CHAPTER 6

STANDBY POWER

6-1. Introduction

The purpose of this chapter is to provide guidance and understanding of standby power systems that may be required depending on the reliability of the primary power supply and the desire to maintain the automated data processing (ADP) system operable and uninterrupted.

a. There are many electrical power applications which require a continuous and high quality power source. An uninterruptible power supply (UPS) is an assembly of equipment dedicated to providing power free of voltage and frequency variation, transient pulses, line noise, and interruption. Techniques to accomplish these purposes are varied. Combining the characteristics of a UPS system, particularly the static systems, and a standby generator set presents special considerations to ensure compatibility.

b. The major problem associated with reliable power for computer systems is how to reconcile commercial short-duration power interruptions with relatively short time domains in electronic circuits. The goal of most manufacturers in today's technology is to build 4 milliseconds to 1 cycle of carryover, or ride-through time, into their equipment.

c. Table 6-1 identifies computer input power quality parameters for several manufacturers. This table should be used only as a source of some examples since computer designs vary with size of computers, their processing power, and the technology available when the design was created. They are continually changing and the parameters of power needs are changing rapidly with the designs. Although there is a degree of variance between computer manufacturers, the following represents the principal power parameters which are considered important by most major companies. While several of these parameters, such as frequency variation, can be relatively insignificant when power is derived from a commercial power source which embodies vast tie networks, they can become an important design consideration when supplemental or independent power sources are applied as a means of power quality improvement.

d. Two common sources of standby power are ac generators and dc batteries.

(1) A standby generator can be on line in a matter of seconds and continue operating as long as the utility outage lasts. A standby generator set is defined as a unit which supplies continuous electrical service during interruption of normal power.

(2) Battery power is a group of electro-chemical cells interconnected to supply a nominal voltage of dc power to a suitable connected electrical load. The number of cells connected in series determines the nominal voltage rating of the battery. The number of positive and negative plates in a battery cell is the basic factor that determines the discharge capacity rating of the entire battery.

(a) "Primary" type cells are capable of being discharged a single time and cannot be recharged effectively, e.g., zinc-carbon flashlight cells. "Secondary" type cells, however, can be discharged and subsequently recharged many times.

Table 6-1. Typical range of input power quality and load parameters of major computer manufacturers

	Parameters*	Range or maximum
1)	Voltage regulation, steady-state	+5, -10 to +10 percent, -15 percent (American National Standards Institute (ANSI) C84.1 1970) is +6, -13 percent
2)	Voltage disturbances/momentary undervoltage	-25 to –30 percent for less than 0.5s with –100 percent acceptable for 4 to 20 milliseconds
	Transient overvoltage	+150 to 200 percent for less than 0.2 milliseconds
3)	Voltage harmonic distortion**	3-5 percent (with linear load)
4)	Noise	No standard
5)	Frequency variation	60 hertz ±0.5 to ±1 hertz
6)	Frequency rate of change	1 hertz/s (slew rate)
7)	Three-phase voltage unbalance***	2.5 to 5 percent
8)	Three-phase load unbalance****	5 to 20 percent maximum for any one phase
9)	Power factor	0.8 to 0.9
10)	Load demand	0.75 to 0.85 (of connected load)

*Parameters 1), 2), 5), and 6) depend on the power source while parameters 3), 4), and 7) are the product of an interaction of source and load and parameters 8), 9), and 10) depend on the computer load alone.

**Computed as the sum of all harmonic voltages added vectorially.

***Computed as follows.

$$\text{percent phase voltage unbalance} = \frac{3\,(V\,max - V\,min)}{Va + Vb + Vc} \times 100$$

****Computed as difference from average single-phase load.

(b) Lead-acid cells are by far the most popular type of secondary cell. Properly sized, installed, and maintained, a stationary battery using lead-acid wet cells can have a life expectancy of up to 25 years in stationary applications, depending upon plate design, relationship between cell capacity and load demand, cycling, care during installation, maintenance, control of discharges and recharges, and site environmental conditions. Sealed valve regulated lead-acid (VRLA) batteries offer reduced maintenance and can be placed in rooms without special ventilation since there is no hydrogen off-gas. VRLAs also offer higher power densities than equivalent lead-acid wet cells.

(c) Nickel-cadmium (NICAD) batteries are increasingly applied to emergency lighting and other standby service. The active materials are nickel hydroxide in the positive plate and cadmium oxide in the negative. No gases are generated during discharge, and the gases given off during charging are not corrosive. Initial cost of NICAD batteries is higher than lead-acid on an ampere-hour (Ah) basis. However, at short rates of discharge, from 90 minutes down to 30 minutes the NICAD battery discharges a greater percentage of its capacity than does the lead-acid. This high discharge feature is even more important at extreme rates of discharge. In some applications the Ah capacity of a lead-acid battery must be twice the Ah capacity of a NICAD battery to do the same job.

6-2. Codes and standards

a. "Emergency systems" are those classified as essential for human life. The National Electrical Code (NEC), Articles 700, 701, and 702 in the 1999 edition address the electrical safety of the installation, operation, and maintenance of emergency, legally required, and optional standby systems respectively. "Legally Required Standby Systems" which are those systems required and so classed as legally required standby by municipal, state, federal, or other codes or by any governmental agency having jurisdiction. The systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source. Article 702 covers "Optional Standby Systems" which are intended to protect private business or property where life safety does not depend on the performance of the system. Optional standby systems are intended to supply on-site generated power to selected loads either automatically or manually. The sources of power discussed are storage batteries, generators, UPS, separate service, and unit equipment.

b. Institute of Electrical and Electronic Engineers *(*IEEE) 446-1995 entitled "Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications" addresses the uses, power sources, design, and maintenance of emergency and standby power systems. It includes a general discussion of needs for and the configuration of emergency and standby systems, the power needs for specific industries, the selection of power sources, recommendations for protecting both power sources and switching equipment during fault conditions, recommendations for design of system grounding, recommendations for designing to reliability objectives, and recommended maintenance practices.

6-3. Off-line/on-line ADP systems standby power requirements

Most ADP installations can be grouped into two general classes of operation in accordance with their usage. These classifications are off line and on line. These categories will be helpful in identifying a data processing system's vulnerability to electrical power disturbances, since an off-line process will rarely require power buffering or backup sources of equipment. Conversely, it is common for an on-line system to warrant the additional expense of buffering or backup equipment.

a. Off-line ADP systems are generally set up to perform one or more programs at a time in a sequential or batch type. Often, 24-hour operation for a heavily loaded system may be necessary.

(1) In the off-line category, for the most part, are business, scientific, and computer center applications. Systems of this type are particularly vulnerable when the programs are lengthy (several hours in duration). Thus the insertion of several natural breaks or checkpoints in the program for segmentation of long programs is highly desirable.

(2) Programming can be designed to save intermediate results at a checkpoint and to have the option of restarting at the last checkpoint which preceded the power interruption. Such a practice in program interruption can be valuable in protecting against peripheral equipment failure. Many current programs are being designed without checkpoint techniques even though the practice has been found to be feasible. Data dependent programs have running times which vary in duration of the magnitude of input data, and accordingly it is difficult to limit the run to much less than a 20-minute period.

b. On-line ADP systems, or as they are often called, “real time” systems, are systems which are time and event oriented. They must respond to events which occur randomly in time, often coincidentally. An awareness by the system of events which occur that are external to the computer and beyond its influence is a requirement.

(1) In this category are such applications as industrial process monitoring and control systems, airline passenger reservations systems, vehicular traffic control, certain specialized scheduling applications, international credit/transaction systems, plus many more. With these systems the computer outage problem due to power interruption is usually more critical than in off-line applications. Further, there is generally no merit in segmenting programs. In most cases any outage or power interruption will result in the loss of some data which was available only during the time period of the usage. The form of the input data is not conveniently available for a rerun, but may come from sensors such as thermocouples or pressure transducers which are scanned by a computer.

(2) When a computer controls a process, potential problems resulting from a power disturbance are generally serious enough in terms of product damage or equipment malfunctioning to warrant the use of a reserve or backup power source. Further, any solution, to be adequate, must accomplish the necessary switching to the backup source without power interruption to the computer. It is obvious that the potential losses to several hundred users, or input stations, to a time-shared computer system would warrant the providing of a backup source which can practically guarantee uninterruptible power.

(3) In cases where equipment or process monitoring must be made, as through data logging, protection from destruction of only the core memory content during a power interruption may be adequate. Automatic restart upon return of power is possible to minimize time that the equipment is down and can often be utilized with the additional provision for a manual means of updating the system data or information not gathered or scanned during an interruption.

c. Further differentiation of the single-phase versus the three-phase systems can be made by the magnitude of load. As with most power utilization equipment, smaller power consuming devices can generally be supplied from a single-phase source. The differentiation between single-phase versus three-phase power consuming systems is often necessary since the methods of protection against input power disturbances and outages can be quite different for each system. Some of the data processing systems which use single-phase power will employ micro-processors or minicomputers. Others may consist of multiple single-phase load units distributed in their connection to three-phase power so as to achieve a reasonable load balance when all units are operating. This may result in load unbalance when some of the units are turned off. In general, computers and peripheral units which draw less than 1.5 kVA will often be single-phase. Those which draw more than 10 kVA often require three-phase power. In most cases single-phase loads can be connected to three-phase sources provided load unbalance at maximum load is not excessive, generally taken as 25 percent or less.

6-4. Diesel generator standby systems

The use of a diesel generator for the UPS source can provide extended power for an indefinite power outage and also supply air-conditioning and lighting loads. Data processing equipment rooms will typically overheat within a 15- to 30-minute period if the ventilation system is not working, making the generator set a near necessity for outages in excess of this time. Analysis of battery cost will often justify a generator set at lower cost than choosing a long battery support time with an accompanying restriction of eventually implementing an orderly critical load shutdown. A battery support time of as little as a few minutes may be specified with generator set backup; however, longer support times in the range of 15 minutes are more typical. This minimizes unnecessary starting of the generator set during short power interruptions of a few minutes, which occurs more frequently than extended outages.

a. When a power failure occurs, the generator set is automatically started after a short delayed command. When stabilized at normal frequency and voltage, a transfer switch connects the generator set to the UPS. The rectifier/charger frequently is equipped with “power walk-in” that gradually applies load over approximately a 15-second interval when making the transition from battery power to ac source. This minimizes any large block loading disturbances on the source.

b. During normal operation from utility source, the UPS inverter frequency stability is assured by a synchronizing signal that maintains the inverter output phase and frequency in synchronism with the incoming line. While operating from the battery, the inverter operates from a precise internal oscillator to maintain frequency. During generator set operation, the UPS inverter must maintain frequency control or be equipped with over/under frequency disconnect to maintain the inverter frequency within acceptable critical load tolerance despite frequency deviations of the generator set caused by such things as large air-conditioning motor starts. An isochronous governor on the generator set is not usually required with a UPS system if the inverter maintains frequency control during generator set operation. Depending upon UPS system load, it may be desirable or necessary to bypass the UPS in the event of failure within the system, momentary overloads, or system maintenance. When using nonbreak “make-before-break” transfer, both sources are momentarily connected to the critical load. Therefore, the UPS must have synchronizing circuitry to assure the inverter output and bypass source are in synchronism. The bypass source must be within acceptable voltage and frequency parameters for the load. Whenever a standby generator set serves as UPS bypass source, an isochronous governor is recommended to provide minimal frequency deviation to the critical load.

c. The following is a procedure suggested by a generator set manufacturer to use in sizing generator sets that have static UPS systems as part or all of their load. This procedure has four parts.

(1) Establish UPS input kW using supplier data. If not available from supplier, the following procedure and guidelines are recommended to approximate or estimate UPS input kW.

$$\text{UPS input kW} = \frac{\text{UPS output kW} + \text{battery recharge kW}}{\text{UPS efficiency}}$$

(a) UPS output for computer loads is stated in terms of kVA. For approximating, if UPS output kVA is given and kW is unknown, use 0.9 power factor (typical for computer systems).

(b) Battery recharge kW generally ranges from 0 to 25 percent of input kW (15 percent is typical). If unknown, use 25 percent of output kW for an approximation.

(c) If UPS efficiency is unknown, the following guidelines are recommended.

0.85 if UPS	<100 kW
0.875 if UPS	≥ 100 kW but <500 kW
0.90 if UPS	≥ 500 kW

NOTE: Maximum input with redundant systems is less than total rating of individual systems.

(2) Establish the minimum size generator to contain wave form distortion, i.e., quality of electric power.

(a) For 6-pulse rectifier/charger: minimum standby rated generator set = UPS input kW x 1.6

(b) For 12-pulse rectifier/charger: minimum standby rated generator set = UPS input kW x 1.4

(3) Size the generator to accommodate other loads. Minimum standby generator rating with other loads = (UPS input kW x K) + kW of other loads. Where:

K = 1.15 for 6-pulse rectifier/charger
K = 1.10 for 12-pulse rectifier/charger

(4) Combine "(2)" and "(3)" for final selection. Select larger of value and round to nearest larger size standby generator set.

d. For example, select a standby generator set for powering a UPS rated 200 kVA/180kW. Other loads connected to the generator set total 100 kW.

(1) From supplier data, the UPS input is 255 kW, including battery recharge.

(2) The rectifier/charger is a 6-pulse circuit. Minimum standby rated generator set = 255 kW x 1.6 = 408 kW.

(3) Size for other loads. Minimum standby generator set rating with other loads = (255 kW x 1.15) + 100 kW = 393 kW.

(4) 408 kW is larger than 393 kW; therefore, a standby generator set of at least 408 kW is recommended. A 450 kW standby generator set will satisfy this application. Loads on the generator set frequently include large motors for air conditioning; and other support functions. Following selection of the generator set, a check should be made to determine if the generator set has adequate motor starting kVA capability.

e. Most system incompatibility problems involving generator sets and UPS systems arise because the equipment selection and system design did not consider any power source other than a stiff utility system or "unlimited bus." When problems do arise, particularly if the system performs satisfactorily on utility, it is very easy to erroneously conclude that it must be the generator set because it works fine on utility. It is important to note that loads drawing harmonic currents cause distortion from the source, the source does not produce distortion.

f. A standby generator is characteristically of higher impedance than a transformer. Also contributing to the impedance difference is a significant difference in kVA rating between the two sources. Where a unit transformer is sized to carry the total facility load, the standby generator set is often only sized to carry the emergency or critical loads. A generator may have 5 to 100 times greater sub-transient reactance than the normal source transformer. Consequently, non-linear loads which work fine on utility supplied power may react entirely different when powered by a generator set.

g. Using an oversize generator to reduce reactance may be of some benefit, but a significant reduction in reactance is not usually economically feasible. A doubling of generator rating is required to reduce reactance by one-half.

h. Generators are usually rated for 0.8 power factor. The rectifier/charger may have a lower power factor. Displacement of current with respect to voltage occurs with rectifier phase control. Line power factor can vary depending upon silicon controlled rectifier (SCR) conduction angle. Compounding this are the high frequency harmonic currents which result in added kVARs.

i. Harmonic currents produce high frequency flux changes and cause heating in stator cores. Generator rotor losses also occur because harmonic currents in the stator will induce currents in the pole faces and amortisseur windings. Higher magnetic core temperatures will produce higher winding temperature. Generator stator heating is also a function of I^2R loss, and the winding heating is proportional to the effective or root mean square (RMS) current squared (RMS current being 1.11 times the average value). The RMS value of the distorted SCR circuit input current wave form is typically greater than 1.11 times average current. Derating or using a low temperature rise generator is a means of compensating for increased heat losses.

j. Three-phase sensing minimizes effects of wave form distortion by providing an average of all three phases at any given instant. Since the SCRs in three-phase rectifier loads do not all “gate on” at the same instant, a minimized distortion, average signal of the three phases is processed. In comparison, a single-phase sensing regulator will sense severe distortion occurring at a given instant during the cycle in one phase. Generators having a three-phase sensing network with a floating neutral are common so that wave form notching is effectively blocked from the regulator. Regulator circuits must include features to isolate field power control from effects of distortion. If SCRs are used within the regulator, circuits must be used to prevent the distortion from loaded SCRs interfering with triggering of regulator SCRs.

k. Generator field power must be filtered to minimize interaction with distortion from the load. A well filtered regulator combined with the inherent inductive filtering of a brushless design generator virtually eliminates this problem. Self-excited generators have a well filtered regulator and excitation system which provides voltage control and stability equivalent to that obtainable with a permanent magnet pilot exciter. It is also fully capable of sustaining excitation during the short circuit periods occurring during the commutation of load SCRs without the benefit of excitation sustaining options. A permanent magnet exciter while capable of sustaining excitation during a sustained fault condition, has no advantage in providing excitation during the short duration of load SCR commutation.

l. Common instrumentation used in electric power generation is characterized by wave form distortion error. Measurement of ac current and voltage is standardized on the basis of RMS value, but departure from a sinewave may introduce significant error in many instruments. Accuracy of moving iron-type voltmeters and ammeters, commonly used on generator set panels and switchboards, is generally limited to commercial power frequencies. These are RMS responding meters; however, high frequency harmonics may produce eddy current, hysterisis, and inductive reactance effects which can cause indication errors of as much as 40 percent. True RMS ammeters and voltmeters employing non-linear converting circuits are available in switchboard cases at a premium cost. These should be capable of at least 5:1 peak to RMS ratio to ensure accuracy.

m. Most electrical devices and equipment will operate relatively unaffected when powered by generator sets with UPS loads. However, knowledge of potentially sensitive devices may be of value in system planning. Many electronic devices containing internal ac to dc power supplies with filtering electronic or control devices that depend upon source voltage “zero crossings” for timing may perform erratically. If these devices are of low power, a simple and low cost filter will usually eliminate any problem.

n. Caution must be exercised where power factor correction capacitors are used. A resonant condition at one of the harmonic frequencies with some part of the line inductance such as a transformer, on-line motor, or the generator is possible. Excessive and possibly damaging currents at the harmonic frequency can flow through the equipment.

(1) Power factor correction capacitors are used primarily for economic reasons; however, they can also be effective in reducing wave form distortion. It may be advisable to keep them off the line until the effects of operating on an emergency generator set with non-linear loads can be observed.

(2) Three-phase motors connected to the same supply lines as an SCR-controlled load have a damping effect on harmonics. Some harmonic energy is absorbed by the motors as heat and may be observed as higher than normal motor temperature rise. A filter or power factor correction capacitor to attenuate harmonic current may be required if temperature rise is excessive.

o. Regulating devices, such as battery chargers, voltage regulators, automatic speed controls, and engine governors with closed loop controls which typically have a reference, error detector, and error correction elements may be susceptible to instability or self-oscillation. This problem is not frequent but may occur where response times coincide and create oscillatory response between equipment. Altering time constants of one of the control systems will usually correct the problem.

p. Another effect of harmonic wave forms is electromagnetic interference (EMI) /radio frequency interference (RFI) noise induced into low level signal circuits such as carrier current, telephone, and electronic engine governors. Basic practices of using shielded wire, good grounding techniques, physical separation, and/or avoiding parallel runs between power leads and signal leads will minimize these problems.

q. A review of the entire generator set distribution system should be made to determine if loads exist which require a source with low distortion wave form. Unless the generator set system is large, it is quite common for other loads to share a common bus with the UPS and distortion may occur.

6-5. Battery standby systems

This section reviews the factors to be considered when specifying a stationary battery and the accessories serving the battery system.

a. A stationary battery system consists of three interconnected subsystems, normally specified in the following sequence – (1) the electrical dc load; (2) the battery; and (3) the battery charger. Each subsystem is described.

b. The combination of the charger and the battery becomes a system when it is connected to an electrical load. The load is the equipment that draws dc power from the charger and/or battery. The charger-battery load combination is most efficient only when all of the components are properly matched to each other. The charger converts ac power into dc power that is compatible with the battery’s voltage and current characteristics. The charger is the converter section of the UPS which charges the batteries and supplies dc to the inverter.

c. When the charger and battery are connected permanently to each other and to the load, and the charger regulates the voltage supplied to the load and the battery, the system is known as a floating battery system. The battery in such systems is mounted normally on a rack or racks housed inside a building or enclosure. The load in this case is the inverter.

d. Major users of stationary battery systems are telephone companies and electric power generating and transmission systems. Stationary battery systems also are used widely by industrial manufacturing plants, communications systems, pipe line companies, airports, airline reservations systems, hospitals, police and fire-fighting headquarters, computer backup systems, sewage treatment plants, and many other facilities that place critical reliance on power continuity. Some applications include:

(1) Voltage dips in the primary power supply can be corrected to specified levels with battery power.

(2) Voltage spikes can be absorbed by the battery system before they reach critical equipment.

(3) Electrical ‘noise” produced by other power sources can be filtered from power circuits by the battery.

(4) Current demands that temporarily exceed the capacity rating of power input lines and/or the charger can be met with battery power.

(5) During the interruption of primary power (converter or rectifier) supply, the battery system is used as an emergency power source to supply selected loads for a specified time period.

(6) When operations require uninterrupted dc power supply for lengthy periods after an outage of primary power occurs, the battery system can serve as a power “bridge” during the time required to switch from the primary power input lines to the alternate power input sources, such as a standby utility power circuit from another substation or an on-site standby generator set.

e. A storage battery uses chemical interactions to produce desired voltage; therefore, it is affected by changes in temperature. Performance ratings of stationary batteries are based on a standard temperature of 77°F (25°C). Any deviation from that temperature will affect battery performance and life expectancy.

f. The storage battery is constructed of a group of identically sized cells connected in series. The number of cells connected in series determines the voltage rating of the battery. The discharge capacity of the battery is basically its ability to supply a given current for a given period of time at a given initial cell temperature while maintaining voltage above a given minimum value. This capacity is stated in amperes (A) at a given discharge rate. Most stationary battery cells are rated for 8-hour, 3-hour, 1-hour, 15-minute discharge rates to 1.75 volts per cell.

(1) The rated capacity of the individual cell is the rated capacity for the whole battery. Connecting the cells in series does not increase the capacity rating.

(2) The ability of a fully charged cell to deliver a certain number of Ah at a given discharge rate is determined primarily by the size and/or number of positive and negative plates in the cell. Another important factor is the type of construction used.

(3) There are three basic types of lead-acid positive plates, available in a wide range of plate sizes for various capacity ratings. The following choices are available for modern stationary lead-acid batteries.

(a) Pasted plates use either antimony or calcium alloy grids. The design uses the pasted or "flat" plate for both positive and negative plates. A lattice grid in each plate is cast of either antimony or calcium alloy, needed to strengthen the basic lead content of the grid. Antimony alloy contains ingredients that reduce positive plate wear, local action, and charging current requirements. Cadmium alloy grids drastically reduce the frequency of watering when the battery is float charged and seldom cycled. However, frequent cycling will cause the calcium grid in the positive plate to "grow" or physically enlarge, shortening the cells' life expectancy. For this reason, calcium cells are best suited for applications where deep discharges are infrequent. The life expectancy of a pasted plate battery is usually shorter than either a tubular type or a Plante type.

*(b)*Multi-tubular positive plates use antimony alloy grids only. Multi-tubular positive plates enclose the active material exposed to electrolyte. The antimony alloy grid consists of spines extending downward from a top bar. Each spine forms the center of a tube filled with powdered active material. Tubular cells provide the greatest power density of any lead-acid stationary battery design. This means that more Ah of capacity are provided per cubic foot of battery volume (at moderate rates of discharge). This feature can be especially important when battery room space is limited. Tubular cells have a relatively long life expectancy when used at moderate rates of discharge.

(c) Plante plates use either pure heavy lead or "Manchex" rosettes in heavy antimony alloy frames. Basic construction of this grid is a heavy antimony alloy configuration in which circular holes have been cast with specially formed walls. Heavily corrugated strips of high purity lead are rolled into spiral buttons or "rosettes" that are forced into the holes. The walls of each hole are convex, having a slightly smaller inside diameter at mid-point in the wall thickness. This "pinches" the button firmly into place. Each lead button exposes five times more active material surface area to the electrolyte than a comparable area on a pasted plate. The buttons also help prolong cell life expectancy by providing a reserve supply of unformed lead for gradual conversion. Manchex cells have recorded performance lives of 25 years or more in many heavy-duty applications. This battery cell combines long life with exceptional reliability. Its precise construction requires the highest investment per Ah capacity, but this cost is substantially reduced when prorated on an annual basis. Manchex cells are an excellent hedge against inflationary trends that could greatly increase the costs of a replacement battery if shorter-lived, low-priced cells are used in an installation.

g. Basic components of a lead-acid cell design for stationary battery applications are listed in their sequence of assembly at the factory:

(1) An element is an assembly of positive and negative plates insulated from each other by separators and "burned" to metal straps. The element is the key assembly of the cell. Its inter-reaction with the electrolyte determines the cell's performance characteristics.

(a) Each plate consists of a rigid lead alloy grid that provides physical support for relatively porous active materials. The active materials in the positive plates are different from those in the negative plates.

(b) Reaction of the electrolyte and active materials creates a current flow when a load is imposed on the cell. The grids and straps are electrical conductors that carry the current to and from the posts.

(c) The size and number of plates in the element control the discharge characteristics of the cell. The positive and negative plates are sandwiched together in an alternating pattern (neg-pos-neg-pos-neg) with a negative plate at each end of the assembly.

(d) Each positive plate must be separated from its neighboring negative plate by an insulating material, usually a thin sheet of microporous material, ribbed on the side facing the positive plate.

(2) A cell cover is usually a molded plastic cover through which protrude the positive and negative posts to which the element is attached; also includes a vent well with flame arrester.

(a) The cell cover normally is opaque. The element is connected to the posts that usually protrude through the cell cover.

(b) Positive posts are marked either with a plus sign (+) or the letters “POS;” negative posts carry a minus sign (-) or the letters “NEG.” Cells with four or six posts are designed for the highest current discharge rates.

(c) The flame arrester vents protect the cells against ignition of internal gases by external flame or sparks.

(3) A cell jar is usually a transparent plastic container which houses the element and electrolyte; a multi-cell jar has a separate compartment for each cell. The cell jar is usually made of a transparent impact-resistant plastic material.

(a) The jars must be large enough to enclose the element while providing reservoir space above and below the element. The upper space accommodates gradual lowering of the electrolyte level, caused by water loss during charging.

(b) The bottom space serves as a collection basin for sediment shed by the plates during many years of service. This sediment must be kept away from the element; otherwise the cell would be short-circuited when the sediment contacts both positive and negative plates simultaneously.

(c) The cell cover is sealed in the cell jar during or after assembly in which the element has been lowered into the empty jar.

(4) Electrolyte is a liquid solution of dilute sulfuric acid in which the element is immersed for the lifetime of the cell.

(a) Electrolyte in lead-acid battery cells is a dilute solution of sulfuric acid and water. The ratio of acid weight to water is measured as specific gravity. Pure water has a specific gravity of 1,000. The quantity of electrolyte in a cell is specified in pounds, kilograms, gallons, or liters.

(b) Acid electrolyte recommended for most stationary batteries has a nominal specific gravity of 1.215 at 77°F, when the cell is fully charged. The specific gravity of acid electrolyte gradually drops as the cell is discharged. When the charger resumes operation after a discharge period, the charging process gradually raises and restores the specific gravity of the electrolyte.

(c) A tropical (low) specific gravity of electrolyte can be considered for longer battery life of cells where the battery room ambient averages above 85°F more than 30 days per year.

(d) A medium or high specific gravity electrolyte is available for special applications such as UPS which in some cases will reduce the battery size. For such types the float and equalize voltages will have to be increased for normal life.

h. *S*pecification of the charger and the lead-acid battery depends on the dc load. Each single item of electrical equipment that will be powered by the stationary battery system must be analyzed. Pertinent data required for each item of the load includes: voltage range (window); current or kW draw; duration of operation (time); number of cycles; frequency of use; depth of discharge; and operating temperature range. After this data has been compiled, the battery and charger can be sized and specified.

(1) A stationary lead-acid battery system can be designed to meet practically any desired voltage rating. Most dc-powered equipment systems are within one of the following major dc voltage groups.

(a) 6-12 volts (emergency lighting units)

(b) 24 volts (audible and visual alarm systems, engine cranking, communication systems)

(c) 32 volts (emergency lighting systems, engine cranking, electric clock systems)

(d) 48 volts (switchgear systems, telephone systems, microwave systems, engine cranking)

(e) 120 volts (switchgear systems; boiler flame control; emergency lighting systems; communication systems; telemetering; supervisory control systems; teletype systems, fire alarm systems, uninterruptible ac power supply systems, large engine cranking, test bench power)

(f) 240 volts (switchgear systems; uninterruptible ac power supply systems, large engine cranking)

(g) Higher voltages (uninterruptible ac power supply systems)

(2) Stationary battery systems are maintained at voltages higher than the nominal system voltage. For example, a nominal 120-volt system is operated usually at 130/135 volts. This is due to a tendency of a battery cell to gradually lose some of its electrical charge due to minor electrochemical reactions that are taking place constantly on the plate surfaces. These losses are made up by constant "float" charging during normal system operations. Float charging voltage is maintained at a precise pre-set level, virtually always higher than the nominal system voltage but lower than the recharge or equalizing charge voltage.

(3) The equipment powered by dc is usually designed to operate within a fairly broad range of voltage supply. This is necessary for two reasons:

(a) to accommodate the gradual decline of battery voltage during discharge, and

(b) to accept voltage increases when required by recharging or equalizing charge operations.

(4) The minimum and maximum permissible voltages accepted by the dc equipment are vitally important to the battery and charger selection. This information is used in selecting the size and number of plates per cell as well as specifying the number of cells in the battery. Voltage ranges for various operating mechanisms are based normally on the Standards of the ANSI, the National Electrical Manufacturers Association (NEMA), and the IEEE.

(a) One common electrical load in stationary battery systems is switchgear. Operating voltage ranges for various types of dc switchgear are listed in the "C37 Series" of standards available from the organizations listed above. These standards include: IEEE C37.13-1990, Standard for Low-Voltage ac Power Circuit Breakers Used in Enclosures; IEEE C37.14-1992, Standard for Low-Voltage dc Power Circuit Breakers Used in Enclosures; IEEE C37.20-1-1993, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear; ANSI C37.16-1997, Low-Voltage Power Circuit Breakers and ac Power Circuit Protectors Preferred Ratings, Related Requirements, and Application Recommendations; ANSI C37.17-1997, Trip Devices for ac and General Purpose dc Low Voltage Power Circuit Breakers.

(b) A typical example of approved voltage ranges, based on a nominal 120-volt system, lists dc voltages between 105 and 140 volts for tripping mechanisms of low-voltage air circuit breakers. If this system is served by a conventional antimony alloy lead-acid battery, it would have 60 cells float charged at 2.20 volts per cell equivalent to a system voltage of 132 volts. During recharging operations following a battery discharge, the system voltage would be raised to 140 volts by temporarily increasing the charger's output to 2.33 volts per cell. At the end of a pre-set recharging period, the system voltage would return to the float voltage level.

(c) When electronic components in communications and control circuits require a narrow range of permissible dc voltages, the battery engineer must be advised of the fact. The minimum/maximum voltages of such critical hardware should be grouped separately in the equipment description.

(d) One method of lowering maximum battery system voltage is to use fewer cells in the battery. This design can allow recharging at 2.33 volts per cell without exceeding the maximum permissible voltage accepted by the dc equipment. However, the battery must be equipped with cells that are higher in rated discharge capacity, in order to meet the minimum voltage limits.

(e) Another method of reducing maximum battery system voltage is to eliminate the charger's recharge and equalizing charge voltage. The float charge level in such systems is raised to a voltage which will maintain the battery system under all conditions. This higher float voltage (at 1.215 specific gravity) must never exceed 2.20 volts per cell, except when a special float voltage is recommended. However, such systems require a substantially longer recharge time following a power outage, since the recharge current is limited.

(f) When the dc electrical load inventory includes loads rated for different voltages (i.e., a 120-volt pump motor and a 48-volt circuit breaker), battery engineers recommend that each voltage class be served by a separate battery and charger. It is technically possible to modify the main battery by connecting supplementary cells to provide a higher voltage level for selected loads, but two chargers are essential – one to recharge the 48-volt battery and a second to charge the 120-volt battery.

(5) Another critical factor that must be considered by the system engineer is the voltage drop caused by resistance in conductor runs. Any equipment powered by a battery should be located as physically close to the battery as possible. If the distance between the battery and the load is substantial, the voltage drop can be minimized by using a larger conductor. If this is not feasible, the calculated voltage loss should be added to the voltage requirement of the load. This will allow the battery engineer to compensate by specifying larger cells for the battery. Voltage drop is especially severe in high ampere applications, where special attention to the problem is recommended.

(a) Each item of electrical equipment is assigned a nominal current or kW rating by its manufacturer. This rating is used by the electrical engineer as a guide when sizing the circuits that feed power to that equipment and any other equipment connected to that circuit.

(b) The battery engineer must know the current ratings, which are a vital part of the load specification. If the load is a given constant wattage, the current output of the battery will increase as the battery voltage declines during discharge.

(c) In addition to the normal A rating, some electrical equipment has another current factor that is seldom rated by the equipment manufacturer, but which is highly important to the battery engineer. This is the temporary high ampere demand, called inrush current, imposed on the power supply when electric motors, etc., are activated. Inrush demands must be determined – or estimated on the high side – so that battery supply voltage will not drop below critical specified minimum limits during the inrush.

(d) Individual equipment operations are normally classified in one of the following categories - continuous load for indicating lights, relays, alarm systems, and other items; time-limited loads, such as motors, emergency lighting, communications systems, etc., which are longer than a minute but shorter than the battery's duty cycle; and momentary current demands, particularly the power needed to close or trip switchgear, which may be imposed at intervals during the duty cycle.

(6) The operational cycle of required equipment is an important factor for consideration in specifying the battery requirements. The duration of operation of each equipment item should be specified in hours, minutes, or seconds, whichever is pertinent. The battery engineer collates this time data with the equipment's ampere or kW rating to determine its effect on the total duty cycle.

(a) When an equipment item is used more than once during the duty cycle, the anticipated frequency of such usage must be specified.

(b) If this frequency is considered variable, depending on such circumstances as equipment positions or status at the time the duty cycle began, the maximum number of possible operations should be specified in the duty cycle. This is necessary to ensure sufficient battery capacity to handle a worst-case situation.

(7) Environmental conditions and location must also be considered when specifying the battery. Normally, storage batteries are sized to perform at 77°F but allowance must be made in the calculations for lower temperatures which require more capacity to meet the load criteria. Freezing of the electrolyte results in water crystals forming but a solid mass is seldom formed. Such crystals damage the plates resulting in reduced life.

(a) Charger and UPS performance are adversely affected by altitudes higher than 3,300 feet (approximately 1,000 meters) above sea level or ambient temperatures above 105°F (40°C). Compensations for these factors can be designed into the lead-acid battery system.

(b) Battery capacity is reduced when battery room temperature is normally lower than 77°F. Battery life expectancy is shortened when the battery room temperature is consistently higher than 85°F.

(8) After an equipment inventory has been compiled, describing all of the electrical loads intended for operation using battery power, the sequence of operation must be scheduled. This listing of dc loads in sequence during the battery discharge is called the duty cycle schedule.

(a) Selection of the proper size of battery depends not only on the current or kW draw and duration of each load, but also the sequence in which they occur. Careful scheduling of the load sequence in the duty cycle can be of considerable help in keeping battery cell size to a minimum, which lowers costs.

(b) A simple stationary battery system with only one continuous load throughout the duty cycle is easy to size. A typical example would be an emergency lighting system in which 50 A are demanded for three hours. Cell selection tables are provided in catalog sheets.

(c) Many stationary battery systems are multi-load rather than single-load systems. When a variety of loads are connected to the battery, sudden increases and decreases in current demands are imposed on the battery system. If the high-current loads can be scheduled for the beginning of the duty cycle, the battery can be sized smaller than if the high-current loads are activated at the end of the discharge cycle. However, if a load is random in nature and could occur at any time during the duty cycle, it is normally good practice to indicate the random load on the schedule as occurring at the end of the duty cycle, when its effect would be most severe. In some cases, it may be advisable to show the random load occurring simultaneously with the highest ampere load in the discharge schedule. The battery engineer must plan for the worst-case situation to ensure meeting the specified protection time requirements. A company representative should be consulted if there is any question regarding placement of the random load in the sequence of the duty cycle.

i. Short-circuits affecting stationary battery systems usually involve the total system voltage and occur chiefly in the dc switchgear or other electrical load circuits. Instantaneous high currents, as high as 9 to 12 times the 1-minute discharge rate to 1.75 volts per cell of the battery, can occur. Therefore, the stationary battery system should be equipped with fault current protective interrupting devices strategically located throughout the power distribution system. This assumes that the power distribution system is capable of carrying the high current rating of the interruption devices.

(1) The individual tripping and closing circuits of each power circuit breaker should have separate fault protective devices. This is necessary to prevent any fault in the closing circuit of a breaker from jeopardizing tripping. A fault in the control circuit of any one device or breaker should not be allowed to interrupt the control power supply to all the breakers and other electrical loads served by the stationary battery system.

(2) Some stationary battery systems are operated without a main protective device because failure of such a device could accidentally shut down the entire system. The designing engineer must review the applicable codes and pertinent factors of the installation before deciding whether or not to install protective devices on the battery's distribution. However, if the battery is installed before the electrical loads are ready to be connected, and if construction work is underway in the general area, engineers recommend protective devices until such time as the loads are ready for connection.

(3) Either one-time fuses or molded-case breakers may be used as short-circuit protective devices. The fuses operate much faster than the breakers when an over-current occurs. A one-time fuse, with 10 times rated current passing through it, will interrupt the circuit in about 0.1 second, compared to approximately 0.7 to 2 seconds for magnetic breakers. Switchgear manufacturers generally recommend and furnish fuses in battery control power circuits.

(4) When sizing these fuses or breakers, engineers generally assume a zero resistance at the location in the circuit for which the short-circuit calculations are to be made. This theoretically represents a worst-case example. In actual practice, the current delivered through a fault will depend on resistance of the short-circuit path; battery's state of charge; battery's electrolyte temperature; and voltage existing at the battery terminals at the time the short-circuit occurs.

j. During the charging and discharging process of battery operation, hydrogen gas is formed. Hydrogen gas is very explosive when exposed to open flames, sparks, and cigarettes.

(1) The room in which the battery is located should be provided with ventilation, so as to prevent the buildup of liberated hydrogen gas. In the USA, Occupational Safety & Health Administration (OSHA) specifies that the concentration of hydrogen gas should not exceed 1 percent. Other countries may permit other levels of hydrogen concentration. Room ventilation must be adequate to assure that pockets of trapped hydrogen gas do not occur, particularly at the ceiling.

(2) Significant amounts of hydrogen are evolved only as the battery approaches full charge. When the cell is fully charged, each charging ampere produces 0.016 cubic feet of hydrogen per hour from each cell. This volume applies at sea level when the ambient temperature is 77°F.

k. Battery chargers used in stationary battery systems are normally constant voltage chargers. Voltage adjustments can be made with precision to $1/100^{th}$ of a volts per cell. This is necessary because floating voltage and equalizing; voltage levels critically affect battery performance and life expectancy. Voltage level specifications are normally expressed to two decimal positions; i.e., 2.25 volts or 2.33 volts.

(1) Proper specifications and adjustments of the battery charger are the most important factors affecting the satisfactory performance and life of the battery cells in a stationary battery system. Voltage levels from the charger also usually serve the electrical load, so changes in charger voltage output affect the load.

(2) Battery chargers for stationary battery systems normally are specified after determining: system voltage, current, filtered or unfiltered dc output voltage, wall-hung or floor-mounted housing, ac voltage, single- or three-phase ac input power, and frequency of ac input power. The current of ac input power can be specified by the manufacturer after the above factors have been determined.

l. Valve regulated lead acid (VRLA) batteries are sealed except for a valve that opens to the atmosphere when the internal buildup of gas pressure exceeds atmospheric pressure by a predetermined amount. The electrolyte within a VRLA is immobilized either by adding a gelling agent or by using absorbent separators. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption. VRLA batteries can be used for the same applications as conventional vented wet cell batteries; however, they are susceptible to two failure modes that are not normally associated with vented cells, dry-out and thermal runaway.

(1) Dry-out can result from excessive water loss as a result of electrolysis or diffusion through the jar and cover walls. Both mechanisms of water loss result from operating at elevated temperatures. The high temperatures can be caused by operation at higher than normal float voltages or higher positive grid corrosion rates.

(2) Thermal runaway can occur if the rate of heat evolution due to the recombination reaction is greater than the rate of heat dissipation. The hotter the battery, the higher the current needed to maintain the float voltage. The increased current then results in still more recombination and heat generation, which further raises battery temperature. The net effect can be the accelerated dry-out or melting of the battery. The potential for thermal runaway can be minimized by appropriate ventilation around each cell and by limiting the charger output current and voltage by using temperature compensated chargers.

(3) Maintenance and surveillance requirements for VRLA batteries are similar to those required for vented cells except that specific gravity readings and water additions are not possible. Instead, internal impedance or conductance tests can be used to provide information for comparison of individual cell measurements with either initial baseline values or with present values obtained from similar cells.

m. NICAD batteries with high-rate discharge performance are used for applications demanding a heavy surge of current for short periods, such as engine/turbine starting, switchgear control, or inverter supply. This type of cell is characterized by a great number of very thin plates, closely spaced, creating an extremely low-resistance electrical path. Intra-cell members, such as collector bars and posts, as well as inter-cell connectors, are of large cross-section to ensure low resistance. This design takes advantage of the fact that high-rate, short-duration discharge efficiency is more a function of plate surface area and the conductivity of current-carrying structures than of the amount of active material (which establishes the battery's Ah rating). High rate units are available in cell sizes from 85 to 570 Ah capacity and in plastic or steel containers.

(1) For long-rate discharge performance when plate surface area and current-carrying structures have little effect on the efficiency of discharge, it is more economical to use a cell construction with fewer plates, each with relatively more active material. Long rate discharge units are available in cell sizes from 10 to 1245 Ah capacity.

(2) For intermediate-rate discharge performance, plate thickness and plate separation are greater than the high rate discharge type and less than long rate discharge. Intermediate rate discharge units are available in cell sizes from 13 to 1180 Ah capacity.

(3) Proper battery and system performance can be optimized if installation aspects are properly considered during the design. The battery and its charger should be located close to one another for convenience in checkout and servicing. It is particularly important that the battery also be installed as close as possible to its load to minimize cable length and subsequent voltage drop. Cables of sufficient size must be used, particularly in high-rate applications such as engine-cranking and switchgear. The ordinary rules of wire sizing pertaining to 120-volt ac circuitry cannot be used when figuring wire sizes for high-rate discharges. Calculate wire size based on current, voltage, and cable length.

(4) Normal ventilation is entirely adequate for the room in which a NICAD battery is installed. A hood or exhaust fan is not necessary unless the room has no ventilation. During the last portion of high-rate charging, all batteries give off gas (a mixture of hydrogen and oxygen).

(5) If it is necessary to install the battery in a closed compartment, ensure that there is adequate ventilation by arranging for large vents in the bottom, sides, and top. Small holes in each corner must be drilled to allow for drainage of water that might be spilled during battery servicing operations.

(6) If the battery is to be serviced through a cover or hinged door on top of the compartment, allow a minimum clearance of 3 inches between the top of the vent plugs or caps and the battery box cover.

(7) If the battery is to be serviced from the side, allow additional clearance between vent plug or cap tops and cover.

(8) The battery charger is vital to the proper performance, long life, and reliability of the battery it is connected to.

(9) The charger must meet two requirements: its nominal voltage must be the same as the battery and its capacity must be adequate to handle the load – both for the charging of the battery and for any external load, intermittent or continuous.

(10) Battery chargers are usually described in terms relating to their dc voltage and ampere output:

(a) Constant current has a rating and characteristics which permit a constant-current charge to the battery by manual or automatic adjustment over the full charge voltage range of the battery.

(b) Constant potential has a regulated dc voltage output and theoretically has a sufficiently high current output to furnish the maximum current the battery will accept at the regulated voltage.

(c) Modified constant potential has a regulated output voltage with current limiting. Chargers used with NICAD batteries are generally of this type – either float chargers or with the capability of two-rate charging, either manually or automatically switched to high-rate as required by the battery. This type is considered the most satisfactory for standby service.

(11) Like all vented storage batteries, the gas given off by NICAD batteries during high-rate charging is a mixture of hydrogen and oxygen, which is a result of the decomposition of water by the passage of current through the electrolyte.

(12) The gas is completely non-corrosive – cut, under certain conditions, can be potentially explosive. However, even slight movement of air around the battery such as normal room ventilation will dissipate the concentration of the gas.

(13) The NICAD battery uses an alkaline electrolyte – potassium hydroxide (KOH) instead of sulfuric acid.

(14) The specific gravity of the electrolyte of the NICAD battery remains essentially constant (1.180 + 0.020) in both charged and discharged conditions, unlike the electrolyte of the lead-acid battery whose specific gravity changes.

(a) The nominal individual cell voltage is 1.2 volts.

(b) The float charging voltage is 1.40 – 1.42 volts per cell.

(c) High-rate charging voltage is 1.50 – 1.65 volts per cell.

(15) Stationary batteries of the lead-acid or NICAD type have a standard Ah rating based on either the eight- or the ten-hour rate to a specific end voltage, such as 1.14 volts per cell in the case of a NICAD battery which is similar to 2.22 volts per cell in a lead acid system. The number of cells in series will determine the system voltage where for a NICAD battery, 1.2 volts per cell is normally used. Table 6-2 compares the cells required for certain voltages for NICAD and lead-acid batteries. These are typical voltage ratings which represent series connections of cells. The Ah capacity rating is a fixed basis for a constant current discharge for a specific time where the battery is guaranteed to stay above that minimum voltage per cell at that temperature where the base temperature rating is given as 77°F. It must be emphasized that the Ah rating of the battery as a basis for calculation is only good at the particular time given such as eight hours. If a battery is discharged at higher rates, i.e., shorter times than eight hours, it will not perform as efficiently and less total Ah will be obtained. Similarly, a battery discharged for longer than eight hours will operate somewhat more efficiently and extra capacity can be obtained on discharges of 24, 48, or 72 hours. The factory should be consulted in such load profiles in order to gain the most competitive battery sizing for the application.

Table 6-2. Comparison of cells required for NICAD and lead-acid batteries

Voltage	NICAD Cells	NICAD Cells (nom)	Lead-Acid Cells
12	10	9 – 11	6
24	20	18 – 22	12
48	37	36 – 40	24
125	92	90 – 96	60
240	184	180 – 192	120

(16) NICAD batteries have an advantage when it comes to sizing because of low, medium, and high rate battery types to choose from. Often, a high rate NICAD battery will give substantially higher currents than a competitive type of unit of the same total Ah rating. On this basis, it may offer a much better economic picture.

(a) As an example, three different simple load situations and assuming 25°C and 1.14 end voltage in all three cases, the first case would be the eight-hour discharge rate. The most economical choice here may be the low-rate battery. A comparison of the data and cost for the medium rate and high rate cells must be performed to substantiate this choice.

(b) The next check is the 1-hour discharge rate. Similar comparisons must be performed.

(c) The last check would be to compare the 1-minute rate. After examining the data, it can be determined if the low-rate battery is the most economical choice. Tripping in the switchgear may be a concern where a small medium-rate cell will adequately do the job versus a high-rate battery. Also certain control loads, while they have short durations, have very low currents, therefore, the smallest low-rate battery is quite sufficient for the load application. However, as a general statement, short duration high-rate discharges will be best served by high-rate batteries.

n. Continuous battery monitoring equipment is available which is used in conjunction with a battery charging system. These systems can monitor float charge rate, voltage levels of individual cells or the complete bank, monitor liquid level, and adjust charge cycle and rate of charge.

(1) A well-designed monitoring system can add significantly to the reliability of a system, but it is not designed to replace monitoring and maintenance by qualified personnel.

(2) To insure satisfactory operation of batteries in all types of systems, the batteries must be maintained on a regular schedule. Special safety precautions must be observed to protect maintenance personnel and the equipment when working around batteries.

(3) The area where the battery is installed must be ventilated. Maintaining a proper, well-ventilated environment is the most important maintenance technique that can be performed for batteries since hydrogen, an explosive gas, is emitted from batteries during charging.

(4) During charging, some of the water molecules in the battery electrolyte break down and are separated into the elemental components, hydrogen, and oxygen. The hydrogen and oxygen escape from

the battery through the vent plugs, which lowers the level of the water. Therefore, the water should be replaced periodically.

(5) The battery jar is marked with high and low level marks. The level of electrolyte should always be between these marks. A cell or battery could suffer permanent damage if the electrolyte were left to drop below the top of the metal plates. The procedure for adding water depends on whether the cells are equipped with explosion-proof vent plugs or regular plugs. Specific instructions are given by the battery manufacturer. Water is poured through the center of the plug or hole, and eye guards should be worn for safety. Unless there is a specific recommendation from a qualified chemical engineer, acid or electrolyte should never be added to the cells. Water from the plant drinkable water supply can be used in batteries, as long as periodic analyses for impurities are made. When the normal water supply is not suitable, distilled water should be used. No special powders, booster chemicals, or jellies should be added to station batteries.

(6) One sign that the float level charging current is too high is that water must be added more frequently than the normal, once a year addition. Float charge voltage is critical and should only deviate from the recommended level by 1 percent. A very accurate voltmeter should be used in setting float specific to the type of battery and manufacturer and should be checked against the battery supplier's recommendation. A typical voltage for lead acid batteries is 2.22 volts per cell.

(7) A short-duration charge at higher than the float voltage is made periodically to insure that all cells in a battery have an equal charge. Battery chargers are equipped with an equalize/float switch or with a timer switch which automatically limits the duration of an equalize charge.

(8) Specific gravity is read at least once a year. An on-going record is kept both in the battery room and in other plant maintenance records. Specific gravity is read with a hydrometer syringe. The instructions which accompany a battery indicate the safe range of reading for a particular type of battery. To obtain an accurate reading, the battery must have been charging at the specified float rate for at least a few days. The hydrometer reading may be misleading if the battery has been charging at an incorrect rate. Before making a hydrometer reading, hydrometer indication must be corrected for temperature to obtain a reading comparable with past readings. The base temperature for correction is 77°F.

(9) The following safety precautions should be performed during periodic inspections and maintenance on the batteries.

(a) Replace explosion-proof fixtures such as globes for explosion-proof room lights with exact replacement parts.

(b) Do not smoke around batteries or in the battery room.

(c) Turn the room vent fan on for a few minutes before entering.

(d) Wear safety eyeshields or approved goggles while checking or handling the batteries.

6-6. Transfer switches for standby systems

The purpose of the automatic transfer switch in the electrical system along with its related controls, is to switch power from either the normal or the emergency source to the electrical loads. For maximum protection, the automatic transfer switch should always be located as close as possible to the electrical loads it serves.

a. The controls have the intelligence to monitor the normal source. If there's a power outage - a supply transformer burns out, a power line is knocked down, lightning strikes, or any other cause for power to fail – the controls signal the standby engine generator to start. When the generator reaches proper voltage and frequency, the controls cause the switch to transfer the connected loads to the generator. When the normal source is restored, the loads are transferred back to the normal source, and the engine is shut down after a cool-down period. It is all handled automatically by the automatic transfer switch.

b. The transfer switch should include all of the features that are necessary to fulfill its requirements. Such features are voltage and frequency sensing, various time delays, engine control contacts, manual controls, and indicators.

c. When selecting a transfer switch, certain considerations should be made. Some of the basic things that should be considered when selecting a transfer switch are given below.

(1) The two sources (normal and emergency) should never be connected to the load at the same time unless the system is designed for this type of operation. Doing so could create a short circuit from one source to the other with damaging results.

(2) The switch contacts should always be closed on one source or the other – never in-between. In-between (not closed on either source) is undesirable because it would mean that the load would not be getting power from either source. The only type of switch that will satisfy proper operation is a true double-throw, inherently interlocked switch; that is, closed on normal and open on emergency, or closed on emergency and open on normal.

d. Power to the load is always going through the transfer switch. It is important that the switch be designed for continuous duty from either source and be able to transfer to and operate from one or the other source at any time. While the switch is connected to one source, the contacts on the other source can become coated from exposure to the atmosphere and thus cause poor contact when the switch transfers to them. The arc that is formed at the contacts when the switch transfers can also cause the current-carrying contacts to deteriorate. To keep them clean and operable, the current-carrying contacts should have high contact pressure and be able to clean themselves with a wiping action when they operate.

e. Emergency systems must respond quickly to assure minimum outage time in accordance with the NEC. Fast operating transfer time is also important when protecting motors with in-phase transfer. Therefore, the operating time for transfer switches through 4000 A should not exceed $1/6^{th}$ of a second in either direction – normal to emergency and emergency to normal.

(1) A solenoid operator will provide the inherent double-throw operation that is needed. With the single solenoid operator, there are only two possible positions that the switch contacts can be closed on normal, open on emergency; or open on normal, closed on emergency. Obviously, if both contacts were closed, there would be a short circuit from one source to another. If both were open, the load would be disconnected from both sources.

(2) The single solenoid operator power drives the contacts from one source to the other, then mechanically locks them in place with high contact pressure. This simple mechanism eliminates any need for hooks, latches, or motor drives.

(3) Because of the erosive and destructive action of arcs, the main current-carrying surfaces must be protected. Construction should be such that the arc is pulled away from the main contacts. Switches

over 400 A should utilize separate arcing contacts to properly protect main contacts. Switches 400 A and under, where arc energy is lower, should utilize arc runners and contact tips.

(4) To prevent the arc from short circuiting one source to another, the arc must be extinguished rapidly regardless of current level or power factor. A wide arc gap is necessary to accomplish this.

(5) To reduce heat and lengthen insulation life, switches over 400 A should have segmented contacts to provide multiple paths for current flow.

(6) Conventional contacts can separate due to the electromagnetic (EM) forces that occur during fault currents. The consequence at this time, if contacts open, is violent arcing with severe erosion and deterioration of dielectric. Blow-out contact construction on switches over 400 A uses EM forces to keep contacts closed until the over-current device clears the fault.

f. Transfer switches are generally located in the main or secondary distribution bus which feeds the branch circuits. The switch must be designed to close against high inrush currents, to interrupt current, to carry full rated current continuously, and to withstand fault currents.

(1) When the contacts on a transfer switch close, they may be required to pass a substantial inrush, or surge, of current; the amount will depend upon the load.

(a) For tungsten lamp load, the cold resistance is approximately $1/15^{th}$ to $1/17^{th}$ of the hot resistance. This means that theoretically the initial lamp current will be 15 to 17 times normal operating current. Such inrush currents may take as long as 14 cycles (.23 second) to return to a normal or steady-state condition. These characteristics vary depending upon lamp wattage.

(b) Motor loads are also a source of high inrush currents. If a stalled rotor motor is connected to a source of power, the inrush currents will be in the neighborhood of six times normal running current. A ratio of ten times running current is generally used in designing motor controllers. This may not be a realistic inrush ratio for transfer switches. Transfer switches must be capable of transferring a running motor from one source to another. These two sources are not necessarily synchronized and, therefore, the residual voltage of the motor may be 180° out of phase with the voltage to which the motor is to be transferred. This means that the motor may momentarily draw as much as 15 times normal running current. The transfer switch must be capable of closing on such loads. In-phase monitors are designed to minimize the condition when large motor loads are transferred.

(c) There must be no tendency for the contacts of a transfer switch to weld when closing on loads having high inrush currents. This means that the physical construction of the switch must provide a minimum of contact bounce and have ample thermal capacity. Good engineering practice demands a transfer switch capable of withstanding inrush currents of 20 times full load rating.

(d) Transfer switches should be rated for all classes of load including any combination of motors, electric discharge lamps, electric heating (resistive) loads, and tungsten lamp loads.

(2) Upon retransfer to normal, the switch is normally required to interrupt rated current at full voltage. Ordinarily on transfer to emergency the current interrupted will be zero or relatively small. The transfer switch can also be called upon to interrupt full load currents at full voltage under test conditions. Accordingly, the automatic transfer switch ratings must apply to both normal and emergency contacts.

(a) Wide arc breaking distances combined with magnetic blowout insure rapid arc interruption during transfer from one source to the other. Magnetic blowout coils are less effective at lower current

levels and, therefore, the use of wide arc breaking gaps is also required. It is often more difficult to interrupt currents at the 20 percent level than at higher levels.

(b) Installations often require transfer switches to be capable of interrupting at any current level from 20 to 600 percent of the continuous duty rating at a power factor less than 50 percent.

(3) A transfer switch differs from other emergency equipment in that it must continuously carry current to critical loads. The engine generator set is generally required to provide power only during the emergency period, whereas current flows through the transfer switch continuously during both normal and emergency conditions, with an expected minimum life of 20 to 40 years. During this period, fault currents, repetitive switching of all types of loads, and adverse conditions should not cause excessive temperature rise nor detract from reliable operation. Continuous duty operation should be achieved with minimum maintenance.

(a) To meet the requirements for continuous duty, the contact temperature rise of a transfer switch must be well below that established for an eight-hour rated device, and the quality of contact must be sustained through proper contact design, including separate arcing contacts on larger switches rated above 400 A. Arcing contacts prevent or minimize arcing at the main contacts, which would cause contact erosion and affect the ability of the switch to carry current continuously.

(b) When selecting a transfer switch, determine the maximum continuous load current which the transfer switch must carry. Momentary inrushes, such as occur when lighting or motor loads are energized, can be ignored. Select a transfer switch that is either equal to or greater than the calculated continuous current.

(c) Sometimes the transfer switch size is selected to be the same as the over-current device ahead of it on the normal side. Although this may not be necessary, it is a convenience which permits the addition of future loads while remaining within the system's capacity. Sometimes, to obtain a higher withstand current rating, a higher continuous duty rating, a higher continuous duty rated transfer switch may be used.

(4) Transfer switches are designed to withstand the magnetic stresses and dissipate the heat energy resulting from high fault currents. Withstand current ratings vary depending on the switch size and type. For most applications, transfer switches have adequate withstand current rating when used with current limiting fuses or breakers.

(a) To properly evaluate application and coordination of transfer switches with protective devices, a system short-circuit calculation should be made to determine the symmetrical fault current magnitude and the X/R ratio at each point of application. The X/R ratio is the ratio of the reactance to the resistance of the circuit. As the X/R ratio increases, both the fault withstandability of a transfer switch and the fault interrupting capacity of an over-current protective device become more critical.

(b) A transfer switch should be capable of withstanding the available fault current at its location in the system until the over-current protective device clears the fault. The system designer should determine the available RMS symmetrical fault current at the transfer switch location, the X/R ratio, voltage, and types of protective devices (current limiting fuse, molded case breaker, power breaker) before a properly rated transfer switch with adequate withstand current can be selected.

(c) Transfer switches are rated in terms of the available RMS symmetrical current with a specific X/R ratio and specific types or classes of over-current protective devices. For example, a 600 A transfer switch is rated for use with Class L fuses in a system having an available fault current of 200,000

symmetrical RMS A. This is based on a maximum size fuse rating of 1200 A, and an X/R ratio not exceeding 6.6. Most installations normally do not exceed an X/R ratio of 6.6 (i.e., power factor of 0.15).

(d) The factors that account for the high withstand current ratings of transfer switches, include blow-on contact structure, thermal capacity, and operational time delay.

(e) In many switching devices, the EM fields which encompass the current-carrying conductor act to force the contacts to separate. Since these EM forces increase exponentially with current, it can be anticipated that the contacts will separate during short-circuit currents because of magnetic effects. The consequence is substantial arcing accompanied by severe erosion, deterioration of dielectric, and possible flashover.

(f) The amount of heat generated at the transfer switch is proportional to the resistance of the parts that carry the current through the switch, multiplied by the square of the current. To provide the thermal capacity needed to cope with this heat, the cross section of the current-carrying parts must be of substantial magnitude to keep the resistance down to a reasonable value. It is also necessary to provide adequate radiating surfaces, along with high contact pressures, to keep heating to a minimum. Most importantly, the contacts on larger switches should provide multiple current paths.

(g) On large transfer switches segmented contacts are utilized to provide multiple paths for current flow through to main contacts. This reduces the heat generated and thereby provides longer life without replacement of contacts.

(h) A voltage drop normally accompanies large fault currents. It is important that the voltage drop does not cause an automatically operated switch to transfer while the switch is carrying the fault current.

(i) Two safeguards are provided: the mechanically held mechanism and a time delay to override momentary dips in voltage. The mechanically held mechanism assures that the switch will not transfer until control voltage is applied to the transfer switch solenoid coil. To prevent energizing the solenoid coil until the over-current protective device clears the fault, a standard nominal time delay, adjustable up to six seconds, is incorporated into the control circuit.

g. Facilities in which relatively large motors are used have been exposed to the sometimes destructive consequences of switching motors off and then back on again (even to the same bus), before the motor residual voltage has decayed. The consequences of reconnecting a motor to a power source while motor residual voltage is high – i.e., the motor rotating the substantial speed at the instant of reconnection – can be extremely high inrush currents which lead to possible breaker tripping, motor damage, and/or coupling damage. The damage is the result of the abnormal mechanical forces which can develop. The problem is growing as more and more motors are being added to emergency and standby systems. The need to understand the cause of high inrush currents and how to avoid them becomes apparent.

h. Two types of loads, which may be termed passive and active, must be considered.

(1) Passive loads include incandescent lamps, heaters, or any load that is predominately resistive. These loads do not store electrical energy. When they are disconnected from a voltage source, the voltage across the load drops to zero almost immediately.

(2) Active loads include rotating electric motors. They store energy in their rotating mass and magnetic fields. The instant the motor is disconnected, it acts as a self-excited generator that can deliver substantial amounts of current because the magnetic flux within the air gap does not collapse

immediately. The resulting residual voltage decreases in amplitude exponentially. The length of time it takes is determined by what is called the motor's open circuit time constant. (One time constant is that length of time it takes the residual voltage to fall to 37 percent of its initial amplitude.) Large motors can have time constants of four to five seconds. Thus, when such a motor is disconnected, it will take four to five seconds for its residual voltage to drop to 37 percent of its original value. It will take 20 to 25 seconds, or five time constants, for the residual voltage to go to zero.

(3) In addition to the motors' residual voltage decreasing, the relative phase angle between the motor voltage and supply voltage changes. After the motor is disconnected, its mechanical speed starts to decrease. This, plus the effect of slip (peculiar to induction type motors), causes an ever-increasing change in relative phase between the motor's residual voltage and the supply to which it is being transferred. The motor is now acting as a self-excited generator of decreasing frequency that is coasting in and out of synchronism at an ever-increasing rate until its residual voltage ultimately goes to zero.

i. Out-of-phase transfer (or even reconnection to the same source) presents a problem. The electric utilities have always been concerned with this problem of large motor load transfer and for obvious reasons. But the problem of motor load transfer is not exclusive to utilities. The same situation is becoming more apparent in general applications as electrical loads get larger. Mechanical loads like air conditioners, ventilating fans, elevators, pumps, grinders, crushers, radar antennas, etc., are requiring motors of higher and higher speeds and horsepower. This compounds the problem of motor transfer. Electrical design engineers must be concerned with the design solutions to avoid the abnormal inrush currents which the motor could develop upon reconnection.

j. There are three basic solutions recommended for transferring motor loads without incurring excessively high inrush currents.

(1) One solution is to let the residual voltage across the motor be allowed to drop to zero value where reconnection currents are similar to normal startup currents. This solution creates some problems. For example, the motor must be disconnected until its residual voltage drops to where it can be safely reconnected. The time that the motor must be disconnected is unacceptable in many applications. Furthermore, the motor's residual voltage versus time profile must be known so enough time is allowed for the motor's residual voltage to drop to a safe value. A reconnection voltage of 25 percent is generally accepted as the maximum. However, if the motor were 180° out of phase with the reconnected source, the maximum reapplied voltage would still be 125 percent. The maximum inrush current could be from 25 to 35 percent higher than normal, and the resulting stresses placed on the motor would be from 156 to 183 percent above normal. The manufacturer should be checked to see if the motor could take the 25 percent overvoltage when 180° out of phase.

(2) A second method, overlap (closed transition) transfer with momentary paralleling of the two power sources appears to be an ideal solution at first glance. An uninterrupted load transfer should provide the least amount of system and process disturbance. However, overlap can only be achieved when both power sources are present and properly synchronized by voltage, frequency, and phase angle. In the case of a failing source, overlap transfer may be extremely difficult, if not impossible, to achieve. Overlap transfer can only be used during test transfers and retransfer back from the generator to the utility when both sources are at full voltage. While the overlap arrangement is technically feasible, it is not always practical because of the reluctance of the utility companies to permit paralleling of extraneous power sources to their lines.

(3) In most applications a more practical solution is to use a conventional automatic transfer switch with an in-phase monitor. This combination is the most popular with system designers and allows the motor loads to be reconnected almost immediately without excessive inrush current. The in-phase

monitor, prior to transfer, samples the relative phase angle that exists between the source being transferred to. Once the two voltages are within the required phase angle and approaching zero phase-angle difference, the in-phase monitor signals the transfer switch to operate and reconnection takes place close to synchronism.

(a) With this arrangement, the asset of rapid transfer becomes evident. Also, it is not necessary to know the residual voltage profile of the motors. In most cases, it will probably be high, but it will also be almost in phase. The result is minimal or even non-existent electrical and mechanical shock; thus avoiding unwanted breaker trip and mechanical damage. Furthermore, this result is accomplished without altering the speed of the generator.

(b) In addition to voltage and current ratings, it is also important to consider the operating transfer time of automatic transfer switches used with in-phase monitors.

(c) The operating transfer time of an automatic transfer switch is a primary factor in the proper utilization of an in-phase monitor. For example, the advance angle adjustment of the in-phase monitor is a direct function of the operating transfer time and the frequency difference between the two sources. (For a given advance angle, the faster an automatic transfer switch can transfer, the wider the allowable frequency difference.)

(d) Consider a typical motor load in terms of its mechanical characteristics. Loads are either high inertia or low inertia. High inertia loads include cooling tower fans, chiller motors, centrifugal pumps and fans, centrifuges, rolling mill machinery, motor-generator (M-G) sets, etc. Low inertia loads include rock crushers, conveyor belts, reciprocating pumps, compressors, etc.

(e) The mechanical energy stored in the driven load is a contributing factor to the residual voltage open-circuit time constant. Therefore, high inertia loads are more likely to have longer open-circuit time constants than low inertia loads.

(f) There is a need for in-phase transfer in many existing and proposed systems. For example, there may be a need in an existing installation that has a history of trips on over-current, and/or damage to motors and couplings.

(g) The need for in-phase monitoring is usually determined by the size of the motor and the inertia of the load. As a guideline, difficulties can be expected with motors of 50 horsepower or more, especially if they constitute the only load on the transfer switch. High inertia loads tend to lengthen residual voltage time constants. Still another consideration concerns the nature of the miscellaneous load, other than the motor, connected to the transfer switch.

(h) Dissipative loads reduce residual voltage times. However, capacitive loads used for power factor correction have a tendency to increase open-circuit time constants since they provide additional excitation to the motor's stator windings.

(i) Motor manufacturers will usually provide data regarding their motors' residual voltage time constants under varying degrees of load. However, several motors connected in parallel present problems since it is somewhat difficult, if not impossible, to theoretically determine the resultant time constant of the motor combination. This is so because the larger motors, upon disconnect, tend to drive the smaller motors. Also, the individual loads inertia interact upon one another. Here it is best to empirically find the resultant time constant through the use of recording instruments in order to determine the need for in-phase monitoring. The determination is a function of not only motor size, but also driven

load inertia and location of the motor in the distribution system with respect to the automatic transfer switch.

k. Another design accommodation to meet today's needs is provision for proper ground-fault sensing. Ground-fault sensing requires special consideration. This necessitates proper interfacing between various Articles of the NEC.

(1) Article 230-95 of the 1999 NEC states: "Ground-fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150 volts to ground, but not exceeding 600 volts phase-to-phase for each service disconnecting means rated 1000 A or more."

(2) Article 445-1 of the 1999 NEC states: "Generators and their associated wiring and equipment shall comply with applicable provisions of Articles 695, 700, 701, 702, and 705."

(3) Article 250-30 of the 1999 NEC defines the grounding requirements for a "separately derived system." A "separately derived system" is defined in Article 100 as follows. "A premises wiring system whose power is derived from a battery, a solar photovoltaic system, or from a generator, transformer, or converter windings, and that has no direct electrical connection, including a solidly grounded circuit conductor, to supply conductors originating in another system."

(4) Article 250-24(a)(5) of the 1999 NEC states: ". . . A grounding connection shall not be made to any grounded circuit conductor on the load side of the service disconnecting means except as otherwise permitted in this article."

(5) Article 250-2 of the 1999NEC, defines the general requirements for grounding and bonding.

l. These code requirements have a number of bearings on "Emergency Systems," "Legally Required Standby Systems," and "Optional Standby Systems" as covered by Articles 700, 701, and 702 of the NEC. Consider a 480Y/277 volt system with a three-pole transfer switch and zero sequence ground-fault sensing. A preferred method for isolating the normal and emergency source neutrals is for the automatic transfer switch to provide overlapping neutral transfer contacts. This arrangement also conforms to Section 250-24(a) and provides continuity of the grounded neutral conductor, in accordance with Section 250-2, through utilization of overlapping neutral transfer contacts. This feature provides the necessary isolation between neutrals, and, at the same time, minimizes abnormal voltages. By means of overlapping contacts, the only time the neutrals of the normal and emergency power sources are connected together is during transfer and retransfer. With a solenoid-operated, conventional double-throw transfer switch, this duration can be less than the actuating time of the ground-fault sensor, thus avoiding false tripping due to unbalance current that might result when using a solid neutral.

(1) In addition to meeting code requirements, features of this arrangement include:

(a) No flow of ground-fault current through neutral conductor that would detract from or effectively reduce ground-fault detection.

(b) No flow of unbalanced current through the generator neutral which would alter pickup of ground-fault sensor and possibly cause nuisance breaker tripping.

(c) The load neutral is always permanently connected to either source of power. There is no momentary opening of the neutral conductor when the transfer switch operates.

(d) Abnormal voltages and transient voltages are kept to a minimum, in that the neutral-to-ground is not broken.

(e) There is no erosion of the overlapping contacts due to arcing, thus maintaining the integrity to carry current with minimum maintenance. The impedance of the neutral circuit does not change.

(f) Conventional ground-fault detectors may be used on both normal and emergency sides.

(g) Permits ground-fault sensing and alarm on the emergency side.

(2) Four pole switches have also been satisfactorily applied where the loads are passive and relatively balanced, providing complete isolation of service and generator neutral conductors. As with the overlapping neutral contacts described above, this approach eliminates possible erroneous ground-fault sensing and nuisance tripping caused by multiple neutral-to-ground connections and satisfies the NEC definition of a separately derived system. However, unbalanced loads may cause abnormal voltages for as long as 10 to 15 milliseconds when the neutral conductor is momentarily opened during load transfer. Transfer switches are frequently called upon to operate during the total load imbalance caused by a single-phasing condition. Inductive loads may cause additional high-transient voltages in the microsecond range. Consequently, the contact of the fourth switch pole may interrupt neutral currents causing arcing and contact erosion. The contact erosion can be minimized if the fourth pole is designed to open last (after three other poles interrupt the load current) and make first without contact bounce. A good maintenance program must reaffirm at intervals the integrity of the fourth pole as a current carrying member with sufficiently low impedance. Both the NEC and Underwriters' Laboratories (UL) recognize the use of four-pole switches for three-phase, four-wire systems. In some countries, including Germany and France, it is mandatory to use four-pole switching devices.

(3) Automatic transfer switches that include full-phase protection have voltage sensor connected across the line on single-phase, two-wire systems, and across the outside conductors on a single-phase, three-wire system. On a three-phase, three- or four-wire system, each phase is monitored; therefore, three voltage sensors are required.

(4) There are cases where only two voltage sensors, connected between the three-phase conductors, have been used to monitor the three phases. However, should one phase conductor open, feedback through the load from the other two phase lines will maintain near full voltage on both voltage sensors and neither will drop out.

(5) Voltage sensors must be the voltage sensitive type since the release voltage of ordinary sensors is generally less than 50 percent of normal voltage. Consider the single-phase, three-wire system under a condition where a fuse has blown in one line. Any relay connected across the outside conductors will have impressed across it one-half of the normal voltage due to feedback through the load. If the relay is not the voltage sensitive type set to drop out above 50 percent voltage, transfer will not be affected.

(6) Where the possibility exists that under open phase conditions (and this applies to both single-phase and three-phase applications) terminal voltage will be sustained at a relatively high value due to generator action of connected motors, voltage sensors having close differential between pickup and dropout are required to detect this condition.

(7) This possibility, as well as the characteristics of present-day lighting, computer instrumentation, and other voltage sensitive loads, has been a contributing factor to the selection of voltage sensors.

m. Static transfer switches use SCRs to conduct current from source to load. These devices turn on when gated, and turn off at the first current zero crossing following removal of the gate signal. The major advantage of static transfer switches is fast transfer without source interconnection. The response to an outage is, in the worst case, less than 8 milliseconds, provided the second source is available. Static transfer SCR technology should be considered when an 8-millisecond outage is the maximum that can be tolerated. It should be noted that most modern computer equipment can withstand a 20-millisecond outage as described in the Information Technology Industry Council (ITI) Curve and Application Notes (appendix B).

(1) The SCRs require the semiconductor junctions to be forward biased. This results in a voltage drop of approximately 1.5 volts per line (or 225 watts per phase in a 150 A switch). This power loss generates considerable heat, which must be dissipated by fans. The fans run continuously, and over-temperature sensors are usually required to set an alarm if there is a cooling malfunction. The switch may not be able to support the load under an overtemperature condition and automatic bypassing may be required to protect the SCRs.

(2) Detection circuits are employed to prevent transfer if an SCR shorts (which would result in a source-to-source connection). If a shorted SCR on the connected source is detected, the opposite source breaker is shunt tripped as protection against a source-to-source connection and transfer to the alternate source is inhibited. Similarly, if circuitry detects an open-phase SCR, the load is transferred to the opposite source to restore power, providing the opposite source is available. Transfer back to the original source is then inhibited.

(3) Unlike the mechanical switch, the controller must be functioning, and providing continuous gate pulses to the SCRs to keep them on or the static switch itself will cause the load to lose power.

n. The hybrid solid-state transfer switch takes advantage of both static and mechanical switching elements. It utilizes the best of each technology and virtually eliminates their shortcomings. A standard electro-mechanical switch provides power to the load through mechanical contacts. The switch is electrically operated and mechanically held. The reliability and cool operation of mechanically locked contacts are maintained. SCRs are added to transfer to the opposite source with fast and precise timing. The result is a transfer switch that meets all requirements of the ITI Curve (appendix B). Planned transfers result in less than a 3-millisecond disruption to the load. An unanticipated loss of source supplying the load will result in an unplanned transfer in less than 20 milliseconds without source-to-source interconnection. The SCR conduction is limited to approximately 15 milliseconds during transfer, and the mechanically locked contacts support load at all other times. This results in low voltage drop across the contacts, and cool operation without requirement for fans or over-temperature alarms.

o. Many users, local governing authorities, Federal agencies, electrical inspectors, etc., frequently require that the transfer switch meet some form of minimum performance criteria before it is considered acceptable. The performance criteria may vary depending on the degree of reliability and quality level desired. Factors which involve the life of the equipment, such as ease of maintenance, fire safety, shock hazards, overload, endurance, temperature rise, and ability to withstand available fault currents, frequently receive consideration as measures of performance.

p. Other organizations also have recognized the need and developed standards to satisfy specific requirements. Such standards include IEEE Recommended Practice for Emergency and Standby Power Systems, Standard 446-1995; IEEE Recommended Practice for Electric Power Systems in Commercial Buildings, Standard 241-1990; NEMA Standard ICS 10-1993 Industrial Control and Systems: AC Transfer Switch Equipment; CSA Standard C22.2 No. 107.1-95, General Use Power Supplies; and EGSA 100S-1996, Performance Standard for Transfer Switches for Use with Engine Generator Sets.

q. Federal agencies, such as the Veterans Administration, General Services Administration, Federal Aviation Administration, and Corps of Engineers have written stringent performance criteria requiring certified tests which must be met before a transfer switch can be accepted. Other approving authorities may simply require that the transfer switch be UL listed and labeled. UL has written a safety standard for transfer switches. The standard is identified as UL 1008 and contains the criteria by which UL evaluates a transfer switch for fire and shock hazards to determine if it meets the basic safety standards for a UL listing. This standard has been written to embrace many manufacturers of transfer switches and, therefore, defines only safety criteria. Each application should be carefully evaluated to determine the acceptable quality and reliability levels in addition to UL's safety requests. It may be necessary to specify performance requirements above and beyond UL 1008 in order to obtain proper performance. For example, UL's test to withstand short circuit current requires an X/R ratio which may be exceeded in the actual application.

r. Special consideration should be given to systems that utilize adjustable frequency drives (AFDs) to control motor operation. These electronic devices often consist of SCR assemblies to change the voltage and frequency applied to the motor to vary its torque and speed.

(1) With some AFDs, interruption of the input, be it caused by transfer switch operation or other momentary power outages, causes the device to see a low voltage input. To maintain motor speed, some control sensors immediately change the conduction angle of the controlling SCRs to compensate for the low line condition. The result is that upon immediate reapplication of power, the controlling SCRs are turned fully on causing a severe current inrush. This current inrush is of such a magnitude that protective devices such as fuses can blow or worse yet, the SCRs themselves can be irreparably damaged.

(2) This problem is only partly solved by conventional in-phase transfer or other load disconnect arrangements because other extraneous interruptions of power (such as disturbances on the high lines) will also confuse the AFD voltage sensing circuitry.

*(3) S*ome manufacturers of AFDs have recognized this problem and have included in their systems special high-speed voltage sensing circuitry that detects momentary power outages and shuts down the AFD entirely. Upon reapplication of voltage, the SCRs go from an off condition to a soft start current limiting startup that automatically protects the solid-state switching devices.

(4) When other provisions are lacking, the motor load disconnect control circuit previously described (i.e., disconnect before transfer) can be considered for transfer of SCR controlled loads for AFD motors and other loads such as used by communications companies. The contact, which must be integrated by the AFD system manufacturer, simply signals the SCR control to "power down" before transfer and permits a soft restart after transfer. As indicated above, such controls may protect the SCRs during a power interruption when the transfer switch is operating, but offer no protection when the power interruption is extraneous to the transfer switch.

6-7. Grounding standby power systems

Since the primary consideration in the installation of emergency and standby power systems is to satisfy the need for continuity of electrical service, the type of system grounding that is employed, and the arrangement of system and equipment grounding conductors, will affect the service continuity. Grounding conductors and connections must be arranged so that objectionable stray neutral currents will not exist and ground fault currents will flow in low impedance, predictable paths which will protect personnel from electrical shock and assure proper operation of the circuit protective equipment.

a. Where phase-to-neutral loads must be served, systems are required to be solidly grounded. However, 600 volt and 480 volt systems may be high resistance grounded or ungrounded where a grounded circuit conductor is not used to supply phase-to-neutral loads. High resistance grounded or ungrounded systems may provide a higher degree of service continuity than solidly grounded systems.

b. Where grounded (neutral) conductors are used as circuit conductors in systems that have emergency or standby power supplies, the grounding arrangement must be carefully planned to avoid objectionable stray currents. For example, stray neutral currents and ground-fault currents in unplanned, undefined conducting paths may cause serious sensing errors by ground-fault protection equipment.

c. A grounded (neutral) circuit conductor is permitted to be solidly connected (not switched) in the transfer equipment. Therefore, a neutral conductor is permitted to be solidly interconnected between a service-supplied normal source and an on-site generator which serves as an emergency or standby source. Grounding connections to the grounded (neutral) conductor on the load side of the service disconnecting means is not recommended, so the grounding connection to the generator neutral should not be made.

(1) Such multiple grounding of the neutral circuit conductor may cause stray currents that are likely to be objectionable and will cause ground-fault current to flow in paths that may adversely affect the operation of ground-fault protection equipment. Grounding connection to the neutral conductor at the on-site generator on the load side of the service disconnecting means is not recommended and may not satisfy code requirements. Where the grounded (neutral) conductor is solidly connected (not switched) in the transfer equipment, the system supplied by the on-site generator should not be considered as a separately derived system.

(2) The grounding connection to the neutral conductor at the on-site generator completes a conducting path for stray neutral current. The magnitude of the stray current will be a function of the relative impedances of the neutral current paths. Where ground fault protection is provided at the service disconnecting means, the stray neutral current may adversely affect the operation of the ground fault protection equipment.

(3) The multiple grounding connections to the solidly interconnected neutral permit a portion of the ground fault current returning to the normal source to flow through the neutral grounding bond at the on-site generator and bypass the sensor for the ground fault protection at the service equipment. The main service disconnecting means is not supposed to trip for a ground fault on a feeder or branch circuit, so this is not a serious problem provided the feeder to the transfer switch does not have ground fault protection equipment that is actuated by a ground fault current sensor. However, ground fault protection for feeders may be required if the service disconnecting means is equipped with ground fault protection.

d. Where ground fault protection is applied to a feeder from the service equipment to the transfer equipment, the ground fault current may not be accurately detected by a zero sequence ground fault current sensor.

(1) The multiple grounding connections to the solidly interconnected neutral permit a portion of the ground fault current returning to the on-site generator to pass through the sensor for the ground fault protection at the service equipment. This arrangement could result in tripping the service disconnecting means by ground fault current supplies from the on-site generator.

(2) The transfer switch may have an additional pole for switching the neutral conductor, or the neutral may be transferred by make-before-break overlapping neutral contacts in the transfer switch. Where the neutral circuit conductor is transferred by the transfer equipment, an emergency or standby system supplied by an on-site generator is a separately derived system. A separately derived system with

a neutral circuit conductor should be solidly grounded at or ahead of the system disconnecting means. The neutral conductor between the service equipment and the on-site generator is completely isolated by the transfer switch and is solidly grounded at the service equipment and at the on-site generator. Where the neutral circuit conductor is switched by the transfer equipment, the stray neutral current paths and the undesirable ground fault current paths are eliminated.

(3) The normal supply and the alternate supply are equivalent to two separate radial systems because all of the circuit conductors from both supplies are switched by the transfer switch. Since both systems are completely isolated from each other and are solidly grounded, ground fault sensing and protection can be applied to the circuits of the normal source and the emergency or standby source as it is applied in a single radial system.

e. Unintentional neutral grounds will cause stray neutral currents that may be objectionable. Therefore, in addition to carefully planning the intentional grounding connections, systems should be kept free of unintentional grounds on the neutral circuit conductors.

(1) Where there are two on-site generators connected for parallel operation, the neutral conductor is grounded at the generator switchgear instead of at the generator. Where the generator switchgear is adjacent to the generators, the grounding connections may be made in the generator switchgear.

(2) Switching of the neutral conductor permits grounding of the neutral at the generator location. This may be desirable for the following reasons.

(a) An engine-generator set is often remotely located from the grounded utility service entrance, and the ground potentials of the two locations may not be the same.

(b) Good engineering practice requires the automatic transfer switch to be located as close to the load as possible to provide maximum protection against cable or equipment failures within the facility. The distance of cable between incoming service and the transfer switch and then to the engine-generator set may be substantial. Should complete cable failure occur with the neutral conductor not grounded at the generator location, the load would be transferred to an ungrounded emergency power system. This could jeopardize emergency service continuity and possibly lead to additional failures. Concurrent failure of equipment (breakdown between line and equipment ground) after transfer to emergency power may not be detected. Thus the generator frame may approach line potential, causing a substantial voltage difference between the generator frame and the neutral conductor.

(c) Some local codes require ground fault protection while the engine-generator is operating. This may present a sensing problem if the neutral conductor of the generator is not connected to a grounding electrode at the generator site and proper isolation of neutrals is not provided.

(d) When the transfer switch is in the emergency position, other problems may occur if the engine-generator set is not properly grounded. A ground fault condition could cause nuisance tripping of the normal source circuit breaker even though load current is not flowing through the breaker. Furthermore, both the normal neutral conductor and the emergency neutral conductor would be simultaneously vulnerable to the same ground fault current. Thus a single fault could jeopardize power to critical loads even though both utility and emergency power are available. Such a condition may be in violation of codes requiring independent wiring and separate emergency feeders.

f. Where a transferable load is supplied by a system that is derived from an on-site isolating transformer and the transfer equipment is ahead of the transformer, a grounded (neutral) circuit conductor is not required from either the normal or alternate supply to the transformer primary.

(1) The isolating transformer permits phase-to-neutral transferable loads to be supplied without a grounded (neutral) circuit conductor in the feeders to the transfer switch.

(2) The system supplied by the isolating transformer is a separately derived system, and if it is required to be solidly grounded, it should be grounded in accordance with code requirements. The neutral circuit conductor for the transferable load is supplied from the secondary of the isolating transformer.

g. If the on-site generator is rated 480Y/277V or 600Y/347V, its neutral may not need to be solidly grounded because the neutral is not used as a circuit conductor. Therefore, the type of system grounding for such a generator is optional. However, the generator frame should be solidly grounded whether its neutral is ungrounded, high resistance grounded, or solidly grounded.

h. In ground fault current return paths where the grounded (neutral) circuit conductor of a transferable load is isolated by a transformer, any stray neutral current or ground fault current on the secondary of the isolating transformer will have no effect on ground fault protection equipment at the service equipment or at the generator.

i. Where the grounded (neutral) circuit conductor is solidly connected (not switched) in the transfer equipment, an emergency or standby system supplied by an on-site generator should not be considered a separately derived system. The solidly interconnected grounded (neutral) conductor need only to be grounded at the service equipment.

(1) The solidly interconnected neutral conductor is grounded at the service equipment only and there are no conducting paths for stray neutral currents. If the generator is not adjacent to the service equipment, the generator frame should be connected to a grounding electrode such as effectively grounded building steel.

(2) Where the solidly interconnected neutral conductor is grounded at the service equipment only, the ground fault current return path from the transferable load to the on-site generator is through the equipment grounding conductor from the transfer switch to the service equipment, thence through the main bonding jumper in the service equipment and the neutral conductor from the service equipment to the generator.

j. The ground fault current might trip the service disconnecting means even though the ground fault is on a circuit supplied by the generator. A signal could be derived from a ground fault sensor on the generator neutral conductor to block the ground fault protection equipment at the service in case of ground faults while the system is transferred to the generator. Such blocking signals require careful analysis to ensure proper functioning of the ground fault protection equipment.

k. If the neutral conductor between the service equipment and the transfer switch is intentionally or accidentally disconnected, the generator will be ungrounded. Therefore, the integrity of the neutral conductor must be maintained from the service equipment to the transfer switch while the load is transferred to the generator. The equipment grounding conductor must also be maintained from the service equipment to the transfer equipment in order to provide a ground fault current return path from the transferable load to the generator.

l. For increased reliability, multiple transfer switches, located close to the loads, are often used rather than one transfer switch for the entire load. Therefore, consideration should be given to the possibility of cable or equipment failure between the service equipment and the transfer switches, thus possibly causing an ungrounded emergency or standby power system.

m. Three-phase, three-wire, 480 volt and 600 volt systems, which are used prevalently, do not require the use of grounded conductors as circuit conductors. There are more system grounding options where emergency and standby power systems do not require a grounded circuit conductor to supply phase-to-neutral loads.

n. In many installations the service to the premises will be solidly grounded, three-phase, four-wire where a grounded (neutral) circuit conductor is not required for loads that are provided with an on-site emergency or standby supply. An on-site emergency or standby supply is not always required to have the same type of system grounding as the normal supply to the premises.

o. The generator supplies a three-phase, three-wire system. If the generator is rated 480Y/277V or 600Y/347V, it need not be solidly grounded because its neutral is not used as a circuit conductor. An on-site generator that is not required to be solidly grounded may be high resistance grounded or ungrounded. A high resistance grounded or ungrounded emergency or standby power supply provides a high degree of service continuity because the circuit protective equipment will not be tripped by the first ground fault on the system. If the generator is solidly grounded, it must be grounded at or ahead of the generator disconnecting means.

p. Interlocked circuit breakers are used as the transfer means. Where a grounded (neutral) circuit conductor is not required, the type of transfer equipment that is employed is not a consideration in selecting the type of system grounding for the emergency or standby supply.

q. Interlocked circuit breakers should not be selected as a transfer means without considering additional means to isolate the normal and alternate circuit conductors and equipment for maintenance work. The overall reliability of a system may be reduced due to additional exposure where the circuit conductors from the normal supply are solidly connected to the circuit conductors from the emergency or standby supply. The circuit wiring for an emergency system should be kept entirely independent of all other wiring or equipment except in transfer switches or in junction boxes and in fixtures for exit and emergency lighting.

r. A 480 volt or 600 volt, three-phase, three-wire, on-site generator that is high resistance grounded may serve as an emergency or standby power supply for a three-phase, three-wire system that is normally supplied by a solidly grounded service.

s. Where the three-phase, three-wire critical load is relatively large compared with loads that require a grounded (neutral) circuit conductor, a high resistance grounded emergency or standby power supply is sometimes considered. This arrangement requires an on-site transformer for loads that require a neutral circuit conductor. If an on-site transformer is provided for emergency lighting, it must be supplied from the normal service and the emergency supply through automatic transfer equipment.

t. The supply transformer for the normal service and the on-site generator are both high resistance grounded. There are no provisions to supply phase-to-neutral loads.

u. The ground fault current return path to the on-site generator is completed through the grounding resistor. The grounding resistor limits the line-to-ground fault current to a magnitude that can be tolerated for a time, allowing the ground fault to be located and removed from the system.

v. High resistance grounded systems should not be used unless they are equipped with ground fault indicators or alarms, or both, and qualified persons are available to quickly locate and remove ground faults. If ground faults are not promptly removed, the service reliability will be reduced.