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Emergency Power Supplies for Physical Security Systems

Prepared by G. L. Bowers

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Oak Ridge Y-12 Plant

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ABSTRACT

This report on emergency electric power for security systems at nuclear reactor and fuel cycle facilities was prepared for use in the Safeguards program of the United States Nuclear Regulatory Commission. The report includes information that will be useful to those responsible for the planning, design, and implementation of emergency electric power systems for physical security and special nuclear materials accountability systems. Basic information concerning different types of emergency power supply systems is presented. Those individuals with a comprehensive understanding of electrical power systems may find segments of the text very fundamental. Basic considerations for establishing the system requirements for emergency electric power for security and accountability operations are presented. Methods of supplying emergency power that are available at present and methods predicted to be available in the future are discussed. Such emergency power considerations as capacity, cost, safety, reliability, and environmental constraints are presented. The report includes basic consideration for the development of a system concept and the preparation of a detailed system design. A bibliography, with most items annotated, is included. Within the content of the report the user will find answers to the following questions.

1. What types of systems are available, and which systems can best meet the licensee's needs?

2. What is the estimated purchase and installed price range of the various systems per kilovolt-ampere?

3. What are the operating and maintenance requirements for maintaining system reliability?

4. Where can additional information on the various systems discussed be obtained?

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1. INTRODUCTION

The subject of this report is the supply of emergency electrical power to safeguard hardware systems at licensee facilities in the event of failure of the normal power source. Power failure is defined as any variation in electric power supply which causes unacceptable performance of the user's equipment. The purpose of the report is to present basic concepts to be considered before designing or assembling an emergency electric power subsystem for security monitoring and control systems.

A variety of detection, assessment, response, and communications systems will require reliable sources of electric power. Voice radio, video, data, telephone, and other communications used to transmit, receive, and display or sound alarms for notification all require dependable electric power supplies.

The assessment and response activities may involve the employment of such measures as additional fixed lighting, portable or mobile lighting, voice radio, video, data, telephone, or other communications devices, system monitoring devices and portable or mobile detection devices. The response activities may involve the remote control operation of the access and egress portals of the facility to confine, minimize or delay the effect of the incident. The assessment and response operations will require reliable electric power supplies.

The detection, alarm, assessment, and response activities mentioned above occur only in the event of a threatened or actual breach of security, the misplacement of special nuclear materials, or the occurrence of a false alarm. Emergency electric power is required in the day-to-day security and materials accountability operations. The monitoring and control of the various alarm systems and the communications systems employed in normal operations all require emergency power supplies.

Emergency power for fire alarm systems, criticality and radiation detection systems, process cooling control systems and for other similar systems is not included in the scope of the report. The power source for such systems is referred to in the report as the plant emergency power system.

2. GENERAL REQUIREMENTS FOR EMERGENCY POWER SUPPLY SYSTEMS

2.1 GENERAL

Certain elements of security and materials accountability systems must be operable, either in their entirety or in part, irrespective of the interruption of the normal source of their electrical power. The elements of the security and materials accountability systems that require emergency power must be determined by those responsible for the operation of the systems. The electrical loads, electrical characteristics and allowable tolerances, allowable interruption periods, and locations of the various components requiring emergency power must be determined.

The establishment of general requirements for emergency electric power involves analysis of the various types of electrical loads that must be supplied by the emergency power requirements; voltage, direct current, alternating current, permissible interruptibility, location, and physical security constraints. Included in this analysis must be the provision for a locally maintained, survivable supply of fuel for the emergency generators. This means the location of tanks and plumbing within the protected area to thwart an external adversary. Measures are also required to protect this supply specifically and the emergency system generally from subversion by one or more employees acting as the "insider" adversary element.

Conclusions derived from the analysis will establish the general system requirements. Consideration of the established basic requirements and familiarity with available methods of supplying emergency power will provide general indications of practical methods to serve the various electrical loads.

A typical basic determination that may be evolved from the establishment of general systems requirements is whether a particular electrical load may be satisfactorily served by the plant emergency power supply or requires a separate source of emergency power. Considerations involved in this basic determination are discussed below.

2.2 SEPARATE EMERGENCY POWER SYSTEM

A separate emergency power system is required if any of the following conditions exist.

1. The plant emergency power system does not have sufficient capacity to serve the required load.

2. The response time of the plant emergency power system is insufficient to serve the required load.

3. Regulations prohibit use of the plant emergency power system.

4. It is uneconomical to connect to the plant emergency power system because of the cost of distribution lines, inverters, rectifiers, voltage stabilizers, transformers, or other costs that may be encountered.

5. The plant emergency power system does not provide the required degree of reliability or security. Typically, separate emergency power supply systems will be required for physical security and safeguards instrumentation at nuclear reactor and fuel cycle facilities.

2.3 USE OF PLANT EMERGENCY POWER SYSTEM

The plant emergency power system may have reserve capacity that could supply the emergency electrical power to the entire protection system. In the event that the plant emergency power system is not suitable or sufficient to meet all of the protection system's electrical requirements, it may be capable of meeting portions of the requirements. Devices that are of secondary importance to the protection system and devices that can be dropped from service for short periods of time with minimal detrimental effect upon the protection system's efficiency may be served adequately by the plant emergency power system. Examples of such devices are heating, ventilating, and air conditioning equipment, secondary lights, and battery chargers.

2.4 UNINTERRUPTIBLE POWER SYSTEMS

Some protection devices are rendered ineffective or are reduced in effectiveness if there is any interruption of their input power. Interruption of the electric power input to automated data handling systems may cause the loss of the executive and operating programs and the data in volatile storage in the computer. Most computers of recent manufacture will detect a power slump and will go into a power-down mode automatically in order to preserve all executive and operational programs and transfer all data from core to disc storage. When power returns, the system will return automatically to operating status. Most intrusion alarm detectors are activated by input power line transients or a complete power failure. Each element of a protection system must be analyzed to determine if it can withstand momentary failures of the electric power input without significant detriment to the protection system. Components of the protection system that are unable to tolerate power interruptions require the employment of an uninterruptible power system. An uninterruptible power system is any source that protects a critical load from fluctuations or interruptions of the incoming AC power that drives it. Examples of uninterruptible power supply systems are shown in Figures 1 and 2.

2.5 INTERRUPTIBLE POWER SYSTEMS

An interruptible emergency power system is applicable whenever a separate emergency power supply system is necessary and a momentary interruption of power is acceptable. The capacity of the source, the period of interruption permissible, and the type of available energy source determine the type of power system that should be employed. In some instances, it may be economically advantageous to use more than one emergency power supply in time sequence. For example, a vital device can be kept operating for a short period of time with batteries until an emergency engine-driven generator can

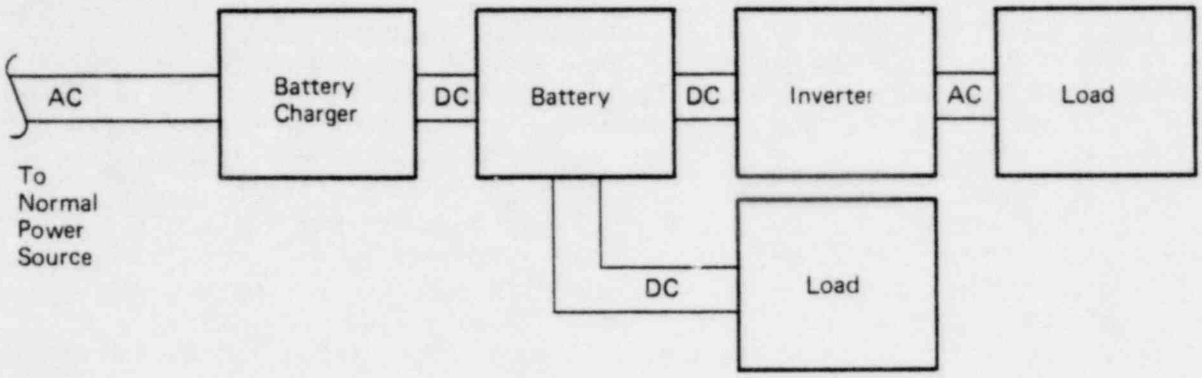

Figure 1. UPS with A.C. or D.C. Load

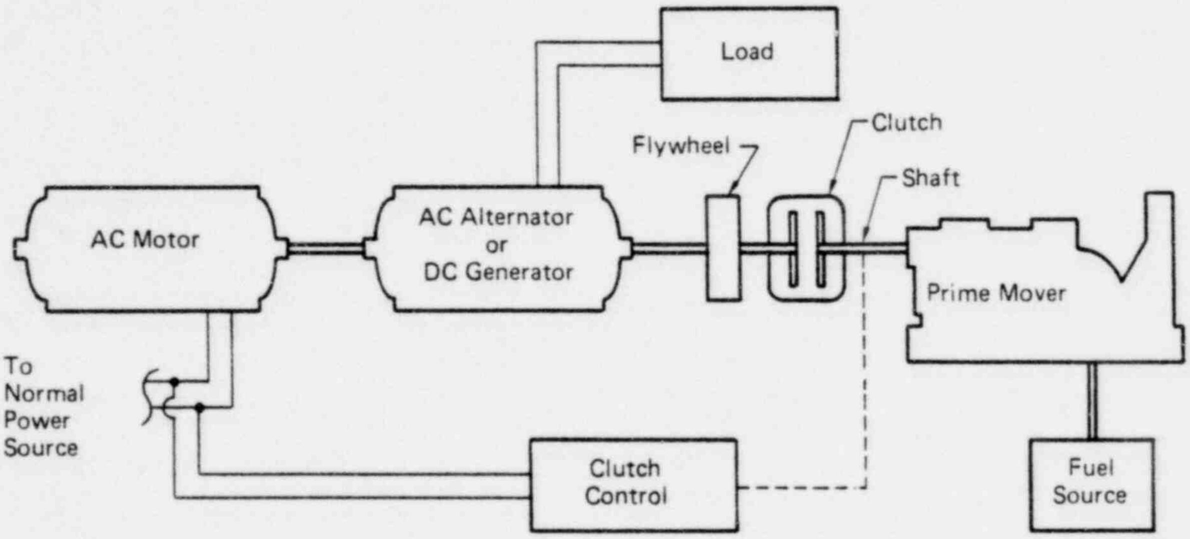

Figure 2. UPS with Prime Mover Drive

be employed, until connection can be made to the large plant emergency power system, or until power from the normal source is restored. Another example would be the area of external Protected Area Lighting for use with closed-circuit television (CCTV) for remote assessment of alarms. The CCTV system, with low light cameras, would need to operate continuously during a commercial outage, although the dropout and delayed restart of the halide-type lights might be tolerated.

3. EMERGENCY POWER SUPPLY TECHNIQUES

Most existing emergency electric power supply systems, whether interruptible or uninterruptible, employ engine-driven generators and/or batteries. Other types of systems such as solar-powered photovoltaic and thermoelectric systems may be applicable at present to special requirements for emergency electric power or may become more feasible for such use in the future. In Sections 3.1 through 3.3, the systems hardware and general characteristics of the various techniques in practical use today are presented. In the future, other sources of electric energy may be developed which could fill some of the needs for emergency power supply systems. Possible new technologies foreseen for future applications are

1. Inertially powered generators,
2. Fuel cells which convert chemical energy directly into electrical energy,
3. Wind or wave-powered generators,
4. Nuclear-powered generators,
5. Solar-powered generators, and
6. Thermoelectric-powered generators.

3.1 ENGINE GENERATORS

3.1.1 Engine Types - A wide variety of engine movers may be used to drive a generator/alternator to produce electric power. Internal combustion reciprocating engines, rotary and turbine engines, wind or water-powered engines, steam-powered engines, and many others have been used or considered for use as prime movers in electric power generation. An external combustible Rankin Cycle engine that uses almost any combustible fuel to drive a turbine and produce 200 to 3000 W of electrical power is commercially available. Power take-off devices on engine-driven vehicles and conversion devices to produce 100-V, 60-Hz electric power from vehicle alternators are available. The engine generator of this report is an Otto or diesel cycle internal combustion reciprocating engine driving a rotating machine that converts the mechanical power of the engine to electrical power.

3.1.2 Future Improvements Expected - Engine generators are used extensively throughout industry. Presently, generators are the most common source of emergency electric power. Existing trends of increased efficiency, decreased weight, and greater reliability for reciprocating internal combustion engines are expected to continue and thus keep these engines in their present dominant position in the emergency electric power field for a number of years.

3.1.3 Generators/Alternators - Generators and alternators convert the mechanical power of the prime movers to electrical power. Most engine generator units are used to serve an alternating current load and have the internal combustion engine directly coupled to a four-, six-, or eight-pole self-excited alternator.

A schematic of a basic alternator is shown in Figure 3. The rotor contains the magnetic field winding which is ~~supplied with a~~ dc current through slip rings. Usually, a small dc generator or exciter mounted on the rotor shaft is used to provide the field current. The stator contains the armature winding, which is represented by the concentrated coil aa'. In general, additional coils are placed about the stator and connected in series, thus more effectively utilizing the available stator space.

For sinusoidal distribution of the angular flux, the voltage induced in the coil aa' varies sinusoidally as a function of time, as shown in Figure 4. The generated voltage goes through a complete cycle for each revolution of the motor. Therefore, if the frequency of the generated voltage is 60 cps, then the rotor speed must be 60 rps or 3600 rpm. If a gas or steam turbine is the prime mover, then it is usually feasible to drive the rotor at this rather high speed. However, for other prime movers, slower rotor speeds must be used. If four rotor poles are used as in Figure 5, an electrical cycle is completed for half a mechanical revolution of the rotor, and consequently a four-pole alternator is driven at 1800 rpm to produce 60 cps electric power. Similarly, if six poles are used, then the rotor speed must be reduced to 1200 rpm. The relationship between the frequency f, the number of poles P, and the speed S in rpm is therefore

$$f = \frac{P}{2}\frac{S}{60} \text{ cps.}$$

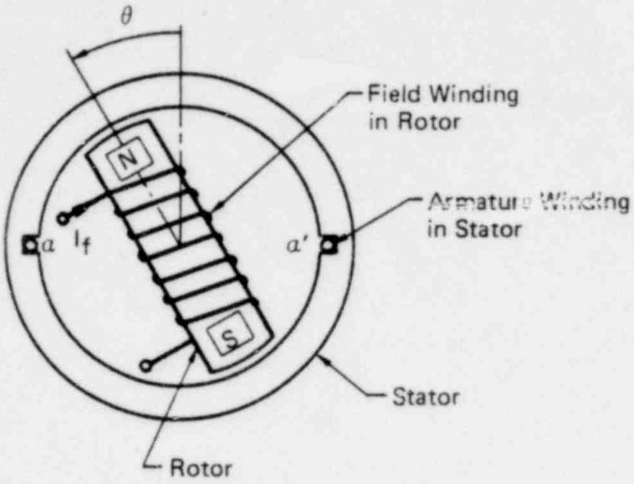

Figure 3. Schematic of the Basic Single-Phase Alternator

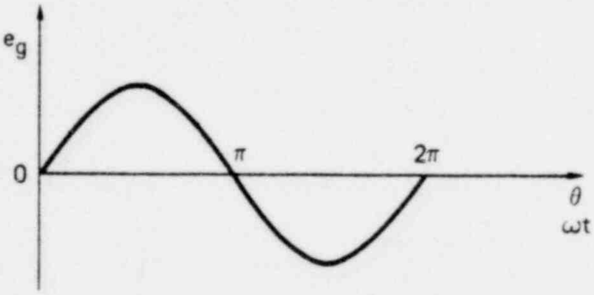

Figure 4. Generated Voltage Waveform

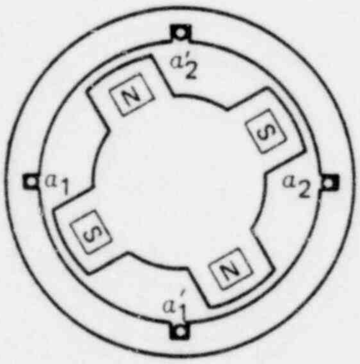

Figure 5. Schematic of a Four-Pole Single-Phase Salient-Pole Alternator

An expression for the induced armature voltage is given by

$$E = \left(\frac{PZ}{60P' \times 10^8}\right) \phi S$$

where

P = number of poles,
Z = total number of conductors on the surface of the armature,
P' = number of parallel paths through the armature,
S = speed of the armature in rpm,
ϕ = total flux in maxwells.

For a given generator, the quantity within the parenthesis is constant and may be denoted by K. Hence,

$$E = K\phi S.$$

Therefore, the induced emf in a generator is directly proportional to the flux and to the speed. If the speed is kept constant, the induced emf is directly proportional to the flux ϕ.

The excitation for the alternator may be obtained from a combination rectifier and regulator or from a separate excitation generator built into the alternator. The speed of these units (therefore, the output a.c. frequency) is controlled by a simple governor, or on the smaller and less expensive units, a vane in the path of the cooling air flow. Units are available for the generation of a wide variety of single-phase and three-phase alternating current voltages, direct current voltages, and combinations of alternating and direct current voltages. The combinations available at present in capacities ranging from 1 kW to 115 kW are tabulated in Table 2.

3.1.4 <u>Capacity</u> - The engine generator must have enough capacity to serve the largest total continuous load that it will be expected to carry and to start the largest motor it will drive without excessive voltage dip. The largest voltage dip tolerable will be equal to, or slightly less than, the smallest of all of the permissible dips of the loads connected to the generator. The engine generator units commercially available will provide a voltage regulation and surge protection that exceeds the requirements of most communications alarm and control equipment, providing their capacity is not exceeded.

Nominal Capacity (KW)	Nominal Electrical Characteristics	Cooling	Fuel
1, 1.25, 1.5	120 V. A.C., 60 Hz., 1 PH., 2 W. 12-15 V. D.C. 24-30 V. D.C. 32-40 V. D.C.	Air	G,N,LP
2.5	120 V. A.C., 60 Hz., 1 PH., 2 W. 120 V. A.C., 60 Hz., 1 PH., 2 W. & 12-15 V. D.C. 240 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W.	Air	G,N,LP
3	120 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH. 3 W	Air	G,N,LP,D
4	120 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W.	Air	G,N,LP
5, 6.5	120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W.	Air	G,N,LP
7.5	120 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W. 277/480 V. A.C., 60 Hz., 3 PH., 4 W. 240 V. A.C., 60 Hz., 3 PH., 3 W.	Air or Liquid	G,N,LP,D
10	120 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W. 277/480 V. A.C., 60 Hz., 3 PH., 4 W.	Air or Liquid	G,N,LP,D
12.5	120 V. A.C., 60 Hz., 1 PH., 2 W. 240 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W. 277/480 V. A.C., 60 Hz., 3 PH., 4 W. 240 V. A.C., 60 Hz., 3 PH., 4 W.	Air or Liquid	G,N,LP,D
15	120 V. A.C., 60 Hz., 1 PH., 2 W. 120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W. 120/208 V. A.C., 60 Hz., 3 PH., 4 W. 277/480 V. A.C., 60 Hz., 3 PH., 4 W. 240 V. A.C., 60 Hz., 3 PH., 3 W.	Air or Liquid	G,N,LP,D
30, 45, 55, 60, 65, 70, 85, 90, 100, 115	120/240 V. A.C., 60 Hz., 1 PH., 3 W. 120/240 V. A.C., 60 Hz., 3 PH., 4 W 120/208 V. A.C., 60 Hz., 3 PH., 4 W. 277/480 V. A.C., 60 Hz., 3 PH., 4 W. 240 V. A.C., 60 Hz., 3 PH., 4 W.	Liquid	G,N,LP,D

Table 1. Engine Generator Characteristics

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Normal practice is to specify an engine generator for an installation which has a capacity that is at least 25% higher than the maximum anticipated load (Ref. 1). No matter what the load, a unit smaller than 2.5 kVA sold to the recreational, hobby, and other noncommercial users is frequently not as reliable as the larger units. An additional disadvantage of many of the smaller units is that they employ a two-pole alternator which, in turn, requires a 3600 rpm engine to produce 60-Hz power. This high operating speed is not conducive to long engine life. In fact, experience has shown that many 1800 rpm engine-driven sets are not adequate as continuous power supplies (several weeks' duration). Everything else being equal, the engine selected for a continuous duty application should be one with the 1) largest piston displacement, 2) lowest piston speed, and 3) lowest mean effective brake pressure or the lowest average pressure on the piston over one complete engine cycle at rated output (Ref. 2).

The capacity range of engine generator units normally employed as emergency power sources for communications systems, alarm systems, security systems, etc., is usually between 2.5 kVA and 100 kVA. Manufacturers listed capacity ratings are for sea level installations and must be derated for installations at higher elevations. A general rule for derating engine power loss with altitude increase is to derate about 4% for each 1000-ft increase in altitude. Also, an average derating factor for high ambient temperature is 1% for each 10°F above 60°F. Temperature derating is not considered as important as altitude derating. Information regarding the available capacity increments from 1 to 115 kW is tabulated in Table 1.

3.1.5 Initial Cost - The costs in this section are based on the period of CY 78 and are estimates only. Due to the pace of inflation, adjustments need to be made accordingly when projecting procurement lead times. The initial installed cost of an engine generator may include several costs besides the supplier's price for the engine generator equipment. Accurate determination of the installed cost must include all of the optional accessories (Table 1) needed to meet the requirements of the particular installation. Dual fuel capabilities, if required, will add approximately 1 to 2% to the base price of the generator. Also included in the initial cost should be provisions for a locally maintained, survivable supply of fuel for the emergency generators.

At present, the listed equipment prices for standard engine generator units that are gasoline fueled and air cooled with capacities below 15 kW will vary from approximately \$250 to \$375 per kW of rated output, with the lower end of the price range applying to the larger units. The present prices of standard liquid-cooled gasoline units with capacities below 100 kW range approximately from \$125 to \$400 per kW of rated output, with the lower end of the price range applying to the larger sizes. The present prices for standard liquid-cooled diesel engine generators with capacities below 100 kW range from approximately \$150 to \$450 per kW of rated output. In this category, the lower end of the price range is also applicable to the larger sizes.

3.1.6 Operation and Maintenance Cost - The cost of maintaining an engine generator emergency power system includes the cost of parts, labor, materials, and expendable supplies such as lubricating oil and cooling fluid. The operating cost includes the cost of the fuel expended during the periods that the equipment is exercised or operated due to a failure of the normal power source. Warranties on engine generator systems issued by the manufacturer or installing contractor usually include the replacement of defective parts and perhaps the labor for their installation for a specific period of time after the installation is completed. Substantial savings in maintenance costs may be realized by invoking the provisions of a good warranty where they are applicable. Minimum warranties are generally for a period of one year, but warranty periods of 2, 3, 4, and 5 years are not uncommon. Estimating fuel consumption is discussed in Section 3.1.13, Fuel Considerations. Engine-driven generators when properly maintained and kept warm will dependably come on line within 8 to 15 seconds. To keep the generator in good condition, the unit should be run for 15 to 30 minutes under load at least once a month and preferably once a week. Engine-driven generator manufacturers generally furnish a detailed maintenance, operation, troubleshooting, and spare parts manual with each engine-driven generator set. A typical general maintenance schedule is shown in Table 2.

3.1.7 Training - Adequate training of the maintenance and operations personnel responsible for an engine generator emergency power system is mandatory for reliable performance. Rigid adherence to adequate maintenance procedures will usually ensure that the system will perform as needed if the normal power source fails.

Table 2

TYPICAL OPERATOR MAINTENANCE SCHEDULE FOR ENGINE GENERATORS

Maintenance Items	Operational Hours			
	8	50	100	200-250
Inspect Set	x			
Check Fuel	x			
Check Radiator Coolant Level	x			
Check Oil Level	x			
Drain Fuel Filter Sediment	x			
Check Air Cleaner (Clean if Required)		x1		
Clean Injector Pump Linkage		x1		
Clean and Inspect Crankcase Breather			x	
Inspect Fan Belt			x2	
Check Cooling System			x3	
Change Crankcase Oil			x6	
Replace Oil Filter Element			x6	
Clean and Inspect Battery Charging Alternator				x
Check Starter				x4
Check Injection Nozzles				x5
Replace Fuel Filter Elements				x1
Check Batteries				x

x1 Perform more often in extremely dusty conditions, or every three months.

x2 Adjust to 0.50-inch depression between pulleys, or every three months.

x3 Check for rust or scale formation. Flush if necessary.

x4 Oil front bearing sparingly, check brushes.

x5 Check for proper spray pattern, etc.

x6 Perform every three months or 100 hours, whichever comes first.

3.1.8 Total Life System Cost - The total cost of the engine generator emergency power system for the duration of the useful life of the system is the summation of all of the costs discussed above. The total life system cost may be estimated by estimating the initial and annual operating and maintenance costs and projecting these costs for the predicted useful life of the system and then subtracting the salvage value.

3.1.9 Power Transfer Controls - The transfer switch has the principal functions of exercising the engine generator equipment periodically, sensing a failure of the normal power source, starting the prime mover, and transferring the electrical load from the normal power source to the emergency power system. This element of the emergency power system must be selected carefully to provide the maximum practical reliability. Satisfactory operation of the transfer switch (shown in Figure 6) is vital to the reliability of an engine generator emergency power system (Ref. 12). Transfer switches that are available fall into three general categories: 1) mechanical/manual, 2) electromechanical, and 3) static (Ref. 3).

The mechanical transfer switch is one that is thrown manually to permit no-break transfer to the secondary source when maintenance is necessary. Customarily, it is a make-before-break type. With the inverter phase locked to the commercial power source, it can be thrown without interrupting power to the load (Ref. 3).

The electromechanical transfer switch is used in systems that can tolerate the transients normally encountered on power lines, since its transfer time is normally 50 msec or less (about three cycles). It may operate automatically, being actuated when a power outage or fault is sensed (Ref. 3).

Static transfer switches operate on the same principle as the electromechanical switches. They are used for load switching when the load is adversely affected by short-term transients. The moving armature is replaced by silicon controlled rectifiers (SCR) to reduce transfer time. Transfer time for the static switch is typically 5 msec or less (Ref. 3).

The monitoring and control provisions supplied by the manufacturers of engine generator units will vary with the manufacturer and with the various models offered by any one manufacturer. Most manufacturers offer the monitoring and control items listed in Table 4 either as standard items or as optional accessories.

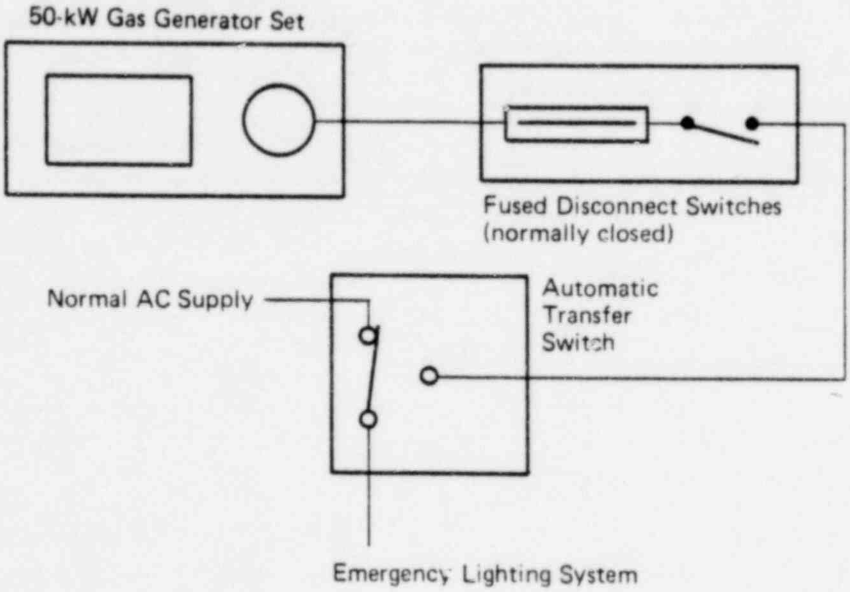

Figure 6. Typical Generator System with Transfer Switch

3.1.10 Safety Considerations - The major manufacturers of engine generator equipment generally comply with the safety requirements of the National Electrical Manufacturer's Association, Institute of Electrical and Electronic Engineers, Occupational Safety and Health Administration, American National Standards Institute, and other safety codes and regulations applicable to the manufacture of the equipment. Compliance may be, in some instances, provided by optional accessories. Several safety code provisions must be considered in the installation of the system. Typical of these considerations are the safety codes, regulations, and policies governing the storage of volatile fuels, penetration of structures by hot exhaust pipes, disconnection of electrical power sources during repair or maintenance operations, the discharge of toxic gases to atmosphere, battery venting, and provisions for combustion air. A list of codes and standards references that may be applicable is included in the Appendix.

3.1.11 Environmental and Physical Facility Considerations - Engine generator emergency power systems and their fuel supplies require space for their installation and access sufficient for maintenance. The allocation of space for an engine generator system must provide for the equipment to be removed and replaced and for adequate maintenance access. Also, the fuel supply must be reasonably nearby and survivable. Engine generator equipment must be protected from the weather if it is to be reliable. Most manufacturers include a raintight enclosure as an optional accessory to their equipment.

The use of emergency power systems in cold climates may require measures to prevent freezing of the engine coolant at low ambient temperatures; and in extremely cold climates, the use of lubricating oil preheaters may be necessary. Installations in locations with high ambient temperatures may require special cooling or ventilating measures to prevent overheating the equipment. Tropical installations may require special moisture and fungus-resistant provisions. Where the equipment is installed inside a building, provisions must be made for the satisfactory discharge of the exhaust fumes, the supply of combustion air, and the intake and discharge of air for cooling. The transmission of objectionable noise and vibration from the unit to the building structure must be prevented.

3.1.12 Lifetime and Reliability Considerations - The length of the useful life of an engine generator emergency power system may be predicted with some degree of accuracy from the manufacturer's records of the operating life of similar installations. Such predictions must consider the predicted quality of the maintenance that the equipment is expected to receive, the environment in which it is installed, and the ratio of idle and operating time periods anticipated, including exercise periods and periods of full and partial load operation. The manufacturer's statement can be verified by communications with the users of the manufacturer's systems. The reliability of an engine generator system may be predicted by analysis of tests previously conducted by the manufacturer. The various branches of the U.S. Armed Forces have conducted extensive tests of numerous emergency electric power systems. Military standard 1058, "Generator Sets, Engine Driven, Methods of Test and Instructions" provides information concerning generator systems. Another useful reference is the Army Corps of Engineers document ETL-1110-3-150 "Engineering and Design of Electric Generator Sets, Diesel Engine Driven; Classification and Testing." System reliability considerations must include all elements of the system and must not be confined to the engine generator equipment.

3.1.13 Fuel Considerations - The prevalent fuels used in engine generator systems at present are gasoline, diesel oil, natural gas and liquefied petroleum gas (LPG). These fuels are discussed below.

Gasoline is used extensively since it is universally available, is a liquid at atmospheric pressure, and is easy to handle. Engines using gasoline fuel have a lower initial cost than diesel engines. Gasoline engines are easier to start than diesel engines under difficult conditions and in extremely low temperatures. Care must be exercised in the storage of gasoline because it vaporizes readily when exposed to air and can create conditions with an explosion potential. The storage life of gasoline is limited, and it will deteriorate and damage an engine in which it is used after approximately six months in storage. Gasoline has a lower octane rating than the gaseous fuels, and it has a greater fouling tendency.

Diesel fuel is less volatile than gasoline and is safer to store and to use. Diesel fuel has a longer storage life than gasoline, is readily available, and easy to handle. Most engine generator manufacturers recommend No. 1-D or No. 2-D grades of diesel fuel for use in their engines, since other grades of fuel in this general class have lower octane ratings and higher sulfur content, both detrimental to engine performance. The initial cost of diesel engines is generally greater than for engines of the same size built to use gasoline or gaseous fuels.

Diesel fuel costs less per gallon than gasoline and has a greater heating value. Fuel consumption in a diesel engine is significantly less than in a gasoline engine operating with the same load. Diesel engines are inherently heavier and more rugged than engines built to use gasoline or gas fuels, and the diesel engine has no points, spark plugs, or condensers, which require frequent maintenance on gasoline or gas-fueled engines.

Natural gas is usually obtained from a municipal distribution system or from a public utility source. If an off-site source is chosen, it should be coupled to an on-site supply of LPG with automatic switchover capability should the off-site supply be cut off. The use of natural gas will generally reduce the capacity of the engine to 85 to 90% of its capacity when using gasoline or liquified petroleum gas. This reduction is due to the lower Btu content of natural gas.

Liquified petroleum gas consists of a mixture of propane and butane. The mixture ratio is usually varied with the seasons to account for the effect of ambient temperature on the vapor pressures of the gases. The fuel is readily available in most areas of the United States, is generally stored in refillable pressure tanks, and is reasonably easy to handle.

Natural gas and liquified petroleum gas both have a higher octane rating than gasoline. They have a lower residue content than gasoline and contain no tetraethyl lead. They mix more thoroughly with the air in the engine cylinders than do liquid fuels and are more completely consumed by the combustion process. The introduction of the gaseous fuels into the cylinders of the engine causes no washing of the lubricating oil from the cylinder walls as occurs with the liquid fuels. The use of the gaseous fuels will produce less engine wear, less carbon formation, less sludge in the lubricating oil, and less fouling than the use of gasoline.

Fuel consumption varies with the manufacturer and varies among different models and sizes of equipment offered by any one manufacturer. Approximate fuel consumption may be estimated at full engine load as follows.

1. Gasoline fuel consumption is approximately 0.16 gal per kWhr of rated generator output and varies approximately from 0.10 to 0.18 gal per kWhr.

2. Natural gas consumption is approximately 18 ft^3 per kWhr of rated generator output and varies approximately from 13 to 25 ft^3 per kWhr.

3. Liquefied petroleum gas consumption is approximately 7.5 ft^3 per kWhr of rated generator output capacity and varies from approximately 4 to 10 ft^3 per kWhr.

4. Diesel fuel consumption is approximately 0.08 gal per kWhr of rated generator output and varies from approximately 0.04 to 0.10 gallon per kWhr.

The selection of a fuel for use in engine generator emergency power systems must consider survivability of the fuel supply, fuel availability, the engine efficiency required, the initial cost of the equipment, fuel cost, maintenance costs, reserve fuel storage requirements, and reliability requirements.

A summary of engine generator units available from 1 to 115 kW nominal capacity is given in Table 1. Table 3 shows the cost figures for diesel generator units ranging in size from 15 kW to 750 kW. Transfer switches will range in cost from $1500 for 30 A to $6200 for 800 A.

Engine generator sets with capacities of 5 kW and smaller are available in portable models with one-man or two-man carrying frames. An optional available accessory is a two-wheeled cart. Two-wheeled and four-wheeled trailers are available for mobile applications for any size of engine generator set listed in Table 1.

Most of the portable units are drip-proof construction for use exposed to the weather. Weatherproof enclosures are available for all sizes listed in Table 1.

Table 3

DIESEL GENERATOR COSTS

30, 60 Cycle, 1800 RPM, 100 AMP Transfer Switch

KW	Cost	Cost/KW
15	8,625	575
17.5	8,823	504
30	9,450	315
45	11,560	256
50	12,240	244
75	15,090	201
100	15,950	159
150	21,275	141
175	21,975	125
200	22,455	112
250	26,180	104
300	33,700	112
350	39,560	113
400	55,400	138
750	93,340	124

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Available starting methods include rope-recoil manual starting on the portable models, local push-button starting using a battery and starter, remotely controlled starting, and automatic starting and load transfer.

Frequency regulation available range from ±1.8 Hz to ±7% of the rated frequency.

Response performance of engine generators varies with the manufacturer and with different models produced by the same manufacturer. The instantaneous voltage dip that occurs upon the application of full load varies from 12 to 20% of rated voltage on the units presently available. The period of recovery from the instantaneous voltage dip to stable operation varies from 1 to 2 seconds, and stable operation ratings vary from 0.50 to 1% of rated voltage.

Most of the engine generator combinations listed in Table 1 are available for dual fuel operation using gasoline and one of the gaseous fuels, natural gas, or LPG. The primary consideration when changing from one fuel type to another is the change in carburetion.

The list presented in Table 4 is representative of the controls, instruments and accessories available with engine generator equipment.

Below is a partial list of the U.S. manufacturers of engine generator units.

General Electric Company
Kohler Company
Generac Corporation
Caterpillar Tractor Company
Onan Division of Onan Corporation
Winco Division of Dyna Technology, Incorporated

Specific availability, delivery schedules, and prices may be obtained from local manufacturer's representatives or distributors.

3.2 Battery Power

3.2.1 General - Batteries are the most convenient source of a limited amount of dc power. The selection of a battery for a particular application involves compromises and tradeoffs. Normally, batteries are located as close as possible to the device(s) to be powered to decrease resistive power loss in the supply bus. This requirement can result in distributed systems as opposed to a system with all batteries in a single location. Theoretically, a battery can be constructed using

Table 4

GENERATOR ACCESSORIES

Current Transformers
Voltmeter
Circuit Breaker
Frequency Meter
Battery Charge Rate Ammeter
Oil Pressure Gauge
Water Temperature Gauge
Running Time Meter
Timed Engine Exerciser
Automatic Overspeed Shutdown
High Water Temperature Cutoff
Remote Start-Stop Control
Automatic Transfer Switch
Cranking Limiter
Local Start-Stop Control
Phase Selector Switch for Three-Phase Models
Radio Interference Suppression
Exhaust Mufflers
Remote Radiators
Priming Tanks, Day Tanks and Fuel Storage Tanks
Safety Alarms and Indicating Panel
Vibration Control
Carrying Frames and Two-Wheeled Carts for Portable Models
Two-Wheeled and Four-Wheeled Trailers
Engine Block Heater
Radiator Duct Connector
Skid Base
Convenience Electric Outlet
City Water Cooling Controls and Filter
Raintight Enclosure

commercially available battery cells to store any desired voltage and current output; however, the size, weight, and cost of such a battery could be prohibitive. The U.S. Department of Justice, under the Law Enforcement Standards Program, commissioned the National Bureau of Standards to compare the performance characteristics of batteries normally used with communication security systems. The result (Ref. 4) is a useful pamphlet which presents a thorough set of definitions of terms, comparisons of characteristics, and suggestions for selecting and using batteries. Batteries are usually grouped into three classifications--primary, secondary, and reserve.

3.2.2 Primary Batteries - Primary batteries are designed to deliver their stored power in a continuous or intermittent discharge. They cannot be recharged efficiently. The amount of energy a primary battery will deliver is determined by the materials used in their manufacture and the size of the cell. When the available energy drops below the point that the battery will deliver a useful voltage/current ratio to the load, the battery is usually discarded. The use of primary batteries as a source of emergency power for safeguards systems is limited because they cannot be efficiently recharged. Primary batteries may be classified by the type of electrolyte used (Ref. 5).

Aqueous-electrolyte batteries use solutions of acids, bases, or salts in water as the electrolyte. These solutions have ionic conductivities around 1 mHO per cm and almost negligible electron conductivity. Examples of this type of battery are the Leclanche cell and the alkaline manganese-zinc cell, both of which are used in flashlight batteries.

Solid-electrolyte batteries are electrolytes composed of solid crystalline salts that have predominantly ionic conductivity. Solid-electrolyte batteries may be classified into two categories: 1) cells with solid crystalline salt as the electrolyte, and 2) cells with an ion-exchange membrane as the electrolyte. The conductivity of either of these types of solid-electrolyte batteries must be nearly 100% ionic because any electron conductivity will cause a continuous discharge of the cell and shorten shelf life. The lead-lead chloride-silver cell is a typical solid electrolyte battery. One cell of such a battery will produce a voltage potential of 0.49 V, and they have been stacked to deliver 90 to 100 V at 10 μA with a capacity of 1 μA/sec. Such a battery is about 3/8 in. in diameter and 1 in. long. A representative of the ion exchange membrane battery is the zinc-silver battery which produces a voltage potential of about 1.5 V. The capacity of such batteries is approximately 0.4 A-hr per in^3 of volume.

Wax-electrolyte batteries use waxy materials in which a small amount of a salt is dissolved. The conductivity of these batteries is low, and the current output is limited to approximately 1 μA per in^2. A 25-cell zinc-polyethylene glycol-manganese dioxide battery is 0.34 in. in length, 0.25 in. square, weighs 1.5 g, and provides an output voltage potential of 37.5 V.

Fused-electrolyte batteries use crystalline salts, or bases, which are solid at room temperature but are used after heating to a temperature above the melting point of the electrolyte.

3.2.3 Secondary Batteries - Secondary batteries, commonly called storage batteries, are the predominant portable energy source in the United States today. A storage battery is composed of one or more identical voltaic cells in which the electrochemical action is reversible so that the battery can be recharged by passing a direct current through the cells in the opposite direction to that of discharge (Ref. 6). The availability and variety of secondary batteries have been developed to the point that they are replacing the use of primary batteries at an ever-increasing pace, including their use in the hand-held flashlight. There are two general classifications of secondary batteries-lead-acid and alkaline.

Lead-acid batteries provide an extremely flexible and dependable tool for maintaining power stability and continuity. They are composed of lead sponge and lead peroxide plates immersed in sulfuric acid. They develop 2.0 V per cell when fully charged and produce 10 to 15 Whr of energy per pound of weight and 0.6 to 1.3 Whr of energy per in^3. The lead in lead-acid batteries is hardened by the addition of 1.5 to 5% antimony or calcium. Batteries used in U.S. automobiles employ antimony hardener, which provides the battery with an improved tolerance for high ambient temperatures and enables rapid recharging. When batteries with the antimony hardened plates are floated across the line, the charges on the individual cells become unequal; and periodic equalizing charges must be applied.

Batteries with calcium-hardened plates may be floated across the line for long periods without equalizing as long as a charge of approximately 2.25 V per cell is maintained. Lead-acid batteries are used to provide power to the load for short periods until the engine generator reaches operating speed and to supply power to electronic equipment when no other power source is available. 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:

12 V (audible and visual alarm systems, communications systems),

24 V (audible and visual alarm systems, communications systems),

32 V (emergency lighting systems, electric clock systems),

48 V (telephone systems, microwave systems),

120 V (emergency lighting systems, communication systems, telemetering, supervisory control systems, teletype systems, uninterruptible ac power supply systems), and

240 V (uninterruptible ac power supply systems).

Care must be exercised in specifying battery capacity, and the capacity should be specified at a definite discharge rate. The slower the discharge rate specified, the thicker the individual plates in the battery can be. The thicker plates provide a longer life expectancy for the battery.

Alkaline storage batteries employ nickel and iron, nickel and cadmium, or silver oxide and zinc plates immersed in an alkaline solution. The nickel-iron battery is known also as the Edison battery. It is lighter in weight than a lead-acid battery of equal capacity and has a longer life because there is no chemical deterioration during charging. The Edison battery is commonly used as an emergency electric power source in industrial alarm and communications applications. Alkaline storage batteries employing nickel and iron were formerly used in large battery banks to provide standby power for telephone and alarm systems. Few (if any) companies still manufacture this type of battery as the functions they used to fulfill are now being fulfilled by the lead-acid battery with the calcium hardener discussed in this section.

The nickel-cadmium batteries are commonly found in pocket calculators, hand-held portable radio transceivers, and similar devices where a reliable, compact source of energy is required. They are reliable, rechargeable, and can be assembled to deliver any voltage-current capacity required; but they are much more expensive than the lead-acid battery. Therefore, they are only used in applications where it is impractical to employ the lead-acid battery with its corrosive liquid electrolyte. Care must be exercised in cycling nickel-cadmium batteries from charge to discharge to charge or the capacity of the battery is greatly reduced. One nickel-cadmium cell will produce an out-put voltage of 1.28 to 1.15 V during the useful discharge portion of its cycle.

The silver-zinc battery has been used widely in military and space applications due to its high stored energy to weight ratio and its constant 1.45-V output over the major part of the discharge portion of its cycle. The silver-zinc battery is the most expensive storage battery commercially available. Extreme care must be taken when charging the battery to develop a full charge and not destroy it by ignoring the flat voltage versus charge characteristics of this type battery.

3.2.4 Reserve Batteries - Reserve batteries transcend the primary and secondary classifications used above. A reserve battery is one which remains inert until it is activated. Initiation methods to activate reserve batteries include the puncture of a seal, the rupture of a membrane, the addition of an electrolyte, the application of heat to melt the electrolyte, and other methods. Fused-electrolyte batteries can be considered to be reserve batteries. The main advantage of all reserve batteries is their extremely long shelf life without deterioration.

3.2.5 DC-DC Converters - In some nuclear reactor facilities, the number of battery cells in operation has become a problem from the standpoint of battery maintenance. In an attempt to reduce the number of battery cells, dc to dc converters are being considered, the advantage being the reduction in the number of individual 12-, 24-, and 48-V systems. These DC voltages are generated using dc-dc converters tied to the 250- and 125-V dc systems. The converters are located close to the high DC voltage source, with the lower voltages being distributed to the user points. An inherent disadvantage with this approach is the overcurrent capability of the converter. Overcurrents cannot exceed approximately 150% of normal converter output. An additional disadvantage of dc-dc converters is their extremely low efficiency.

3.2.6 Future Improvements Expected - Technological improvements of batteries are continually being made. Battery life and battery storage capacity are generally increasing, and battery size and cost are generally decreasing. A wide variety of types and sizes of batteries is available at present, and the availability of additional types and sizes is increasing rapidly. The use of batteries for short-term energy sources will continue to increase in the future. Performance parameters and projected performance parameters for rechargeable batteries are given in Table 5. The characteristics of existing commercially available batteries presented below are limited to secondary batteries of the types and sizes normally used as emergency power sources for components of security systems.

3.2.7 Initial Cost - The initial cost of a battery power system includes the cost of the battery cell plus the cost of the charging and switchover circuitry and equipment. Normally, the cost of the battery cells is the predominant factor and is directly proportional to capacity. The cost of a nickel-cadmium battery is three to four times that of a lead-acid battery of equivalent capacity.

3.2.8 Operation and Maintenance - Typically, stationary battery systems are maintained at voltages higher than the nominal system voltage. For example, a nominal 120-V system is usually operated at 129 V. This is due to a tendency of a battery cell to lose gradually some of its electrical charge because minor electrochemical reactions take place constantly on the plate surfaces. These losses are made up by constant "float" charging

Battery System	Estimated Volts per Cell	Estimated Energy Watt/H per Cell	Estimated Density Watt/H per Cubic Inch	Initial Cost		Estimated Life In Number of Cycles for 50% Discharge
				$/lb	$/Kwhr	
Lead Acid	2.0	10-15	0.6-1.3	1	100	>1000
Nickel-Cadmium	1.2	8-11	0.4-1.0	5	360	3000
Nickel-Iron	1.2	10-14	0.6-1.0	2	---	>1000
Nickel-Zinc	---	-----	-------	4	50	<2000
Nickel-Cadmium Centered	1.2	10-13	1.0	-	---	----
Silver-Cadmium	1.1	15-50	2.5	-	---	----
Silver-Zinc	1.5	20-100	3.0	20	> 360	< 200
Zinc-Chlorine	---	------	-------	> 1	> 15	< 150
Zinc-Air	---	------	-------	< 1	< 36	< 250
Sodium-Sulfur	----	------	-------	> 1	>10	100
Lithium-Sulfur	----	------	-------	3	30	----

Table 5. Secondary Battery Performance Parameters

during normal system operations. Float-charging voltage is maintained at a precise preset level, virtually always higher than the nominal system voltage but lower than the recharge or equalizing charge voltage.

The equipment powered by dc is usually designed to operate within a fairly broad range of voltage supply. This is necessary for two reasons: 1) to accommodate the gradual decline of battery voltage during discharge and 2) to accept voltage increases when required by recharging or equalizing charge operations (Ref. 7).

Battery capacity (c) is usually stated in ampere hours. Ampere-hour capacity is defined as the number of amperes that can be delivered under specified conditions as to temperature, rate of discharge, and final voltage.

Ampere-hour ratings, as stated by the manufacturer, can be very confusing and misleading. The actual ampere hours that a battery can deliver is very much dependent upon a number of factors such as

1. A specified discharge rate,

2. Ambient temperature at which the battery is being operated,

3. Allowable voltage swing from full charge to a low cutoff voltage, and

4. Duty cycle.

An example of the varying degree of battery capacity may be illustrated as follows. A battery with a nominal 9-A-hr capacity rating, when discharged over a 20- hr period, might deliver only 7 A-hr usable capacity when discharged over a 2-hr period, and only a 4-A-hr capacity for a 0.2-hr discharge.

The general condition of a battery can be determined by inspection. Items that should be checked on a quarterly basis are

1. Specific gravity readings of each cell,

2. Voltage readings of each cell and total battery terminal voltage,

3. Electrolyte level of each cell,

4. Float voltage,

5. Temperature of electrolyte of representative cells, and

6. Battery load voltage with battery on float charge.

A major advantage of some battery-powered emergency power systems is that they require very little, if any, maintenance, although some types of batteries must be checked periodically for electrolyte level. Adding water to the electrolyte is the most important single maintenance requirement in stationary battery systems. The best time to add water to the stationary lead-acid battery is when the recharge or equalizing charge is about two-thirds completed. Water tends to float on top of the electrolyte for a while, but the gassing action of the latter part of the charging period will mix the water into the electrolyte. For some safeguards applications, dry cell batteries may be chosen for cost and convenience reasons. In this case, a preventive maintenance practice should be initiated for periodic replacement of the dry cells.

The most efficient type of battery in terms of low watering frequency is the calcium alloy pasted-plate cell. Inspection of electrolyte level and, if necessary, watering of these cells are scheduled usually once a year throughout the battery's service life, if the float voltage is set at 2.17 Vpc and periodic equalizing charges at the recharge voltage of 2.33 Vpc are given. Equalizing charges can be eliminated by raising the float voltage to 2.22 or 2.25 Vpc, but an increase in inspection and watering frequency will be necessary. The frequency of watering required by antimony cells increases as the battery ages.

Periodically, or immediately after a power outage has ended, the lead-acid battery should be given an equalizing charge or a recharge at a higher voltage per cell than the float charge. This is possible only when the electrical load can tolerate the increased system voltage (Ref. 7). Table 6 gives the recharging times for stationary lead-acid batteries based on a 6-A charger serving a 100-A-hr lead-acid battery rated at an 8-hr discharge rate. Equalizing charges and recharges usually are given at 2.33 volts per cell (a system voltage of 140 V in a 60-cell battery).

Table 6

RECHARGING TIMES FOR STATIONARY LEAD-ACID BATTERIES

% of Discharge	Time to 95% Recharge*		
	@ 2.15 vpc	@ 2.25 vpc	@ 2.33 vpc
100	75 hours	16.6 hours	14.8 hours
90	73	14.6	13.0
80	71	13.2	11.7
70	69	11.2	10.3
60	67	9.8	8.6
50	65	8.5	7.1
40	62	6.6	5.8
30	55	4.9	4.0
20	45	3.4	2.5
10	27	1.6	1.0

*For recharging times to 100% recharged, add the following times to the above figures.

At 2.15 vpc, add 70 hours for antimony alloy cells or
add 96 hours for calcium alloy cells (approximate)

At 2.25 vpc, add 2.2 hours for antimony alloy cells, or
add 8.0 hours for calcium alloy cells (approximate)

At 2.33 vpc, add 1.2 hours for antimony alloy cells, or
add 3.0 hours for calcium alloy cells (approximate)

An antimony alloy cell floated at 2.15 Vpc should be given a periodic 2.33 Vpc charge for between 8 to 24 hr. Maximum system voltage can be reduced by lowering the equalizing charge voltage to 2.30 Vpc (138 volts in a 60-cell battery), but the duration of this charge will be lengthened to between 11 and 34 hr.

Calcium alloy batteries, float charged at 2.17 Vpc to 2.21 Vpc, should be given periodic equalizing charges at 2.30 Vpc for 48 to 72 hr. Calcium alloy cells, float charged at 2.22 to 2.25 Vpc, do not normally require an equalizing charge. The purpose of the periodic equalizing charge is to ensure that all the battery's cells are at full charge level. Lead-acid cells are complex assemblies with many variables that affect cell performance. No two cells are exactly alike. Float charging keeps most of the battery's cells at full charge, but some cells may gradually lose a little capacity. These "weak" cells can be upgraded or equalized with all the other cells by periodically feeding a prolonged charge at the specified recharge voltage. The frequency of giving equalizing charges depends on the charge method and also on the charging loads.

Frequency can be as often as once a month or as infrequently as once a year with constant voltage chargers, if the records show that all cells are kept fully charged (Ref. 7). Recommended practices for maintenance, testing, and replacement of large lead-acid storage batteries can be found in the IEEE Standard 450-1975.

3.2.9 Training - Training in battery care usually consists of instruction in the method of checking electrolyte level and normal precautions in handling the electrolyte.

3.2.10 Total Life System Cost - The major component of the total life system cost of a battery system is the initial installed cost of the batteries since the maintenance and operating costs are very minimal.

3.2.11 Monitoring and Control - Monitoring and control of a battery installation must include provisions to prevent battery overcharge, maintain proper trickle charge rate, prevent excessive rates of charge and discharge, and prevent the discharge from exceeding the design limits of the battery. Some of these monitoring and control features are automatically incorporated into the device that employs the batteries; and sometimes in large battery installations, these monitoring and control features require alarms and manual control or manual control override features.

3.2.12 Safety Considerations - Secondary batteries produce hydrogen gas which must be vented to the air in the battery room or compartment. This hydrogen generation occurs primarily during the charging cycle with lead-acid batteries. The greatest amount of hydrogen is produced when the maximum system voltage is impressed on the fully charged cells. Very little hydrogen is produced during float charging operations.

The volume of hydrogen produced is determined by the amount of charging current supplied to the fully charged battery by the charger.

When the cell is fully charged, each charging ampere supplied to the cell produces about 0.016 cubic feet (0.453 liter) of hydrogen per hour per cell. This volume applies at sea level, when the ambient temperature is about 77°F (25°C) and when the electrolyte is "gassing" or bubbling. A fully charged 60-cell lead-acid battery being charged at 1 A would produce a hydrogen volume as calculated:

$$0.016 \times 1.0 \text{ A} \times 60 \text{ cells} = 0.96 \text{ ft}^3/\text{hr}$$

$$0.453 \times 1.0 \text{ A} \times 60 \text{ cells} = 27.18 \text{ liter/hr}$$

Sufficient ventilation should be provided to prevent the hydrogen gas from building up to a level of 3% by volume in the room air at any time.

Another safety consideration is the proper handling of the acid electrolyte. When performing battery maintenance, the following protection equipment should be available:

1. Eye protection - side protection safety glasses or goggles,
2. Protective apron,
3. Acid-resistant gloves,
4. Available source of water in case of acid spills, and
5. Bicarbonate of soda for a neutralizing agent (Ref. 13).

Care should be taken to prevent accidental shorts across the battery terminal.

3.2.13 Sources - A few of the larger U.S. battery manufacturers are listed below.

Acme Battery Corporation
Alexander Manufacturing Company
Bright Star Industries
Burgess, Incorporated

Chromalloy American Corporation
Electra Corporation, Prestolite Battery Division
Electrolite Battery Company
E.S.B., Incorporated, Ray-O-Vac Division
Exide Power Systems Division
Gates Energy Products, Incorporated
General Electric Co., Battery Business Dept.
Globe International Corporation
Globe-Union, Inc., Glode Battery Division
Gould, Inc., Industrial Battery Division
Gould, Inc., Portable Battery Division
Gulton Battery Corporation
Hughes Aircraft Company
Ideal Battery Company
Mallory Battery Company
McGraw-Edison Company, Edison Battery Division
Mule Battery Company
Ramsey Engineering Company
S.G.L. Batteries Manufacturing Co., Dept. SM
Singer Products Company
Solfan Systems, Incorporated
Standard Electric Company
Surrette Storage Battery Company, Incorporated
Union Carbide Corporation, Battery Products Div.
Varta Batteries
Yardney Electric Corporation

3.2.14 Environmental and Physical Facility Considerations - Batteries should be installed in a facility that will ensure that the minimum and maximum environmental operating temperatures of the batteries will not be exceeded. For fuel cycle facilities, this constraint would apply mainly to external systems. Physical protection should be designed into the installation to preclude the possibility of short circuiting the battery and, if the battery is not "maintenance free," to provide ease of checking electrolyte level and adding electrolyte when necessary. Devices which produce sparks, or could otherwise ignite the hyrogen gas produced by the batteries, should not be installed in the same area as the battery bank. The standard ambient temperature for rating stationary lead-acid batteries is 77°F (25°C). The discharge capacity of the batteries is reduced as the ambient temperature falls below 77°F (25°C), and battery life is shortened as the temperature rises above that standard rating temperature. Achievement of the best life expectancy for lead-acid stationary battery systems requires an average ambient temperature in the range of 59°F (15°C) to 86°F (30°C). Solid freezing of the battery electrolyte is rare because as the water in the electrolyte freezes, the specific gravity of the liquid is increased by the increased ratio of acid to the liquid water. Slush ice is formed in a discharged battery at a temperature of approximately -15.8°F (-9°C), while the freezing may not start in a battery with an adequate charge until the temperature drops below approximately -22°F (-30°C). The major battery manufacturers publish data concerning physical and environmental requirements and offer special electrolytes and other provisions to compensate for environmental conditions.

3.2.15 Lifetime and Reliability Estimates - A lead-acid battery bank that is designed for the service that is imposed upon it in terms of charge rates, discharge rates, temperature, depth of discharge, etc., will last from 10 to 25 years. If any of the design limits are exceeded, the life expectancy of the battery will be seriously shortened. For example, the Bell Telephone Company warns that the lifetime of a lead-acid battery bank will be cut in half if the temperature in the room housing the bank goes over 90°F (32°C) more than 30 days a year.

The life expectancy of any stationary lead-acid cell depends heavily on the thoroughness of the maintenance given to it during its service life. Frequency of deep cycling also can affect life expectancy, especially in calcium alloy pasted plate batteries. When the battery fails to produce at least 80% of its rated discharge capacity, it has ended its service life.

3.3 UNINTERRUPTIBLE POWER SYSTEMS

3.3.1 General - One of the most common types of emergency power supply techniques utilized for physical security and safeguards systems in nuclear fuel cycle and reactor facilities is uninterruptible power supplies (UPS). A UPS is any source that protects a critical load from fluctuations or interruptions of the incoming ac power that drives it. The need for a UPS is determined by a number of factors. In general, it can be said that any physical security or safeguards instrumentation system whose operation could be degraded or interrupted by an ac power outage has need for a UPS. Discretion must be used at this point in determining which safeguards systems can tolerate ac line fluctuations or interruptions.

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3.3.2 Rotary UPS - Early development efforts centered on a rotary UPS. This system rectified the commercial ac power and used the DC to drive a solid-state inverter. The inverter output powered a synchronous motor-generator set which supplied the critical load. Poor frequency control, slow start-up time, and reliability and maintenance problems make the rotary units impractical, especially if power demand is relatively small.

3.3.3 Static UPS - More recently, solid-state static UPS systems have become available. The static UPS in its most basic form consists of a rectifier charger, storage batteries, and an inverter, as shown in Figure 7.

Static UPS systems are classified according to the way in which they are operated. There are three common methods, referred to in most cases as continuous, forward transfer, and reverse transfer. There are also three modes of operation for a UPS regardless of its classification. These modes are commonly referred to as operate, emergency, and recovery.

3.3.4 Continuous Method - The continuous UPS system, as shown in Figure 7, is always the final source of power for the critical load. Under normal operating conditions, "operate" mode, the battery charger acts as a rectifier to provide dc to the inverter from the normal ac incoming line. The battery is connected in parallel to the dc being supplied from the charger so that if any failure or voltage drop occurs in the ac line, the batteries provide dc to the inverter. In this manner, no break of any kind occurs in power to the load.

The battery continues to power the inverter until commercial power is restored or the battery output drops to a level that will no longer drive the inverter. How long the battery will drive the inverter depends on the ampere-hour rating and the size of the inverter load.

The "recovery" mode begins when the commercial power returns to normal. At this time, the rectifier-charger begins to drive the inverter and recharge the battery. When the battery reservoir, as shown in Figure 7, is completely recharged, the UPS is once more in the "operate" mode.

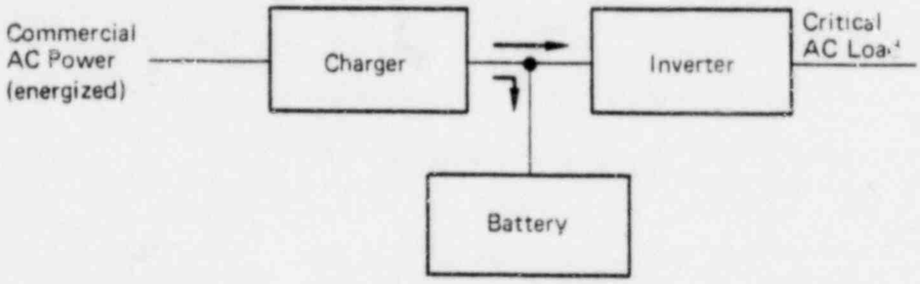

Figure 7. Static UPS

One major advantage of the continuous UPS is that it acts as an ac filter, suppressing voltage transients, power interruptions, waveform distortion, and frequency deviations, ensuring a clean and stable source of power for the critical load (Ref. 3). A major disadvantage with the continuous mode is the lack of a backup power source, as provided with a reverse transfer method of operation.

3.3.5 Forward Transfer Method - In the forward transfer method, the "operate" phase is off-line, and the commerical line actually drives the critical load directly through a transfer switch. During this time, the UPS is rectifying that same commercial line and providing "hot standby" current for the inverter as well as the current necessary to maintain the battery at full charge (Figure 8). The inverter idles during this time, supplying no power to the critical load. When the commercial power is interrupted or fails, a switch transfers the critical load to the inverter. During this 'emergency" mode, the inverter draws current from the battery until commercial power is restored or the battery is exhausted. The return of commercial power is sensed by the UPS. After a fixed delay period (to prevent "nuisance" switching), the load is transferred back to the line. The rectifier-charger again supplies "hot standby" current to the inverter and also begins recharging the batteries.

Since the inverter does not continually carry the critical load, UPS reliability should exceed that of a continuous UPS system. Note also that the rectifier charger is never required to provide current directly to the loaded inverter, but need only be large enough to recharge the batteries. This feature can result in a significant cost saving. There is an inherent limitation in the forward transfer UPS. Since the critical load operates from the UPS only when the commercial power is interrupted, it is vulnerable to the transients generated by commercial power switching or circuit breaker trips and reclosures (Ref. 3).

3.3.6 Reverse Transfer Method - Reverse transfer UPS operating modes occur as follows. In the "operate" mode, like the continuous UPS, it acts as a buffer between the commercial power source and the critical load. The rectifier-charger provides current to the inverter and maintains the battery charge (shown in Figure 7). The principle difference between the continuous UPS and the reverse transfer UPS is the

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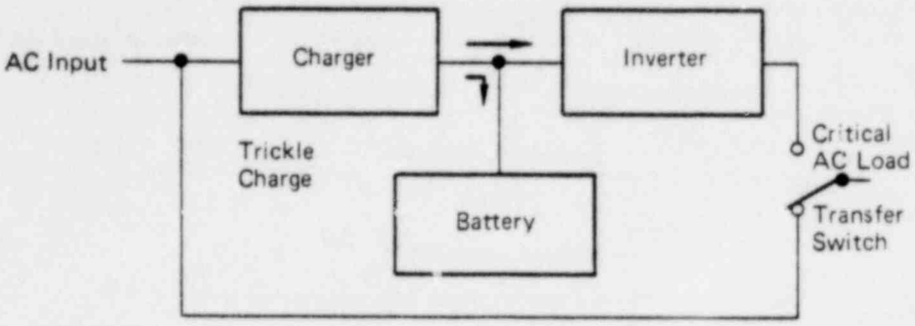

Figure 8. Forward Transfer Mode

inclusion of a backup power source (Figure 17). This alternate power source serves a twofold purpose: 1) it backs up the UPS if it should fail, and 2) it provides a "stiff" current source for clearing faults. This is a vital function since most inverters cannot provide the large amount of current required to blow a fuse or trip a circuit breaker on a branch line of the critical load. The reverse transfer UPS includes circuitry to detect such faults and transfers the critical load to the auxiliary source (usually the commercial line). When the fault has been cleared and the critical load is again normal, the UPS initiates a retransfer.

Hence, the reverse transfer UPS overcomes the disadvantages of both the continuous and forward transfer types. However, the charger must be able to meet the input requirements of the loaded inverter as well as maintain the battery charge. It must therefore be larger than the charger used in a forward transfer system. Also, the inverter is under more stress, since it is always on-line during the "operate" phase (Ref. 3).

3.3.7 Future Improvements Expected - Of the three basic components in a static UPS system (i.e., rectifier charger, battery, and the inverter), future improvements are expected in all three areas. Most UPS manufacturers now use lead-calcium batteries as the storage medium. Considering the current activity in battery technology, it is reasonable to expect an improvement over the lead-calcium battery, a strong candidate being the lead-strontium battery. Battery charger techniques utilizing digital electronics have resulted in significant improvements in charger reliability. The inverter determines the ultimate quality of the power that drives the critical load. Continued improvements are being made in the inverter designs. Currently, the three inverter techniques most commonly used by UPS manufacturers are ferroresonant, step-wave, and quasi-square wave.

All three techniques typically employ a parallel commutated square-wave inverter bridge (Figure 9). The ferroresonant inverter consists of a ferroresonanttype transformer that connects across the square wave output of the inverter bridge (Figure 10). Advantages of the ferroresonant inverter are simplistic design, lack of closed-loop feedback, storage of energy in the secondary of the ferroresonant transformer to supply

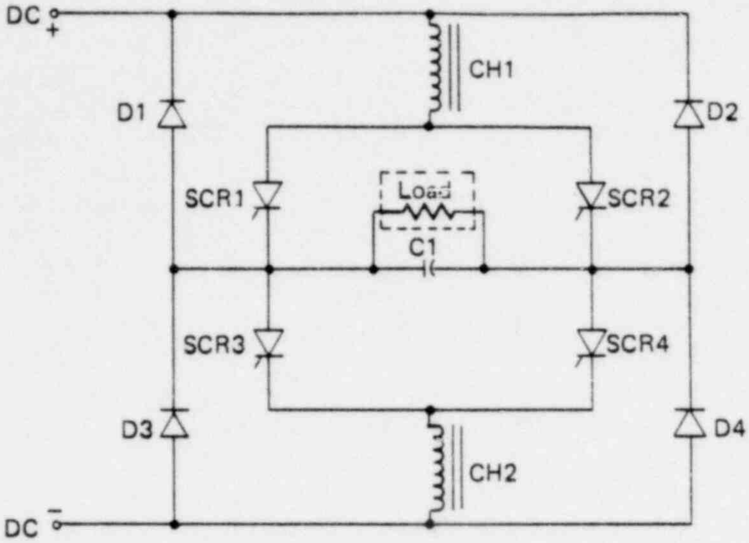

Figure 9. Common Inverter Bridge

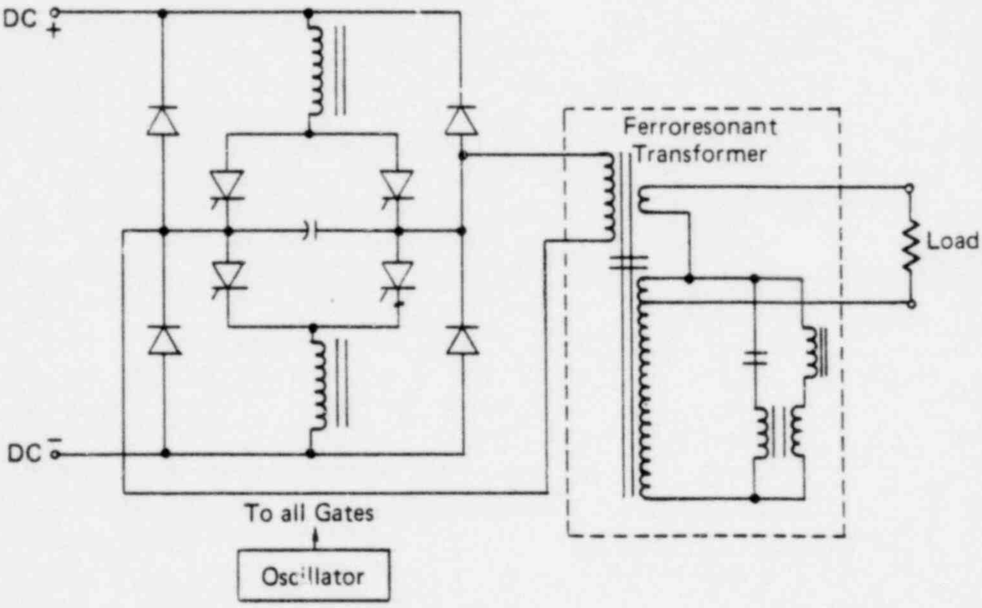

Figure 10. Ferroresonant Transformer Inverter

surge current when necessary, and current limitation of the transformer in a forward and reverse direction. Ferroresonant inverters work well with single phase systems under 10 kVA and three-phase systems up to 30 kVA.

The step-wave inverter typically consists of four three-phase inverter bridges (Figure 11). This inverter technique is used almost exclusively for three-phase systems and, in particular, those three-phase systems above 30 kVA.

The quasi-square wave inverter utilizes a modified square wave inverter bridge to convert the plus-minus dc level to an ac output (Figure 12). As with the step-wave inverter, a voltage-current feedback is required. Typical applications for the quasi-square wave inverter are for single phase systems above 10 KVA (Ref. 14).

3.3.8 UPS Systems Cost - The major disadvantage of uninterruptible power supplies is systems cost. When compared with generators or comparable emergency power supply devices, a UPS is extremely expensive. In most cases when UPS capability is really needed, systems cost is not the overriding factor. Budgetary 1978 prices for nonredundant UPS systems with rectifier, inverter, and battery are given in Table 7. Hardware costs may vary 15% for a given size unit. Installation cost is approximately 20% of the hardware cost. Dollar figures in Table 7 are for CY 78.

When considering UPS operation over a long time period, the efficiency at which the device operates should be a point of concern. The UPS itself consumes power as a result of heat losses and charging of the batteries. A 90% efficient UPS would pass 90% of its power to the critical load, the UPS itself consuming 10%. Based on a per-kilowatt-hour cost of five cents, a 75-kVA UPS and associated air conditioning would cost $25,000 less for electricity over a 10-year period if the UPS were operating with an efficiency of 90% rather than 85%. Optimizing the efficiency of the UPS can be counterproductive, however, in that sometimes efficiency in a UPS can be gained only at the expense of reliability. Due to the important part the inverter plays in UPS system performance (determines quality of output load voltage and contributes significantly to overall system reliability), the specific inverter technique should be considered. Table 8 lists the inverter technique best suited for the particular UPS system requirements.

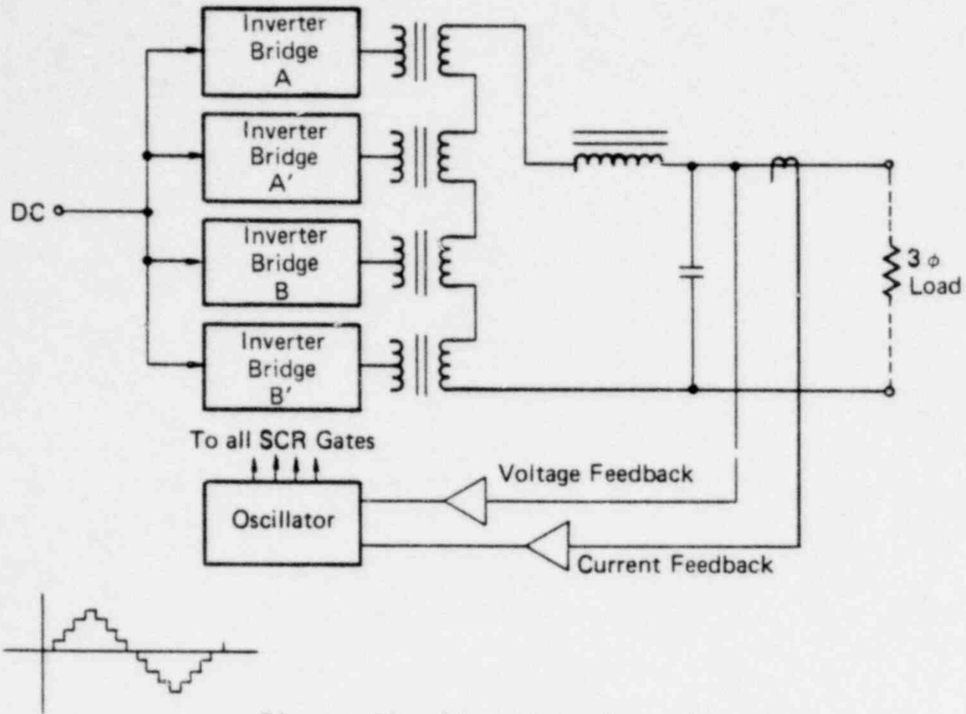

Figure 11. Step-Wave Inverter

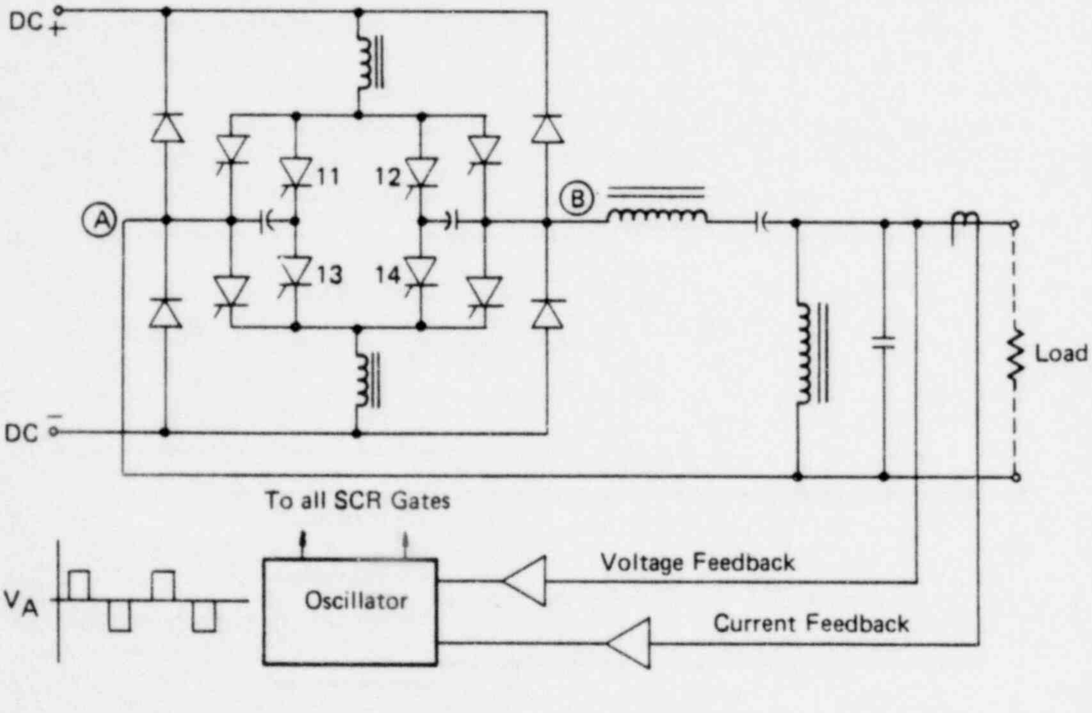

Figure 12. Quasisquare-Wave Inverter

Table 7

UPS SYSTEMS COSTS

Single Phase KVA	30 Minute Backup	Cost Per KVA
1	$ 6,700	6,700
2	7,000	3,500
3	39,600	3,200
5	11,000	2,200
7.5	14,200	1,893
10	16,200	1,620
15	22,500	1,500
20	27,500	1,375
37.5	33,500	893
Three Phase KVA	**15 Minute Backup**	**Cost Per KVA**
37.5	40,000	1,066
75	50,000	666
125	65,000	520
225	80,000	355

Table 8

INVERTER TECHNIQUES

UPS Power Requirement	Ferro-Resonant Transformer	Step Wave Inverter	Quasi Square Wave
1-10 KVA Single Phase	X		
10 KVA and Up Single Phase			X
Up to 30 KVA Three Phase	X	X	
30 KVA and Up Three Phase		X	

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3.3.9 UPS System Selection and Specifications - When selecting a UPS, there are five key points of interest:

1. Load requirements,
2. Protection time limits,
3. Power distribution system,
4. Local and national electrical codes, and
5. Building requirements.

Information contained in Table 9 summarizes each of these considerations. A typical specification for an 85-kVA UPS system is given in Table 10.

3.3.10 Environmental and Physical Facility Considerations - Primary considerations for UPS operation are proper ventilation to outdoor air for the battery room and sufficient cooling for the UPS operations area. Temperature of the battery storage area should be approximately 75°F (24°C).

3.3.11 Lifetime and Reliability Estimates - Reliability estimates of UPS systems are very dependent upon the operating mode. Continuous mode systems with no bypass may have mean time between failure (MTBF) rates as low as 8,000 to 10,000 hr, whereas UPS systems operating in the reverse transfer mode with bypass and static switching can experience MTBF rates of 60,000 to 70,000 hr. Redundant and parallel redundant UPS systems, if configured properly, offer the ultimate in system reliability.

3.3.12 UPS Vendor Selection - A sound approach to obtaining a reliable and reasonably priced UPS system is to develop a limited list of experienced, financially sound vendors. The vendor should be asked to submit a list of installations of similar UPS equipment in service. A list of UPS manufacturers is listed below.

Emerson Electric Company
Exide
Teledyne, Inet.
Solid State Controls, Incorporated
Elgar Corporation
Topaz Electronics
General Electric Company
Westinghouse Electric Corporation
Cyperex, Incorporated
Clary Corporation

Table 9

FACTORS TO BE CONSIDERED FOR UPS INSTALLATION

---

1. LOAD REQUIREMENTS (KVA)

   Present Critical Load - List each item comprising your critical load and gather the following data for each.

   Line-to-Line Voltage
   Average RMS Line Current
   Average Peak Line Current
   Real Power in Kilowatts
   Apparent Power in Kilovolt Amperes
   Power Factor
   Maximum Inrush Current and Time Duration

   (Much of this information will be found on equipment nameplates. Usually, voltage, current, kilowatts, and power factor will be listed. The KVA ratings can be calculated by multiplying voltage and current or dividing kilowatts by power factor.)

2. PROTECTION TIME REQUIREMENTS

   Controlled Shutdown - Enough time to allow notification or remote terminals.

   Continued operation maintaining precise power from battery until standby generator is activated.

3. DISTRIBUTION SYSTEM

   Load - Power lines from UPS to critical components.

   Utility or Input Capacity - Power ratings of utility transformer or substation.

   UPS Location - Distance to both distribution system and critical equipment.

4. LOCAL AND NATIONAL ELECTRIC CODES

5. BUILDING REQUIREMENTS

   Floor space needed (UPS and related equipment, spare parts, switch gear, generators, etc.)

   Floor load-carrying capacity (pounds/square feet)

   Ventilation to outdoor air for battery room

   Additional cooling requirements

   Amount of outside contracting

   Self-installed or turnkey operation (total responsibility to UPS supplier)

Table 10

TYPICAL UPS SYSTEMS SPECIFICATIONS FOR 75-KVA MODULE

INPUT	
Voltage	208 or 480 VAC ± 10%
No. of Phases	
Power Factor	
Frequency	
Power Walk-in	
OUTPUT	
Rating	75 KVA
Voltage	208 or 480 VAC, 30 4W
Voltage Regulation	
Balance Load	± 1%
50% Unbalanced Load	± 2%
Frequency	60 Hz
Frequency Regulation	± 0.1%, Adj. ± 3 Hz
Power Factor	1.0 to 0.8 lag
Phasing	
Balanced Load	120 ± 1°
50% Unbalanced Loads	120 ± 3°
Total Harmonics	5% RMS Maximum
Single Harmonic	3% Maximum
Overload	125% Load for 10 Min. 150% Load for 30 Sec.
Short Circuit Current	150%
VOLTAGE TRANSIENTS (+ 10%, -8%)	
50% Step Load Change	
Loss of AC Input Power	
Return of AC Input Power	
Removal or Addition of One Power Converter Module when Operating in Parallel	
Loss of One Module due to an Internal Failure when Operating in Parallel	
Transfer of Load from UPS to Bypass or Vice Versa	
Recovery Time	
To Steady-State Conditions within 100 Milliseconds	

BATTERY DATA	
Battery Type	Lead Calcium
No. of Cells	180
Voltage Range	405-515V dc
Temperature	77°F
Specific Gravity	1.210
Recharge Time	10X Discharge Time
GENERAL CHARACTERISTICS	
Controls	Automatic Line Synchronization Circuit Breakers: Input, Output, Bypass, Battery and Control Power
Instruments	Input Voltmeter and Ammeter Output Voltmeter, Ammeter, and Frequency Meter Battery Voltmeter and Ammeter
Alarms	Blower Failure, Open Fuse, Low Battery
Efficiency	85% at Full Load
Environment	50°F to 110°F 95% Relative Humidity
Cooling	Blower Cooled, 4800 CFM, Can be
System Compatibility	Paralleled with Like Power Supplies
Weight	4500 Pounds

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4. SYSTEM CONCEPT CONSIDERATIONS - GENERAL

The design of an emergency electric power system must be generated by the application of system engineering principles, not by an attempt to select generators, batteries, and prime movers to supply a given amount of electric power when "the lights go out." This approach to design entails determining objectives and requirements, then synthesizing the required system. The synthesized system must be analyzed in light of the requirements, and the design must be modified, improved, and optimized as indicated by the analysis. After the iterative application of the above process has been completed, the system can be specified and procured. Care must be exercised during this process to include all necessary provisions for support and growth to ensure a viable system.

4.1 OBJECTIVES

The system engineering process commences with the recognition of a problem, problem definition, listing of constraints, and the establishment of objectives. The problem will be a variation of the theme that some amount of emergency power must be ensured for particular operations when the normally used power source fails. Problem definition entails determining the conditions which will require use of the emergency electric power system, who will be responsible for designing it, how it will be procured, how soon it must be installed, and other outside influences on the system engineering project. The constraints will be time, money, people, energy and physical facilities. Physical facility constraints will determine where and how the system is to be installed. After these factors have been determined, the objectives of the project can be established. The objectives will include design responsibilities, procurement responsibilities, project budget, project schedule, and the overall direction of the project.

4.2 REQUIREMENTS

General requirements for the emergency electric power system are stated in section 2. Specific requirements include the following considerations, which must be consistent with the general requirements:

Required system output in dc volts and amperes,
Required system output in ac volts, amperes, and power factor,
Maximum length of time that emergency power system will be required,
Maximum tolerable outage time before emergency power system must be started,
Allowable tolerance in voltage and current,
Availability of energy sources that may be used,
Physical sites and accommodations that may be employed,
Location of points where emergency power must be supplied,
Methods for detecting when emergency power is required, and
Electronic monitoring of emergency electrical power supply system.

Reliability required of the emergency power system,
Effects of the environment upon the emergency power system,
Growth requirements of the emergency power system,
Length of time before the system must be operational,
Policies that affect the design and implementation of the system,
Lightning protection required for towers, control lines, and power lines, and
Survivability of the emergency power supply system.

4.3 SYSTEM SYNTHESIS

The synthesis of the design of the needed emergency electric power system can commence after the objectives and system requirements have been established. The synthesis operation may be no more than determining if a lead-acid or a nickelcadmium battery is to be used to power an emergency telephone system, the capacity rating and other parameters of the battery, and how it is to be charged and switched into service when needed. On the other hand, the requirements may lead to the synthesis of a complicated UPS system with inverters, several different types of power sources, and battery banks. The synthesis must respond to the requirements and produce a system design that will satisfy all requirements.

4.4 SYSTEM ANALYSIS

The resultant design must be analyzed to determine if it is the best method of satisfying the requirements, and if a slight change in the requirements will produce a large simplification in system design. As a result of the analysis, the design may be modified and improved; and the requirements may be examined and modified to enable simplifying of the system design.

4.5 SYSTEM SPECIFICATION

When the system requirements have been analyzed and the resultant system design optimized, the system may be specified. The primary purpose of specifications is to describe a system to meet the established requirements in sufficient detail that misunderstanding between the buyer and seller of the system is avoided. All of the features necessary to meet the system requirements must be described in the specifications since most manufacturers of emergency electric power supply equipment offer a variety of optional features, and there is little standardization among them on the number of features offered on their basic units. The specifications must define the type, size, location, capacity, output characteristics, fuel to be used and overall performance of the system and must establish the responsibility for delivery, installation, testing, and placing the system in operation. The specifications must take into account the procurement method to be used and must include provisions that are compatible with the procurement method.

4.6 SUPPORT REQUIREMENTS

The system design must contain provisions to ensure that system maintenance, resupply of expendable material, and training of personnel are performed.

4.7 GROWTH REQUIREMENTS

The system design and implementation must contain provisions to expand the system as necessary to keep pace with expansions that may occur in the operations which the emergency electric power system serves.

5. EXEMPLARY SYSTEM DESIGNS

Examples of the five basic emergency power supply techniques discussed in this report will be illustrated.

5.1 ENGINE GENERATORS

Figure 13 shows a standby power system in which power fails from the normal source, two engine generators automatically start. The first generator to reach operating voltage and frequency will actuate load dumping circuits and cause the remaining load to transfer to this generator. When the second generator is in synchronism, it will be paralleled automatically with the first. After the generators are paralleled, all or part of the dumped load is reconnected if the standby capacity is adequate.

5.2 BATTERY SYSTEM

A standby system in its simplest form, employing one single battery and charger, is shown in Figure 14. Under normal conditions, the battery is maintained fully charged on automatic float/trickle, and the steady continuous load is supplied by the charger. In the event of loss of the ac supply or a breakdown of the charger, the connected load is taken over by the battery without interruption of supply. 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 stationary or floating battery system.

5.3 UNINTERRUPTIBLE POWER SUPPLY SYSTEM

5.3.1 Continuous Method - Figure 15 is a block diagram of a continuous method UPS system with a bypass transfer switch which transfers the load back to the line in the event that the inverter fails.

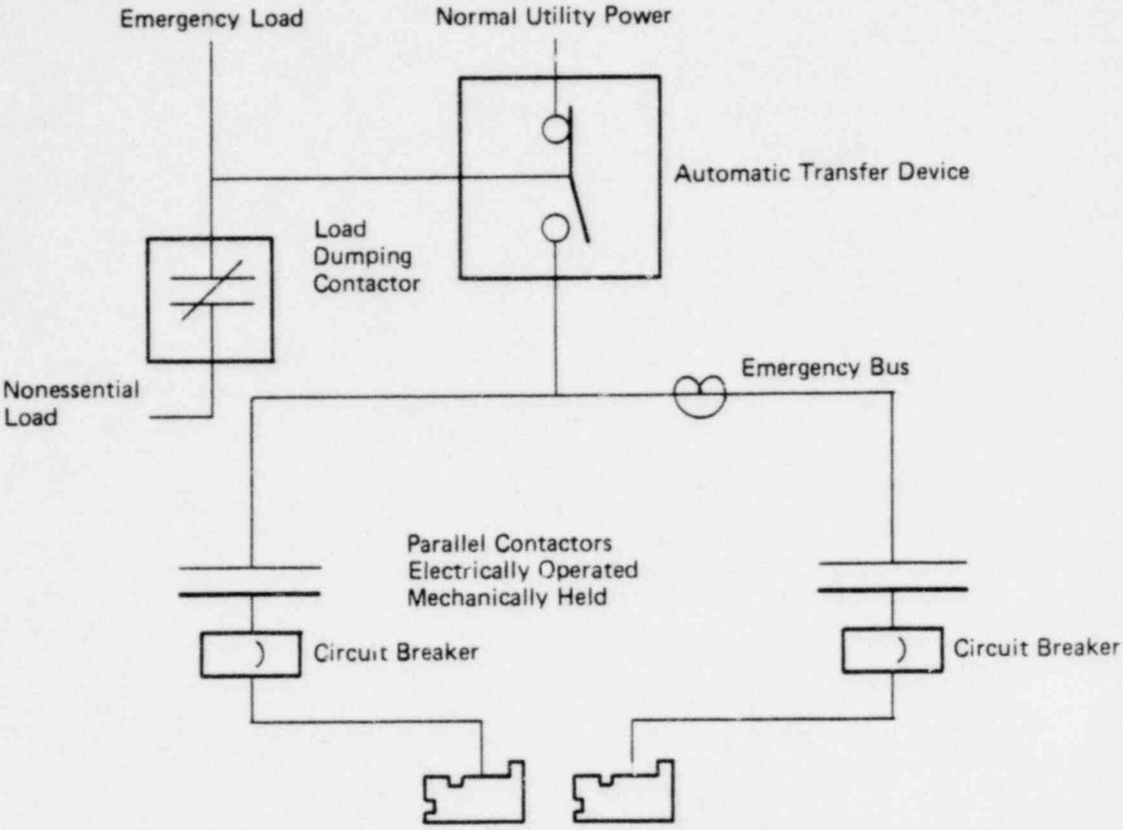

Figure 13. Two Engine Generator Sets Operating in Parallel

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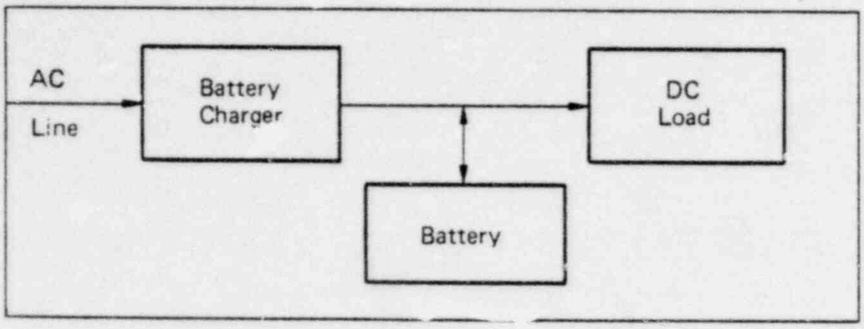

Figure 14. Diagram of Typical Floating Lead-Acid Battery System

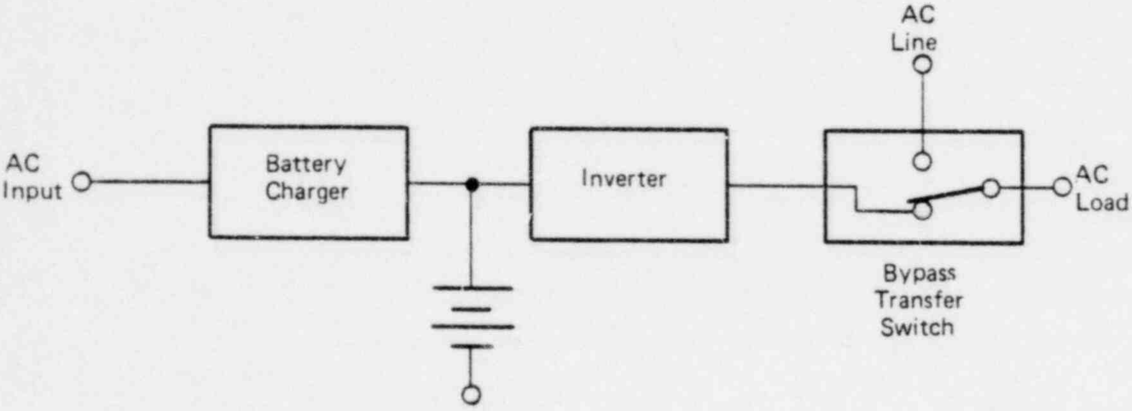

Figure 15. Continuous Mode UPS

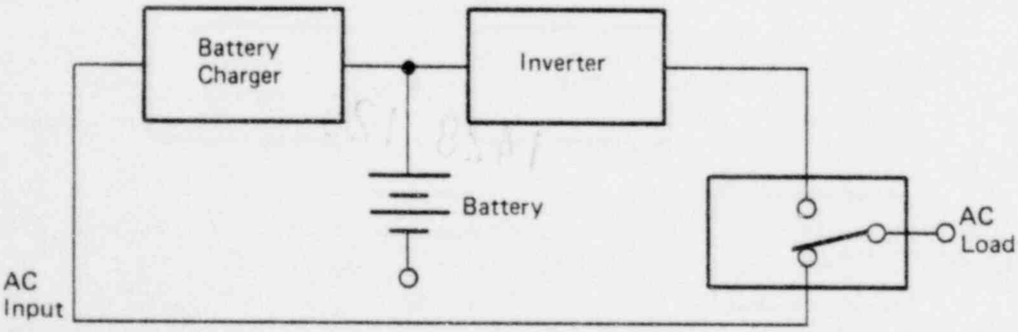

Figure 16. Forward Transfer UPS

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5.3.2 Forward Transfer Method - A forward transfer or line primary type UPS is shown in Figure 16. With this configuration, the load receives power directly from the a.c. line through a switch. When primary power is lost, the load is transferred to the inverter through the switch. This system can be used where short breaks can be tolerated and if inverter isolation and constant regulation are unnecessary. The continuous and forward transfer mode UPS systems are the least desirable systems when compared with the float or reverse transfer systems. Continuous and forward transfer systems constitute less than 2 to 3% of the total UPS sales.

5.3.3 Reverse Transfer Method - By far the most preferred UPS system is the reverse transfer or float-type system (Figure 17). Under normal operating conditions, the battery charger will operate as a rectifier to provide dc to the inverter from the normal ac incoming line. The battery bank will be connected in parallel to the DC being supplied from the charger so that if any failure or voltage drop occurs in the AC line, the batteries will provide DC to the inverter. In this manner, no break of any kind will occur in power to the load. A zero-break automatic static bypass switch provides automatic bypass of the inverter in case of malfunction or overload. Transfer sensing occurs at the inverter switching stages so that all portions of the inverter are bypassed. The transfer can be accomplished with absolutely no loss (not even a fraction of a cycle) of continuity of power to the load. A manual make-before-break bypass switch can be placed on the output of the system so that all electronic portions can be bypassed manually.

5.3.4 Parallel Redundant UPS Systems - To improve the reliability of UPS system operation, the basic power elements (rectifier, inverter, and static switch) can be duplicated, resulting in redundant or parallel redundant UPS operations. A system with dual inverters and static switches is shown in Figure 16. The critical load will normally derive its power from inverter Number 1 through the static transfer switch connected at its output. Upon failure of inverter Number 1, or load fault, the static transfer switch will, without interruption, connect the load to inverter Number 2.

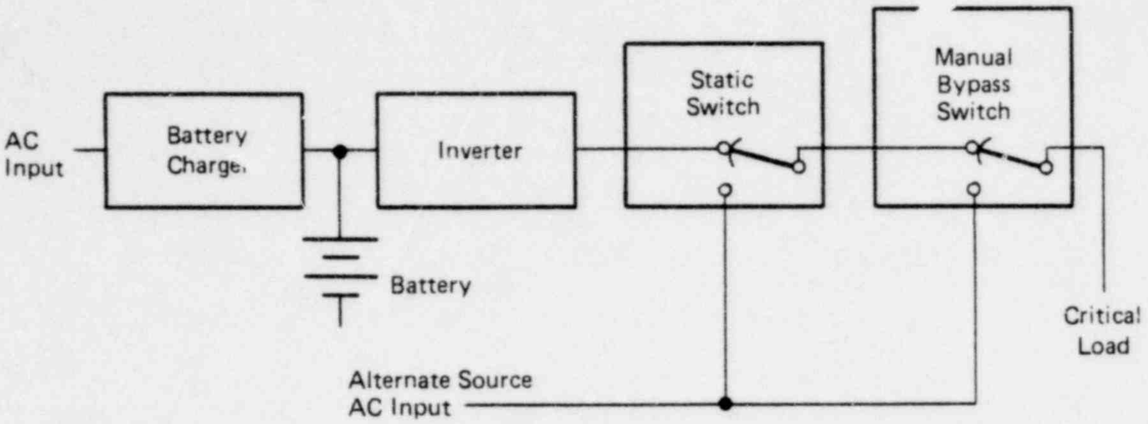

Figure 17. Reverse Transfer UPS

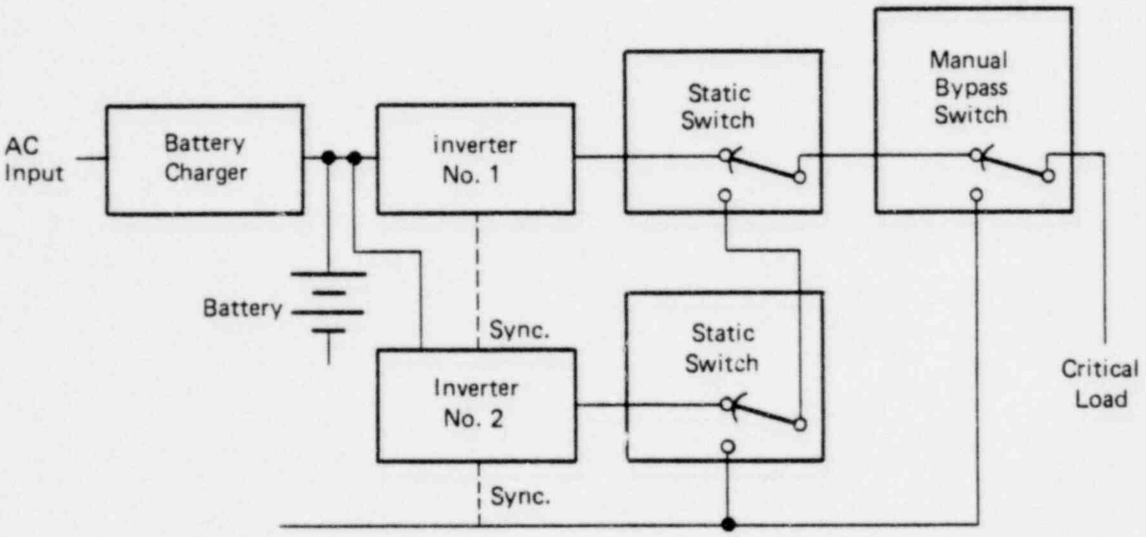

Figure 18. Redundant Inverter and Static Switch Configuration

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For applications requiring large blocks of power and the extra reliability of a redundant system such as the static switching bypass system, two or more inverter continuous systems can be operated in parallel (Figure 19). This requires the addition of paralleling and protection equipment consisting of a static interrupter for each unit as shown, real and reactive load-sharing equipment, and sensing and logic to very quickly detect an individual system problem while operating in parallel with other systems. For example, the logic must detect and isolate a defective reference in a voltage regulator which would otherwise drive the entire system bus voltage out of limits due to the action of the load balance circuit. The systems are sized so that the maximum total load is less than the rating of the combination of all the inverter systems less one. If one system fails, it is detected and isolated by the associated static interrupter rapidly enough so that it will not seriously affect the other systems or the uninterruptible load. The static interrupter is a device similar to the static switch used in the static switching bypass system. Parallel systems requirements should be referred to the manufacturer.

5.3.5 Combination UPS and Engine Generator - The continuous, forward transfer or reverse transfer systems can be combined with an engine generator as shown in Figure 20 to provide for power outages of indefinite duration. The system can also be used to maintain less critical loads such as air conditioning and lighting in a computer installation. Upon power failure, the static UPS provides continuing power to its load. A delay prevents engine starting for short-duration outages. If this short period is exceeded, the engine generator automatically starts, and when stabilized, the transfer switch connects the UPS and the less critical load to the engine generator. While operating from the engine generator, the inverter synchronizing circuit is disconnected so that the UPS will provide stable frequency (and voltage) regardless of starting and stopping of loads such as air conditioners.

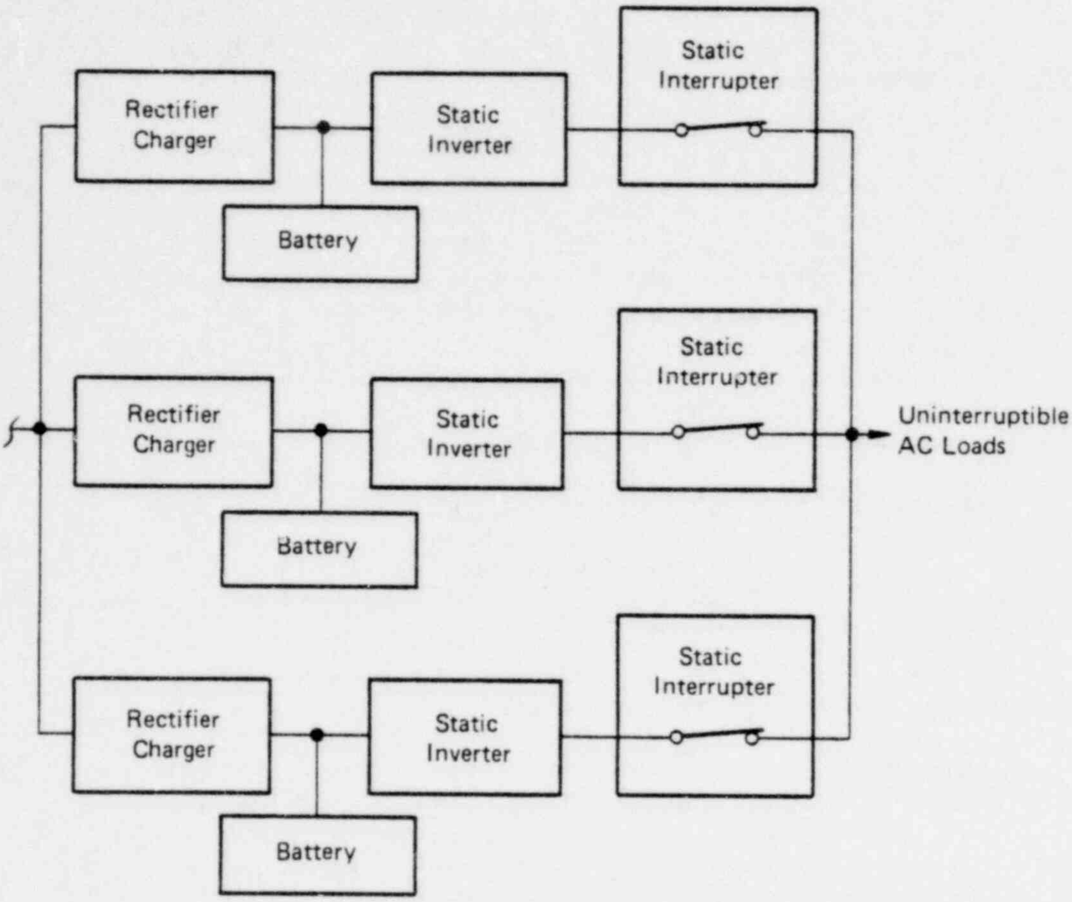

Figure 19. Parallel Redundant System Operation

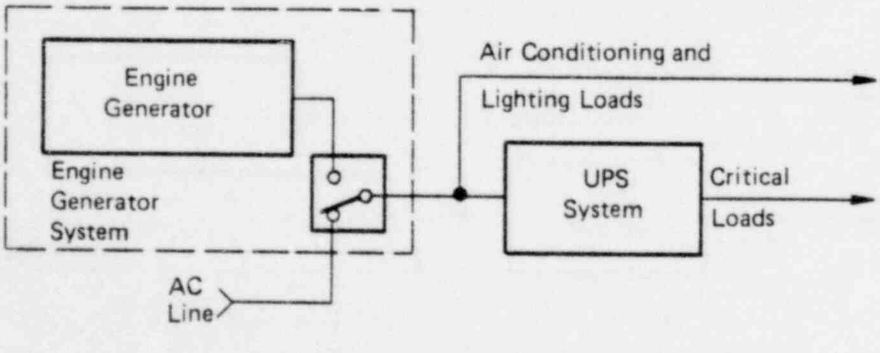

Figure 20. UPS and Engine Generator System

6. SUMMARY GUIDANCE

A reliable, noise-free source of power (ac or dc) is essential for safeguards and security instrumentation. Whether designing emergency power supply systems for a new facility, for an upgrade of existing facilities, or for specific instrumentation, the requirements of the emergency power system must be defined, followed by system design and optimization. General requirements are defined in Section 2, and specific requirements are detailed in Section 4.2. Typical emergency power supply systems for physical security instrumentation consist of one or more combinations of the following devices: 1) engine generators, 2) batteries, or 3) uninterruptible power supplies.

Generators - Typically, diesel-powered generators are recommended. This is due in part to the durability of the unit and the characteristics of the fuel. A nominal capacity of from 20 to 50 kW should be sufficient for physical security instrumentation needs.

Battery Power - Secondary batteries (lead-acid or alkaline storage) are recommended for most safeguards physical security system needs. Operation and maintenance procedures, as defined in Section 3.2.8, should be established and adhered to. Safety considerations are most important for secondary batteries (lead-acid typically) when maintenance functions are being performed (see Section 3.2.12). Optimum battery performance requires proper environmental and physical facilities (see Section 3.2.14).

Uninterruptible Power Systems - A decision must be made concerning the "real" need for UPS in the physical security system operation. UPS is recommended for the central alarm station and the secondary alarm station. Solid-state static UPS systems are available from a number of reliable vendors (see Section 3.3.12). Static UPS systems are classified according to the way in which they are operated. There are three common methods, referred to in most cases as continuous, forward transfer, and reverse transfer. Of the three methods, the reverse transfer is recommended. Details of the different methods of operation are given in Section 5.3. Inverter techniques recommended are ferroresonant transformer or step-wave inverter for three-phase units up to 30 kVA. Step-wave inverter is the choice for three-phase units above 30 kVA.

Consideration should be given for a separate, stand-alone power supply system for physical security and safeguards instrumentation.

1. The central alarm station should have a UPS system for ac and possible dc requirements operating in the reverse transfer mode with generator backup for an alternate ac power input to the UPS.
2. Remote alarm devices should have battery backup with no false alarms generated if primary power is lost. Alarm devices should remain functional during loss of primary power.

3. Consideration should be given for the survivability of the safeguards and security emergency power supply system. A bunkered supply system with capabilities for reactor shutdown only are being contemplated. This system would be onsite and within the protected area. The safeguards and security electrical power source could be part of or physically located within the bunker site.

Each facility should have established an effective maintenance program for emergency power supply systems.

Specific safeguards and security instrumentation devices and appropriate emergency power supply sources are listed in Table 17.

Table 11

SAFEGUARDS AND SECURITY INSTRUMENTATION AND APPROPRIATE EMERGENCY POWER SUPPLY SYSTEMS

Instrumentation	Generator	Battery	UPS	Solar	Thermoelectric
1. Lighting					
A. Control Room			X		
B. Facility Perimeter	X				
C. Strategic			X		
2. Intrusion Alarm		X	X		
3. Computer Operation			X		
4. Communications Equipment		X			
5. Surveillance Equipment	X		X		
6. Isolated Instrumentation				X	X

7. ACKNOWLEDGMENTS

A significant part of this report was written by Bernard Johnson, Incorporated, of Houston, Texas, and the author wishes to express thanks for their effort in preparation of this report.

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Ohntrup, F. F., "Selecting a Standby Battery: Lead-Antimony or Lead-Calcium?" Plant Engineering, Oct. 31, 1974, pp 65-67.

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> Discusses thermal batteries, which can provide high output power within a few minutes, using molten salt as electrolyte and an internally equipped ignition device to melt the electrolyte. They have over five years' shelf life. (In Japanese)

Root, C. B., and R. A. Sutula, Proceedings of the 22nd Power Sources Conference, May 14-16, 1968.

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U.S. Army Signal Laboratories, "Proceedings of the 11th Annual Battery Research and Development Conference," 1957.

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ENGINE GENERATOR SYSTEMS

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> The experiences gained in design and operation of multiple gas engine-driven generator sets are reviewed, pointing out the advantages and disadvantages of such prime movers. Particular attention is paid to clutches, control and intermittent operation. (In German with English abstract)

Bjork, Gosta, et al., "...Gas Turbine Power Plants for Emergency Power in Nuclear Power Plants," Energie, April 1974, vol 26, n 4, p 134-40.

> An outline of the gas turbine standby and peaking power plants is given. General data on design, rating and control are briefly described. (In German)

Carter, James B., "A Study to Reduce the Noise Level of a 60-kW U.S. Army Department of Defense (DOD) Diesel Engine-Driven (DED) Generator Set and Produce a Prototype Modification Kit." NTIS AD-A015 509/35T, Army Mobility Equipment Research and Development Center, Fort Belvoir, VA, June 1975.

> The report describes a program undertaken to investigate the noise characteristics of a 60-kW U.S. (DOD) (DED) generator set, and reduce the noise to the lowest level attainable with a modification kit which would have minimum impact on set operation, performance, maintenance, size, weight, and added cost.

Caunter, J. M., "Low-Cost Emergency Power Generator," <u>Wireless World</u>, Feb. 1975, p 75-77.

Cooper, David T., et al., "Engineering Design Test Report of the 100-KW, 400-Cycle, Gas-Turbine-Engine-Driven Generator Set, Solar Model T-350M-5," Rep No. 1852, Army Engineer Research and Development Labs, Fort Belvoir, VA, April 1966.

> The report covers the engineering design testing and the evaluation of a 100-kW, 400-cycle, gas-turbine-engine-driven generator set for use in the AN/MPA-32 Radar System.

"Diesel-Electric Shunter with a Simplified Power Circuit," <u>Ry Gaz</u>, Sept. 19, 1969, vol. 125, no 18, pp 700-701, 704.

> Discusses an automatic variable field-weakening and contractorless main power circuit with separate excitation of the traction motor.

"Electric Generator Set, Gas Turbine Engine Driver, Skid-Mounted, Alternating Current, Multifrequency," NTIS AD-761 125 Teledyne Cae, Toledo, Ohio, Nov. 10, 1972, 254.

> The report concludes a study performed on 30-KW and 60-KW ground power units for the U.S. Army. Sections 2.0 through 6.0 provide the details of the introduction: generator set description: the engines, electrical systems and packaging investigations and discussions.

"Electrical System with Integrated Drive Generator," <u>Aircraft Engineer</u>, March 1974, vol. 46, no. 3, pp 7-8.

> The electrical power system consists of two engine-driven, integrated-drive generator channels. Each channel includes a 60/75 kVA generator, a miniature generator control unit, and a current transformer package. The two channels have isolated operation, and

each generator supplies power to its associated load bus. However, the two channels are interconnected in an automatic bus transfer configuration. If one channel is lost, its load bus is automatically transferred to the operating channel. Details are given on the generator, generator control unit, and current transformer assembly.

Farinacci, Nick A., et al., "EMU-10/U Generator Set, Gasoline Engine Driven," USAF Bioenvironmental Noise Data Handbook, vol 24, EMU-10/U Generator Set, Gasoline Engine Driven. Rept. No. AMRL-TR-75-50-vol-24, NTIS AD-A029 598/OST, Aerospace Medical Research Lab., Wright-Patterson AFB, Ohio, Aug. 1975, 56 p, NTIS AD-A029 598/OST.

The EMU-10/U Generator Set is a source of precise 60-cycle ac power and is designed to support communications electronics and radar. This report provides measured and extrapolated data defining the bioacoustic environments produced by this unit operating outdoors on a concrete apron at normal rated loaded conditions.

"Gas Turbine Generator Sets for Mammoth Tankers," Tanker and Bulk Carrier, May 1969, vol. 16, no. 1, pp 30-31.

Turbosafe marine gas turbines provide a combined source of standby and emergency power with the Kongsberg 1200-kW gas turbine generating set located outside the engine room in a fireproof enclosure on the poop deck.

Gasper, Kenneth A., and Keith E. Eester, "Cardiac Pacemaker Power Sources," Proceedings of the Intersociety Energy Conversion Engineering Conference, IEEE, Newark, N.J., Aug. 18-22, 1975, pp 1205-13.

Giorgi, Evo., "5-kW Engine-Driven Electrical-Power Generator Set for Amphibious Applications," Rep. No. NCEL-TR-484, NTIS AD-800 626/4ST, Naval Civil Engineering Lab, Port Hueneme, California, Oct. 1966.

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"Humbolt Bay Power Plant, Unit 3. Malfunction of the Propane Engine Driven Generator," NTIS Docket-50133-142 Pacific Gas and Electric Co., San Francisco, California, Dec. 5, 1973, 3 p.

Iwabuchi, Hirco, "Automatic Diesel Engine Driven Standby Electric Generator Plant," National Technical Report, Oct. 1972, vol. 18, no. 5, pp 631-39.

A diesel plant controller utilizing digital integrated circuits that yield a smaller size controller with higher reliability for noncontacting is described.

Jordan, James E., and James E. Griffin, "Development and Test Report of the 3-kW, 60-cycle, Military Standard Engine-Driven Generator Set, Model SF 3.0 MD," Rep. No. AERDL-TR-1777, Army Engineer Research and Development Labs, Fort Belvoir, VA, June 2, 1964.

The development and engineering design testing of a 3-kW, 60-cycle, gasoline engine-driven generator set for general use with the field army.

Kietzman, Robert L., "Natco-Viking Emergency Power for American Express," Sawyers Gas Turbine Int., Sept.-Oct. 1976, vol. 17, no. 5, pp 36-37.

Characteristic data for a backup power supply system module are given. American Express selected turbine-powered generator sets for their emergency power installation over diesel engines due to significant space savings and starting reliability, both prime requisites in the design of major computer complexes.

Marshall, Otis W., et al., "Independent Energy Systems for Better Efficiency," Intersociety Energy Conversion Engineering Conference Proceeding, San Francisco, California, Aug. 26-30, 1974, pp 531-537.

An on-site power plant practical for residential application is described. It used the Roesel generator and a diesel engine.

McCrank, J. M., and G. R. Short, "Power Generation From Shale Oil Process Off-Gas," Turbodyne Corp., Cloud, Minn., 1976.

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The purpose of this work was to develop a noise control modification kit applicable to existing U.S. Army 30-kW, 400-Hz (DOD) diesel engine-driven generator sets, as well as sets in production, and capable of meaningful performance in terms of current noise criteria.

"Offshore Turbine Power," Gas Turbine Int., March-April, vol. 12, no. 2, pp 44-46.

Eight gas turbine packages have been shipped to Australia for installation at the oil and gas development complex off the southeastern coastline in Bass Strait. The new turbines will be installed on the Halibut platform, which is 47 miles offshore in 240-ft-deep water. Two of the solar packages are 750-kW continuous-duty generator sets, which are being fabricated in Australia into self-contained modules.

Okopinski, Charles P., "Development and Test of the 1.5-kW, 60-cycle, Military-Design Engine-Driven Generator Set, Model SF-1.5-MD," Rep. No. AERDL-1860, Army Engineer Research and Development Labs, Fort Belvoir, VA, June, 1966.

The report covers the development and engineering design testing of the 1.5-kW, 60-cycle, gasoline-engine-driven generator set.

Owen, W. T., "Choosing a Diesel Generating Set for Standby and Peak-Topping Applications," Mirrlees Blackstone Ltd., Stockport, Cheshire, England, 1975.

This article covers some of the factors which may affect both the type of plant and the mode of operation in standby diesel generating plants.

Pietrucha, W. J., "Is There a Gas Turbine in Your Future?" Combustion, Oct. 1969, vol. 41, no. 4, pp 35-38.

Equipment available to utilities interested in gas turbine generating unit which employs aircraft-type gas turbines to drive an electrical generator through a pair of power turbines for power generation is described.

Plaxco, John D., et al., "Evaluation of Diesel-Driven Generators for Starting an Isolated System of Motor-Driven Equipment," Southern Services, Inc., Birmingham, Alabama, 1973.

This paper describes a dynamic stability analysis of an emergency power system containing a number of large induction motors supplied by a diesel-driven generator unit.

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"Standby Generator Sets Provide Alternate Power Source," Water and Sewage Works, May 1975, pp 105-108.

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Torpey, P. J., and W. L. Smith, "Performance Evaluation of a 2.1-MW Gas Turbine Generator Set Using Computerized Data Acquisition," Consolidated Edison Co., New York, N.Y., 1971.

A gas turbine generator set intended for use as an emergency power source has been evaluated and tested using a computer-controlled data acquisition and processing system.

"Turbo-Generator Provides 2,000 Watts Remote Power," World Oil, Dec. 1972, vol 175, no 7, pp 67-69.

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Yamada, Masaaki, et al., "10,000-kVA Gas Turbine Generator Plant for Standby," 1974.

The plant, which was developed for emergency power supply to the Tokyo Data Telecommunication Center Office, was installed inside the building. Pertinent details are presented.

Yang, T.R.M., "Determination of the Dynamic Structural Response Characteristics of a Large Diesel Engine by Means of the Low Level Impedance Method," Delaval Turbine, Inc., Oakland, California, 1976.

The application of diesel generators for nuclear standby power requires that the generator and its auxiliaries survive seismic disturbances and remain functional whenever emergency power is called for.

GENERAL

Alich, John A., Jr., et al., "Suitability of Low-Btu Gas/CombinedCycle Electric Power Generation for Intermediate Load Service," Stanford Research Institute, Stanford, California, 1975.

This paper deals with the generalized concept of coal and oil gasification for electric power production. The requirements of intermediate load service are discussed. The suitability of gasification components and systems for this type service are summarized. The economics of low-BTU gas/combined-cycle power generation for intermediate load service are compared with alternatives.

Amberger, Hans, "Control of Emergency Diesel Generating Plants in Nuclear Power Stations," *Siemens Review*, April 1974, vol. 41, no. 4, pp 157-60.

Discusses generating units equipped with automatic controls which take full account of all requirements relating to safety and availability.

Baldwin, Carl F., "How to Specify Independent Power Systems Correctly," *Actual Specifying Engineer*, July 1975, vol 34, n 1, p 71-73.

One of the most recently developed emergency power systems is the dual-service or augmenting power system in which a switching circuit offers an operating option so that the power system can furnish power to either of two processes or sets of equipment.

Beatson, C., "Insure Against the Losses Caused by Generation Gaps," *Engineer*, May 29, 1975, p 46.

___________, "There is Just Time to Install Vital Standby Generation," *Engineer*, Aug. 22-29, 1974, p 44.

Belt, Richard N., "Silent, Electric Power Generators for Tactical Applications," Rep. No. USAMERDC-1954, NTIS AD-784 205/7Army Mobility Equipment Research and Development Center, Fort Belvoir, VA, June 1969.

The report is a study to evaluate candidate power-source technologies for near-term (2- to 5-year) and mid-term (10 to 20-year) tactical applications. The range of power ratings considered was from 0.5 KW to 15.0 kW.

Bluhm, D. D., et al., "Updating a Standby Power System," *Plant Engineering*, Nov. 30, 1972, vol. 26, no. 24, pp 82-84.

Additions to a battery/motor/generator combination emergency power system included a 150-kW diesel generator, dummy load to permit generator load testing, and modification of controls, monitoring, and transfer equipment. Both diesel generators have similar speed-load characteristics for possible in-tandem operation.

Boers, G. H., et al., "Large No-Break System and Emergency Power Plant Installed at Netherlands Railways' Computer Centre," *Holecpost (Eng. Ed.)*, Dec. 1972, vol. 8, no. 2, pp 52-55.

> The computer center is equipped with an extensive installation for emergency power supply to satisfy the quality and continuity requirements as regards of the electrical energy supply. Normal operation when line voltage is available is discussed, along with emergency operation when line power fails. The return to normal operation when line voltage is available again is also considered.

Boretz, J. E., et al., "Component Development of 'TORES' for Artificial Heart Device," *Proceedings of the Intersociety Energy Conversion Engineering Conference*, IEEE, Newark, N.J., Aug. 18-22, 1975, pp 1456-1465.

> The Turbine Organic Rankine Engine System (TORES) consists of a hybrid heat engine capable of generating both hydraulic and electric power.

Castenschiold, Rene, "Obtaining Power Reliability with Multiple Utility Services and On-Site Generation," *Electrical Construction and Maintenance,* Jan. 1976, pp 57-59.

________________, "Combining GFP and Emergency Power Systems," *Electrical Construction and Maintenance*, Dec. 1976, pp 62-65.

Caunter, J. M., "Low-Cost Emergency Power Generator," *Wireless World*, Feb. 1975, vol. 81, no. 1470, pp 75-77.

> Described is an emergency electric generator for home use. A gasoline-fueled lawn-mower engine coupled to a scrap 12-V automobile generator produces a 200-V sinewave output. A 12-V battery supplies the excitation current.

Cowart, Robert L., "System Aspects of Standby Power," *Cablecasting*, July-Aug. 1973, vol. 9, no. 2, pp 11-14.

> The costs of emergency power supplies for cable TV systems are examined. Also, the various kinds of standby power systems that are available are described.

Daley, James M., "Emergency Power Systems for Computer Centers," *Actual Specifying Engineer*, July 1975, vol. 34, no. 1, pp 57-62.

> Presents steps to ensure the integrity and quality of the power system taken at the Merrill, Lynch, Pierce, Fenner & Smith's computer center in New York City.

"Electrical Power Generation Systems for Space Applications," Rept. No. NASA-TM-X-1089 (superseded by NASA-SP-79), National Aeronautics and Space Administration, Washington, D.C., 1965.

"Electrical System," Aircraft Engineering, June 1974, vol. 46, no. 6, pp 24-26.

> During flight operation, two air-cooled brushless generators, engine-driven through a constant-speed drive (CSD), supply 120/208 V, 400-cycle, three-phase ac power. A third generator, identical to the two engine-driven ones, is driven by the APU to supply electric power during ground operation.

"Emergency Plus Standby Power Beats Utility Power Outages," Electrical Construction and Maintenance, Jan. 1976, pp 64-66.

"Emergency Power Source Keeps HID Lamps Operating," Lighting Design and Application, May 1975, vol. 5, no. 5, pp 52-53.

> Am emergency power system is described which is capable of switching over to full power fast enough to maintain an arc in HID lamp.

"Engineering Basics of Emergency/Standby Power," Actual Specifying Engineer, Dec. 1972, vol. 28, no. 6, pp 103-108.

> Four articles are presented reviewing engine/generator sets, turbine generators, uninterruptible power supply systems, and stationary battery systems.

Environmental Impacts of the Generation of Electricity in the Pacific Northwest, Vol. I, NTIS PB-257 096/8ST, Equitable Environmental Health, Inc., Woodbury, N.Y., Sept., 1976.

> The report describes and quantifies the environmental impacts of all existing plants and various scenarios for planned thermal electrical generating facilities through 1995 in the Pacific Northwest.

Epler, E. P., "Our Emergency Cooling Failure," Nuclear Safety, July-Aug. 1970, vol. 11, no. 4, pp 323-27.

> Three identical units that supply emergency power for afterheat protection of the Oak Ridge Research Reactor failed simultaneously, and the reactor was operated without emergency power for the afterheat removal system for 5 hr before the condition was discovered. The reactor was not endangered because a dissimilar unit of low reliability was activated.

Estes, E. M., "Alternative Power Plants for Automotive Purposes," General Motors, N.Y., 1972.

General Motors' latest progress with alternative power plants and their relative feasibility in both the near and more distant future is discussed.

"Feeding Three Services from One Emergency Generator," *Electrical Construction and Maintenance*, July 1975, p 58-60.

Finney, D., "Static-Invertor Systems for Emergency Supplies," *Electronics and Power*, Feb. 1973, vol. 19, pp 32-34.

Discusses matching the inverter to the battery's inherent characteristics, and the means of maintaining the battery in its correct state of readiness to cope with the loss of power.

Gerdes, R. H., "Meeting Tomorrow's Electric Power Needs, New Method, New Concepts," Pacific Gas and Electric Company, San Francisco, California, 1968, *Proceedings of the 7th World Energy Conference*, Moscow, Aug. 20-24, 1968.

This discussion on meeting the growing need in the United States involves mainly the use of nuclear power plants, nuclear magnetohydrodynamic generators.

"Get Standby Generation," *Power*, Jan. 1971, vol. 115, no. 1, p 32.

The steps that can be taken to better ensure availability of emergency power when it is needed are reviewed.

Hagen, E. W., "Standby Emergency Power Systems--The Early Plants," *Nuclear Safety*, May-June 1973, vol. 14, no. 3, pp 206-219.

Reviewed are the performance of standby systems for reactors commissioned from 1959-1967. Covered are on-site power, AC power and battery systems.

Hennigan, Thomas J., et al., "*Proceedings of the 25th Annual Power Sources Symposium*," Atlantic City, N.J., May 23-25, 1972.

A continuation of the list of authors of 56 papers presented concerning battery generators.

Hnatek, Eugene R., "Switching Power Supplies: Design Considerations," *Computer Design*, Feb. 1977, pp 89-94.

Hogrebe, Lawrence F., "Automatic Transfer Switches: Changing State of the Art," Specifying Engineer, Oct. 1975, vol. 34, no. 4, pp 74-79.

A discussion of recent developments in the design of transfer switches to meet the needs of complex emergency power arrangements is presented.

Koch, Wolf H., "New Two-Phase Reluctance Generator for dc Loads," Tech Univ., Hannover, Germany, IEEE Transactions on Power Apparatus and Systems, Sept-Oct. 1974, vol. PAS-93, no. 5, pp 1449-57.

A new two-phase reluctance-type generator, suitable for dc loads, is described.

Lehouchu, J., "Power Supply of MOS RAM in Pulse Rating," Onde Electr., April 1971, vol. 51, no. 4, pp 305-310.

This paper is concerned with the use of a pulsed power supply for MOS RAM's, in order to decrease power consumption. This principle is implemented in a test jig for a particular type of MOS RAM and in an emergency power supply which overcomes the drawback of semiconductor memory volatility. (In French with English abstract)

Long, Lawrence J., and Howard B. Hamilton, "Simplified Approach to Radial Flux Loss Calculation in Cylindrical Rotor Generators," Westinghouse Electric Corp., Pittsburgh, PA, 1975.

This paper describes a technique developed to calculate the eddy-current losses (radial flux losses) induced in the stator conductors of round rotor synchronous generators operating at any desired terminal conditions.

Marlow, J. C., Jr., "Emergency Standby Power Systems for Pulp and Paper MIll Power Plants," J. E. Sirrine Co., Greenville, S.C., 1970.

Self-contained emergency lighting systems, station battery dc power systems, uninterruptible ac power systems, and start-up ac power systems for standby power in pulp and paper mill power plants are discussed. Special emphasis is placed on start-up power requirements for mills where in-plant generation provides 100% of mill electrical requirements. In pulp and paper mills, purchased power is normally the preferred source of energy for standby power requirements from 250 kW to 3500 kW. The economics of standby purchased power versus engine generator and gas turbine power are discussed.

Meckler, Milton, "Options for On-Site Power," Power, March 1976, pp 33-35.

Murthy, K. S. N., et al., "Experience from Operational Testing Program Including Engineered Safeguards at Tarapur," Proceedings from the Symposium on Experiments from Operation and Fueling Nuclear Power Plants, International Atomic Energy Agency, Vienna, Austria, Oct. 8-12, 1973 .

The performance of the systems from the commissioning stages to date and the problems encountered and resolved are presented in the paper.

O'Keefe, William, "In-Plant Electric Generation," Power, April 1975, p 51-74.

Peach, Norman, "Get the Standby Power You Need," Power, May 1972, vol. 116, no. 5, pp 23-26.

Emergency power is not, except in rare instances, provided for the whole plant (or commercial building) load. Circuits separate from the rest of the system must be provided for those portions of the electrical system which must remain energized when the main power source fails. Minimum requirements are for some lighting, one or two elevators, fire pumps, etc., necessary to ensure the safe evacuation of people from the building.

Poetter, Hermann, "Emergency Power Supply Equipment for Measurement and Control Installations in Gas and Water Supply," Gas Wasserfach Gas Erdgas, March 1975, vol. 116, no. 3, pp 119-24.

The use of emergency and reserve power supply equipment in the monitoring and control of gas and water supply in case of an electric power failure is discussed.

Prokhovhik, D. N., and A. A. Arakelov, "Improvement of Transient Behavior in the Type UGP-24 Guaranteed Supply Circuits," Telecommunication Radio Engineer, April 1974, vol. 28-29, no. 4, pp 38-40.

The uninterruptible power supply for multichannel transmission equipment consists of control panels, a storage battery, a synchronous generator supplying the communications equipment, and two drives--an asynchronous motor and a dc motor.

Reichenstein, Hermann W., and Rene Castenschiold, "Coordinating Overcurrent Protective Devices with Automatic Transfer Switches in Commercial and Institutional Power Systems," IEEE Industrial and Commercial Power Systems Technology Conference, Denver, Colorado, June 2-6, 1974.

This paper defines and analyzes important transfer switch functions and application criteria.

Rutschow, Carl, "Simple CMOS Circuit Generates Three-Phase Signals," Aerojet Electrosyst, Azusa, California, 1976.

A micropower, three-phase generator, ideal for such applications as battery-powered inverters, can be simply constructed using a CMOS four-bit shift register and two CMOS inverters (only 1-1/3 total IC packages).

Schmied, Ernest, "Emergency Power for Hospitals," Syska and Hennessy Inc., New York, N.Y., 1972.

> While emergency standby generation has the basic purpose of serving a hospital during full power interruption, the engineer must also consider brownout periods, and he must adjust automatic start and throwover to the emergency system accordingly. The engineer must closely review local electrical and building codes for load types to be connected and for other requirements, including ventilation, cooling, and exhaust of the generating unit.

Schwartz, H. J., and L. I. Shure, "Survey of Electric Power Plants for Space Applications," NASA-MM-X-52158, National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio, Rep. No. 1965.

> Presented at the 58th AIChE National Meeting in Philadelphia, in December 1965. It covers the Brayton cycle, Rankine cycle, spacecraft power supply, thermionic converters, batteries, cells, chemicals, converters, fuel cells, fuels, generators, solar energy, spacecrafts, supplies, thermionics, and thermoelectric systems.

Sharma, G. N., and G. N. Acharya, "Standby Power Source Uses Diodes and Battery," Central Electronic Engineering Research Inst., Pilani, India, 1970.

> A way to provide an instantaneous emergency power supply for small electronic devices normally operated from a battery eliminator is described. A simple combination of two diodes, properly rated for the maximum current drain, provides automatic changeover from ac mains to a battery supply.

Sheets, Marvin W., "Are We Asking Too Much In Qualifying Tests of Electric Motors for Nuclear Power Stations?" Power, Jan. 1975, pp 48-49.

Simmons, Henry E., "Consider the Tradeoffs," E. E., Incorporated, Long Beach, California, 1974.

> Wall-mounted battery supply units of sufficient capacity to handle full branch circuits, ranging in size from 400 to 1200 W, and operating at 208/120 V are discussed.

Sommer, Peter, "...Design Requirements for the Emergency Power Supply of Nuclear Power Plants," Tech Ueberwach-Ver Rheini, Germany, 1975.

> The design requirements for emergency power supply of nuclear power plants are discussed on the basis of operational experience with emergency power diesel units. (In German with English abstract)

"Standby Power Assures Residential Service Continuity," Electrical Construction and Maintenance, July 1975, p 53-54.

Takahashi, Patrick K., et al., "State-of-the-Art of Geothermal Reservoir Engineering," ASCE Journal, (Power Div.), July 1975, vol. 101, no. 1, pp. 111-26.

This paper is a comprehensive survey into the state-of-the-art in geothermal reservoir engineering.

Teets, Rex M., "Protecting Minicomputers from Power Line Perturbations," Computer Design, June 1976, pp. 99-104.

"Thermo-Mechanical Generator," Engineering, Sept. 1974, p 730.

Thorpe, L. J., and W. J. Cosgrove, "Portable Camera Unit for the TKP-45 Color Television Camera," RCA Corporation, Camden, N.J., 1976.

A new self-contained camera control unit (CCU) for a portable color television camera head has been designed. It can be readily carried into the field for portable production applications or for electronic newsgathering.

Wentz, Jill P.,"Emergency and Standby Power: 10 Years After the Blackout," Electrical Construction and Maintenance, Jan. 1976, pp. 51-56, 126-31.

Wiss, J. W., et al., "Military Ground Power," Proceedings of the 7th Intersociety Energy Conversion Engineering Conference, San Diego, California, Sept. 25-29, 1972, pp. 1073-1111.

Woods, D. W., et al., "IEEE Industrial and Commercial Power Systems Technical Conference," IEEE, Atlanta, Georgia, May 13-16, 1972.

List of titles and authors presented at this conference.

Zung, Joseph T. (ed.), "Energy Resources and Management," University of Rolla, Rolla, Missouri, April 24-26, 1974.

Includes 42 papers on energy resources and new methods of conserving increasingly scarce supplies of energy.

SOLAR SYSTEMS

Beale, W., et al., "Design Details and Performance Characteristics of Some Free-Piston Stirling Engines," Proceedings of the 8th Intersociety Energy Conversion Engineers Conference, AIAA Univ. of Penn., Philadelphia, PA, Aug. 13-17, 1973, pp. 190-193, .

The concentric piston-displacer type of free-piston Stirling engine is being developed for use as a solar-powered water pump, a gas-fired air conditioner, and an isotope-powered electric generator.

Daniels, F., "Direct Use of the Sun's Energy," 1965.

Duffie, J. A., and W. A. Beckman, "Solar Energy Processes," 1974.

Durand, H., and G. J. Naaijer, "Water Pumps Driven by Photovoltaic Modules," Proceedings of the International Conference on Heliotech. and Dev., Drahan, Saudi Arabia, Dev Anal Assoc., No. 2-6, 1975, vol 2, p 315-330.

Two water-pumping systems, including a kW-size photovoltaic generator combined with a short-term storage battery, are described.

Gnau, L. H., "Solar Thermoelectric Generator Design and Panel Development Program Fabrication Report," Rep. No. NASA-CR-72386, Radio Corp. of America, Harrison, N.J., March 20, 1968.

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Ehricke, K. A., "Space Industrial Productivity: New Options for the Future," Future Space Programs, Hearings of the House Subcommittee on Space Science and Applications, 1975.

Jordan, R. C., "Solar Energy Powered Systems; History and Current Status," ASTM Standardization News, Aug. 1975, p 13.

Landsman, A. P., and N. V. Pulmanov, "Low-Powered Photoelectric Generators for the Terrestrial Application," Central National d'Etud Spatiales, Paris, France, 1973.

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Loesch, Helmut, R. (ed.), "Photovoltaic Power Generation," Dtsch Ges Fuer Luft-und Raumfahrt, Cologne, Germany, 1974.

Solar radiation has been successfully used for power generation in space, and one session of this conference dealt with the field of space application. However, emphasis of the meeting was on terrestrial application of solar energy.

Ramakumar, R., et al., "Solar Energy Conversion and Storage Systems for the Future," IEEE Transactions on Power Apparatus and Systems, Nov.-Dec. 1975, vol. PAS-94, no. 6, pp 1926-34.

Research and development at Oklahoma State University has resulted in the evolution of several components required to engineer a continuous duty power system running on nonexpendable energy sources, namely the sun and the wind. This paper presents the system and discusses its applicability to the energy systems of the future.

"Reliability Analysis of the Solar Generator of the ESRO 1 Satellite," National Aeronautics and Space Administration, Washington, D.C., Rept. No. NASA-TT-F-14498, NTIS N73-10051, Sept. 1972, 24 p, .

The reliability of the solar generator of ESRO is studied by investigating the reliability of its components.

Synder, Robert E., "Solar Power Generator Cuts Offshore Operating Cost," World Oil, May 1973, vol. 176, no. 6, pp. 81-83.

Solar cells and photovoltaic systems are discussed in the article.

"Solar Thermionic Generator Development Quarterly Report, 1 Dec. 1967 - 29 Feb. 1968," Rep. No. NSAS-CR-94402, TE4055-145-68, Jet Propulsion Lab., California Institute of Technology, Pasadena, California, April 1968.

THERMOELECTRIC SYSTEMS

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Preliminary results of an extensive development program of an organic Rankine cycle total energy system concept for on-site commercial power up to several hundred kW are presented.

Angello, Joseph P., "Static, Silent, Thermoelectric Power Sources: Session on Thermal Energy Conversion," Proceedings of the 23rd Annual Power Sources Conference, May 20-22, 1969.

The 10- and 20-A units were developed and proved to be fully feasible for Army field operation.

Beard, George L., "1.4 GW Centralia Power Plant," 8th World Energy Conference, vol 3, Bucharest, Hungary, June 28-July 2, 1971.

The Centralia thermoelectric generating station is described.

Campana, Robert J., et al., "Thermoelectric Generator," Rep. No. PAT-APPL-451 367, NTIS PATENT-3 388-008 Energy Research and Development Administration, April 1965, .

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A thermoelectric generator comprising an elongated thermopile formed of a plurality of interlaced thermoelectric elements adapted to generate electricity when opposite ends thereof are subjected to different temperatures, means maintaining said opposite ends at different temperatures, and means minimizing the difference in the time rates of change of temperature of said ends of said thermopile incident to ambient temperature changes so as to stabilize the power produced by the generator.

Christenbury, T., et al., "Thermoelectric Generator Design Manual," Rept. No. NASA-CR-109637, INSD-7089-1, Jet Propulsion Lab., California Institute of Technology, Pasadena, California, Feb. 20, 1970.

Cooke-Yarborough, E. H., et al., "Thermomechanical Generator: An Efficient Means of Converting Heat to Electricity at Low Power Levels," Atomic Energy Research Establishment, Harwell, Berkshire, England, 1974.

Research results are reported on thermal energy conversion, which has led to the successful development of an efficient heat engine/alternator system capable of delivering several tens of watts of alternating current.

LaPorte, Alfred, H., "Design and Testing of a 150-Watt SNAP 19 High-Performance Generator," AIAA, New York, N.Y., 1973.

The role of heat pipe technology in enabling the growth of Pioneer and Viking class SNAP 19 radioisotope thermoelectric generators (RTG's) to multihundred watt capacity is described.

Magnuson, K., et al., "Manportable Thermoelectric Generator," NTIS AD/A-002 042/0ST Minnesota Mining and Manufacturing Company, St. Paul, Army Electronics Command, Fort Monmouth, N.J., Nov. 1974.

The report describes the design, fabrication, and test of the 120-W Manportable Thermoelectric Generator (exploratory development model).

Malevskii, Yu. N., "Performance Reliability Calculation for a Modular Solar Thermoelectric Generator," Rept. No. FSTC-HT-23-1434-72, NTIS AD-757 087 Army Foreign Science and Technology Center, Charlottesville, VA, Jan. 10, 1973.

Analysis is given of the overall reliability of a solar energy converter unit composed of thermoelectric modules, as a function of the reliability of individual photocells and component modules.

Messerle, H. K., "Electric Power Generation by M.H.D. - Recent Developments," Institute of Engineering, Sidney, Australia, 1975.

A survey of the status of a magnetohydrodynamic generator design, flow dynamics, and experimental results is given.

Miller, D. F., and A. H. Mayala, "Man-Pack 250-Watt Thermoelectric Generator (Rebuild)," Minnesota Mining and Manufacturing Company, St. Paul Thermoelectric Products, March 24, 1964.

The mode of failure of the 3M-5B1 generator after only 500 hr operation was due to overheating the cold-end solder-type hermetic seal, leading to oxidation of the PbTe thermoelectric material.

Miller, N. C., and R. A. Lockwood, "Portable Thermoelectric Generator," Rep. No. AI-7642, NTIS AD-764-277 Atomics International, Canoga Park, California, Aug. 29, 1962.

Neild, Alton, B., Jr., "Arrangement of Thermoelectric Elements for Improved Generator Efficiency," available from Commissioner of Patents, Washington, D.C., July 27, 1965.

A plurality of thermoelectric generator banks or rows are connected in parallel, each containing a group of series-connected thermoelectric elements which are placed between a heat source and a heat sink.

"Operating Report for Radioisotopic Thermoelectric Generators of the U.S. Navy, Volume 9, Number 1," NTIS AD-A024 531/6ST Naval Nuclear Power Unit, Fort Belvoir, VA, December 31, 1975.

The objective of this operating report is to serve as a vehicle for the accumulation and dissemination of information concerning the application and operation of radioisotopic thermoelectric generators (RTGs) within the Navy.

Prosser, D. L., "SNAP-27 on the Moon," <u>Isotope Radiation Technology</u>, Summer 1970, vol. 7, no. 4, pp. 443-447.

A SNAP-27 thermoelectric generator left on the moon by the Apollo 12 astronauts was designed to provide electric power for five experiments on the lunar surface. The source is fueled with 3735 g (8.36 lb) of Pu-238 dioxide microspheres, which produce 63 W(e) 1480 W(t) of power.

Rosell, Fred E., Jr., "Navy Half-Watt RTG - A Super Battery Becomes Reality," IEEE, New York, N.Y., 1975.

A half-watt radioisotope thermoelectric generator (RTG) being procured by the Navy for use as distributed power sources for remote undersea applications is described.

Russo, Frank A., "Operational Testing of the High Performance Thermoelectric Generator (HPG-02)," ASME, New York, N. Y., 1974.

> This paper describes the activities and observations leading to the successful development of the HPG-02, a thermoelectric generator of 165 W output and specific power of greater than 2 W per pound.

Serksnis, Anthony W., "Thermoelectric Generator for an Automotive Charging System," AICHE, New York, N.Y., 1976, vol. 2, pp. 1614-18.

> Outlines of the basic parameters to be considered and of a proposed design are given.

"SNAP-15A Thermoelectric Generator," Gulf General Atomic, Inc., San Diego, California, Sept. 3, 1968.

> Discusses nuclear power plants, thermoelectricity, auxiliary power plants, and environmental tests, and contains information on radioisotope thermoelectric devices, SNAP and SNAP-15 isotopic generators.

Steen, Donald B., "Development of a Thermoelectric Generator-Powered Solid-State 100-Watt Beacon System," Rep. No. MEL-83/66, Navy Marine Engineering Lab, Annapolis, MD, April 1966.

> A solid-state 100-W navigational beacon power system employing a propane-fired, 30-W, thermoelectric power supply, a capacitor energy storage bank, and a 5-sec, one-quarter duty cycle, solid state flasher has been developed for possible replacement of present Coast Guard battery-powered systems using mechanical flashers.

UPS

Best, C. A., "Uninterruptible Power Supplies," Westinghouse Electric Corporation, Buffalo, N.Y., 1969.

> Advantages derived from installing an uninterruptible power supply (UPS) in industrial plants are outlined. Three types of interruptible power supplies are discussed.

Budzilovich, Peter N., "Thinking of Buying a UPS?" Computer Decisions, May 1977, pp. 84-86, 88-90.

Edwards, Ted, "Scheduled Exercising Keeps Merrill-Lynch Alternate Power Systems Ready to Take Over," Sawyers Gas Turbine Int., Sept.-Oct. 1976, vol. 17, no. 5, pp. 34-35.

> The operational data for an integrated, alternate power system for a computer facility are given.

George, Michael L., "How to Weigh Variables for UPS," Power, March 1974, pp. 68-69.

Holscher, J. N., "Uninterruptible Power System, A Progress Report," Advances in Instrumentation, vol. 24, Pt. 4, 1969.

> There is a generalized discussion of various inverter installations which are useful for providing uninterrupted sources of emergency power.

Krieger, Charles H., "UPS and M-G Sets Combine to Protect Major Computer Center," Electrical Construction and Maintenance, Jan. 1976, pp. 67-69.

Lambert, F. J., "Understanding Uninterrupted Power Systems," Instruments and Control Systems, Oct. 1974, pp. 75-78; Nov. 1974, pp. 53-54.

McGregor, John E., "Specifying Power Line Buffer Equipment for Computer Systems," Computer Design, Nov. 1973, vol. 12, no. 11, pp. 96, 98, 100-101.

> Long-term savings in uninterrupted, error-free operation of a large computer system can more than offset the initial cost of a buffer designed to isolate the computer from power line disturbances and outages.

"Modern UPS Power Utility Control Center," Electrical Construction and Maintenance, Jan. 1976, pp. 60-63.

"UPS Assures No-Break Power," Power, Jan. 1976, pp. 50-51.

Wiener, Hesh, "A User's View of UPS," Computer Decisions, June 1976, pp. 52-53.

10. APPENDICES

10.1 Applicable Codes and Standards

	STD. NO.
AMERICAN NATIONAL STANDARD INSTITUTE (ANSI)	
Std. for Quick Disconnect Devices for use with Gas Fuel (1971)	Z21.41
Std. for Installation for Gas Piping and Equipment on Industrial and Certain Other Premises (1972)	Z83.1
Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines (1960)	C2.2
National Electric Safety Code, Part I: Rules for the Installation and Maintenance of Electrical Supply Stations and Equipment (1971)	C2.1
Safety Rules for the Installation and Maintenance of Underground Electric Supply and Communication Lines (National Electrical Safety Code) (1973)	C2.3
Std. Definitions for Power Switchgear (1972)	C37.100
AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)	
Emergency Std. Spec. for Automotive Gasoline (1974)	ES1
Std. Spec. for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings (1973)	D2517
DIESEL ENGINE MANUFACTURERS ASSOCIATION (DEMS)	
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Gauge Boards, Protective Devices and Instrumentation (1972)	*1-17
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Air Intake and Exhaust Systems	*1-8

	STD. NO.
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Cooling Water Systems (1972)	*1-10
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Erection and Installation (1972)	*1-21
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Factory and Field Testing (1972)	*1-22
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Fuel Oil Characteristics (1972)	*1-14

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA Pamphlet No. 30, "Storage, Handling and Use of Flammable Liquids"

NFPA Pamphlet No. 37, "Installation and use of Internal Combustion Engines"

NFPA Pamphlet No. 54, "Installation of Gas Piping and Gas Appliances in Buildings."

NFPA Pamphlet No. 58, "Storage and Handling of Liquified Petroleum Gases"

NFPA Pamphlet No. 70, "National Electrical Code"

National Building Code

Building Code Standards for Heat Producing Applicances, etc.

Fire Prevention Code

Uniform Building Code

SOCIETY OF AUTOMOTIVE ENGINEERS, INC. (SAE)

Std. for Engine Test Code-Spark Ignition and Diesel (1971)	J816B
Std. for Engine Rating Code Diesel	J270

	STD. NO.
UNDERWRITERS LABORATORIES, INC. (UL)	
Safety Std. for Automatic Transfer Switches (1972)	1008
Safety Std. for Power-Operated Dispensing Devices for Flammable Liquids (1974)	87
Std. for Safety for Pigtails, Expansion Coil, and Flexible Connector Fittings for LP (Liquid Petroleum) Gas Cylinders (1973)	569
Safety Std. for Gas Pressure Reg. (1973)	252
Safety Std. for Hose for Conducting Gasoline	330
Std. for Safety for Flame Arresters (Fire) for Use on Vents of Storage Tanks for Petroleum Oil and Gasoline (1973)	525
FACTORY MUTUAL SYSTEM (FMS)	
Rec. for General Safeguards for Flammable Liquids (1974)	7.35
INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO)	
Uniform Plumbing Code Fuel Gas Piping (1973)	UPC*1-12
INSTITUTE OF ELECTRICAL & ELECTRONICS ENGINEERS, INC. (IEEE)	
Trial Use Std: Criteria for Diesel Generator Units Applied as Standby Power Supply for Nuclear Power Generating Stations (1972)	387-1972
Criteria for Class 1E Power Systems for Nuclear Power Generating Stations	308-1974
Trial Use Criteria for the Periodic Testing of Nuclear Power Generating Station Protection Systems (ANSI N 41.3) (1971)	338-1971
Recommended Pract. for Seismic Qualifications of Class 1E Equipment for Nuclear Power Generating Stations (1975)	344-1975

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	STD. NO.
Guide for General Principals of Reliability Analysis of Nuclear Power Generating Station Protection Systems	352-1975
Def. of Terms Used in IEEE Standards on Nuclear Power Generating Stations	380-1975
Recommended Pract. for Maintenance, Testing, and Replacement of Large Stationary Type Power Plant and Substation Lead Storage Batteries	450-1972
Recommended Pract. for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Systems	484-1975

NATIONAL ELECTRICAL MANUFACTURING ASSOCIATION (NEMA)

Safety Code for Semiconductor Power Converters (1973)	PV3
Std. for Dimensions for Alternating and Direct Current Motors and Generators (Fractional and Integral Horsepower) (1972)	MG1-11
Std. for Application Data for Alternating and Direct Current Motors and Generators (Fractional and Integral Horsepower) (1972)	MG1-14
Std. for Definite Purpose Motors and Generators (Fractional and Integral Horsepower) (1972)	MG1-18
Construction and Guide for Selection, Installation and Use of Electric Motors and Generators (1973)	MG2
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Gaseous Fuel Characteristics and General Spec. (1972)	*1-15
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Generators and Electrical Equipment (1972)	*1-18
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Lubricating Oil Characteristics and General Spec. (1972)	*1-12

	STD. NO.
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Gaseous Fuel Systems (1972)	*1-11
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Operation and Maintenance	*1-23
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Power Plant Bldgs. (1972)	*1-20
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Power Plant Fuel Oil and Gas Systems (1972)	*1-13
Std. Pract. for Stationary Diesel and Gas Engine Ratings and Performance (1972)	*1-4
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Speed Governing and Parallel Operations (1972)	*1-6
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Starting Systems	*1-9
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Vibration (1972)	*1-7
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engine Waste Heat Recovery Systems (1972)	*1-16
Std. Pract. for Low and Medium Speed Stationary Diesel and Gas Engines (1972)	*1
Std. Pract. Definitions for Stationary Diesel and Gas Engines (1972)	*1-1
Std. Pract. for Scavenging and Supercharging of Stationary Diesel and Gas Engines (1972)	*1-3
Std. Pract. for Selection of Engine Generator Units for Low and Medium Speed Stationary Diesel and Gas Engines (1972)	*1-19
Std. Pract. for Preparation of Invitations for Bids and Detailed Specs. for Low and Medium Speed Stationary Diesel and Gas Engines (1972)	*1-24

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10.2 Glossary

Alternator - Synchronous generator that converts mechanical power into alternating current (ac) electric power.

Ampere-hour capacity - The number of amperes that can be delivered under specified conditions as to temperature, rate of discharge, and final voltage.

Asynchronous machine - An alternating-current machine in which the rotor does not turn at synchronous speed.

Asynchronous operation - Operation of a machine where the speed of the rotor is other than synchronous speed.

Btu - British thermal unit, a measure of energy equal to 2.930×10^{-4} kW-hr.

Discharge capacity - The conversion of the chemical energy of the battery into electric energy.

Float charge - A method of operation for storage batteries in which a constant voltage is applied to the battery terminals sufficient to maintain an approximately constant state of charge.

Generator - A machine that converts mechanical power into electric power, either ac or dc.

kVA - Kilovolt-ampere rating is the product of the rated load amperes and the rated range of regulation in kilovolts. The kilovolts-ampere rating of a three-phase voltage regulator is the product of the rated load amperes and the rated range of regulation in kilovolts multiplied by 1.732.

KW - Kilowatts, a measure of electrical energy defined as being 1000 joule/sec. Electrical power can be determined by

$$P = I^2R = VI,$$

where

I = Current (amps),
R = Resistance (ohms),
V = Voltage (volts).

Power apparent - The product of the root-mean-square current and the root-mean-square voltage.

Power factor - The ratio of total watts to the total root-meansquare (RMS) volt-amperes.

$$\frac{\text{Watts per phase}}{\text{RMS volt-amperes per phase}}$$

RMS - Root-mean-square is the square root of the average of the square of the instantaneous amplitude taken over the pulse duration. For alternating voltage or current, it is the square root of the mean of the square of the voltage or current, during a complete cycle.

SCR - Semiconductor controlled rectifier, an alternative name used for the reverse-blocking triode-thyristor.

Synchronous operation - Operation where the speed of the rotor is equal to that of the rotating magnetic flux and where there is a stable phase relationship between the voltage generated in the primary winding and the voltage of a connected power system or synchronous machine.

Thyristor - A bistable semiconductor device comprising three or more junctions that can be switched from the OFF state to the ON state or vice versa, such switching occurring within at least one quadrant of the principal voltage-current characteristic.

Transfer switch - A switch arranged to permit transferring a conductor connection from one circuit to another without interrupting the current.

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This report on emergency electric power for security systems at licensee facilities was prepared for use in the NRC Safeguards program. The report includes information that will be useful to those responsible for the planning, design and implementation of emergency electric power systems for physical security and special nuclear materials accountability systems. Basic information concerning different types of emergency power supply systems is presented. Considerations for establishing the system requirements for emergency electric power for security and accountability operations are presented. Methods of supplying emergency power available at present, and methods predicted to be available in the future are discussed. Emergency power considerations such as capacity, cost, safety, reliability, and environmental contraints are presented. Report includes basic consideration for development of a system concept and the preparation of a detailed system design.

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