride-through during momentary line interruptions, filtering of line disturbances, and voltage regulation to compensate for sustained periods of high or low line voltage. These are suitable only for loads which are not sensitive to line frequency changes or rates of change exceeding several hertz/second.

4.5 Surge Arrestors

Surge arrestors (transient voltage suppressors) are of several basic types with different characteristics, serving similar functions in different ways. When used in combination in a coordinated manner, they provide protection by limiting overvoltage, reducing stress and unnecessary failures in components, and reducing malfunction incidences caused by surges. (See fig. 50.)

There are two types of arrestors which become conductive when their threshold voltage is exceeded. The first type becomes and stays conductive until the current which follows is reduced to zero (i.e., when an alternating current passes through zero in changing direction of flow). The second type becomes conductive when its voltage threshold is exceeded, but regains its open circuit state as soon as the voltage drops below the threshold.

The first type is characteristic of pellet type and gas discharge type arrestors. They are usually capable of handling very high currents because the voltage drop through them becomes very low when they are conducting. However, if a very weak, short duration impulse of a fraction of a millisecond should trigger the arrestor, the shunting action would essentially short circuit the line for at least a half cycle or possibly longer. The transient created by shorting the power conductor may be greater than the event which triggered it.

The second type, typical of nonlinear insulating material, becomes conductive when voltage gradients exceed threshold values. Some semiconductors in an avalanche mode exhibit similar characteristics, not unlike Zener diodes. General Electric for example, markets devices called "Metal Oxide Varistors" or "MOVs." These are constructed of an amorphous oxide material, exhibiting these characteristics. General Semiconductor Industries markets silicon solid state devices called "Transzorbs" which perform a similar function. There are others. Some are polarized; others are unpolarized and handle overvoltages of either polarity.

Like guard rails along a highway, they can be put anywhere. However, it must be recognized that they divert surge currents rather than absorb them. Care must be taken to see that the diversion path does not create another problem. Of course operating voltage ratings must be suitable to the application. There are locations where they can be much more effective than others in protecting ADP equipment and the power

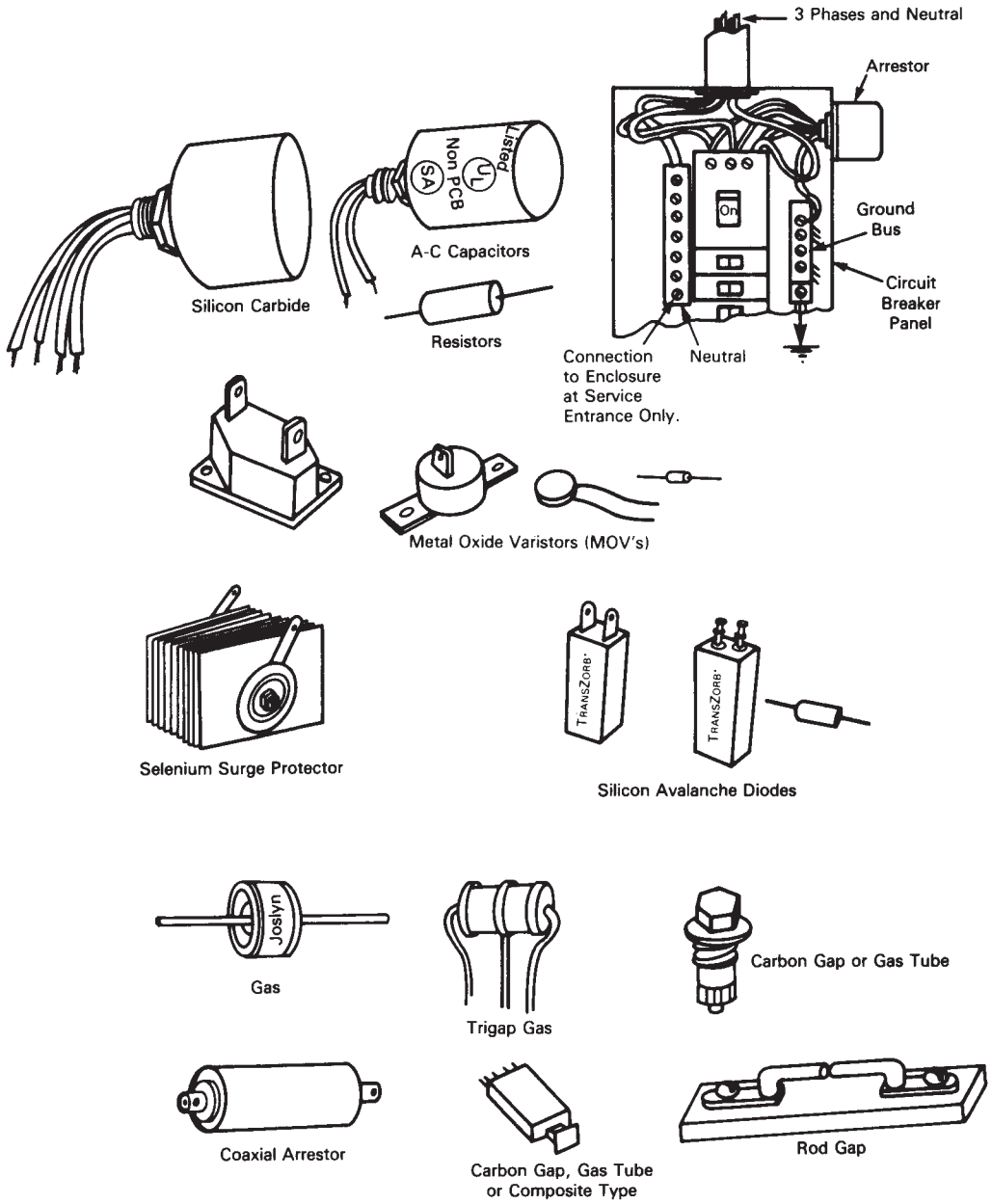


Figure 50. *Surge protectors:* Examples of devices used in ADP power and communications circuits. The linear devices are capacitors and resistors. Semiconductors include selenium rectifiers, silicon diodes, nonlinear resistive devices such as silicon carbide and metal oxide varistors (MOVs). Spark gaps include gas tubes, carbon gaps, rods, and controlled spacing between conductors in component devices.

conditioning equipment which supplies power to ADP equipment. Effective locations include the inputs and outputs of transformers, motor-generators, UPS systems and their automatic bypass static switches and inputs to ADP units. However, there are risks associated with failures of these devices; they may throw flaming material when they fail and must be mounted in a suitable enclosure. To be effective, these devices must be connected to the protected circuit with short conductors not more than 1 ft or so in length.

Selection of surge arrestors, the locations where they can be most effective, and the safety precautions require some depth of technical understanding of surge voltages, the nature of traveling pulse waves, their reflection and diversion. In general, they are most likely to be needed wherever current in an inductive circuit element can be interrupted. They also may need to be placed wherever long conductor cable leads interconnect widely separated systems, as in different buildings, or parts of a system within a very large building. At the entrances where power and communications cables are brought into a building, lightning

and power switching surges can create large voltage surges which should be diverted or reflected before they reach ADP equipment, its power conditioning, and air conditioning or other utility equipment.

Rather than to present applicational recommendations in this Guideline, it is recommended that guidance of a specialist on this subject and lightning protection be engaged to recommend specific devices and locations for installing them. It usually becomes evident that a relatively few locations really need protection. Many other locations might possibly benefit, but the amount of protection installed will have to be up to the judgment of someone who can balance the risks against the cost of insurance.

4.6 Power Factor Correction

Power factor correction has already been partially discussed under the subject of "effects of power factor." Some applicational data are added here.

The use of capacitors and of overexcited synchronous motors are two conventional and feasible methods of counteracting lagging inductive load currents. The delta/wye transformer was cited as one means for improving power factor due to large amounts of third harmonic and multiples of the third.

Capacitors should not be switched for control purposes as this will create transients of sufficient magnitude to disturb ADP equipment. If a preselected quantity of capacitors cannot be connected and left connected to the line in a constantly energized state, the system would probably be better off without them. Since capacitors tend to raise the line voltage, it must be determined that they will not cause the line voltage to run away (force the system into an overvoltage condition) when all other load is removed.

Using a variable ratio transformer to adjust the voltage on the capacitors from some low value up to the maximum conservative operating voltage, the effective value of the capacitors and the amount of power factor correction can be adjusted without creating switching transients. However, this is the equivalent of varying the capacitance, and at some particular value the capacitors will resonate with stray inductance in the circuit, creating a resonant condition. If that resonance should coincide with some periodically varying load or other forcing function, the resonance could create unwanted excessive line voltage distortion and noise signals.

Capacitors, when selected, should be rated for continuous ac voltage with ample margin between the rated working voltage and the actual working voltage. They will require less external fault protection if units are used with self-contained fuse protection.

Capacitors containing polychlorinated biphenol (PCB) or other environmentally dangerous materials are no longer permitted. Many capacitors have been manufactured with this material and are still in use. Because new installations prohibit use of such materials, the new allowable equivalent materials do have a flash point and are flammable. This requires some care in selecting locations and enclosures which are safe from possible fire where the previously used PCB-filled units did not pose a flammability problem.

Again, the reasons for power factor correction are mostly either requirements of energy conservation rulings or economics. The improvement of performance except as a means of controlling line voltage may not be sufficiently attractive to justify the cost and effort now, but as power and distribution capacity become more critical in falling short of demand, this could change.

4.7 Uninterruptible Power Systems (UPS)

Uninterruptible power sources (UPS) have become a virtual necessity for powering large or small systems where the application serves a critical need, as when interruption of the function would risk personal safety or monetary loss [25].

Computers and data communications can be no more reliable than the power from which they operate. The difference between UPS and Emergency Standby Power is that the UPS is always in operation. It reverts to an alternative power source such as the public utility only when the UPS fails or needs to be deenergized for service. Even then, the transfer of power source occurs so quickly (milliseconds) that it does not interrupt the proper operation of the ADP system.

Emergency standby power is normally off and does not start (manually or automatically) until the public utility power fails. Diesels can regularly be started within 10 to 30 s if their condition for rapid starting has been continuously maintained. However, during this interruption, ADP systems would have shut down. Most ADP systems cannot ride through more than 8 to 22 ms of power interruption. Those which can ride through very short duration power interruptions so far as energy continuity is concerned may be interrupted because of the electrical noise created by the interruption. The success of UPS systems

which permit ADP operations to continue without interruption require power switching to be done in substantially less than a half cycle and without substantial transient noise during the switching.

There are some ADP and data communications units which will ride through much longer power interruptions of 0.5 s or longer. Furthermore, the nature of most communications equipment is to be tolerant of momentary interruptions in the communication line and of extraneous noise. Received signals are automatically checked for errors and missing bits regardless of cause. The signals are retransmitted until received correctly. In such systems, momentary interruption of power is not disastrous. Consequently, simple power transfer switching is feasible where one source may be disconnected before the other source is connected. There can be 50–100 ms or longer between these events using a simple break-before-make transfer switch as shown in figure 51.

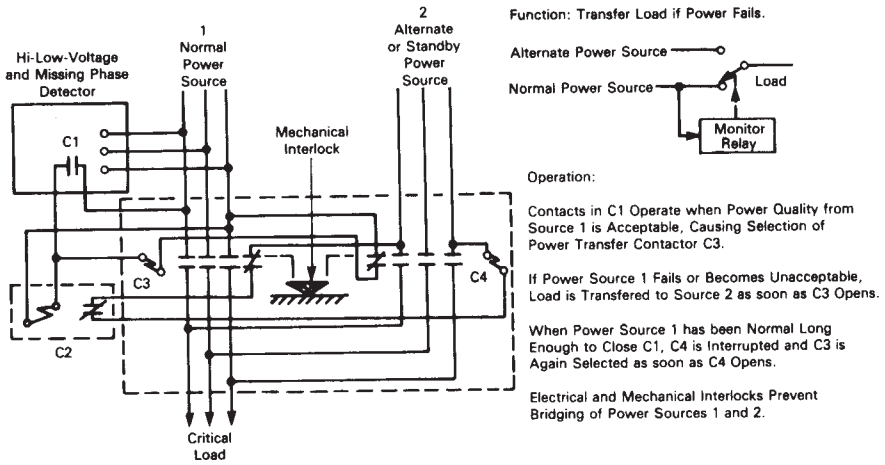


Figure 51. *Transfer switch:* Electromechanical break-before-make contactors can be used to transfer loads from a favored power source to a backup alternate power source if the load can tolerate 0.1 s to 0.25 s interruption. Solid State "Static" transfer switches perform a similar function but because they can operate in one or two milliseconds, they are normally operated "make-before-break" for "uninterrupted" power source transfers.

UPS apparatus which provides "no-break" power is supplied in a variety of forms:

(a) *Motor-generator (m-g) set with ac and dc drives* is shown schematically in figure 52. The ac motor normally supplies the power to drive the three directly coupled machines; an ac motor, a dc motor which also serves as a generator to charge batteries, and an alternator to generate ac power for the critical load at all times except when using the bypass. When line voltage is interrupted, the dc machine runs on battery power. This was an early form of UPS. Some of these are still in use.

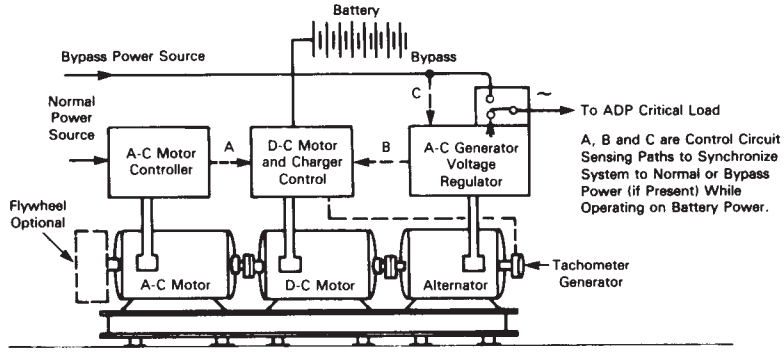


Figure 52. *Uninterruptible motor-generator power with ac and dc motor drives:* This type of m-g set operates from battery power when the power to the ac motor is interrupted. The dc motor becomes a battery charging generator when ac power is supplied to the ac motor. The tachometer generator and dc motor controller maintain constant generator speed for uninterrupted power to the critical load when ac input power is interrupted.

(b) *Motor-generator set with dc drive* (fig. 53) consisting of only a rectifier-charger, a dc motor, and an alternator, is similar to (a) but has no ac motor drive. The rectifier provides power for the dc motor plus power for charging the batteries. Modern silicon rectifiers are more efficient than rotating machines in battery charging service, two rather than three machines are used in the m-g set, and dc machine controller no longer needs to go through the transition from generator to motor with accompanying transitional disturbances. UPS systems of this type are still being manufactured.

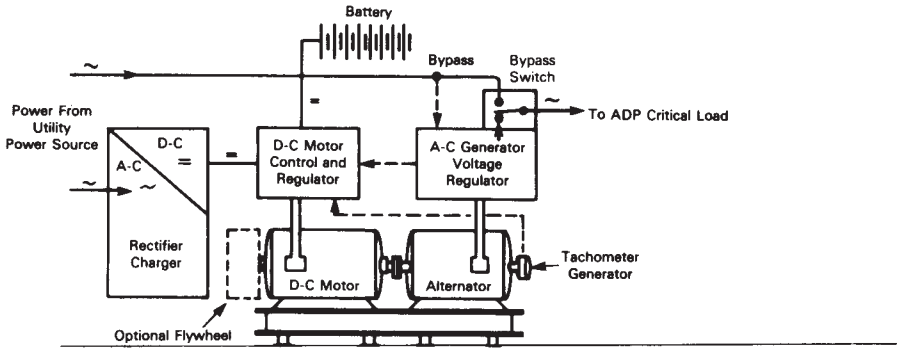
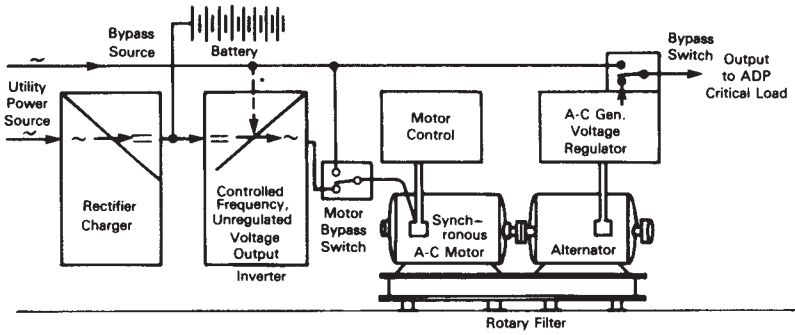


Figure 53. *Uninterruptible motor-generator power with dc motor drive:* When ac line voltage is present, it drives a dc motor and charges batteries via a rectifier. When ac input is interrupted, the dc motor operates from battery power with speed maintained constant by a controller.

(c) *Motor-generator set with ac drive* (fig. 54) is similar to (b) but operates from a dc to ac inverter from a rectifier or battery depending upon whether or not line voltage is present to supply the rectifier charger. The output of the dc to ac inverter need not be a sine wave nor well regulated in voltage. The output from the alternator provides a well regulated sine wave. The m-g set can also be used in a bypass mode which bypasses the rectifier and batteries, but leaves the m-g set between line input and output to the ADP system. Additionally, the entire UPS including the m-g set can be bypassed during service or replacement operations. The m-g sets in this service are also known as "rotary filters." This type of UPS is currently being marketed.



*A-C Line Synchronizing Signal Controls Oscillator Phase Angle for Least Bypass Transfer Disturbance.

Figure 54. *Uninterruptible synchronous motor-generator set:* This uses a solid-state ac/dc rectifier-charger and dc/ac inverter to drive the m-g set for constant frequency and voltage output. The m-g set acts as a "rotary filter" with rotational energy storage to regulate and smooth voltage wave shape, and to handle momentary overloads. An optional motor bypass switch allows the m-g set to be used as a line filter and regulator while solid state equipment or batteries are being serviced.

(d) *Solid state UPS* systems without any rotating machinery employ several design approaches to provide regulated sinusoidal output voltage to their loads:

(1) Ferroresonant transformer (fig. 55) driven by a dc to ac inverter can operate with distorted, unregulated input voltage and deliver regulated, sinusoidal output when properly filtered. Two inverters operating into ferroresonant transformers in a Scott T-connected configuration are able to provide regulated, sinusoidal three-phase output voltage.

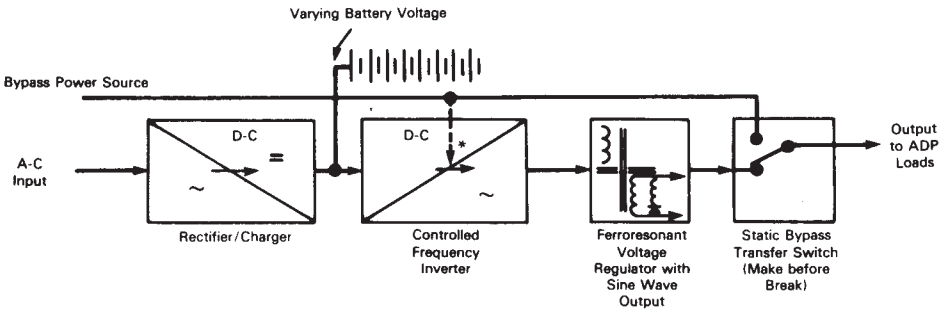


Figure 55. *Static UPS with ferroresonant voltage control:* In some designs, two inverters generate two-phase power which is converted to three-phase output by Scott-Tee transformer connection.

(2) Dc to ac inverters driving an inductor/capacitor L/C "tank circuit" (fig. 56) will produce a sine wave output. Regulation of voltage can be achieved by varying the capacitance or the inductance to control partial resonance and/or power factor. Some units use a saturable reactor in which electronic voltage regulator circuits control the dc control current in the reactor. Other units (fig. 57) use a dc to variable dc inverter/converter to control UPS output voltage through control of the boost voltage. This compensates for battery voltage change.

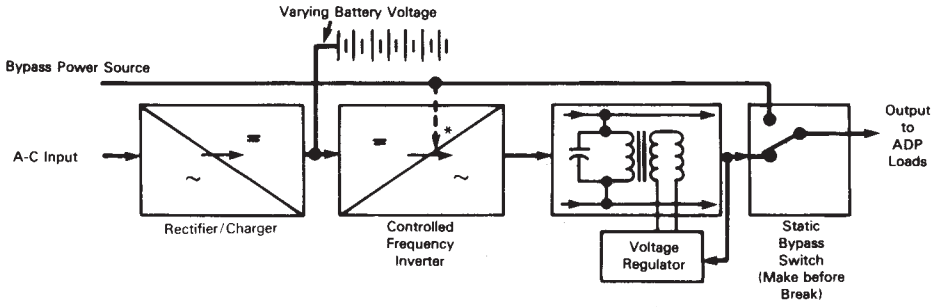


Figure 56. *Static UPS with saturable reactor voltage control.*

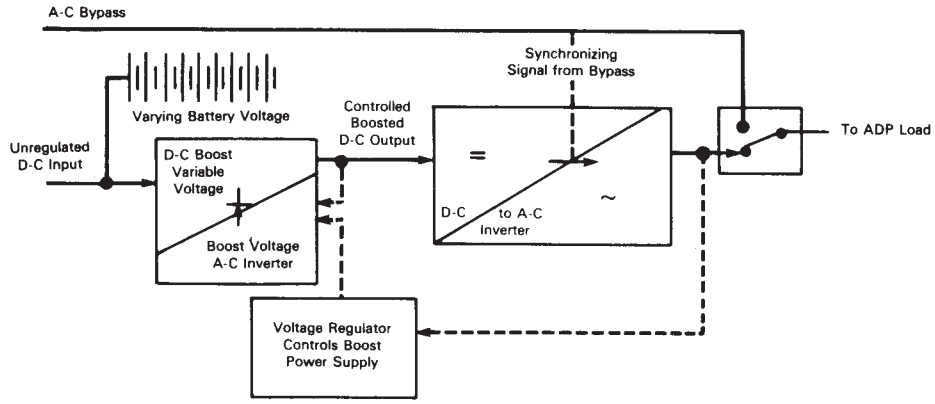


Figure 57. *Static UPS with dc boost voltage control:* Varying battery voltage is adjusted as required for constant output voltage through a controlled "boost power supply."

(3) Dc to ac inverters driving multi-step-wave switching to approximate a sine wave plus filtering create a good sine wave. Voltage regulation is achieved by a "boost" dc to dc power supply in series with the battery and regulated in a manner to provide the desired regulation of ac output (fig. 58).

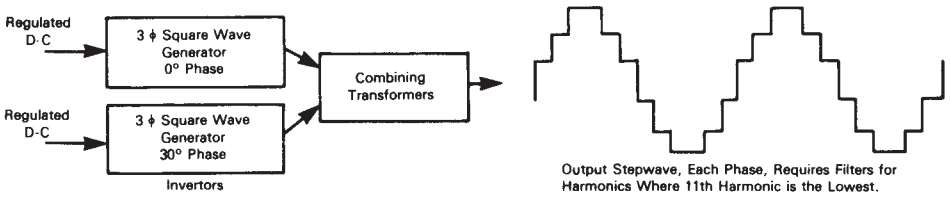


Figure 58. *Static UPS with stepped wave output:* This partial schematic illustrates the design principle used to reduce filter requirements for sinusoidal output. Used mostly in larger kVA UPS sizes.

(4) Dc to ac conversion through phase modulation of two square wave higher frequency signals creates the output voltage which must pass through a low pass filter to remove the carrier signal. An advantage is fast response output regulation capability (fig. 59).

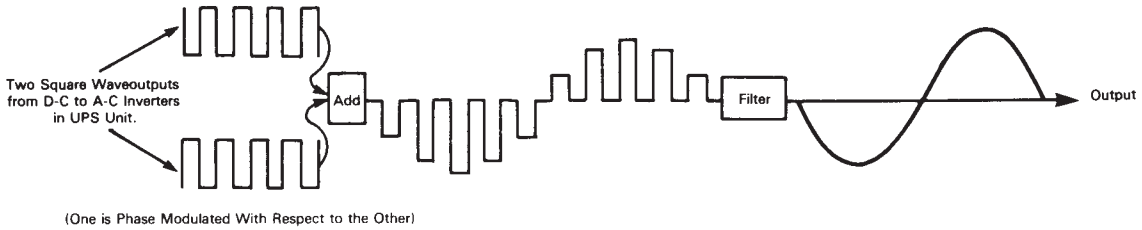


Figure 59. *Static UPS with phase demodulated carrier:* This partial schematic illustrates the principle used in some UPS hardware designs which sums two high-frequency waves. One is phase modulated at the desired output frequency (50, 60, or 400 Hz). A low-pass filter passes current at power frequencies, but rejects the inverter carrier frequency.

(5) Other design approaches include variations of the above. It will not be possible to describe them all in this Guideline.

One characteristic shared by all is sensitivity of solid state switches and rectifiers to overvoltage breakdown and overcurrent failure in very short time durations of a few milliseconds or less. Whereas motor windings and transformer windings can withstand overvoltages and overcurrents for long durations, silicon and other semiconductor devices fail very rapidly when their maximum peak ratings are exceeded. Surge protection is needed here.

For this reason, the maximum peak instantaneous load current is an important characteristic when designing, specifying, or selecting UPS equipment. If the maximum inrush rms (root mean square) current to a load is 100 A, for example, the peak of a symmetrical start would be $\sqrt{2}$ times that value or 141.4-A peak. Fully offset starting transient (depending upon what part of the voltage cycle the switch was closed) can double this for a maximum peak of 282.8 A. The UPS must be rated to handle this peak current.

Currents exceeding the UPS' capability to handle safely a normal output load will cause most systems to go into a current limiting mode. This self protection against overloads or faults prevents any further rise which would destroy the semiconductor. In UPS systems under current limiting conditions, the output voltage will drop. An automatic bypass, in the UPS or as an accessory, would be activated if not manually or automatically inhibited when an usafe condition is detected. The load, overload, or short circuit on the UPS will be transferred to the bypass power source, usually the public utility. This will have sufficient power to supply the overload or to operate the circuit breakers or fuses in case of a fault.

Depending on how the controls have been arranged and selected, the transfer from UPS to bypass can be followed by one attempt to retransfer load back to the UPS. If the UPS is still in the current limiting mode, the load is returned to the bypass and further retransfer must be accomplished manually or following a manual reset. If the retransfer was successful and holds for a preselected time, the lockout of the next retransfer will be reset and permitted to occur.

UPS systems are typically supplied with sufficient battery capacity to carry an ADP load for periods ranging from 5 min to several hours or longer. Once uninterruptible power units have been justified by a need to ride through power interruptions longer than a motor-generator set can handle (typically 0.1–0.5 s), a 5-min ride-through may seem like a long time. It is certainly long enough to start diesel generators if there is no difficulty. However, problems like water in the fuel line, a cranking battery to be exchanged, or a cold water jacket requiring starting fluid to be administered into the air intake might require 15–30 min.

The incremental costs of additional batteries to provide increased ride-through times should be weighed against the added insurance provided in cases where diesel start-up is delayed or power is not restored within 5 min. Thirty or even 15 min would provide onsite personnel with enough time to handle small problems.

UPS systems and batteries belong in protected utility areas and should not be placed in the ADP room. Batteries could represent shock hazards, danger from acid spills, flash heat and sparks from high-energy short circuits, or even explosions. They should be installed in dedicated battery rooms with access controlled and admittance limited to qualified maintenance people. In addition, temperature must be kept at about 70–80° F to ensure long life and capacity. Cold batteries lose substantial capacity and ability to deliver full current. Overheated batteries deteriorate rapidly. Discharge curves as in figure 60 are used to determine low battery voltage warning and shutoff limits during discharge. These points vary with load current and are not constant values.

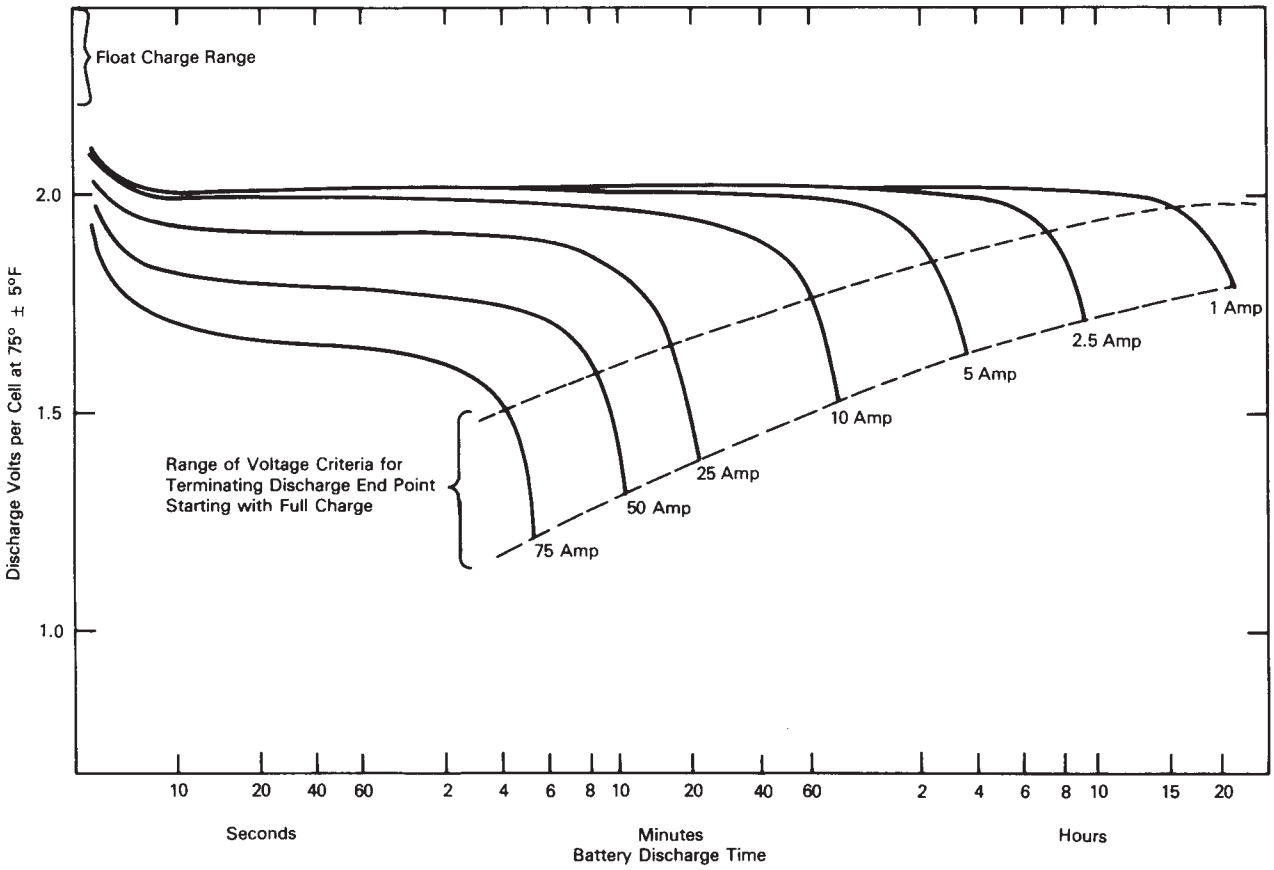


Figure 60. *Typical battery discharge characteristics.*

The UPS inverter hardware must be placed close to the batteries to avoid unnecessary loss in the dc bus and excessive electrical noise and possible shock hazard. Typically, the UPS is placed in a basement utility room or utility corridor area where batteries and UPS can be properly ventilated and kept at reasonable temperatures. This correctly implies that the UPS installation will usually be located at a distance from the ADP equipment.

The bypass requirement is simplified if input and output of the UPS are at the same voltage, i.e., 480 V. This eliminates the need for a step-down transformer in the bypass line and simplifies the use of a secondary bypass as in motor-generator installations. The voltage stepdown to final utilization voltage and common mode isolation belongs in the ADP room.

4.8 Redundant UPS Systems

Redundant UPS systems can be arranged in various ways to achieve greater total capacity without relying upon any single UPS for operation. Two such arrangements are the parallel redundant and isolated redundant modes.

In the parallel redundant arrangement (fig. 61) the UPS outputs are connected together and are designed and adjusted to share loads. Considering the load in kVA and the kVA capacity of each UPS unit to be paralleled, a sufficient number of UPS units are installed to carry the load with any one of the units out of service. If the total ADP load grows to the point where it takes all of the units to supply the load, another can be added.

The parallel system provides the ability to cope with the loss of any unit, either from failure or need for service without having to operate the ADP equipment on bypass utility power. It also offers the ability to add capacity as it is needed rather than having to predict total need at the start. However, there is a higher cost per kVA for small units compared with larger capacity units, and certain failure modes of these systems could shut down the total system.

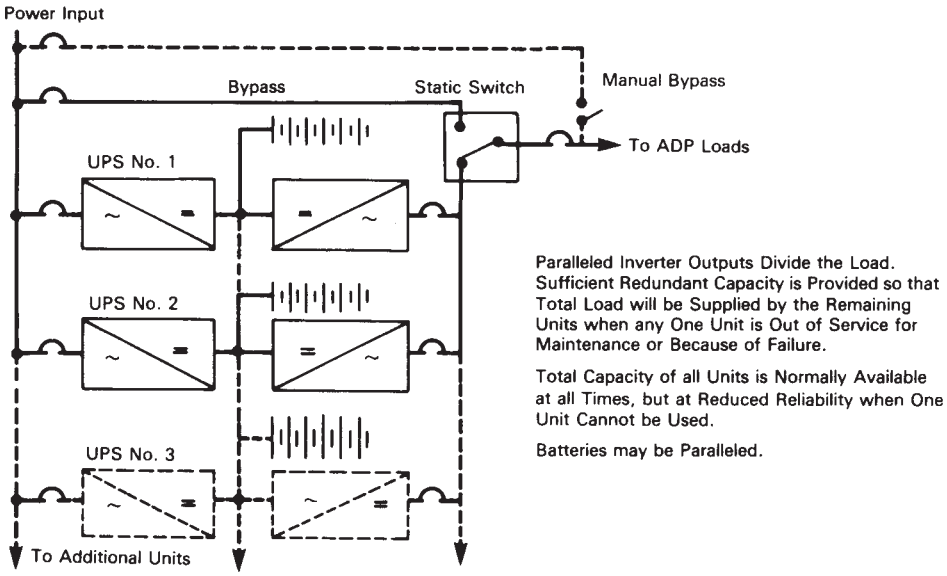


Figure 61. *A parallel redundant UPS system.*

The isolated redundant system (fig. 62) has separate UPS systems each supplying their own designated loads under normal operation. Failures in one will not necessarily affect the others if they are not in parallel. If one of the active systems fails, its static switch bypass will be first to a redundant, standby UPS acting as a backup for any number of UPS units. If the load was a short circuit or an overload and this was transferred to the redundant, isolated UPS unit, that backup unit would in turn retransfer the load, this time via bypass to the public utility. The substantially higher current inrush capability of the utility power source would be sufficient to supply the load or cause the overcurrent protection to open the circuit.

The isolated redundant system will not enable the unused capacity of one UPS to be used by an ADP unit which is loading another unit to or above its maximum. Although the utilization of capacity may not be as good, the isolated redundant system is not as susceptible to failure modes which would be common to all loads in the same incident.

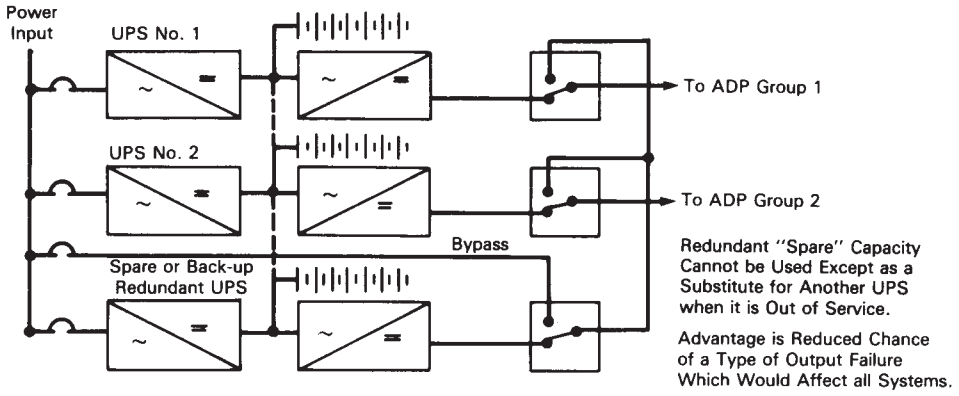


Figure 62. *An isolated redundant UPS system.*

4.9 Redundant Power Feeders (fig. 63)

Redundant power feeders and other sources of power can be very important to high reliability if power can be supplied to any ADP unit under a variety of circumstances. There is the possibility of electrical failure, the need to rearrange existing equipment, replace it, or to add equipment. Every piece of ADP equipment, power conditioning equipment, and power source has an unwritten guarantee. It is guaranteed to fail! The only question is, "When?" The answer is, "Redundancy!" However, the arrangement of power sources, feeders, switches, and loads can become so complex that there would be a high risk of someone making the wrong connection. Instead of shutting down a failing unit, it would be easy to err by shutting down a good unit and leaving the failed unit in service.

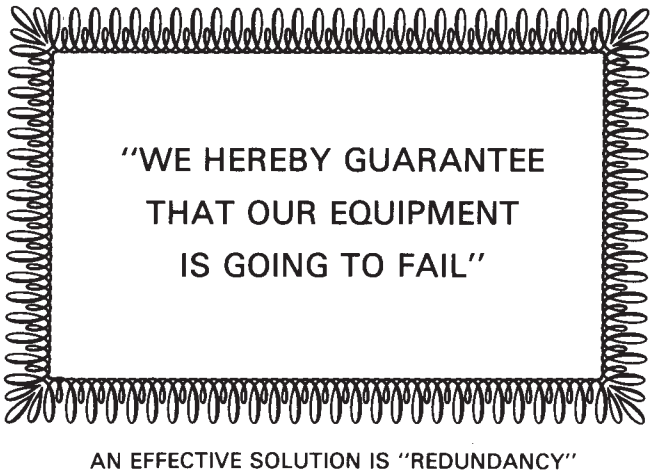


Figure 63. If you cannot tolerate this guarantee, the answer is *"REDUNDANCY!"*

It is important that there be a simplified one-line schematic of the entire power system as well as such other building systems as heating and air conditioning, the security access control, and the various alarm systems for smoke, fire, heat, water, etc. For the power system, a simplified schematic can be developed into what is called a "mimic board." This is a panel which depicts the system and has active indicators on it to show the status of what is turned on or off, what functions have been disabled, and some of the parameters such as load currents, kW, or kVA in terms of a percentage of their normal full load values.

In some instances, controls or extensions of controls can also be mounted on the panel. For safety, however, these should be limited to Emergency-Off buttons which would not endanger anyone if the equipment were to be shut down from the remote location of the mimic board. It is usually safest to require an operator to go to the apparatus or machine to energize or activate it. The equipment can be inspected to

verify that it is safe to turn on. Once energized, the operator can also verify that it is running and all indicators appear normal.

Of course there will be some functions which will operate automatically in response to predetermined conditions unless manually or automatically disabled for conditions which would create problems.

After giving so much attention to continuity of electric power to ADP systems, almost as much attention must be given to their need for continued temperature, humidity control, and cooling fluid if liquid cooled. If air conditioning is interrupted but the computers continue to run, temperatures will quickly rise to the point where computer components are damaged or computers are automatically shut down by overtemperature protection. It may not be necessary to require cooling fans, chillers, heat exchanger pumps, and other such equipment to operate with zero interruption. However, any interruption should not be longer than a 1–2-min duration. Typically, liquid-cooled ADP units may withstand a 1-min cooling interruption. Air-cooled ADP units may tolerate 5–10 min of cooling interruption.

Air conditioners and related equipment are usually operated from emergency and standby power from diesels or gas turbines rather than from the UPS and battery power. However, some advantages can be found for operating air handlers and coolant pumps with the power from UPS equipment, even though the power to the chillers is interrupted until the diesels or gas turbines are generating power. In case the diesels do not start, the rate of temperature rise of ADP equipment will be much slower still if air and coolant can be circulated.

Where ADP continuity of operation is critical, redundancy is carried throughout the system. The site should never have to depend upon one critical path for power. If there is only one large transformer between the public utility and the ADP site, a lightning stroke or other possible cause of transformer failure could halt the entire site. A replacement may require days or weeks.

Where concern for continuity exists, at least two power feeders from the public utility should be available (fig. 64). They should be separated so that one lightning stroke or one ditch digger will not get to both of them in the same incident. There should also be at least two transformers, each of which is capable of handling the critical loads. There should be a switching arrangement so that all essential loads can be connected to one or the other power sources during maintenance, additions or alterations to the system, or following any failure of one of them.

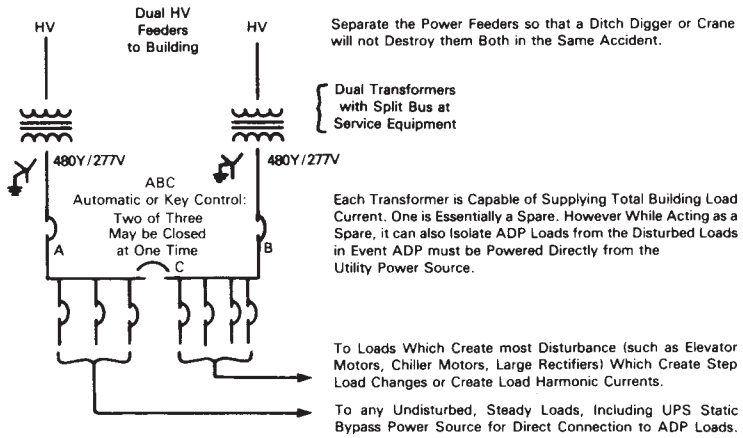


Figure 64. *Redundant power feeders and transformers:* These can provide extra isolation while serving as "spares."

Air conditioning chillers and associated equipment should also be modular so that failure of any unit can be tolerated for the time it must be out of service.

In any large ADP installation, the apparatus which supports the environment including conditioned power requires constant monitoring for unwanted changes. Microcomputer-based data logging equipment with limited process control capability can be of considerable help. The logger can be programmed to record all values periodically, but report and record significant changes and abnormal conditions by exception. At the same time, it can sound an alarm so that maintenance personnel can be dispatched to examine and correct the problem.

It is not desirable to go too far in controlling many functions at a central control site. If it fails, too much can go wrong. The diversity of separate controllers, plus the redundancy of a separate monitoring to assist data logging and early warning of abnormalities appear to be desirable.

5. LIFE-SAFETY

5.1 Life-Safety Systems (fig. 65)

Life-safety systems include fire protection equipment such as sensors and alarms, extinguishing systems, exit lights, control of emergency exits, emergency lighting, control of fire dampers, smoke exhaust and ventilating fans, and some aspects of site security. These protect life and property from harm or loss in event of various accidents and natural or man-made threats which can occur. Various ad-hoc controls for each safety feature can result in some being at cross purposes and cause considerable confusion for those who may be expected to operate any part of the system. The intent should be to facilitate proper responses.

A rational approach is first, develop a list of all the various life-safety subsystems and individual devices and controls, then list the operating modes of each item. Second, develop the intertie and priority philosophies, showing which systems trigger other systems or prevent other systems from operating. Finally resolve the time delays, inhibitions, and sequences necessary to eliminate logical conflicts and establish priorities.

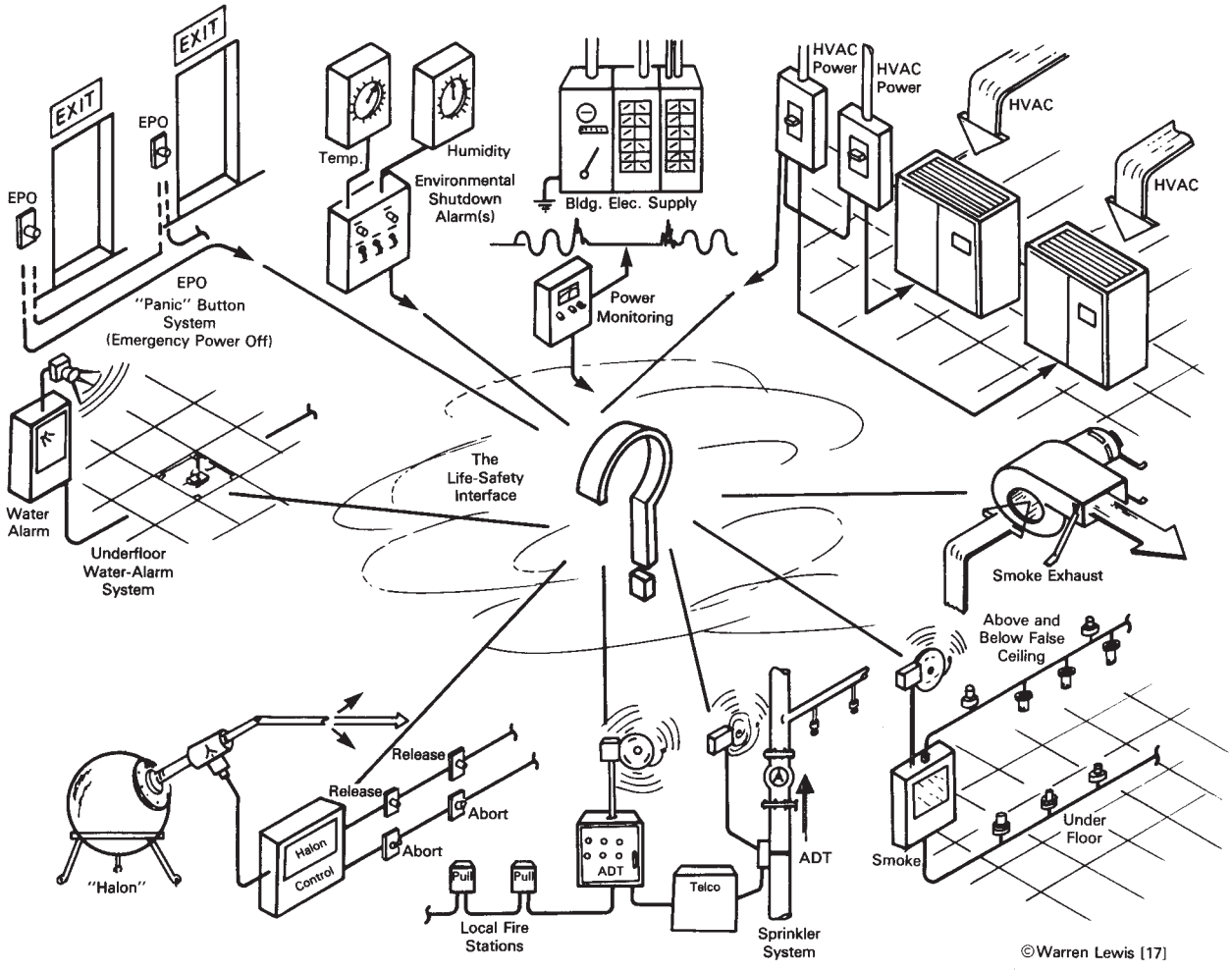


Figure 65. *Life-safety interface elements.*

With this approach, the requirements of a common interface for coordination of the various life-safety functions can be established. If these can be put into a single, readily accessible cabinet and the circuit properly and clearly documented for installation, maintenance, testing and future additions, this can avoid much unnecessary expense, confusion, and the possibility of not achieving the required result (see fig. 66).

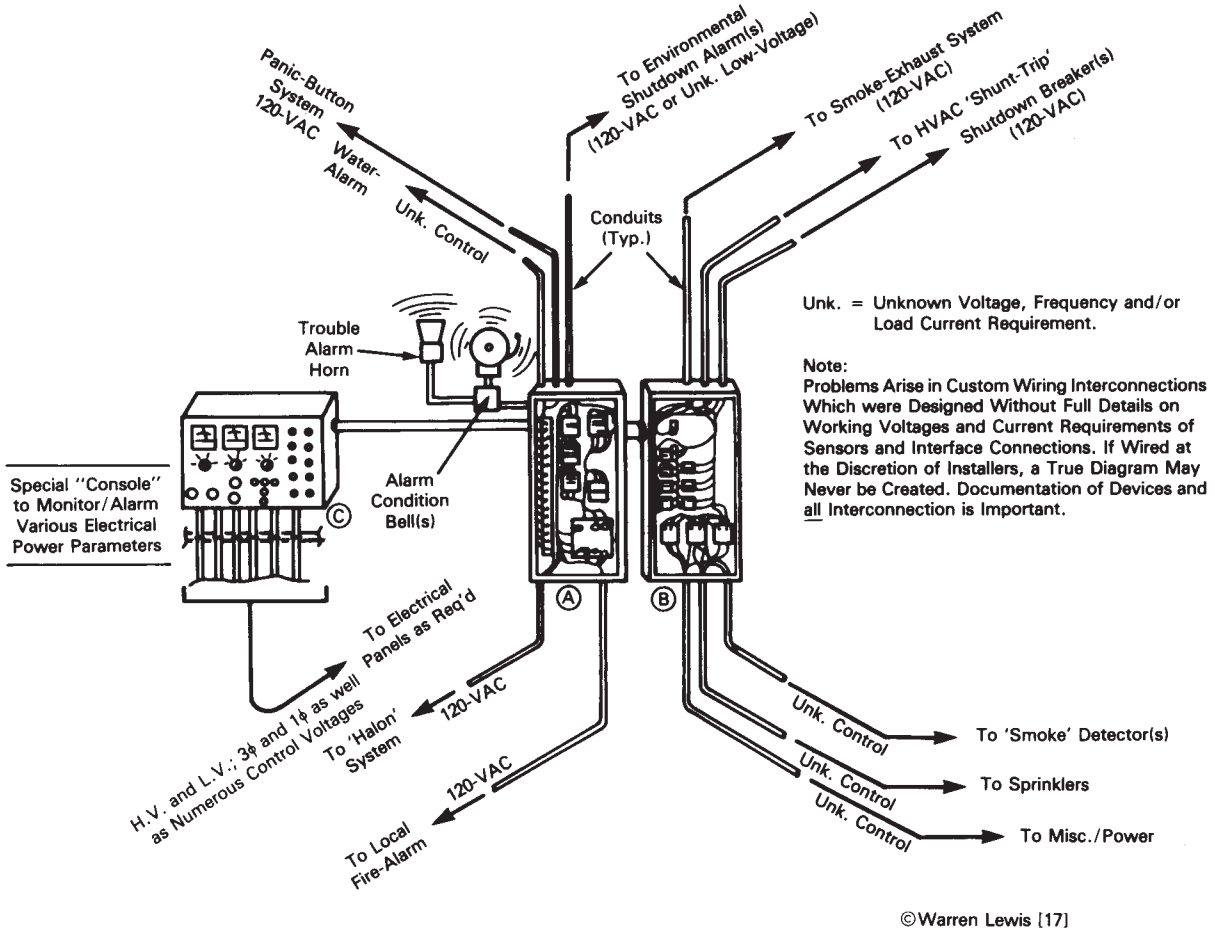


Figure 66. *ADP site basic life-safety system elements to be coordinated include:* A—the halon fire suppression control system cabinet; B—the smoke, fire and sprinkler alarm and arming system cabinet; C—a "console" to monitor other parameters of the environment such as room temperature, humidity, water under the floor, status of power sources, HVAC equipment, etc.

Some of the life-safety functions to be coordinated are described below.

REPO and EPO "Panic Buttons" are the remote emergency power off and emergency power off switch push buttons required by safety code. One must be at each principal exit from the ADP room. Others may be located on the life-safety console and near operator's work stations. They are intended for emergencies only since they drop all power to the ADP equipment and other loads in the computer room except lighting, and at the same time initiate shutdown of ventilation and air circulating blowers. The surge from an EPO operation stresses ADP hardware and can cause component damage. It should never be a substitute for orderly shutdown of ADP equipment in the normal, prescribed method.

Smoke detectors are available with at least two different operating principles. One simply compares the transmission of light through air in the room with light through a sealed optical path into which smoke cannot penetrate. Smoke causes a differential or backscattering detection. This creates a signal which will trigger an alarm when a threshold has been exceeded.

A more common smoke detector senses the ionization of combustion products rather than visible smoke. A mildly radioactive source (usually nickel) ionizes the air passing through a screened chamber. A charged probe catches ions and detects the small current which is proportional to the rate of capture. When combustion products or material other than air molecules enters the probe area, the rate of ion production changes rather abruptly, generating a signal which triggers the alarm contacts. Such detectors can be set off by sudden leaks of freon refrigerant (in fact they can be tested in that manner) or by the propellent in many spray cans. They can also be set off by a spider making a web or by excessive dust. The probe and screened chamber require occasional cleaning.

Temperature limit and rate of rise detectors are the basis on which many fire detectors operate. Some detectors contain both, either of which will trigger the alarm contacts. The temperature limit detector is not suitable for areas which naturally become very hot, such as under an uninsulated roof or over a boiler. The rate of rise detector is unsuitable if placed near a door which is opened to outside air in the winter. The combination may be used to respond to either condition irrespective of the other (contacts in parallel), or to overtemperature only if there is also a simultaneous rapid rate of rise (contacts in series). The proper type must be selected for each location.

Flame detectors are available which respond to infra-red when it flickers with the unique characteristic of flame, but not to heated surfaces or objects. Such detectors will respond to a lighted match, for example, but not a cigarette. These are used around hot objects where heat is expected but flame is unwanted. The ultraviolet light from flames is also used to distinguish between hot, glowing objects and open flame to actuate an alarm from an ultraviolet sensing detector.

Halon discharge control units accept the inputs from sensing alarms. They perform the functions of system supervision, audible alarm, pre-alarm, manual actuation, manual override, time delays, and equipment shutdown. Relay contacts are provided for operation of remote alarms, actuating the ADP system's EPO circuit which in turn shuts down room air conditioners, air handlers, other forms of ventilation, and possibly fire dampers. Units may contain standby batteries in event of main power failure.

The Halon fire extinguishing agent is a low toxicity compressed gas (Halon 1301) which is contained in pressure vessels. Discharge nozzles in ADP rooms and tape or disk storage areas are arranged to dispense the entire contents of a central container or multiple smaller containers of Halon when actuated by an electrical signal from a control unit. The charge is sufficient to extinguish flame and stop combustion of most flammable substances. Only 5% by volume of Halon 1301 is needed to extinguish fires, yet the mixture with air is capable of supporting life of the occupants without impairing their ability to react and escape.

Halon has virtually replaced carbon dioxide (CO_2) as a fire extinguishing agent in ADP installations. In concentrations sufficient to extinguish fire, CO_2 would suffocate individuals exposed to it or who might remain in the room. If CO_2 were to be directly discharged into the interior of an ADP system enclosure, the sudden temperature drop would create widespread damage and most likely a need to replace the hardware. In the case of Halon, components not directly exposed to fire or heat would unlikely be damaged. Combustion products (soot and film) spread before the discharge of Halon could create a cleaning problem.

It is not recommended that individuals remain in a room where Halon has been discharged, but they would not suffocate or suffer serious consequences by breathing a fire extinguishing concentration. If fire or heat prior to the Halon discharge had created combustion or decomposition products, these would most likely be toxic and could become mixed with the room air and Halon.

While Halon is one of the prime fire extinguishing agents used in many ADP installations, it may not be practical in large open space computer centers. Halon gives a one-shot approach. The use of pre-action water sprinkler systems is more realistic, particularly as a back-up, but it should require activation of at least two smoke detectors in adjacent bays before the sprinkler system is charged with water. The first smoke alarm should also initiate an immediate investigation of the cause by the computer operators, giving them a chance to fight a local fire as in a waste basket before the firefighters arrive. The operators can also initiate intelligent emergency power shutdown procedures before a large fire melts the fusible links in the sprinkler heads and initiates water discharge. Where sprinklers are used, floor drains and emergency power off (EPO) push button controls must be provided.

While water will cause damage, the consensus is that its impact on people and equipment is the lesser of two evils when compared to the consequences of fire.

In smaller, confined spaces (tape storage vaults, smaller computer rooms, or where large amounts of combustible carbon paper and printed forms are being stored, processed or handled), Halon has been shown

to be very effective upon its initial discharge. If on ventilating and purging the Halon there should be another fire, the back-up of a water sprinkler system could be welcome.

Where the data stored in tape libraries are particularly valuable or critical, some tape libraries and vaults require special fire protection with fire-rated walls of a minimum of 2 h fire resistance.

The greatest disadvantage of Halon is its cost. Replacement of one charge after intentional or accidental discharge in a computer room may cost $2,000–$20,000 or more. For this reason Halon 1301 is sometimes arranged for local application rather than total room flooding. Underfloor cable and plenum areas are often required to have firewall barriers to partition large ADP plenums into smaller areas. This prevents the spread of fire and reduces the amount of Halon needed for any local application, but may complicate the underfloor cable and air flow paths. Fire detection and Halon discharge may then be divided into zones.

Automatic power removal to ADP equipment must be a consequence of fire detection as well as operation of any "panic" REPO button.

Automatic shutdown of cooling air and ventilation must also be a response to any fire, heat or smoke detector in that area or zone, or to any REPO actuation.

Fire dampers blocking air ventilating passages must close in response to the fire, heat, or smoke detectors. This prevents fires from spreading through such passages and prevents fresh air from fanning the flames. This and the shutdown of cooling and ventilating air enables the Halon to be retained in the protected space until the fire is extinguished and it is time to remove smoke and Halon.

Automatic start-up of smoke removal fans must be given very careful consideration to ensure it does not occur before the fire is out since it will remove the Halon.

The mechanical design of the smoke removal blower system should ensure that the floors above and below the fire floor will have a slightly higher air pressure so smoke will not migrate from the fire floor to the adjacent floors.

Large ADP rooms with relatively few occupants do not need as much make-up air from outside ventilation as rooms with normal occupancy. For this and other obvious reasons, the make-up air fans are usually inadequate to purge smoke. Therefore smoke evacuation fans are usually needed to supplement the normal exchange of outside air. Even though there may be an automatic control, it must be capable of being overridden and controlled manually from a safe location.

Controlled personnel access to ADP areas has become a virtual necessity. The opportunities for mischief, vandalism and sabotage, and the consequences justify an access control system. A side benefit of reduced traffic is less dust and dirt. An air lock with two separated doors controlled with electric locks can serve as a combined access control and control for dust and dirt. The ADP room should have a slightly higher air pressure than the surrounding rooms so air and dust will be expelled rather than drawn into the ADP room.

In the interest of security, there may be a desire to control all door openings for entrance or exit with electrically controlled locks, access control systems, and access cards or keys. In the interest of safety, provision must be made for emergency exiting, even though it may be a panic bar. In event of a fire or other emergency in the ADP room which may occur simultaneously with a power failure, means must also be provided for emergency access by the fire department or other authorized people. Door locks which unlock when power to access control is interrupted is not in the best interest of controlled access, but safety may take precedence.

5.2 Coordination of Life-Safety and ADP Functions

"What to automate?" and what to do manually requires considerable judgment. If all the override switches are made readily available, alarms can be left disabled when they should be active. Yet, there must be some provision for working on the alarm systems, testing them, welding in a protected area with close supervision, and other situations where false alarms would result if they could not be disabled.

If the life-safety control panels are accessible to many site employees, most functions should be made automatic. Important alarm silencing controls should be under lock and key. While any function is disabled, a conspicuous indicator light showing what function is disabled and a master indicator light showing that at least one function is disabled will help remind all concerned that the life-safety function is impaired and must be restored. Lights can be arranged in orderly columns or rows with large, legible identifications; they can be put on a mimic board to help identify function and location, or a combination of both.

Sensors which detect smoke, heat, rate of rise, and flame should not be easily disabled. Many such systems are designed so sensors will have a fixed resistance in the safe condition, but will cause an alarm signal if the circuit is either opened or shorted by contacts, an unwanted short circuit, or open circuit. Damage to the sensor or its circuits would be much more likely detected by this scheme.

While any alarm override or silencing switch is preventing EPO tripping, Halon discharge, or sounding of audible alarms, these override and silencing switches must not deactivate the sensors or their alarm indicator lights.

When enabled, and the master alarm is tripped by a sensor, the alarm should first remain restricted to the ADP area for a sufficient time for site personnel to investigate the source of the alarm condition and verify that there is or is not a fire. If within a preset time delay of typically 2 minutes it cannot be verified there is no fire and the RESET has not been actuated with a key, the continued alarm condition will activate the fire alarm system to the local fire department. However, before any such plan is put into effect, discussions with and concurrence by the local fire department should be achieved.

Alarms for water under the floor, unauthorized intrusion, and serious problems with power and air conditioning requiring immediate action may not be as urgent as a fire, but should be handled in a similar manner. However, instead of sending the alarm to the local fire department, the alarm might be directed to the building engineer and/or security guards.

Automatic features should not prevent manual initiation of an alarm for fire, unauthorized intrusion, or other observed emergency condition such as a need for medical attention.

Location of life-safety controls, indicators, and reset buttons need to be convenient to the personnel expected to respond to them. If this is to be the shift supervisors of the ADP room, a console or cabinet assembly can be near the operating console for the computer system. If it is to be the security guard on duty, it should be located where it is convenient for the guard. Some functions need to be displayed at both locations.

If a security guard is not free to leave his post to investigate alarms, or if he leaves regularly to make inspections and his post is often unattended, the ADP shift supervisor or his assistant may be better able to respond to alarms. It can be important for someone familiar with the ADP total site to go quickly to an indicated alarm area to determine by inspection whether there is a real problem or an alarm malfunction. Smoking in an unauthorized area or a wastebasket fire may not be worth an emergency power off, discharging $5,000 worth of Halon and calling the fire department. Intelligent use of an override switch (under lock and key in many cases) can save time, wasted effort and money.

An organized but inconvenient life-safety system is shown in figure 67. With some thought and planning, the system can be both organized and convenient as shown in figure 68. A checklist of life-safety system features suggests the following actions be taken:

- -Group controls, indicators, and silence plus reset buttons by function such as those relating to fire, spilled liquid, unauthorized intrusion, heating, ventilation, air conditioning, and power sources including power conditioning, etc.
- -Be consistent among similar functions in use of position, color, style, and arrangement for switches, indicator lights, and other indicators. However, use differences in appearance and tactile feel to distinguish functions which must not be confused with each other. The REPO button should be unlike a doorbell.
- -Use human engineering to keep it simple. Use pictorial identification if possible. Label all indicators and controls. Post simplified instructions. Use manuals.
- -Interface the life-safety system with automatic data logging, if available.
- -Insist upon and get complete schematic diagrams, including "as wired" and "as installed" corrections for all devices and interconnections.
- -Prepare and conduct formal acceptance tests, plus periodic scheduled maintenance and testing to verify the viability of the system. All systems require exercising (with the exception of Halon discharge) to verify their capability, typically on an annual or semiannual basis.

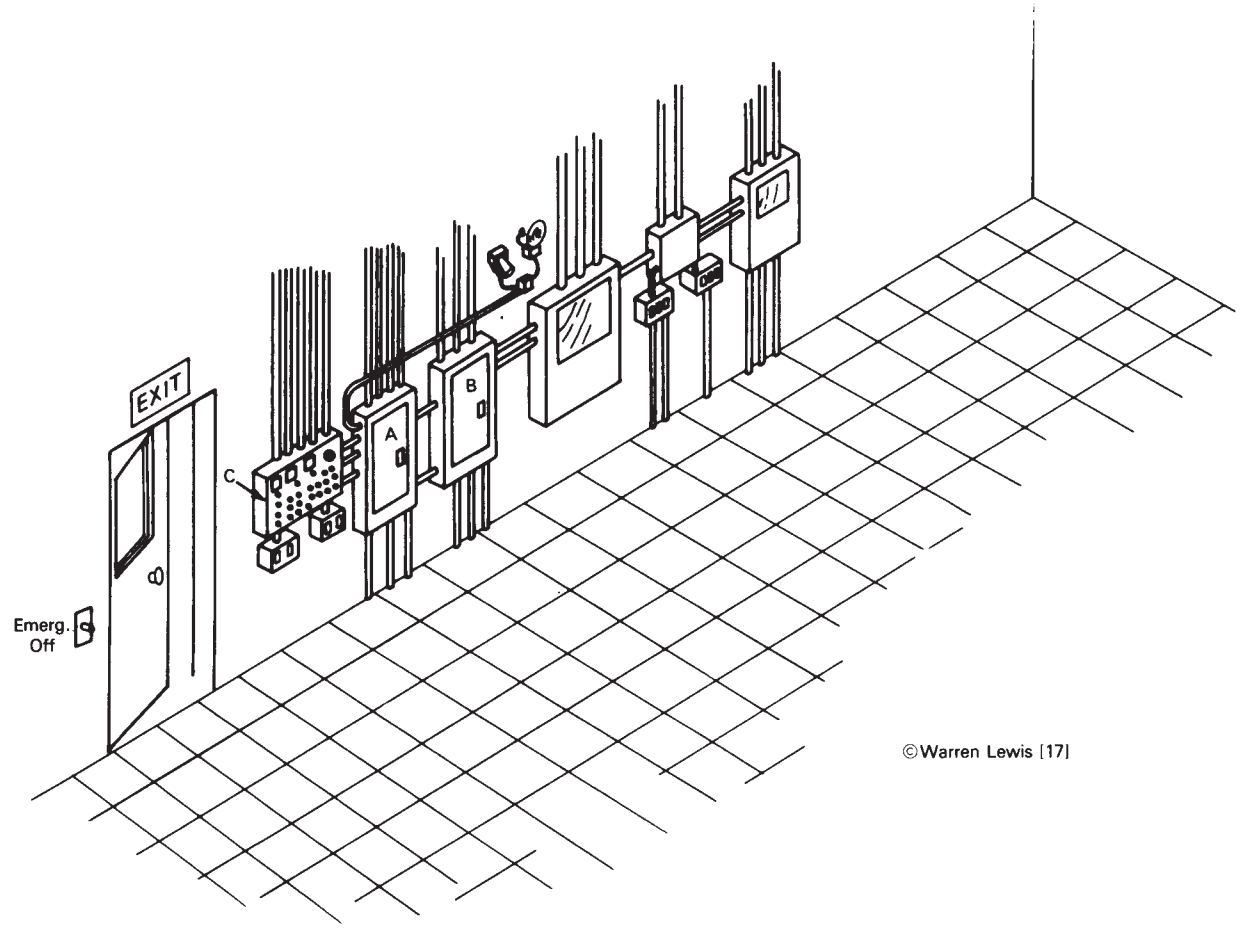


Figure 67. *Organized, but inconvenient life-safety controls.*

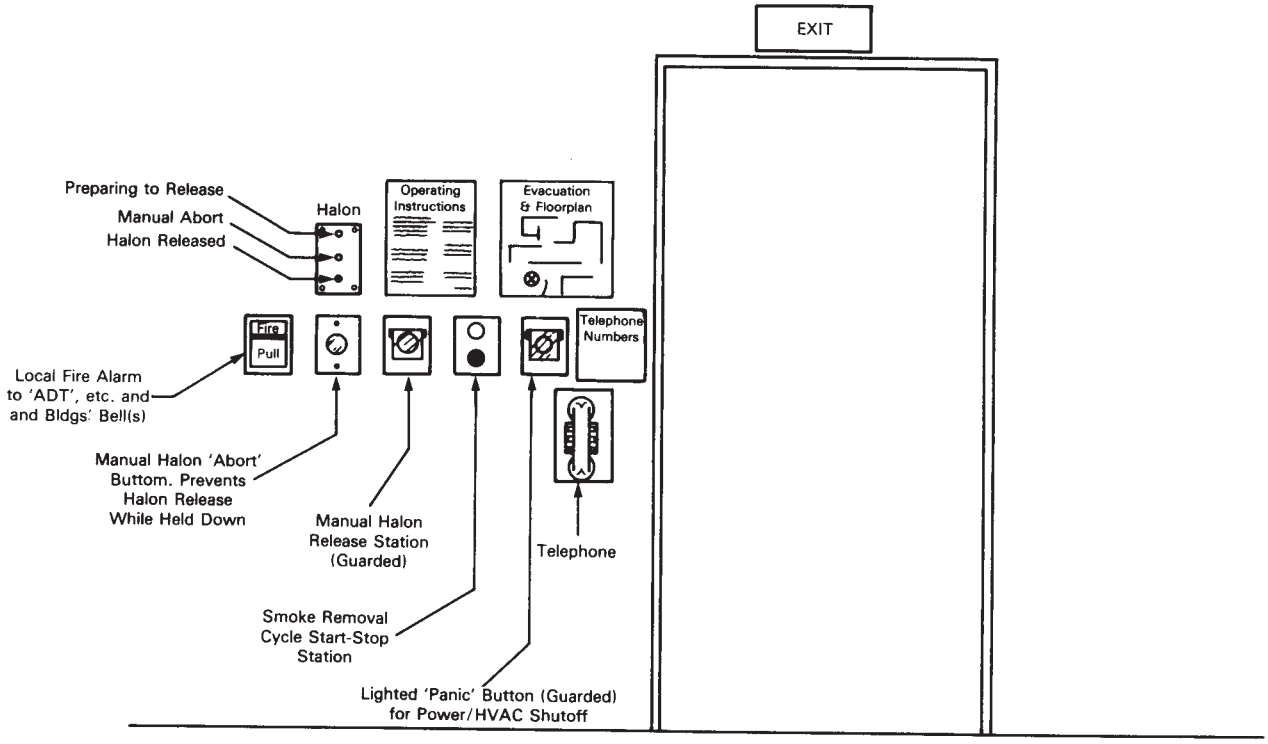


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Figure 68. *A well-organized, convenient, and coordinated arrangement of life-safety indicators and controls:* An emergency telephone with separate line (not via PBX or switchboard) is needed near the exit and the life-safety indicators and controls. The audible alarm should not be so close to the telephone as to defeat attempts to communicate.

Power for life-safety functions is very important because lack of power will render them ineffective. The more important functions such as fire-related sensors and alarms require self-contained back-up batteries in addition to a normal source of ac power. If UPS power is available to the ADP system, it can be used as a primary source of ac power. If it fails, a transfer relay can automatically connect the life-safety system to an alternate power source. Means must be provided and a schedule established for periodically verifying that the battery has not deteriorated to the point where it cannot supply power for many hours.

Interfaces with other building services raise problems of where the power sources are to be located and where the contacts and controlled relays are to be located. Without planning, there will be power sources for remote sensing on each side of the life-safety's interface with other building services, and it will be impossible to take all voltage off of interface wires without interrupting power in several locations. The system can be simplified by using a common control voltage, typically 12- or 24-V ac with a high enough impedance power source that accidental short circuit will not cause damage.

If a wire pair or cable is used to connect each remote sensor to the life-safety watch and warning panel, the number of conductors and cables can become unreasonably large. Some of the functions of sensors at remote locations can often be logically combined to give an overall indication that all sensors are "normal" or at least one sensor is in an alarm condition. Decisions must be made on the amount of detailed information needed at the central panel. It may be acceptable for that detail to be available only at a subpanel near the area its sensors are monitoring.

Fire-related alarm circuit conductors are generally required to run separately in conduit containing only those conductors, with size and type prescribed by code.

Interfaces must not be permitted to create unwanted ground loops capable of conducting electrical noise into the ADP grounding system. This can be controlled to a large extent by following the single entry point principle as described in subject matter on grounding.

Electrical noise, often present on the conductors to remotely located sensors, can be controlled by various methods appropriate to the type of signal to be transmitted and the characteristics of major noise sources. The signal should be filtered before entry into the life-safety cabinet's logic and control circuits. If

filters reject all input frequencies except those needed to conduct the needed intelligent signal (often using a simple low pass filter), much of the noise current will be reflected, diverted, or made incapable of causing malfunctions in other nearby circuits. Optical isolators can be used in conjunction with simple low-pass filters to reject both normal and common mode noise.

Operating the life-safety panel from the same power source and ground used for the ADP units will reduce the need for isolation of sensor circuits in the ADP room.

Provide a telephone with an outside line (for outgoing calls only) at the life-safety control panel. If someone finds himself holding down a push button which will inhibit the release of Halon as long as he holds his finger on the button, and if he has no key to override the system, it may cause an unnecessary Halon discharge and recharge if the telephone is not within reach. Another telephone should be provided for regular telephone service and incoming calls.

At night if the switchboard is unmanned, or if the power to the switchboard is interrupted, it may not be possible to use an extension or any other direct dial phone if it must pass through the switchboard. An outside direct line will be useful for necessary communication if other office telephones become unusable during a power outage which would disable a PBX or other automatic switchboard on the premises.

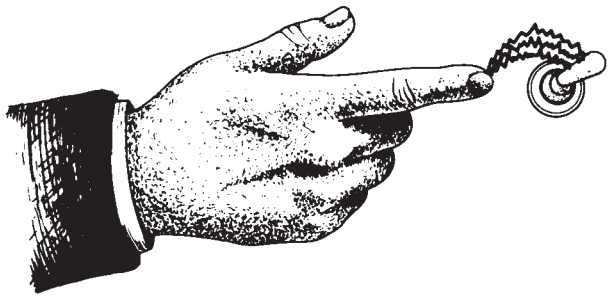
Future expansion capability must be a part of life-safety systems for the same reasons ADP system facilities must be expandable. Many of the life-safety device control cabinets are offered in forms which can be mounted on walls or in forms which can be mounted in telephone relay rack cabinets suitable for mounting 19-in-wide panels. The cabinets enable more flexibility to change and add functions to installations as needed. Moreover, the connecting cables and multiple small power supplies can be neatly arranged out of sight, but easy to access within the cabinets.

If the life-safety system also has a data logging system with a microcomputer-based processor for identifying significant changes and logging only those and their time of occurrence, this can facilitate recordkeeping and can send the condensed output to remote printers or video display panels. Moreover, the status of any specific sensors or all sensors can be requested remotely to initiate a response. Being programmable, such systems can record as little or as much information as desired. Such systems are most helpful in assuring that all events of interest are recorded and not left up to the judgment of the person who must decide at the moment whether or not an event is significant.

Data logging and process control computers are subject to malfunctions, unwanted halts, and failure. They should not be depended on to process warning signals and to sound alarms where failure would result in great danger to life or property. Such output warnings should not be ignored if available, but the primary alarms and warnings resulting from hazardous conditions should be by more direct means than through a computer.

6. CONTROL OF STATIC ELECTRICITY AT THE ADP SITE

Electric charges, dislodged and trapped when insulating materials touch and are forcefully separated, can create significant voltages. The phenomenon is called "static electricity." Besides causing materials to cling to or repel each other, the charge supplies the necessary energy to produce a spark discharge when the distance between oppositely charged bodies becomes short enough. A 10,000-V charge can create a spark approximately 0.5 in long (fig. 69).



10,000 Volts can Create a Spark 1/2 inch Long.
20,000 Volts can Jump a One-inch Gap Between Points.
The Average Subject may be Unaware of a Spark Discharge if Voltage is Less than 3,000 Volts, Which can be Sufficient to Halt a Computer.

Figure 69. *Static discharge.*

Such discharges are in effect miniature lightning bolts. The total energy is far less than lightning strokes can deliver, but these discharges are much closer to the sensitive electronic equipment they are able to disturb. A discharge to any conducting surface creates very fast rise-time impulse noise current. All static discharges have become notorious for their ability to cause malfunctions and even destroy semiconductor circuits and devices.

Unfortunately, ADP sites often have static discharge problems without anyone being aware of it. Few subjects can feel a discharge of less than 3,000–4,000 V from their own charged bodies, but this is more than enough to disrupt a computer circuit. It is not until discharge voltage exceeds 10,000–15,000 V that subjects learn that discharges can be unpleasant or painful.

Some of the techniques for controlling static problems are outlined below.

6.1 Humidity Control

Humidity control to achieve 50% or higher relative humidity will greatly inhibit electrostatic problems. Too much humidity, however, will create corrosion problems and may make some paper products dimensionally unstable and too limp to handle. Most ADP equipment manufacturers recommend 40–60% relative humidity. Others say they can tolerate 20–80%. Correcting humidity (raising it in winter and trying to lower it in summer) requires much energy and is expensive. If other techniques are effective, the cost may be less. However, humidities below 30% and occasionally 40% may create static electricity problems and dimensional change problems with printing paper.

6.2 Conductivity of Floor Surfaces

Conductivity of floor surfaces is a selectable characteristic which will prevent or limit static buildup on personnel who walk on them. Nylon carpeting can be among the worst. Vinyl-asbestos can be marginal. Pressure laminates are better but not perfect. Conducting synthetic rubber and other special purpose floor coverings for use in hospital operating rooms and munitions loading areas meet all conductivity requirements, but often lack attractive appearance and are costly. Floor polishes can make them unacceptable. It takes only a thin coating of carnauba wax to create a problem.

Typical floor surfaces which are acceptable at 50% relative humidity and which remain acceptable down to about 20% relative humidity include pressure laminates (unwaxed) and some carpeting with

strands of conducting fibers in the yarn and semiconducting backing to spread the charge. The 20% is a lower humidity than most ADP equipment can tolerate without malfunctioning. Floor surfaces and their coverings can be tested by instrumentation illustrated in figure 70.

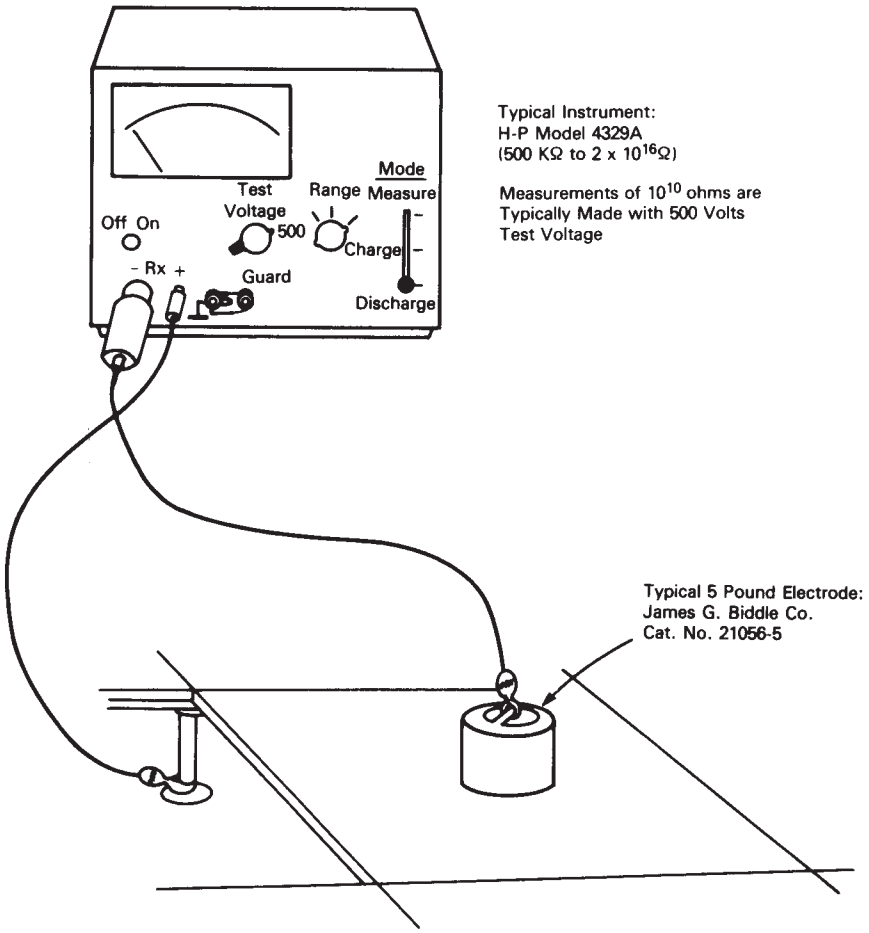


Figure 70. *Static electricity control:* This becomes easier to accomplish if floor resistance to "ground" does not exceed 20,000 megohms (2×10^{10} ohms) during the lowest relative humidity condition in the ADP room. This can be achieved through initial selection of floor surface material and its installation, plus the use of materials and methods for cleaning and polishing (if polished) which will not cause resistance to rise.

6.3 Static Drain Paths

Static drain paths from floor tiles or mats to the nearest grounded metal may be needed in heavy traffic areas. The charges from someone walking on the floor surface will be spread through any conducting sheet, but a path to ground through conducting material is needed to dissipate the accumulated charge. This need not be a low resistance path. A resistance range from 0.5–20,000 megohms at 50% relative humidity has been specified by a number of computer manufacturers, measured between a weighted electrode on the surface of the floor and the grounded subfloor. Another manufacturer specifies a maximum of 1,000 megohms. Many materials will qualify when humidity is 50% or better, but very few do so at 20% or less.

Metal contacts between removable floor panels and supporting metal structures are not necessarily needed. The fiber or synthetic cushions or gaskets which are sometimes used to make a floor quiet to walk on are acceptable if they are sufficiently conducting to meet the specified resistance range deemed adequate to drain static charge. If the facility is intended to operate at less than 50% relative humidity, the resistance should not exceed the 20,000 megohms maximum at the lowest humidity to be encountered.

A separate static drain path may not be necessary if there is sufficient conductivity of the floor surface and carpeting, if any, to remove static charge as it is generated. Resistances in the drain path of less than 0.5

megohm are believed to increase the hazards of electric shock and the possibility of spark discharges which create unwanted electrical interference.

6.4 Carpeting with Low Propensity to Static Electricity

Carpeting with low propensity to static electricity and suitable for ADP installations is available in the form of mats, continuous material in customary widths, and in squares which may be permanently attached to each of the removable floor tiles (fig. 71). Where underfloor access is needed, the continuous material is not feasible. Some mats with heavy, flexible backing and bound edges will lie flat without being permanently attached to the floor. They can easily be lifted for underfloor access, cleaning, or replacement. They do not appear to create a tripping hazard since the edges appear to remain on the floor [18].

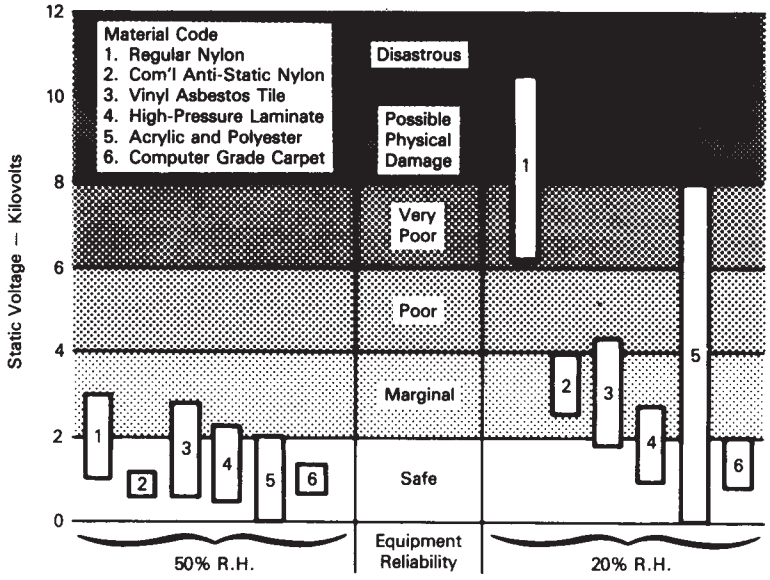


Figure 71. *Typical static voltages generated by walking on common floor covering materials* [18].

6.5 Furniture and Upholstery

Furniture and upholstery in ADP rooms and in offices where terminals are in use can be a contributory cause of static electricity. A person sitting in a chair and rising can generate a very large voltage. This can cause energetic spark discharge and cause corruption of data or even damage. The same materials used for computer room carpeting can be used for furniture upholstery and alleviate the problem. The casters on chairs and other movable office furniture should have metal or conducting rubber or plastic wheels. All stationary feet should be uninsulated.

6.6 Shoes and Clothing

Shoes and clothing of personnel also generate static. Treating shoes and clothing with the antistatic preparations sold in markets appears to solve this problem.

6.7 Ion Generators

Ion generators for neutralizing localized chronic static problems are a product commonly used in semiconductor assembly plants and in the printing industry to dissipate static charges. Without them, charges which accumulate on personnel and containers for semiconductor products become the source of spark discharges which damage or destroy the semiconductor product. In the handling of paper, static charges deflect the paper movement or cause it to stick.

There are several types of ion generators: passive, high-voltage ionizers, and radioactive ionizers. The passive units operate on the basis of exposing multiple sharp points to the electric field. If it is intense, the high-voltage gradient at each point or edge causes the dissociation of air molecules into ions free to move toward opposite charges. These become a mechanism for discharge without creating a spark. They can be simple and inexpensive, but will not operate until a charge and voltage gradient have already appeared. The metal tinsel rope braid draped across the paper output path from high speed printers is an example. It should be noted that grounding the tinsel improves its effectiveness.

The high-voltage energizers work on a similar principle, but are supplied by high voltage from a transformer, with or without rectification. Thus an unwanted charge need not be present before ions are generated. The use of ac alternately creates positive and negative ions in the airstream created by a blower in the ion generator. Ions of each polarity will neutralize charges of opposite polarity to which they are attracted. No charge transfer takes place between ions and charges of the same polarity because they repel and never make contact. Leftover charges of opposite polarity will find each other and recombine into a neutral entity; others drift until they finally find an oppositely charged body.

The radioactive ionizers create ions without high voltage and may contain a small blower to move air past the ion source. Such devices containing radioactive material are leased rather than sold to maintain control over use and disposition of the radioactive material when no longer needed or when radioactivity has decayed to ineffective levels. These units are not generally recommended for use where the potential hazards are not completely understood and where the responsibility for having and returning radioactive material is unacceptable.

These ion generators can solve problems with the handling of charged paper and document handling and can dissipate charges on objects where other attempts to prevent static buildup are ineffective. They are not suitable for filling a computer room with ions to neutralize static in a large area, but are restricted to small, localized, or confined areas.

6.8 Desensitizing Electronic Circuits

Desensitizing electronic circuits highly susceptible to static discharge has become a specialized art. It is much easier to begin with the basic design of circuits, their layout, and packaging than to fix a product which has already been manufactured and found to be overly sensitive. There are some steps which can be taken external to the product, however, such as installing an antistatic mat or installing balun filters in the data interface cables (see avoidance of ground loops under grounding techniques). It may also help to stop for a minute before touching an ADP unit, for during that interval any charge on a person may leak off and be reduced to an acceptable level.

7. LIGHTNING PROTECTION [28]

Lightning can adversely affect ADP systems in several ways. It can be responsible for interrupting power without excessive voltage or current surges ever reaching the ADP system. It can open distribution circuits or create voltage surges accompanied by current surges. These will enter conductive paths, following power conductors, communications lines, piping, structural steel, and ducts until they pass through portions of the ADP hardware and its interconnections on its way to earth ground. The powerful electromagnetic pulse (EMP) created in the vicinity of a lightning stroke [5] can induce significant noise impulse voltages and currents in the interconnections of an ADP system without having to flow through conductors to reach the system.

The noise signals from lightning can easily corrupt data signals. They can also be large enough to destroy insulation, conductors, contactors, and other circuit elements and devices. Unless a direct stroke is encountered at or immediately outside the facility, the impulses which reach the ADP facility will most likely travel some distance along power or communications lines before they enter the facility building as illustrated in figure 72. As they travel, they are fortunately attenuated and the voltage wave front becomes less steep. Arrestors will have more time to respond to the more slowly rising voltage wave. Distance between the ADP system and the lightning stroke helps the chances of survival.

The energy in lightning strokes is incredibly great. The energy needed to destroy or disrupt operation of a semiconductor is incredibly small. No single device can provide complete protection. The survival of ADP equipment and its chances of continuing operation without interruption or error during lightning storms in the vicinity depend upon a series of protective devices, starting with the protection of overhead power lines and ending with filters and grounding at the ADP hardware.

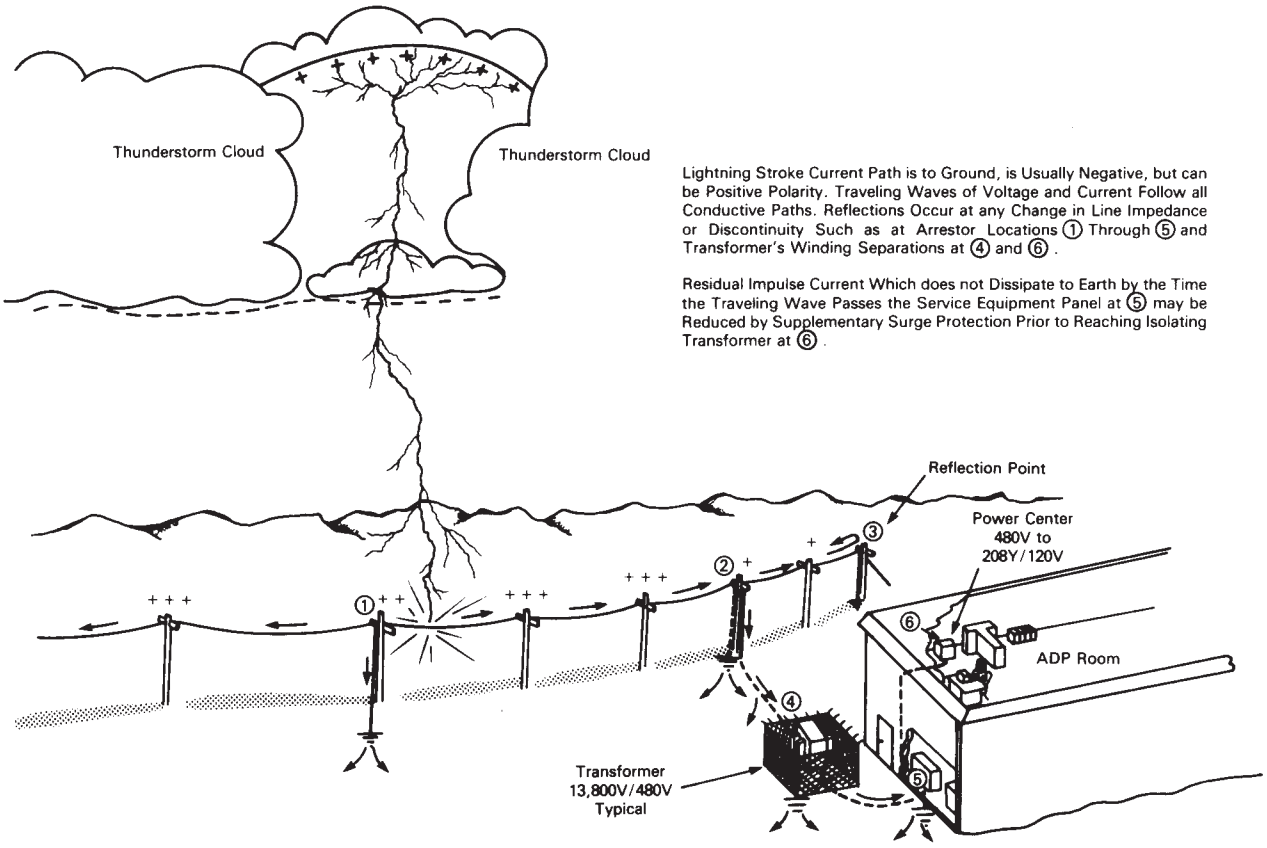


Figure 72. *Lightning strike to overhead distribution line.*

7.1 Primary Protection Belongs Outside the Computer Room

Protective devices are incapable of absorbing the energy of a lightning stroke or even a small part of that energy. Lightning arrestors should more properly be called lightning diverters. Upon being exposed to an overvoltage, they become conducting and create a direct path to a grounding conductor leading to a driven earth ground rod or other earth electrodes. The conduction will cease when the current reaches zero and remains at or near zero long enough for the path to deionize and recover its insulating state. This may take several cycles and may involve a number of restrikes.

The traveling voltage waves on the overhead lines are created by the sudden appearance of large voltage drops through utility conductors as lightning currents pass through them on their journey to earth. Usually this is through the overhead grounded "static" wire which is usually strung above the phase conductors. It is connected periodically to ground via wires on the poles and driven ground rods at their bases. In areas with frequent lightning storms, surge arrestors between each phase and the ground wire plus a ground rod may be located at every pole.

When the traveling wave reaches any discontinuity in the line such as at the last pole where an overhead line may be terminated without a service tap, the voltage wave is reflected from the open end while voltage is momentarily doubled in the process. Service taps should not be located at the end pole, but preferably 100 feet or more from it.

Although arrestors on the overhead line will pass much current to ground, the voltage drop between the line and earth could easily be more than 100,000-V peak at the first grounding point near a direct strike. This will attenuate as it travels along the line and it may attenuate more as it passes other surge arrestors. At the point the surge enters an underground cable, the capacitance to ground will cause a further reduction in crest voltage. By the time it reaches the transformer primary for reduction to a typical voltage of 480Y/277 V on the secondary, the magnitude of the lightning surge will have been reduced significantly.

The input circuits to many transformers in this type of service may have self-contained gap protectors inside the unit. Whether or not the input fuses may blow, the purpose is to protect the transformer windings from insulation breakdown. The gaps shunt excess voltage to ground at the transformer if the gaps should spark-over. By this time, the surge voltages and currents which have reached the transformer primary have been greatly reduced from the magnitude of the original lightning stroke.

The gaps may be supplemented by lightning arrestors on the primary, but it is the decision of power companies to provide them if needed.

7.2 Residual Surge Protection in Power and Communication Lines

As the lightning surge moves toward the load, it is greatly attenuated by the separation of primary from secondary windings. Between the secondary winding and the service equipment for the building is an effective location to install supplementary low-voltage arrestors where the potential is typically only 277-V rms from each line to ground.

This is where the power actually enters the building, so arrestors at this point will "condition" all the power entering the building and not just a portion which is directed to the ADP room. If only part of the circuits into the building have arrestors, the surges could easily find other paths into the building and reach computer circuits by devious paths.

The last place one wishes to have lightning surge currents is in the computer room. To accomplish this, the current diversion must be accomplished as far from the ADP system as feasible. If the surge is allowed to reach the ADP room and a lightning arrestor is installed there, the only ground to which the surge current could be diverted at that point would be the ADP system ground. That could be a disaster! However, supplementary surge protection to reduce residual impulse voltage from primary arrestors is not a bad idea. Figure 73 illustrates the elements and their application to ADP systems.

In understanding surge voltage and current waves, one must remember that the energy within conductors can be neglected. All of the energy of the electromagnetic wave will be between conductors (electrostatic field) and around conductors (magnetic field). The conductors merely guide the wave. The coupling of those fields with other conductors which may parallel or cross them becomes a major path for energy to transfer to them.

If a set of surge arrestors is installed at the service equipment, only three will be needed, one for each phase to ground where ground and neutral are common. If located downstream where neutral and ground are not a common conductor, an additional arrestor would be needed for the neutral if a neutral were in use.

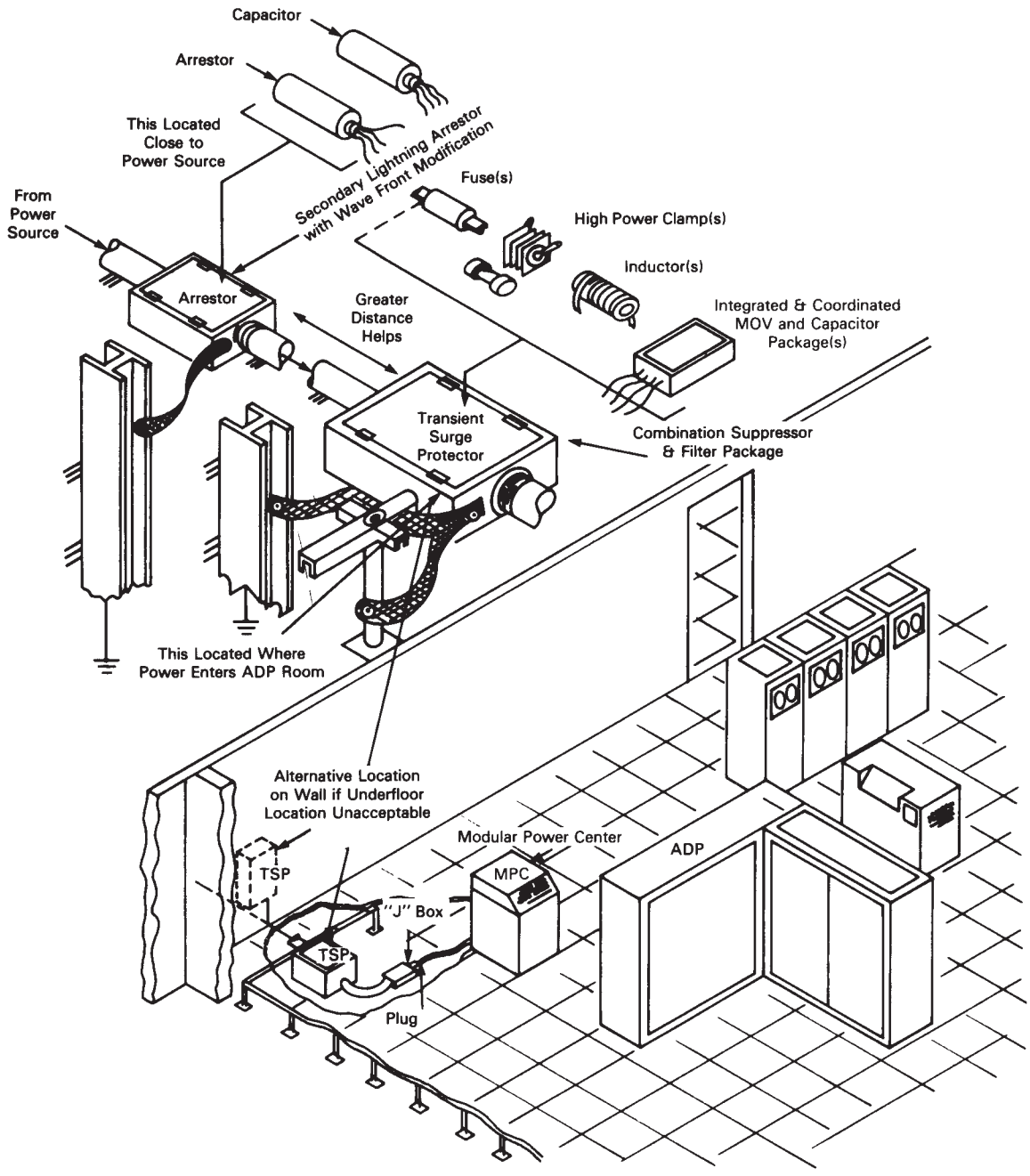


Figure 73. *Supplementary surge protection elements.*

Communications lines need protection as much as power lines. Arrestors should be located near the communication cable entrance to the building. For best protection, a coordinated combination of protective devices is needed. Carbon block gap or gas tube protectors should be the first elements to take the largest currents to ground. Going toward the data communications equipment, the communications conductors can be passed through such current limiting elements as resistors. On the protected equipment side of the current limiters, one can install devices which will limit the surge voltage to a much lower voltage with silicon protective elements which clamp on overvoltage and prevent further rise, yet become an open circuit at normal operation voltages.

Residual surge protection can be placed directly at the input terminals of power and communications devices being protected. The longer the distance between the primary protection at the building entrance and the protected equipment, the more protection this distance will provide in attenuating the strength of the surge impulse from a lightning stroke.

7.3 Protective Device Locations

Protective device locations have been implied in the previous description. The primary protection devices should be located where the services enter the building. If the entrance points are not more than 25–50 ft apart, the voltages occurring between their respective grounding points will not be difficult to limit. Voltage differences between grounding points at greater distances may require substantial interconnections of copper grounding busbar or strap in order to limit them.

7.4 Unwanted Paths for Surge Entry Into the Computer Room

Unwanted paths for surge entry into the computer room can be identified by a careful review of all conducting paths, whether by power conductor, communications lines, radio or television antenna cable, water pipe, ducts, and structural members.

If air conditioning equipment heat exchangers or condensers are located in a penthouse on the roof, make certain that the refrigerant or cooling pipes from penthouse to computer room are not a virtual lightning rod which when struck by lightning will guide the lightning into the computer room and its grounded cables as a path to the earth.

In lightning storm areas, buildings of reinforced concrete should be constructed with steel reinforcing welded together for good electrical continuity before the concrete is poured. Any structural steel bolted to concrete reinforced columns should be electrically bonded to the reinforcing. When the building is completed, lightning protection should be installed in accordance with applicable codes. A perimeter conductor, to which all lightning protection down-wires and driven ground rods are attached at or below ground level serves to help equalize the voltage gradient around the building at the time of a lightning stroke.

A lightning protection ground rod system is not to be used for an electrical power ground required by code. However, this does not imply that they cannot be interconnected.

Ducts, vents and pipes, and all roof mounted electrical equipment are to be bonded to structural steel for electrical continuity wherever this is feasible to do so. The lightning protection system with sky-pointed lightning rods must be coordinated with the electrical equipment grounding. The two systems should be complete in their own right, neither requiring use of the other system's conductors for integrity.

Within the building, conducting members such as pipes, ducts, conduits, and steel structural members should be bonded together electrically with short, direct, robust connections at intervals of about 12 ft or less. The structural steel bars for common support of multiple conduits, pipes, and ducts usually accomplish this. The result is that large voltage differences will be safely equalized during a stroke of lightning current if it should enter the building.

Special attention should be given to conducting members within the building which may be within, say, 6 ft of an exterior lightning down-wire to ground. To avoid the damage which could be caused by a side flash from the down-wire to the interior conducting members, an interconnection is sometimes made with or without a series spark gap inserted in that path. This predetermines the lightning current side path taken in the event that a surge is great enough to break down the gap. Without such a controlled path, alternate paths could create great damage. ADP interconnecting cables should be routed to avoid the possibility of their involvement in a direct or side-flash lightning path.

8. APPENDIX

8.1 Electrical Attributes of the Environment

Table I. Electrical attributes of the environment
(See sec. 2.2, page 16 for descriptions)

Some of the observable attributes of the power source at a computer site:

- Frequency and Rate of Frequency Change
- Line Voltage(s)
  - Number of phases and phase relationships
  - Slow average rms voltage, highest and lowest annual excursions
  - Phase unbalance
  - Wave shape; harmonics, modulation, deviation factor, dc component
  - Transients; "surges" and sags (slow), impulses (fast), volt-seconds
  - Damped oscillations, noise bursts
  - Radio Frequency Interference (RFI, EMI, EMC)
  - Common mode vs normal transverse mode voltages and currents
- Load Carrying Capability and Source Impedance
  - Effects of load current on voltage, steady and dynamic response
  - Effects of load power factor under starting and steady state conditions
  - Effects of load current unbalance
  - Inrush current limitations, current limiting and tripping
  - Impedance to harmonic current flow
  - Tolerance to dc component and even harmonics in the load current
  - Phase shift with load and rate of change
  - Available short circuit current during faults
- Grounding
  - Voltages to neutral and to phases
  - Ground fault impedance
  - Ground fault leakage current interrupter limits (GFCI's)
  - Single point grounding vs multiple grounds and ground loops
  - Grounding conductor impedance over broad frequency spectrum
  - Ground offset voltages between separate systems

In addition to the above, there are:
- Static electricity and other electrical discharges
- Stray magnetic fields, dc through high-frequency electromagnetics

8.2 Some Representative Power Quality Attributes

Table II. Some representative power quality attributes

Environmental attribute	Typical environment	Typical acceptable limits for computers and power sources		
		Normal	Critical	Units affected and comments
Line frequency	±0.1%–±3%	±1%	±0.3%	Disk packs, tape, regulators
Rate of frequency change	0.5–20 Hz/s	1.5 Hz/s	0.3 Hz/s	Disk packs
Over and undervoltage	±5%–+6, -13.3%	+5%, -10%	±3%	Unregulated power supplies
Phase imbalance	2%–10%	5% max	3% max	Polyphase rectifiers, motors
Power Source: Tolerance to low power factor	0.85–0.6 lagging	0.8 lagging	Less than 0.6 lagging or 0.9 leading	Indirectly limits power source or requires greater capacity unit with reduced overall efficiency
Tolerance to high steady-state peak current	1.3–1.6 peak/rms	1.0–2.5 peak/rms	Greater than 2.5 peak/rms	1.414 normal; departures cause wave shape distortion.
Harmonics (Voltage)	0–20% total rms	10–20% total 5–10% largest	5% max total 3% largest	Voltage regulators, signal circuits
dc load current capability of power source	Negligible to 5% or more	Less than 0.1% w/exceptions	As low as 0.5%	Half wave rectifier load can saturate some power sources, trip circuits.
Voltage deviation from sine wave	5–50%	5–10%	3–5%	Affects regulators, signal circuits
Voltage modulation	Negligible to 10%	3% max	1% max	Voltage regulators, servo motors
Transient surges/sags	+10%, -15%	+20%, -30%	+5%, -5%	Regulated power, motor torque
Transient impulses	2 to 3 times nominal peak value (0–130% V-s)	Varies; 1,000–1,500 V typical	Varies; 200–500 V typical	Memory, disks, tapes having high data transfer rates, low level data signals
RFI/EMI and "tone bursts" normal and common modes	10 V up to 20 kHz; less at higher freq.	Varies widely 3 V typical	Varies widely 0.3 V typical	Same as above
Ground currents	0–10 A rms + impulse noise current	0.001–0.5 A or more	0.0035 A or less	May trip GFI devices, violate code, introduce noise in signal circuits

8.3 Checklist of Considerations for Suitable ADP Power and Grounding

1. Importance of continuity of ADP "glitch-free" operations.
   - 1.1 How much down time can be tolerated in your ADP operations?
     - a) How long, each instance?
     - b) How frequently?
     - c) Are momentary interruptions acceptable if they require a halt-restart or an occasional reload of program, audit trail, and data entry?
     - d) What is the cost of the above events? [25]
       Cost of interruptions may be justification for power and grounding improvements and for power conditioning such as UPS installations.
   - 1.2 What power-quality related events will interrupt ADP input, processing, and useful output? For example, even with continuous power to ADP hardware, interruption of a separately powered heating, ventilating, and air conditioning (HVAC) plant could halt ADP operations.
   - 1.3 Are ADP operations dependent upon communications lines which also require continuity of electrical power?
   - 1.4 Is the ADP "back-up" site operated from the same power source, and are its communications also dependent upon electrical power?
2. Site location problems—can your site be subjected to:
   - 2.1 Natural hazards: storm damage from wind, rain, snow, sleet, ice, lightning, flooding, tidal waves, or moving ice; also fire, earthquakes, slides. An ice storm can break overhead conductors and topple poles of a power distribution system on a massive scale, for example, as in Wisconsin's experience approximately every 10 years or so.
   - 2.2 Man-made hazards: onsite vandalism, sabotage, malicious mischief, arson, collisions from vehicles, trains, and aircraft (maybe boats?) plus riots, insurrection, and war.
   - 2.3 Offsite damage to power and communications lines and essential services such as gas, water, and sewage pipes upon which supporting services depend. Overhead lines are subject to interruption by vehicles hitting poles, birds and small animals such as squirrels on power lines, falling items such as kites, tree limbs, and airplanes. Even salt used on roads in winter will be deposited on insulators as a fine dust, only to become conductive during the first fog or light mist. The result can be numerous wood pole fires in addition to much electrical noise from arcing and excessive ground leakage currents.
   - 2.4 Underground services are protected from many of the above-mentioned hazards, but are still subject to lightning damage and to excavation damage. Underground services require much longer to repair than overhead services in most instances. The risk of excavation damage may be decreased if a "dig-safe" program is enforced in the community. If there is more than one power feeder and more than one communications cable to the building, each should be placed in a separate trench rather than in the same trench. Excavation damage would then be more likely limited to one rather than both cables at any one time.
   - 2.5 Are the local electrical safety and other building codes overly restrictive in the construction materials and assembly methods which are permitted? Communities which follow the National Electrical Codes NFPA 70-1981 [20] and NFPA 75-1976 [21] without using their own restrictive definitions and interpretations permit a wider choice of safe and sometimes superior electrical construction for ADP sites. Unnecessary restrictions can dictate the use of expensive, labor intensive construction materials, and assembly methods which increase initial installation costs and continuing maintenance expense in some instances. Some ADP sites have been chosen away from municipalities with such restrictions for these very reasons.
   - 2.6 Is the cost of electricity excessively high for commercial power users at the proposed site? What are the demand charge penalties and the low power factor penalties, if any? A 250-kW load, including air conditioning, for a typical medium- to large-ADP installation would have an energy bill of more than $200,000 per year at $0.10 per kWh. Power at $0.05 per kWh would save $100,000 per year. In 1983, there are communities which charge more than $0.10, others still charge approximately $0.05 or less per kWh for a 250-kW average load.
   - 2.7 Can separate routes for distribution lines to separate power substations be provided in the event one is accidentally disabled or taken out of service for maintenance? Also, can the same strategy

be followed for telephone data communications cables? Sometimes a communications radio microwave link can be established as an alternative link to solve this problem without the necessity of running separate cables.

2.8 Are those responsible for public power and for onsite wiring and electrical apparatus reasonably concerned over and responsive to the needs of ADP user's needs? Are they adequately trained and do they have the necessary technical understanding to work cooperatively with ADP users to help them solve power-quality related problems? Are they apt to make operating errors?

3. Quality of Public Power

3.1 Review power outage and disturbance records of the local public utility. Note that some utilities record only "outages" which may be defined typically as, "An interruption of power lasting more than 5 minutes."

3.2 Review the power quality surveys such as those in references [4,5,6]. These indicate what items are typically measured and reported. How does the local utility power quality history (if available) compare with these?

3.3 Ask other ADP users in the area to show you their power quality records.

3.4 Start your own recording of power quality. Use a Power Disturbance Analyzer which records the varying values of slow-averaged rms line voltage as well as the surges, sags, and impulses. If your intended site is not available for beneficial occupancy, install the recorder at a neighboring site using the same power source as the one to be used for the ADP system, and then move it later to your site.

3.5 Exert influence in the planning stages, if possible, to have heating, ventilation, and air conditioning (HVAC) equipment supplied by a transformer and feeders other than the one(s) to be used for the ADP system. The ADP power should be provided, if possible, by separate transformers and feeders, not shared with other loads. If shared loads can be restricted to those which produce no interference, some exceptions are possible. However, they require continual monitoring to prevent addition of loads which produce problems.

4. ADP Hardware Power Requirements:

4.1 Obtain from the selected or prospective ADP vendors the following:

a) General specifications for overall power quality and grounding requirements.

b) Proposed ADP Equipment list with the following information:

-Line frequency with tolerance limits and maximum rate of change.

-Line voltage(s), phases, nominal value(s) with upper and lower limits.

-Load characteristics of each ADP unit, including kVA, kW, phases, and amperes on each phase for both normal running and starting.

-Combined system kVA, kW, power factor, amperes (both rms and peak), and heat output in Btu/hr or equivalent metric units.

-Maximum starting inrush currents for units having the 10 largest values.

c) Site preparation and installation planning manuals.

4.2 Compare ADP unit power requirements with power which is available or can be made available. Remember that voltage transformation can easily be performed with a transformer at the ADP room with the added benefit of referring the secondary voltage to the ADP central grounding point in the ADP room (common-mode voltage isolation). The feeder to the computer room area can be typically 480 V (or 600 V) three-phase when the utilization voltages at most ADP units are typically 208 V or 120 V. However, any normal mode (line-to-line or line-to-neutral) voltage variations in the higher voltage will also occur in the secondary output voltage to the ADP units. Most ADP units operating on 208 V will also operate on 240 V, and vice versa. However, equipment ratings should be observed.

4.3 If a power peripheral containing an isolating transformer and output circuit breakers is to be used to power other ADP units, the power peripheral will require a branch circuit to supply its input voltage. This can be typically 208-, 240-, 480-, or 600-V three-phase. The higher voltages are more efficient. They have lower percentage line voltage drop and generally cost less to install for a given kVA rating. In this type of installation, the secondary output circuit breakers and conductors to ADP unit loads are not called branch circuits because they are ADP system interconnections rather than part of the building site's wiring. As part of the ADP system, the power peripherals and their connecting cables are subject to UL 478 examination and listing

rather than inspection under NFPA 70-1981 or other applicable electrical code for building wiring.

4.4 List the loads and draft a wiring connection schedule.

a) Place each ADP unit which draws more than, say 5 A, on a separate circuit with its own circuit breaker and connecting cable to the ADP unit.

b) Arrange single-phase loads so they will be evenly distributed over the three phases or phases to neutral. The objective is to balance the load currents with all units in operation.

c) All ADP loads need not use the same power source to avoid ground potential differences. Using separate isolating transformers, some loads may be operated from uninterruptible power system (UPS) output while others not so critical (printers, for example) could operate on public power. These can both be referenced to the same local ADP system central grounding point if the secondary winding grounding points of each isolating transformer are interconnected with short, direct bonding straps to the common system grounding point.

d) Separate isolating transformers may be used to separate easily disturbed loads (memory, for example) from loads which create disturbances (document sorters, for example).

e) Air handler cooling units in the ADP room which use multiple continuously running three-phase fan or blower motors of not more than, say, 2 hp each can be powered from the ADP isolating transformers. This will help stabilize the load circuits against unbalance, harmonics, and external sources of line voltage disturbances. If air handlers are grouped according to the ADP units they are intended to cool, turning off power to any specific isolating transformer will turn off heat-producing ADP units simultaneously with the drive motors of units which cool them. This simplifies the task of maintaining constant temperature in the ADP room.

f) Be aware of any loads which have a dc load component of current, as created by a load with half-wave or unsymmetrical rectification or SCR control. Be aware, also, of loads having a very high harmonic content in their load currents. These can create operating problems due to saturation or overheating in the first up-stream transformer or motor-generator set. Besides high temperature rise, the observable effects may be excessive operating costs, poor efficiency, and distorted output voltage and input current waves. Such effects can render UPS inoperative and can cause very high peak magnetization current pulses at the inputs to some distribution transformers. Refer such problems to the ADP manufacturer first to see what can be done to eliminate or reduce the problem. Otherwise special line conditioning equipment may be required.

5. Matching ADP power requirements to available power

5.1 What capacity is needed in kVA and kW?

a) The sum total of power in a specific equipment list is the "connected load." However, actual measured power use may be less because each ADP unit may not have all options installed and may not draw maximum connected load continuously or simultaneously.

b) Make allowances for future ADP systems growth. Power requirements for memory and the controllers, multiplexors, and exchanges needed to address and share large memory may grow faster than the rest of the system. Build power facilities for long range.

c) Divide total power in watts by the ADP room floor space devoted to ADP use. Typical large systems use 50–60 W per square foot. A 50×100-ft ADP room full of equipment might be expected to use approximately 250 kW of power, exclusive of HVAC power requirements, for example. If the proposed installation should be substantially more or less than this energy density, it may be worthwhile to verify the reasons.

d) Are the internal impedances and momentary overload characteristics of the power source adequate to handle them without installing larger capacity than needed for the steady-state load? Are the internal impedances low enough that transient currents will not create excessive load induced line voltage disturbances?

5.2 "Ride-through" and other power conditioning requirements, if any

a) What level of power continuity will satisfy ADP operating requirements? Without supplementary energy storage devices, many ADP units will ride through a 5–20-ms interruption of power without malfunction, provided noise impulses associated with the interruption do not reach and corrupt digital signals by other paths.

b) Ferroresonant transformers may enhance ride-through slightly in some cases, provided the ADP loads are not sensitive to phase shifts during their correction of line voltage variation.

c) Motor-generators can extend ride-through to as long as 0.1–0.5 s. Check the ADP manufacturer to determine whether synchronous 60-Hz power is needed or whether induction motor drives with lower varying frequency of output power can be tolerated.

d) UPS can extend ride-through to typically 5–30 min or longer. When requesting quotes on UPS installations, ask for incremental costs of increasing ride-through times, say in 5- or 10-min increments. The incremental cost of extra ride-through may be worthwhile, especially if there is a backup diesel which will not start because of water in the fuel line or need to change a cranking battery. Not much can be done in 5 min; more can be done in 30 min or longer to restore emergency power.

e) A UPS installation with emergency standby diesel power can extend ride-through almost indefinitely, depending upon fuel available and the rated running time of the diesel between overhauls or downtime for service. This may range from 200 h to more than 2,000 h. Turbines generally run longer between service attentions.

f) Any power conditioner or independent power source will have limits on load current, kVA, and kW output. This will vary with power factor of the load. Some devices such as static UPS have very little overload capability and depend upon a stiff, low impedance bypass power source (usually the public utility) to supply large starting loads. If the power quality of the bypass power source is not suitable for the ADP load, the UPS must be large enough to carry the starting load without UPS current limiting and bypass action. Verify that the power source will supply all starting needs and still provide the power quality which is needed.

g) If voltage regulators are used, verify that their response times are fast enough to follow line voltage changes, yet will not interact with regulators in the ADP loads. A low internal impedance of a voltage regulating power source may be more important than fast regulator response or highly precise voltage control. The low internal impedance will limit the line voltage drop in response to load change, whether or not a regulator has a fast response time.

5.3 What are the predicted line voltage sags, surges, and impulse transients? Note that ordinary switching of loads on a 120-V circuit can be expected to create momentary impulse voltages as high as the peak value of the sine wave (170 V). ADP units should be designed to withstand such impulses without difficulty.

5.4 What are the significant sources of load induced transients? Some ideas to minimize their effects include:

a) If the ADP system has a "soft-start" option, specify and order it.

b) Put ADP units with high starting inrush currents on separate circuits with their own circuit breakers and conductors to the ADP unit.

c) Put highly sensitive ADP units and other units which create disturbances on separate isolating transformers.

d) Power needed at the field engineers service workbench adjacent to the ADP system room should be powered from a source which is separate from the power supplying the ADP system. Service on ADP units can expose the power source to many unwanted momentary overloads, line-to-line, and line-to-ground faults. In the interest of fast repair service, these faults may be unavoidable. However, it is unnecessary to expose the ADP system to them.

6. Grounding

6.1 Are grounding requirements of the ADP manufacturer consistent with this Guideline? Differences and underlying rationale should be discussed and agreed to. There may be good reasons for differences.

6.2 Is an isolating transformer required or recommended? This affects the point where computer logic ground conductors and power source neutral grounding points will come together at a common point.

6.3 Where will the ADP system's central grounding point be located? If a modular power center (power peripheral) is used, it may be located there.

6.4 Will the computer room raised floor structure be specified with interconnecting bolted horizontal struts, suitable for use as a signal reference grid? This could save much money compared with construction using copper conductors or straps, and could enhance performance.

6.5 Are the ground conductors for non-ADP equipment separated from ADP grounding conductors except at some upstream common connection, typically at the building service equipment or other common separately derived power source (such as a transformer)?

6.6 Will the communications and power grounding systems in the building be bonded together at an appropriate upstream common grounding point? This is needed for safety and to minimize noise voltage differences without providing conducting paths through the ground conductors of the ADP system. Use modems or baluns to accommodate interconnection of systems having voltage differences between their respective grounds.

6.7 Are all grounding conductors and conducting pipes which penetrate the ADP area bonded together by short, robust connections *before* they enter the computer room? Equalizing currents need not flow in the ADP room if this practice is followed.

6.8 Are all ADP units and their accessories listed or approved by UL or other acceptable safety testing laboratory which is recognized by the municipality in which the ADP units are to be installed?

6.9 Does the ADP premise's wiring meet the local/national electrical code requirements?

7. Redundancy

7.1 Perform a simple failure analysis by assuming each piece of ADP equipment, its power source, wiring, and wiring devices can fail or must be deenergized for service. How will the ADP system continue to function and recover in such instances? Will redundant bypass paths in the power sources around conditioning equipment and major pieces of electrical apparatus provide the ability to continue in event of failure or need to service or replace it?

7.2 Review the above in light of probable failure rates and frequency of necessary maintenance attentions. If this still suggests redundant power sources, interconnecting paths, or redundant ADP units would be useful, install them.

7.3 Should margin for future growth be supplied by redundant smaller units rather than initially selecting a single unit (such as a transformer) adequate for all expected future growth?

7.4 Is there sufficient floor space and HVAC capacity to enable a new system to be installed and become operational before discontinuing and dismantling the existing unit? This may be needed to avoid disrupting work flow during system expansion or modification as well as during system replacement. Reserve amounts of power may not require power conditioning for this purpose, but once a new system is operational, there is the problem of transferring the power source with a minimum interruption to services. This needs to be planned for smooth transition.

8. Life-Safety

8.1 Gather building and electrical wiring code requirements and add your own requirements.

8.2 Is the system which meets these requirements easy to understand, maintain, and operate?

8.3 Is anyone responsible for the overall design, installation, conformance to specifications, testing, acceptance and training of others to use it?

8.4 How will it be tested without risk of discharging Halon, setting off fire alarms, and shutting down ADP operations unnecessarily?

9. Static Electricity

9.1 Humidity not less than 40%. (High humidity can cause other problems such as corrosion, gold scavaging, and ion migration on circuit boards and connectors.)

9.2 Appropriate floor coverings (pressure laminates with upper limit of 10^9 ohms on resistance to ground and surface resistivity). Carpeting to have acceptably low propensity to static (below 2,000 V at 40% relative humidity).

9.3 Appropriate static-free floor care materials and cleaning methods.

9.4 Furniture surfaces and upholstery with low static propensity. Use conducting glides, casters and wheels on legs and carts used in ADP room.

9.5 Restrictions on static-prone clothing and footwear.

9.6 Precondition printing media, tape, and punched cards in controlled humidity storage area prior to bringing into the ADP room.

9.7 Select ADP equipment which has been designed and tested to withstand electrostatic discharge (ESD) to 10 kV or more without failure.

10. Lightning
    10.1 Does the building structure have lightning protection? (refer to Underwriters' Laboratories, Inc. Subject 96A and National Fire Protection Association, Lightning Code NFPA 78.)
    10.2 Building in which structural steel is bonded together by welding (as opposed to reinforcing steel in concrete which is electrically discontinuous or merely touching) offers better lightning protection of circuits within the building.
    10.3 Down-wires from roof-mounted air terminals (lightning rods) should not create a path to ground via ADP circuits. Air conditioning coolant pipes from the roof to computer room air handlers must not become a direct path for lightning to reach the ADP circuits.
    10.4 Lightning protection down-wires to ground should be separated by at least 6 ft from ADP power or communications circuits to avoid a side flash.
    10.5 All incoming power and communications equipment conductors should be protected by surge protection devices having shunt overvoltage paths to ground and series impedances, if necessary, to limit surge currents. Short ground connections (a few inches or less, if possible) between each conductor and the surge protectors (line-to-line, line-to-neutral, and neutral-to-ground conductor) make surge arrestors much more effective on fast rise-time impulses than if leads are a foot or more in length. The place for primary lightning protection is at the building entrance. Supplementary protection may be placed at the input and output of load devices such as rectifier/chargers for UPS installations, motor-generators, voltage regulators, isolating transformers, and filters.
    10.6 Metal oxide varistors (MOVs) are effective in shunting impulse voltages, but they have been known to deteriorate with repeated exposure to impulses, and sometimes fail in a short-circuit mode which will throw flaming material about. MOVs must be properly protected in enclosures and use of interrupting devices for sustained currents. There are also other devices with similar characteristics, each with advantages and limitations.
11. Supervision of Technical Details
    11.1 It is recommended that a competent architect/engineer be employed to supervise the preparation of specifications, request for bids, awarding of contracts, inspection of delivered materials, and completion of installation. The architect/engineer's services may also benefit from the services of consultants on specific issues as may be required.
    11.2 Acceptance criteria based upon performance during final test at the factory and other tests after installation are recommended. These should be under the supervision of qualified architect/engineers and/or consultants, and should approach full load stress conditions if possible.
12. Documentation
    12.1 It is recommended that procurement specifications require delivery of documentation for all electrical apparatus. This should include instruction manuals, service manuals, schematics, part identifications, adjustment criteria, and all other information needed to properly service the equipment. This documentation and selected spare parts should be maintained onsite.
    12.2 All onsite wiring and interconnections, fuse and circuit breaker ratings, conductor wire sizes, terminal block connection schedules, and circuit identifications should be included and updated on "as built" drawings.
    12.3 Each panelboard, disconnecting switch, fuse, or circuit breaker should have labels identifying the power source as well as the loads controlled by each device. These should correspond to identifications on drawings and connection schedules. The size and type of each fuse and circuit breaker plus the nominal ampere rating should be clearly labelled on each device as well. Each interconnecting feeder should be identified by a name and/or number and be listed in a schedule of connections.
    12.4 It is recommended that provision be made to withhold substantial final payment until acceptable documentation which reflects "as built" equipment and its installation has been received and examined by the purchaser. In case of differences of opinion on "acceptibility," the criteria should be that documentation is correct and is sufficiently complete. It should permit someone with servicing training to perform diagnosis and unscheduled maintenance in case of malfunction, to replace components, and to perform scheduled maintenance adjustments and tests for proper performance.

This is particularly important on high technology apparatus such as uninterruptible power supplies in the event of service personnel turnover, or even if the equipment manufacturer changes ownership.

12.5 Establish a maintenance log including a schedule of maintenance attentions to be performed, a record of the work done, a log of unscheduled problems and malfunctions, and the steps taken to diagnose and repair or adapt to the difficulties.

12.6 Train employees by familiarizing them with the documentation and its use before they need it.

12.7 Create a record of changes made to the documentation. Keep it current with "as built" and "as installed" configurations. Record all changes made from time to time. Make spare copies and keep originals in a separate place where they can be reproduced if working copies are lost, mutilated, or destroyed.

8.4 Annotated Bibliography

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