Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 11—Electrical Power Supply

Refining Department

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SECTION 11—ELECTRICAL POWER SUPPLY

11.1 Scope

This section is intended as a guide for the design and selection of equipment for a highly reliable electrical power distribution system for plant process instrumentation and controls. For additional information on the installation of electrical systems, refer to API RP 540, *Recommended Practice for Electrical Installations in Petroleum Processing Plants*.

11.2 General

A supply of continuous electrical power to a plant process instrumentation and control system is essential for safe operation and the manufacture of on-grade products. When power interruptions occur, the plant must be designed either to continue to operate on standby steam-driven turbines or to shut down in a safe and orderly manner. Control systems and monitoring devices must continue to provide information and control during this period; therefore, the electrical power system reliability requirement is much greater for instrument system supplies.

11.2.1 PLANT POWER RELIABILITY

The reliability of the service to a plant depends on many factors. Utility companies invest considerable time and effort in improving the reliability of their systems. This includes providing redundant equipment, alternate sources of power such as neighboring electrical utilities, and various contingency plans to permit operation during emergency conditions.

The reliability of electric power varies from region to region, and in most areas seasonal outages are predictable. Unpredicted events, such as earthquakes or man-caused disasters, also cause long, unexpected outages or curtailments.

The configuration of the transmission and distribution system can be arranged to provide maximum reliability. For an all-electric-drive plant where service is critical, at least one redundant feeder line is required together with transformers, main breakers, and a tie-breaker for fast automatic transfer. Typical utility substation arrangements are shown in Figure 11-1.

If the plant has sufficient steam and electric operation is only a matter of economics, then a single utility feed could be used with steam-driven turbines to back up electric motors. Most utility companies will provide whatever configuration the customer requires. In return for this service, a facilities charge may be added to the monthly billing for any electrical equipment which exeeds what the utility company considers necessary for standard service.

The trend in the processing industry is to rely more heavily on the utility company's ability to deliver power with minimal, if any, interruption. New plants are relying less on uneconomical standby steam drivers, especially in locations where the utility has a reliable service record.

As a result, only the critical services, such as essential digital and analog control systems and shutdown circuits, are being served with uninterruptible power supplies in new installations. The processing portion of the plant is left to circulate down as much as possible by using critical-standby steam drivers (generally on circulating pumps) when power failures occur.

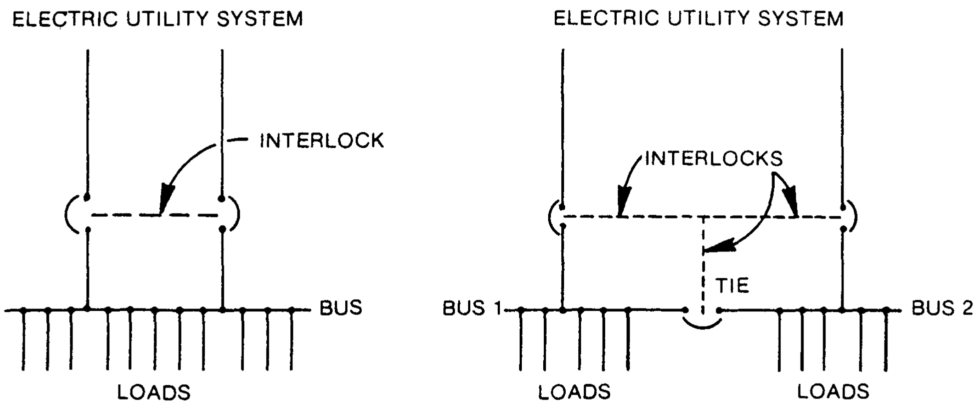


Figure 11-1—Secondary Transfer Using Circuit Breakers

11.2.2 POWER OUTAGE

A utility finds it virtually impossible to provide constant voltage and frequency power to its customers because of power outages resulting from incidents such as automobiles hitting transmission poles, dirty insulators flashing over, falling lines, lightning surges, and operating switching surges.

By utility-company definition, a power outage occurs when its system voltage and frequency fall to zero for a one-cycle time duration. Voltage dips and frequency slowdowns are considered system disturbances, except during power outages. In either case, critical loads such as digital control systems or computers would be severely upset or go off line if no electrical system backup is available.

Some digital systems require that input voltage never exceed precise limits of nominal voltage while other systems may sustain an outage lasting as long as 30 milliseconds before shutting down. The degree of voltage-cycle variation tolerance for a specific critical load, such as a computer, a shutdown system, or a digital temperature indicator, is generally only a few volts or cycles. When the electrical supply approaches the voltage limits or partial-cycle variation, the critical load is in trouble.

11.3 Instrument Load Characteristics

11.3.1 PNEUMATIC SYSTEMS

Where pneumatic control systems are used for plant process control, the electrical requirements can usually be supplied from a relatively simple electrical system. Instruments in service together with pneumatic control systems that require electrical power are multipoint temperature indicators, recorders, annunciators, shutdown circuits, and various process trips. These devices may not require closely regulated voltage, frequency, and harmonic content characteristics. Special attention will be required for devices such as flame monitors, dropout valves, or solenoids that may require a no-break electrical supply.

11.3.2 ELECTRONIC ANALOG SYSTEMS

Electronic analog systems may receive alternating current (ac) directly and convert to direct current (dc) internally, or receive dc directly from a common dc power supply. In most electronic controllers, even a momentary loss of power may bump the output and cause disturbances in the process. During total power failure and plant shutdown, backup must be provided to the instruments long enough to bring the plant down in an orderly and safe manner.

11.3.3 DIGITAL SYSTEMS

The use of digital systems for monitoring, supervising, or controlling is becoming more common. The power supply requirements, listed in the respective supplier system installation manual, must be followed closely. This usually requires no-break power with closely regulated voltage, frequency, and harmonic content. The designers of the power supply must consider the control system transient and steady state conditions and must provide suitable isolation to prevent noise scattering from component to component. In most cases, purchased utility power or in-plant

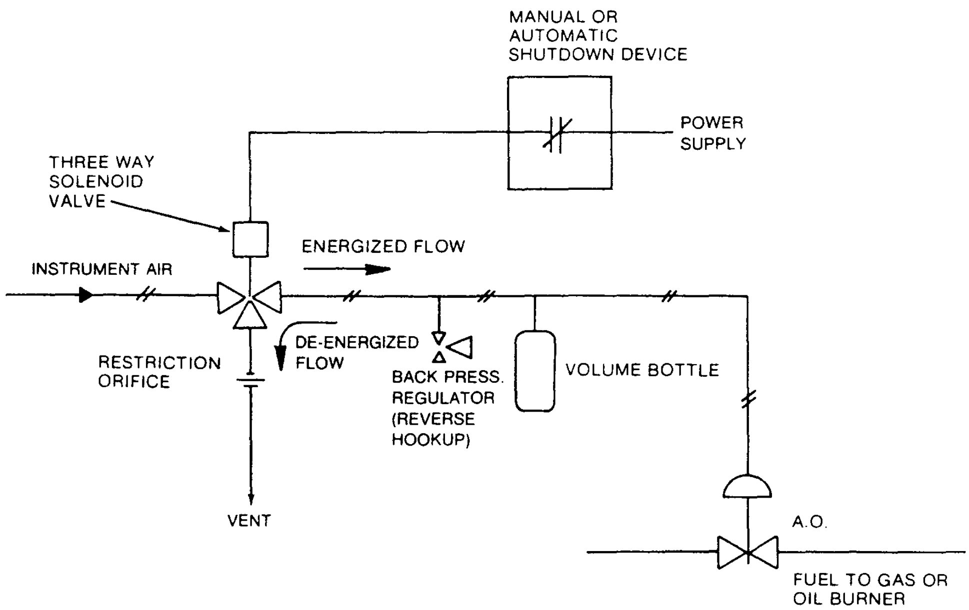


Figure 11-2—Fuel Supply Shutdown Circuit for Momentary Power Failure Security

generated power will not satisfy these requirements and a special system must be provided.

11.4 Instrument Load Requirements

11.4.1 GENERAL

The power supplies for control, alarm, and shutdown systems can be grouped into different categories depending on whether the system is required during power outages or disturbances. Frequently this is determined by whether the service is control or non-control. In general, control loops are those which operate modulating valves, on-off devices or directly control equipment such as motors and turbines in the performance of shutdown circuits. Non-control loops can be indicators, recorders, annunciators, certain analyzers, and so forth. Careful consideration must be given to the type and service of each control device so that its power reliability requirements are met. Operational requirements during both normal and emergency conditions, such as a plant or unit power failure, will also dictate power reliability requirements.

11.4.2 RELIABILITY REQUIREMENTS

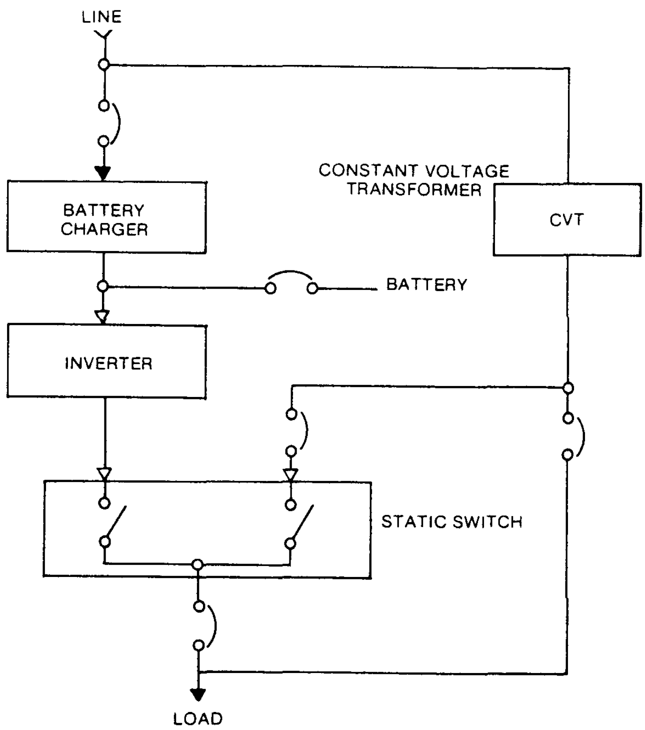
Reliability requirements are determined by the need for the device to function during power interruptions. The permissible interruption times are used to illustrate the categories. These times will vary according to control equipment characteristics. For instance, it is possible that use of a delayed dropout provision as shown in Figure 11-2 in a control loop would shift it from a ''critical'' to ''semi-critical'' supply. Typical categories are listed in 11.4.2.1 through 11.4.2.3.

11.4.2.1 Critical

A critical load is a control system that is essential for normal and emergency operation and that cannot tolerate a power outage greater than approximately 4 milliseconds. Critical loads require sources which are independent of the normal plant power supply. Alternating current loads may be supplied by a static uninterruptible power supply (UPS) or a rotating motor-generator set with a high inertia flywheel. Transfer of supply from a normal to a standby source requires solid state static switches that have essentially zero switching time (see Figure 11-3). Direct current loads can be supplied by battery-backed dc power supplies. The transfer of dc from a normal to a standby source requires solid state diodes or silicon controlled rectifiers that also have essentially zero switching time.

11.4.2.2 Semi-Critical

Semi-critical loads must operate during emergency conditions but can operate satisfactorily through short interruptions. An independent power supply source that is separate from the utility is required during power outages (see Figure 11-4). Semi-critical loads may be further categorized into loads for which interruptions of the ac supply as long as 0.2 second are permitted and those for which interruptions as long as 20 seconds may be permitted. The typical control loop is in the first category; the noncontrol loop—recorders, indicators, annunciator systems, and so forth—is in the second. Faster transfer from normal to standby power, using electromechanical (contactor) switches which have approximately a 100 millisecond switching time, is required for the first category. Usually, the normal plant power system delayed transfer of startup of standby generators is sufficient for noncontrol instruments.



NOTES:

1. Select branch circuit fuses to coordinate with SCR fuses in inverter.
2. Stored energy in CVT provides power during part of transfer time to minimize the interruption. Redundancy may be required for reliability.
3. On an overload or short-circuit, the CVT output voltage typically drops rapidly toward zero and at short-circuit, the output current is limited to approximately 150 percent of rated value. uninterrupted power supply systems typically bypass via the solid state switch to the ''stiffer'' alternate line on overloads and short-circuits. Use of a CVT in alternate line could cause problems with protective device (fuse or circuit breaker) operation and proper clearing of branch circuit overload or short-circuit.

Figure 11-3—Power Supply for Critical Instrument Load

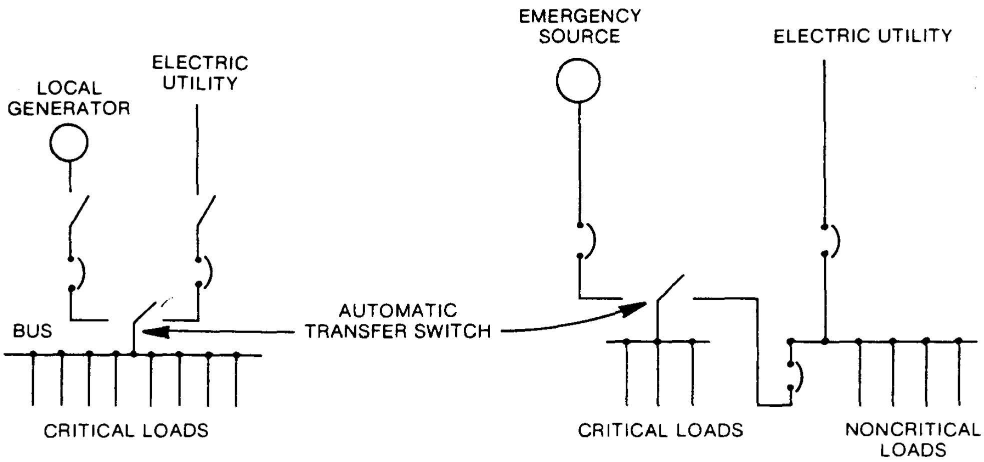


Figure 11-4—Typical Automatic Transfer Switching Methods

11.4.2.3 Non-Critical

Tank gaging systems and process quality analyzers are examples of non-critical loads that may be dropped during a power outage without affecting safe and orderly emergency operations. However, the power supply during normal operating conditions must have a high degree of reliability.

11.4.3 POWER QUALITY REQUIREMENTS

Quality grading will group loads according to the requirements of the control devices to ensure that realistic and not excessive limits are placed on supply fluctuations. Typical grading limits are as follows:

For ac loads:	
Voltage regulation	±2 percent
Frequency regulation	±1 hertz for 50/60 hertz systems
Total harmonic distortion	5 percent maximum
For dc loads:	
Voltage regulation	±1 percent
Voltage ripple	½ percent maximum

11.4.4 EMERGENCY POWER SOURCE CAPACITY

An important aspect of load requirements is the length of time the particular load must function during abnormal or emergency power supply conditions. Loads can be divided into categories to determine the required capacity for standby power sources. A 1-hour period may be adequate for some; an 8-hour period for others; still others may require longer periods. Capacities for periods of 2 minutes to 8 hours are commonly available for rectifier-battery-inverter systems. When longer periods are required or requirements exceed about 20 kilovolt-amperes, rotating equipment sources may be more economical.

Certain control system devices such as digital control systems with heavily filtered power supplies, or high speed disc storage devices, will have very high inrush currents when energized. In some instances, fast transfer solid state switches have sensed the high inrush currents and attendant voltage drop and then transferred loads that should not have been transferred. Consideration must be given to these design problems to minimize voltage or frequency variations during high inrush.

11.5 Electrical Power Supply

11.5.1 GENERAL

The power supply for process control systems must be designed to the following criteria:

1. Provision must be made for a reliable supply, meeting the required voltage, frequency, and harmonic characteristics, during all normal and abnormal plant operating conditions.
2. For plant emergency conditions, such as loss of steam or power, reliable power must be provided for the period required to put the plant in a safe holding condition or to shut down safely.

11.5.2 CONDITIONS

The power supply shall be designed to handle such conditions as:

1. Momentary interruptions to plant power supply.
2. Extended outages of plant power supply.
3. Abnormal or transient conditions incompatible with quality requirements of process control loads.

4. Internal faults in the process control system.
5. Isolation of major components of the process control power system without unacceptable load interruptions.

11.5.3 INSTRUMENT POWER SUPPLY SOURCE

The instrument power supply should be isolated from other loads. A separate transformer fed directly from the essential loads bus is recommended. When two independent buses are available, an automatic transfer switch should be used to improve continuity. The transformer should have taps on both the primary and secondary windings to permit compensation for prolonged voltage variations. The transformer should be located as close to the instruments as practical, preferably within 100 feet.

11.5.4 POWER SUPPLY REGULATION

Utility companies have lost system capacity from catastrophic failures in generation or transmission systems that resulted in long periods of reduced voltage to the customer. Such periods are commonly known as brownouts. If a utility is voltage-regulated, then it will move service from grid to grid for short periods. This system is known as rotating blackouts. When motors are started, lines are switched, and so forth, poor voltage regulation within the plant can cause isolated local brownouts or voltage fluctuations.

Several types of regulation systems are available which give increasing amounts of protection against voltage fluctuations. The uninterruptible power supply, which is recommended for many process control applications, protects against both voltage fluctuations and power outages. Simpler voltage regulators may be suitable for some of the less critical installations.

The following is a list of the types of power regulation systems available and the amount of protection they afford:

1. Motor-Generator Sets. Motor-generator sets use mechanical inertia to "ride through" in case of a power interruption. Ride-through capabilities can be provided for periods from 300 milliseconds to several seconds. This provides protection against transients but not against brownouts or blackouts.
2. Line Conditioners. These are electronic analogs of motor-generator sets. They can react to transients as short as several milliseconds and afford protection under brownout conditions.
3. Voltage Regulators. These are usually either constant voltage transformers or electronic-magnetic regulators which have a response time of approximately 100 milliseconds. In addition to smoothing out incoming power, they can compensate for brownouts.
4. Uninterruptible Power Supplies (UPS). A UPS is the first device in this listing that not only smooths voltage fluctuations to the instrument load but also maintains a load under longer term outage (blackout) conditions. The key components of UPS systems are an ac to dc rectifier/battery charger, storage batteries, a dc to ac inverter, and a static transfer switch (see Figure 11-4). A UPS allows the user either to shut down critical loads in an orderly fashion or to transfer to onsite power generation equipment as described below.

UPS systems normally are designed to provide from 15 to 30 minutes of support. Beyond this, it becomes uneconomical to increase the battery capacity. This is also about as long as electronic instruments and computers can safely run without air conditioning. (Most uninterruptible power supplies do not support a computer's environmental system.)

11.5.5 PNEUMATIC SYSTEM POWER SUPPLIES

Generally, the electrical components of a pneumatic analog control system can be satisfactorily supplied from the normal plant power system assuming that this system has normal and alternate sources which are reasonably independent of each other. This independence should be maintained in providing normal and alternate supplies to the main distribution bus of the process control power system. When the plant has only a simple radial supply, some provision should be made for an alternate supply to the process control system main bus. In all cases, particular attention must be paid to the requirements of critical circuits and components. Examples of these are the boiler plant control, safety devices and associated circuits, compressor control and shutdown circuits, and critical motor-operated valves which must function after total power failure. Special provisions, such as emergency generator sets or battery-inverter combinations, may be required.

11.5.6 ELECTRONIC SYSTEM POWER SUPPLIES

The electronic analog control and digital monitoring and control systems impose much more stringent requirements on the power supply system. Independent normal and alternate supply sources to main ac and dc distribution buses are required. In most plants, it will be necessary to provide an independent generation source in the form of an engine-generator, turbine-generator, motor-turbine-generator set, rectifier-battery-inverter (UPS), or a combination to serve as one source. Where stringent supply quality requirements are applicable, the generation source may serve as the normal supply. Particular attention must be paid to determine to what extent the supply from the plant power system can serve as the alternate source. By applying the reliability and quality requirements and degree of redundancy which must be provided, the capacity of independent generation can be held to an economic minimum.

Distributed control and monitoring systems used in petrochemical process control have a computer operating as the heart of the system. These devices, with memory storage and large-scale integrated circuits, are very susceptible to low voltage deviations and shut down rapidly if this occurs. This protects information that is in the memory from being improperly modified and possibly causing an erroneous operation or data shortage. An uninterruptible power supply is highly desirable to buffer out voltage dips and transients and minimize nuisance shutdowns.

Cathode-ray tubes, disk-storage devices, high-speed printers, and other peripherals are also very sensitive to voltage and frequency variations and should be isolated by separate transformers and buffered by an uninterruptible power supply.

There are several design problems to consider for a backup power supply for a computer system. Computer-system power supplies are heavily filtered and have a high inrush on startup, which has been measured as high as 10 times the normal circuit load on some systems. The backup power supply which may be a rotating motor-generator set or uninterruptible power supply, must be designed to supply this current inrush, or a bypass system must be provided to supply power from the alternate source for startup. Computers on process control may be started around the clock, and for this installation it is generally better to have a backup that can supply the starting current.

Another possible problem is a distorted sine wave output from the uninterruptible power supply. Most uninterruptible power supplies have inherently higher impedances than the critical load to which they are connected. If the mismatch is severe, a distorted wave form and poor power factor result. Distortion, or high harmonic content, in the ac power supply can cause unusual disturbances in the operation of a digital device.

Isolation transformers generally contribute to the mismatch. The normal solution is to change the firing-phase angle of the inverter silicon controlled rectifier. This should be done by the uninterruptible power supplier after the system is running with a full load.

For digital systems, installation manuals should be obtained and a site survey conducted with the supplier's customer engineer to discuss all aspects of the installation.

11.5.7 TYPICAL DESIGNS

The degree of electrical system backup depends on the nature of the load being supplied. Simple devices like coils or solenoid valves can be held in for short durations with diodes, capacitors, and variable resistors. Complicated electronic systems may require a more sophisticated backup, the ultimate being an uninterruptible power supply.

A diesel engine or steam-turbine-driven emergency generator can be used. These generators vary in size from 5 kilowatts to 250 kilowatts, with single or three phases and voltages up to 480 volts. Larger generators with higher voltages are available and can be driven with gas turbines or diesel engines.

Steam turbines driving emergency generators are kept on standby by bypassing a fast-opening control valve with enough steam to keep the turbine hot. When a power failure occurs, the control valve opens and brings the turbine rapidly up to speed to provide the backup power. This requires up to 1 minute and often the governor will trip the turbine on overspeed before it can recover and bring the turbine back to synchronous speed. The turbine-generator should be tested frequently by stroking the control valve and actuating the governor to ensure that it will operate properly when needed.

A more satisfactory method is to operate steam-turbine emergency generators continuously at synchronous speed with a light load. When a power failure occurs, the critical load is transferred by an automatic transfer switch in as few as seven cycles to the emergency generator. This arrangement is possible because of new developments in turbine technology. When a governor valve controls an unloaded turbine, the valve is almost pinched off and hard seat material now available must be specified to prevent "wire drawing." Wire drawing is defined as erosion of the

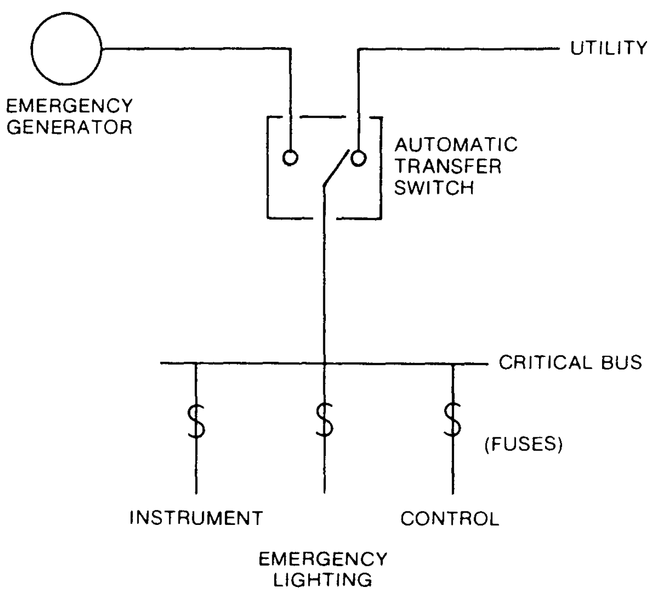


Figure 11-5—Semi-Critical Supply

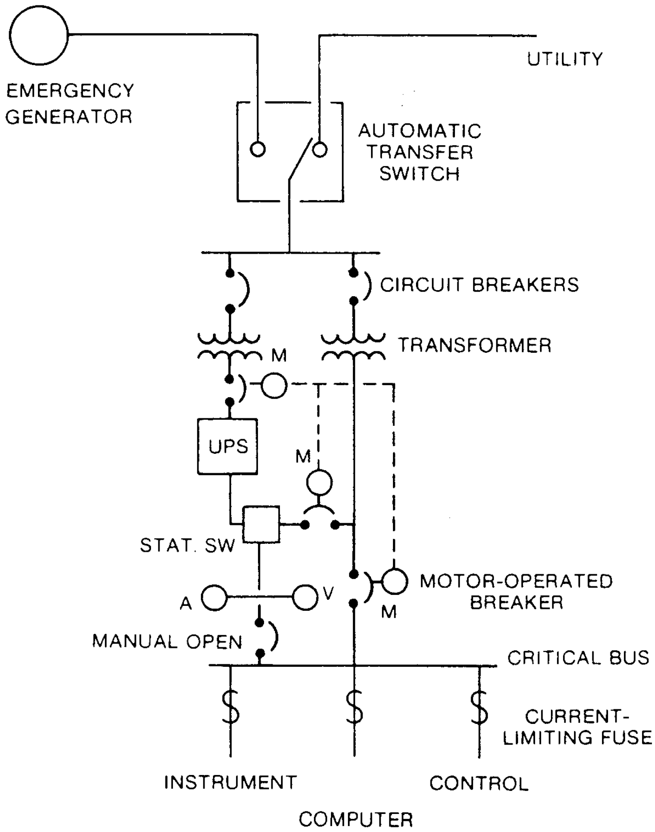
seat, accelerated by the high steam velocities through the narrow valve opening. Also a National Electrical Manufacturers Association Class D governor should be specified, as a minimum. This is a precision hydraulic governor that maintains very precise control on the turbine speed from no-load to full-load condition. This Class D governor is necessary to provide suitable frequency and voltage stability.

If the critical load requires continuous power, an uninterruptible power supply may be required. This device operates with battery power and supplies continuous ac power to critical loads. It inverts the dc battery voltage to a square wave and usually smooths and filters the output to an ac voltage with less than 5 percent harmonic distortion. The batteries are charged by battery rectifiers from the ac normal or standby power.

Since an uninterruptible power supply is very complex equipment with many electronic components, it may have a mean time between failure that is less than the serving utility. Therefore, design of the installation must be carefully planned to provide a bypass or proper backup with greater reliability than the utility service. During installation of an uninterruptible power supply, various arrangements can be made to accomplish this.

One arrangement provides two 100 percent capacity uninterruptible power supplies tied to the critical bus. Another arrangement uses a static switch to transfer the critical load off the uninterruptible power supply when a failure occurs. Transfer times of ¼ microsecond are common for static switches. They can detect uninterruptible power supply failure and switch to bypass before the critical load is affected. For maintenance purposes, a make-before-break manually operated bypass switch should be provided to completely bypass the uninterruptible power supply and static switch.

Typical one-line diagrams of power supply arrangements and a power conditioning and distribution system are shown in Figures 11-5, 11-6, and 11-7. Each process plant requires a design uniquely suited to its particular load requirements.



NOTES:
1. V—The voltage detector senses 90 percent.
2. A—Ampere sensor. If 150 percent is full load current, the uninterruptible power supply goes to limit mode.
3. UPS—Voltage output drops to 90 percent static switch and transfers to bypass in ¼ cycle. 300 miliseconds later the motor-operated bypass switch operates and the load is off the uninterruptible power supply.

Figure 11-6—Critical Power Supply

11.6 Automatic Transfer and Parallel Power Sources

11.6.1 GENERAL

In all cases where normal and alternate sources are provided, a means of automatic transfer between the sources or parallel operation is required. Reliability criteria will establish those loads that require rapid solid-state switching and those for which electromechanical switching is acceptable. Solid-state switching costs may triple the cost of electromechanical switching.

11.6.2 DESIGN PROBLEMS

Special equipment design and application problems are encountered where automatic transfer or parallel operation of sources is used. There are many combinations of rotating and static generation sources and plant power supply sources which may be used. The operating conditions that must be met and the unique characteristics of the combination selected should be understood thoroughly before a final design is established.

11.6.3 PROBLEM AREAS

Some specific problem areas requiring a thorough examination of operating conditions and equipment characteristics are:

1. The capability of a static inverter uninterruptible power supply to operate in synchronism with another uninterruptible power supply or plant power source.

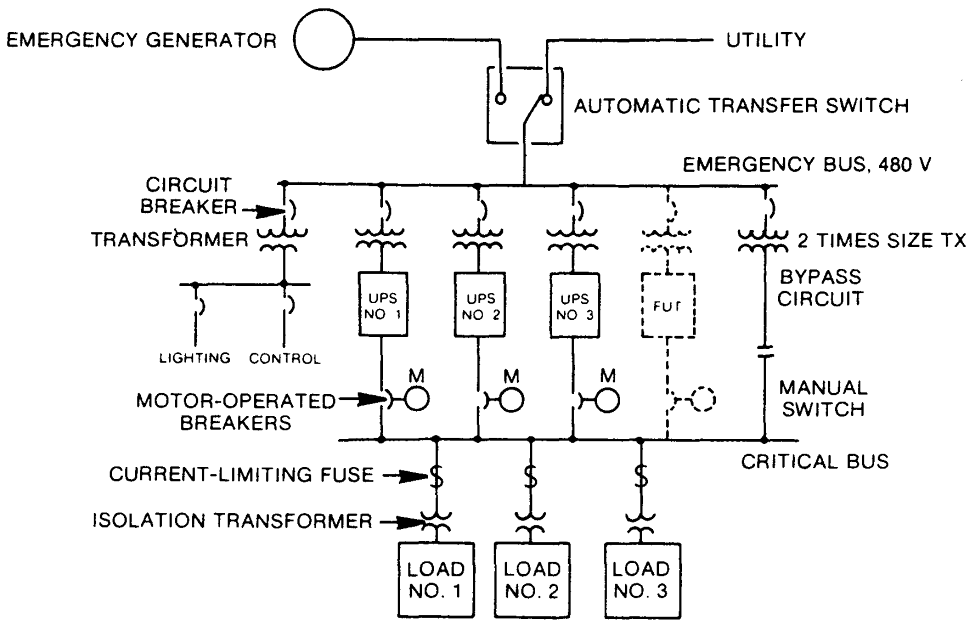


Figure 11-7—Critical Power Supply with Redundancy

2. The limitation on the load that may be switched on or off an uninterruptible power supply and the desirability of using several small inverters in place of one large unit.

3. The uninterruptible power supply voltage response to inrush surges and the necessity of switching temporarily to the "stiffer" plant source that will supply the starting inrush without extreme voltage dips.

4. The effect of input and load spikes.

5. The coordination of downstream circuit protective devices. The uninterruptible power supply current-limiting characteristic limits available fault current and generally requires the use of coordinated fuses designed for semiconductor applications throughout the instrument power supply system.

6. The amount of flywheel effect for the inertia required in rotating motor-generator sets to maintain voltage and frequency during load increases, decreases, or emergency operation load transfers.

7. A load flow and transient stability study of the plant distribution system to determine the magnitude and severity of power sytem disturbances during normal and emergency operating conditions.

8. The coordination of load characteristics and turbine governor and governor valve response on steam turbine-driven generators.

9. Motor starting, synchronizing, and voltage regulation limitations of rotating generation sources.

10. The effect of switching into a dead short with the alternate backup system.

11.7 Distribution System

11.7.1 GENERAL

The design effort and investment necessary to provide suitable power supply sources can be nullified by failure to specify the details of the distribution system and its equipment. All equipment and circuits from the main distribution buses to the individual instrument power supply circuit must be considered in the distribution system design and installation. The distribution system must be compatible with the reliability and quality requirements of the loads served and must maintain the voltage levels that have been provided in the power supply sources. The basic system design should, by means of load division and circuit and equipment redundancy, ensure that any system fault or overload trip affects an acceptable minimum number of instrument loads.

11.7.2 REQUIREMENTS

Requirements for the following components must be specified in the distribution system design:

1. Normal and backup feeders from supply sources to the main instrument power panel.
2. Branch feeders to the main instrument power panels and to the local instrument and control panels.
3. Circuit breaker or fused panelboards.
4. Automatic transfer switches.

11.7.3 CRITERIA FOR SYSTEM DESIGN

The following are some considerations for system design:

1. Provision should be made for normal and alternate feeders to distribution panels as required by reliability requirements.
2. Particular attention should be paid to distribution panels load assignment. The loads of each process unit or major process section should be split so that a distribution panel failure cannot affect all control loops.
3. Main and critical branch panels should have at least two separated or isolated bus sections, or separate panels should be used.
4. Provision should be made for the availability of preventive maintenance.
5. Circuit protection and a disconnect means for each instrument device supply should be provided. If a specific device shorts and is not individually protected, the fault could trip a branch breaker or fuse that may cripple the plant by de-energizing a number of instruments. All overcurrent and short-circuit protective devices must be coordinated so that the device closest to fault trips first to isolate the fault from the rest of the system.

11.8 Wiring Methods

11.8.1 GENERAL

The actual circuit requirements for the individual instrument will be determined by the type of instrument being served and is a part of the instrument system design. API RP 550, Part I, Section 7, "Transmission Systems," discusses wiring requirements as well as grounding and shielding requirements in detail.

11.8.2 POWER WIRING

The part of the power supply and distribution wiring system that brings the power from the supply sources to the instrument and control panel should comply with requirements of the *National Electrical Code* and recommendations of API RP 540, *Recommended Practice for Electrical Installations in Petroleum Processing Plants,* plus any other requirements for separation and isolation which may be needed to maintain the reliability required.

11.8.3 SPECIAL PROCEDURES

Wiring methods which are acceptable for power wiring should be used. Attention must be paid to special requirements, which are a result of the circuit function. For instance, special attention should be paid to routing safety control and shutdown circuits. It is desirable to segregate these circuits from normal circuit routes to prevent a fire, explosion, or other accident from disabling critical circuits. It may be necessary to route underground or fireproof the exposed components of these circuits to preserve circuit integrity during a fire.

11.9 System and Equipment Grounding

11.9.1 INSTRUMENT SIGNAL GROUNDING

Power supply, equipment, and instrument signal grounds should not be interconnected. Generally, instrument signal cable shields are grounded on an isolated bus that is connected to a separate ground. The exception can be thermocouple shields, which in many instances are grounded in the field at the thermocouple head.

11.9.2 INSTRUMENT POWER SUPPLY GROUNDING

Instrumentation power should be supplied from a transformer that is dedicated to instruments only. The transformer serves as an electrical isolating device as well as transforming the voltage to the proper utilization level. If the transformer has a Y-connected secondary, then the neutral should be solidly grounded. On a 120/208-volt three-phase transformer, the 120-volt phase to neutral is used to serve most instrument requirements. The 208-volt phase to phase can be used for larger loads, such as computers or common dc power supplies. The solid ground neutral holds fixed the phase to neutral voltage and provides a return path for a phase to ground fault that allows ground fault sensing devices to quickly isolate the faulted circuit.

11.9.3 EQUIPMENT GROUNDING

When there is unintentional contact between an energized circuit or conductor and a metal structure or housing that encloses it, the structure or housing tends to become energized at the voltage level of the energized circuit or conductor. To prevent shock hazard when this occurs, non-current carrying components such as frames and racks must be solidly grounded to earth by a low impedance path, such as a ground conductor connecting to a ground wall. This will also minimize conducting paths, or ground loops, that may be inductively or capacitively coupled to the instrument signal circuits. Again, the equipment ground must not be interconnected to the instrument signal ground bus. It is acceptable to connect the equipment ground to the power supply ground well. It is recommended that a grounding conductor connect the equipment directly to the ground well to ensure a low impedance ground path.