ASCENTRUST LLC

The POWER of ENGINEERING

POWER PLANT DESIGN MANUAL

FOR

DESIGN AND CONSTRUCTION
OF A NATURAL-GAS FIRED, POWER PLANT

POWER PLANT DESIGN MANUAL

PART ONE: INTRODUCTION

1.1. PURPOSE: This manual provides engineering guidelines and criteria for designing electric power plants where the size and characteristics of the electric power load and the configuration of the node on the grid will provide the stakeholders with the required economics model to warrant investing in the power production facility.

1.2. DESIGN PHILOSOPHY:

A. General: Electric power plants fall into several categories and classes depending on the type of prime mover. This manual will only specifically address those power plants where the primary prime mover is a frame-type gas turbine. The general outline will also apply to **Combined Cycle Gas turbine power plants.**

B. Reliability. Plant reliability standards will be equivalent to a l-day generation forced outage in 10 years with equipment quality and redundancy selected during plant design to conform to this standard.

C. Maintenance. Power plant arrangement will permit reasonable access for operation and maintenance of equipment. Careful attention will be given to the arrangement of equipment, valves, mechanical specialties, and electrical devices so that rotors, tube bundles, inner valves, top works, strainers, contactors, relays, and like items can be maintained or replaced. Adequate platforms, stairs, handrails, and kick-plates will be provided so that operators and maintenance personnel can function conveniently and safely.

D. Future expansion. The specific site selected for the power plant and the physical arrangement of the plant equipment, building, support facilities and access roads will be arranged insofar as practicable to allow for future expansion

1.3. DESIGN CRITERIA:

A. General requirements: The design will provide for a power plant which has the capacity to provide the quantity and type of electric power required. Many of the requirements discussed here have limited applicability, and do not always apply to the power plants with which we will be involved and are to be used solely for the purpose of orientation on the design requirements of the Company.

B. Electric power loads: The following information, as applicable, is required for design:

1. Load analysis at the node which has been selected will have a large influence on the generating capacity to be developed on the site.
2. Forecast of annual diversified peak load to be served by the project.
3. Typical seasonal and daily load curves and load duration curves of the load to be served.

4. If the plant is to operate interconnected with the local utility company, the designer will need information such as capacity, rates, metering, and interface switchgear requirements.
5. If the plant is to operate in parallel with existing generation on the base, the designer will also need:
   (a) An inventory of major existing generation equipment giving principal characteristics such as capacities, voltages, steam characteristics, back pressures, and like parameters.

   (b) Incremental heat rates of existing boiler, turbine units, diesel generators, and combustion turbine generator units.

   (c) Historical operating data for each existing generating unit giving energy generated, fuel consumption, steam exported, and other related information.
6. Existing or recommended distribution voltage, generator voltage, and interconnecting substation voltages.
7. If any of the above data as required for performing the detailed design is unavailable, the designer will develop this data.

C. Export steam loads:

1. **General requirements:** If the plant will export steam, information similar to that required for electric power, as outlined in subparagraph c above, will be needed by the designer.
2. **Coordination of steam and electric power loads**: To the greatest extent possible, peak, seasonal, and daily loads for steam will be coordinated with the electric power loads according to time of use. This type of information is particularly important if the project involves cogeneration with the simultaneous production of electric power and steam.

D. Fuel source, and cost: The type, availability, and cost of fuel will be determined in the early stages of design; taking into account regulatory requirements that may affect fuel and fuel characteristics of the plant.

E. Water supply: Fresh water is required for thermal cycle makeup and for cooling tower or cooling pond makeup where once through water for heat rejection is unavailable or not usable because of regulatory constraints. Quantity of makeup will vary with the type of thermal cycle, amount of condensate return for any export steam, and the maximum heat rejection from the cycle. This heat rejection load usually will comprise the largest part of the makeup and will have the least stringent requirements for quality.

F. Stack emissions: A steam electric power plant equipment which meets federal, state, and municipal emission requirements. For a solid fuel fired boiler, this will involve an electrostatic precipitator or bag house for particulate, and a scrubber for sulfur compounds unless fluidized bed combustion or compliance coal is employed. If design is based on compliance coal, the design will include space and other required provision for the installation of scrubber equipment. Boiler design will be specified as required for **NOx** control.

G. Waste disposal:

1. **Internal combustion plants:** Solid and liquid wastes from a diesel or combustion turbine generating station will be disposed of as follows: Miscellaneous oily wastes from storage tank areas and sumps will be directed to an API separator. Supplementary treating can be utilized if necessary to meet the applicable requirements for waste water discharge.

2. **Steam electric stations:** For steam electric generating stations utilizing solid fuel, both solid and liquid wastes will be handled and disposed of in an environmentally acceptable manner. The wastes can be categorized generally as follows:

   a. **Solid wastes:** These include both bottom ash and fly ash from boilers.

   b. **Liquid wastes:** These include boiler blow-down, cooling tower blow-down, acid and caustic water treating wastes, coal pile runoff, and various contaminated wastes from chemical storage areas, sanitary sewage and yard areas.

H. Other environmental considerations: Other environmental considerations include noise control and aesthetic treatment of the project. The final location of the project within the site area will be reviewed in relation to its proximity to hospital and office areas and the civilian neighborhood, if applicable. Also, the general architectural design will be reviewed in terms of coordination and blending with the style of surrounding buildings. Any anticipated noise or aesthetics problem will be resolved prior to the time that final site selection is approved.

1.4. ECONOMIC CONSIDERATIONS: The selection of one particular type of design for a given application, when two or more types of design are known to be feasible, will be based on the results of an economic study in accordance with the requirements of the primary stakeholders of the project. Standards for economic studies shall be specified before the issuance of the contract for the study. The economic study shall be compiled by an independent third party.

CHAPTER 2: SITE AND CIVIL FACILITIES DESIGN

SECTION ONE: SITE SELECTION

2.1. INTRODUCTION: Since the selection of a plant site has a significant influence on the design, construction and operating costs of a power plant, each potential plant site will be evaluated to determine which is the most economically feasible for the type of power plant being considered.

2.2. ENVIRONMENTAL CONSIDERATIONS:

A. Rules and regulations:. All power plant design, regardless of the type of power plant, must be in accordance with the rules and regulations which have been established by Federal, State and local governmental bodies.

B. Extraordinary design features: To meet various environmental regulations, it is often necessary to utilize design features that will greatly increase the cost of the power plant without increasing its efficiency. For example, the cost of the pollution control equipment that will be required for each site under consideration is one such item which must be carefully evaluated.

2.3. WATER SUPPLY:

A. General requirements: Water supply shall be adequate to meet present and future plant requirements. The supply may be available from a local municipal or privately owned system, or it may be necessary to utilize surface or subsurface sources.

B. Quality: Water quality and type of treatment required will be compatible with the type of power plant to be built.

C. Water rights: If water rights are required, it will be necessary to insure that an agreement for water rights provides sufficient quantity for present and future use.

D. Water wells: If the makeup to the closed system is from water wells, a study to determine water table information and well drawdown will be required. If this information is not available, test well studies must be made.

E. Once-through system. If the plant has a once through cooling system, the following will be determined:

1. The limitations established by the appropriate regulatory bodies which must be met to obtain a permit required to discharge heated water to the source.
2. Maximum allowable temperature rise permissible as compared to system design parameters. If system design temperature rise exceeds permissible rise, a supplemental cooling system (cooling tower or spray pond) must be incorporated into the design.
3. Maximum allowable temperature for river or lake after mixing of cooling system effluent with source. If mixed temperature is higher than allowable temperature, a

supplemental cooling system must be added. It is possible to meet the conditions of (2) above and not meet the conditions in this subparagraph.

4. If extensive or repetitive dredging of waterway will be necessary for plant operations.

5. The historical maximum and minimum water level and flow readings. Check to see that adequate water supply is available at minimum flow and if site will flood at high level.

2.4. FUEL SUPPLY: Site selection will take into consideration fuel storage and the ingress and egress of fuel delivery equipment. For a natural gas, frame-type turbine power plant considerations have to be given to the cost of bringing a pipeline of adequate size to the site to provide fuel for the turbine. Substantial costs can accrue if there is no access to a natural gas pipeline on the site and these costs have to be factored into the economics of the project.

2.5. PHYSICAL CHARACTERISTICS: Selection of the site will be based on the availability of usable land for the plant, including yard structures, fuel handling facilities, and any future expansion. Other considerations that will be taken into account in site selection are:

- Soil information.
- Site drainage.
- Wind data.
- Seismic zone.
- Ingress and egress.

For economic purposes and operational efficiency, the plant site will be located as close to the load center or sub-station, as environmental conditions permit.

2.6. ECONOMICS: Where the choice of several sites exists, the final selection will be based on a combination of economics and engineering analysis.

2.7. SOIL INVESTIGATION: An analysis of existing soils conditions will be made to determine the proper type of foundation. The soils report shall be incorporated into the **Project Manual** and shall be readily available to all **Stakeholders.** Soils data will include elevation of each boring, water table level, description of soil strata including the group symbol based on the Unified Soil Classification System, and penetration data (blow count).

The soils report will include recommendations as to type of foundations for various purposes; excavation, dewatering and fill procedures; and suitability of onsite material for fill and earthen dikes including data on soft and organic materials, rock and other pertinent information as applicable.

2.8. SITE DEVELOPMENT:

A. Grading and drainage.

1. **Basic Criteria:** Determination of final grading and drainage scheme for a new power plant will be based on a number of considerations including size of property in relationship to the size of plant facilities, desirable location on site, and plant access. based on topography. If the power plant is part of an overall complex, the grading and drainage will be compatible and integrated with the rest of the complex.

   To minimize cut and fill, plant facilities will be located on high ground and storm water drainage will be directed away from the plant. Assuming on site soils are suitable, grading should be based on balanced cut and fill volume to avoid hauling of excess fill material to offsite disposal and replacement with expensive new material.

2. **Drainage:** Storm water drainage will be evaluated based on rainfall intensities, runoff characteristics of soil, facilities for receiving storm water discharge, and local regulations. Storm water drains or systems will not be integrated with sanitary drains and other contaminated water drainage systems. Drainage criteria set by the County will be used as the basis for the development of the overall drainage plan.

3. **Erosion prevention:** All graded areas will be stabilized to control erosion by designing shallow slopes to the greatest extent possible and by means of soil stabilization such as seeding, sod, stone, riprap and retaining walls.

B. Roadways:

1. **Basic roadway requirements:** Layout of plant roadways will be based on volume and type of traffic, speed, and traffic patterns. Type of traffic or vehicle functions for power plants can be categorized as follows:

   - Passenger cars for plant personnel.
   - Passenger cars for visitors.
   - Trucks for maintenance material deliveries.
   - Trucks for fuel supply.
   - Trucks for removal of ash, sludge and other waste materials.

2. **Roadway material and width:** Aside from temporary construction roads, the last two categories described above will govern most roadway design. Roadway material and thickness will be based on economic evaluations of feasible alternatives. Vehicular parking for plant personnel and visitors will be located in areas that will not interfere with the safe operation of the plant. Turning radii will be adequate to handle all vehicle categories.

C. **Railroads**. If a railroad spur is selected to handle fuel supplies and material and equipment deliveries during construction or plant expansion, the design will be in accordance with American Railway Engineering Association standards. If coal is the fuel, spur layout will accommodate coal handling facilities including a storage track for empty cars. If liquid fuel is to be handled, unloading pumps and steam connections for tank car heaters may be required in frigid climates.

2.9. BUILDINGS

A. **Size and arrangement:** Main building size and arrangement depend on the selected plant equipment and facilities including whether turbines and steam generators are indoor or outdoor type; coal bunker or silo arrangement; source of cooling water supply relative to the plant; the relationship of the switchyard to the plant; provisions for future expansion. Consideration will be given to aesthetic and environmental concerns.

Generally, the main building will consist of a turbine bay with traveling crane; an auxiliary bay for feed-water heaters, pumps, and switchgear; a steam generator bay (or firing aisle for semi-outdoor units); and general spaces as may be required for machine shop, locker room, laboratory and office facilities. The general spaces will be located in an area that will not interfere with future plant expansion and isolated from main plant facilities to control noise. For very mild climates the turbine generator sets and steam generators may be outdoor type (in a weather protected, walk-in enclosure) although this arrangement presents special maintenance problems. If incorporated, the elevator will have access to the highest operating level of the steam generator (drum levels).

B. **Architectural treatment:** The architectural treatment will be developed to harmonize with the site conditions, both natural and manmade. Depending on location, the environmental compatibility may be the determining factor. In other cases the climate or user preference, tempered with aesthetic and economic factors, will dictate architectural treatment. Climate is a controlling factor in whether or not a total or partial closure is selected. Semi-outdoor construction with the bulk of the turbines and steam generator not enclosed in a boiler room is an acceptable design.

For special circumstances, such as areas where extended periods of very high humidity, frequently combined with desert conditions giving rise to heavy dust and sand blasting action, indoor construction with pressurized ventilation will be required not only for the main building but also, generally, for the switchyard. Gas enclosed switchyard installations may be considered for such circumstances in lieu of that required above.

Control rooms, offices, locker rooms, and some out-buildings will be enclosed regardless of enclosure selected for main building. Circulating water pumps may be installed in the open, except in the most severe climates. For semi-outdoor or outdoor stations, enclosures for switchgear and motor controls for the auxiliary power system will be enclosed in manufacturer supplied walk-in metal housings or site fabricated closures.

C. Structural design.

1. **Building framing and turbine pedestals:** Enclosed power stations will be designed utilizing conventional structural steel for the main power station building and support of boiler. The pedestal for supporting the turbine generator (and turbine driven boiler feed pump if utilized) will be of reinforced concrete. Reinforced concrete on masonry construction may be used for the building framing *(not* for boiler framing); special concrete inserts or other provision must be made in such event for support of piping, trays and conduits. An economic evaluation will be made of these alternatives.

2. **Exterior walls:** The exterior walls of most power stations are constructed of insulated metal panels. However, concrete blocks, bricks, or other material may be used depending on the aesthetics and economics of the design.

3. **Interior walls:** Concrete masonry blocks will be used for interior walls; however, some specialized areas, such as for the control room enclosure and for offices, may utilize factory fabricated metal walls, fixed or moveable according to the application. The living areas of the plant may be constructed of metal stud framing and gypsum sheeting on both sides. Attention should be paid to areas requiring firewalls.

4. **Roof deck:**. Main building roof decks will be constructed of reinforced concrete or ribbed metal deck with built-up multi-ply roofing to provide waterproofing. Roofs will be sloped a minimum of 1/4-inch per foot for drainage.

5. **Floors:** Except where grating or checkered plate is required for access or ventilation, all floors will be designed for reinforced concrete with a non-slip finish.

6. **Live loads:** Buildings, structures and all portions thereof will be designed and constructed to support all live and dead loads without exceeding the allowable stresses of the selected materials in the structural members and connections. Typical live loads for power plant floors are as follows:

   a. Turbine generator floor 500 psf

   b. Basement and operating floors except turbine generator floor 200 psf

   c. Mezzanine, de-aerator, and miscellaneous operating floors 200 psf

   d. Offices, laboratories, instrument shops, and other lightly loaded areas 100 psf Live loads for actual design will be carefully reviewed for any special conditions and actual loads applicable.

7. **Other loads:** In addition to the live and dead loads, the following loadings will be provided for:

   a. Wind loading: Building will be designed to resist the horizontal wind pressure available for the site on all surfaces exposed to the wind. Special care shall be taken in the design of wind loading for coastal areas which have a finite probability of being in a hurricane.

b. **Seismic loading:** Buildings and other structures will be designed to resist seismic loading in accordance with the zone in which the building is located.

c. **Equipment loading:** Equipment loads are furnished by the various manufacturers of each equipment item. In addition to equipment dead loads, impact loads, short circuit forces for generators, and other pertinent special loads prescribed by the equipment function or requirements will be included.

D. Foundation design.

1. Foundations will be designed to safely support all structures, considering type of foundation and allowable bearing pressures. The two most *com*mon types of foundations are spread footings and pile type foundations, although "raft" type of other special approaches may be utilized for unusual circumstances. Foundation design will incorporate the specific design features called for in the **Soils Report.**

2. Pile type foundations require reinforced concrete pile caps and a system of reinforced concrete beams to tie the caps together. Pile load capabilities may be developed either in friction or point mined by an approved formula or by a load test. Piles can be timber, concrete, rolled structural steel shape, steel pipe, or steel pipe concrete filled.

3. Design of the reinforced concrete turbine generator or diesel set foundation, both mat and pedestal, will be such that the foundation is isolated from the main building foundations and structures by expansion joint material placed around its perimeter. The design will also insure that the resonance of the foundation at operating speed is avoided in order to prevent cracking of the foundation and damage to machines caused by resonant vibration.

   The foundation will be designed on the basis of deflection The limits of deflection will be selected to avoid values of natural frequency by at least 30 percent above or 30 percent below operating speed.

4. Vibration mounts or "floating floor" foundations where equipment or equipment foundation inertia blocks are separated from the main building floor by springs or pre-compressed material will generally not be used in power plants except for ventilation fans and other building service equipment. In these circumstances where such inertia blocks are considered necessary for equipment not normally so mounted, written justification will be included in the project design analysis supporting such a necessity.

5. The location of turbine generators, diesel engine sets, boiler feed pumps, draft fans, compressors, and other high speed rotating equipment on elevated floors will be avoided because of the difficulty or impossibility of isolating equipment foundations from the building structure.

2.10. SAFETY:

A. Introduction: The safety features described in the following paragraphs will be incorporated into the power plant design to assist in maintaining a high level of personnel safety.

B. Design safety features. In designing a power plant, the following general recommendations on safety will be given attention:

1. Equipment will be arranged with adequate access space for operation and for maintenance. Wherever possible, auxiliary equipment will be arranged for maintenance handling by the main turbine room crane. Where this is not feasible, monorails, wheeled trucks, or portable A-frames should be provided if disassembly of heavy pieces is required for maintenance.
2. Safety guards will be provided on moving parts of all equipment.
3. All valves, specialties, and devices needing manipulation by operators will be accessible without ladders, and preferably without using chain wheels. This can be achieved by careful piping design, but some access platforms or remote mechanical operators may be necessary.
4. Impact type hand-wheels will be used for high pressure valves and all large valves.
5. Valve centers will be mounted approximately 7 feet above floors and platforms so that rising stems and bottom rims of hand-wheels will not be a hazard.
6. Stairs with conventional riser-tread proportions will be used. Vertical ladders, installed only as a last resort, must have a safety cage if required by . the **Occupational Safety and Health Act** (OSHA).
7. All floors, gratings and checkered plates will have non-slip surfaces.
8. No platform or walkway will be less than 3' feet wide.
9. Toe plates, fitted closely to the edge of all floor openings, platforms and stairways, will be provided in all cases.
10. Adequate piping and equipment drains to waste will be provided.
11. All floors subject to wash-down or leaks will be sloped to floor drains.
12. All areas subject to lube oil or chemical spills will be provided with curbs and drains,
13. If plant is of semi-outdoor or outdoor construction in a climate subject to freezing weather, weather protection will be provided for critical operating and maintenance areas such as the firing aisle, boiler steam drum ends and soot blower locations.
14. Adequate illumination will be provided throughout the plant. Illumination will comply with requirements of the Illuminating Engineers Society (IES) Lighting Handbook.

15. Comfort air conditioning will be provided throughout control rooms, laboratories, offices and similar spaces where operating and maintenance personnel spend considerable time.

16. Mechanical supply and exhaust ventilation will be provided for all of the power plant equipment areas to alleviate operator fatigue and prevent accumulation of fumes and dust. Supply will be ducted to direct air to the lowest level of the power plant and to areas with large heat release such as the turbine or engine room and the boiler feed pump area. Evaporative cooling will be considered in low humidity areas. Ventilation air will be filtered and heated in the winter also, system air flow capacity should be capable of being reduced in the winter. Battery room will have separate exhaust fans to remove hydrogen emitted by batteries.

17. Noise level will be reduced to at least the silencers, compressor silencers, mufflers on internal combustion engines, and acoustical material as required by the County Officials and the Stakeholders to the project. Consideration shall be given to locating forced draft fans in acoustically treated fan rooms since they are usually the largest noise source in a power plant. Control valves will be designed to limit noise emissions.

18. A central vacuum cleaning system should be considered to permit easy maintenance of plant.

19. Color schemes will be psychologically restful except where danger must be highlighted with special bright primary colors.

20. Each equipment item will be clearly labeled in block letters identifying it both by equipment item number and name. A complete, coordinated system of pipe markers will be used for identification of each separate cycle and power plant service system. All switches, controls, and devices on all control panels shall be labeled using the identical names shown on equipment or remote devices being controlled.

CHAPTER THREE: GAS TURBINE GENERATING FACILITIES

3.1. GENERAL: Gas turbines will be the primary source of power used for the generation of electricity. Gas turbines are easy to install and can be used in simple or combined cycle mode of operation. Applications to be evaluated include:

A. Supplying relatively large power requirements in a facility where space is at a significant premium.

B. Peak shaving, in conjunction with other types of generating capacity.

C. Emergency power, where a gas turbine’s light weight and relatively vibration-free operation are of greater importance than fuel consumption over short periods of operation.

D. Combined cycle or cogeneration power plants where turbine exhaust waste heat can be economically used to generate additional power and thermal energy for process or space heating.

3.2. TURBINE-GENERATOR SELECTION:

A. Packaged plants: Gas turbines are normally purchased as complete, packaged power plants. The packaged gas turbine power plant will include the prime mover, combustion system, starting system, generator, auxiliary switchgear and all turbine support equipment required for operation. This equipment is usually “skid” or base mounted. The only “off base” or additional auxiliaries normally required to supplement the package are the fuel oil storage tanks, transfer pumps and oil receiving station, distribution switchgear, step up transformer and switchyard, as required.

1. Selection of unit size requires establishment of plant loading and the number of units required for reliability and turndown. Wide gaps in the standard equipment capacity ratings available may force reconsideration of the number of units or the total plant capacity,

2. Initial selection of the gas turbine unit begins using the International Standards Organization (ISO) rating provided on the manufacturer’s data sheets. This is a power rating at design speed and at sea level with an ambient temperature of 590F (150C). The ISO rating considers inlet and outlet losses to be zero. Initially, ISO ratings will be reduced 15 percent for typical applications, which will further be refined to reflect actual site and installation conditions. The four variables which will be considered in unit rating are:

a. Elevation.

b. Ambient temperature.

c. Inlet losses.

d. Exhaust losses.

The following subsections define the impact of each of these variables.

a. Elevation:. For a specific site, the ISO rating reduction due to site altitude is read directly from an altitude correction curve published by the various manufacturers. There is little difference in such curves. The operating altitude will be used to determine the unit rating.

b. Temperature: Accurate site temperature data will be obtained. The design temperature selected is normally the $2^{1/2}$ percent dry bulb temperature, although the timing of the load curve peak will also be considered. Unless the choice of equipment is tight, there is usually sufficient overload capability to carry the unit during the 2 1/2 percent time of higher temperature.

Another temperature related selection parameter is icing. Icing is caused when the right combination of temperature and humidity levels occurs, and is manifested by ice formation on the downstream side of the inlet filters or at the compressors bell mouth intake. Chunks of ice can be sucked in the compressor with possible blade damage resulting. Icing occurs when ambient temperatures are in the 35^0 to 42^0 F. range and relative humidity is high. This problem will be avoided by re-circulating hot air from the compressor discharge to the filter inlet, either manually or automatically. This causes some loss of turbine efficiency.

c. **Inlet losses:** Inlet losses are a critical performance variable, and one over which the designer has considerable control. Increases in the inlet air friction cause a significant reduction in power output. The total inlet pressure loss will not exceed 2 inches of water and will be as close to zero as space limitations and economics will permit. Additional ductwork costs will be quickly amortized by operating fuel savings.

Dust, rain, sand and snow will be prevented from entering the combustion air inlet of the engine. Inlet air filter design will preclude entrance of these contaminants with minimal pressure loss. The air inlet will be located to preclude ingestion of combustion products from other turbines or a nearby boiler plant, or hot, humid discharge from any cooling towers.

d. **Outlet losses**. Outlet friction losses also result in a decrease of turbine-generator output and will be accounted for in the unit design. The major factor in outlet losses is the requirement to attenuate noise. More effective silencers typically have higher pressure losses. Exhaust back pressure has a smaller overall effect on performance than inlet losses but will be kept as low as possible, and will be less than 6 inches of water. Since increasing exhaust silencer size costs considerably more than ductwork design improvements, the return on investment for a low pressure loss exhaust is significantly longer.

3.3. FUELS: Each manufacturer has his own specification on fuel acceptable for his turbine. The preferred fuel shall be **Natural Gas,** preferably from a pipeline, if not then the gas will be provided in the form of **Liquified Natural Gas.**

The high grade liquid fuels such as Diesel No. 1 or 2 and JP-4 or JP-5 will likely be acceptable to all manufacturers. Use of heavier oils is possible with a specially designed turbine. The heavy oil will have to be cleaned up to reduce corrosive salts of sodium, potassium, vanadium, and sulfur–all of which will elevate the cost of the fuel. Storage and handling at the site will also be more costly, particularly if a heavy oil such as No. 6 was involved because of the heating requirement. No. 4 oil will increase transfer pumping costs a bit but, except in extremely cold regions, would not require heating.

3.4. PLANT ARRANGMENT:

A. **General:** Turbine generator units are frequently sold as complete packages which include all components necessary to operate, ready for connection to the fuel supply and electrical distribution system. This presents the advantages of faster lead time, well matched components and single point of performance responsibility.

B. **Outdoor vs. indoor.**

1. **Outdoor:** Outdoor units can be divided into two sub-types.

   a. The package power plant unit is supplied with the principal components of the unit factory assembled into three or more skid mounted modules, each with its own weatherproof housing the separate modules have wiring splits, piping connections, and housing flanges arranged so that the modules may be quickly assembled into a unit on a reinforced concrete pad in the field. Supplementing these main modules are the inlet and exhaust ducts, inlet silencer and filters, exhaust silencer, fuel tanks, unit fuel skid, and unit auxiliary transformer which are connected by piping and cables to the main assembly after placing on separate foundation as may be required.

   b. The other outdoor sub-type is a similar package unit except that the weatherproof housing is shipped knocked down and is, in effect, a prefabricated building for quick field assembly into a closure for the main power plant components.

   c. Outdoor units to be provided with all components, auxiliaries and controls assembled in all-weather metal enclosures and furnished complete for operation will be specified for Class “B” and “C” power plants having a 5-year anticipated life and requiring not more than four generating units.

3. **Indoor:** An indoor type unit will have the compressor-turbine-generator mounted at grade floor level of the building on a pad, or possibly raised above or lowered below grade floor level to provide space for installation of ducts, piping and cabling. Inlet and exhaust ducts will be routed to the outside through the side wall or the roof; the side wall is usually preferable for this so that the turbine room crane can have full longitudinal travel in the turbine generator bay. Filters and silencers may be inside or outside. All heat rejection equipment will be mounted outside while fuel oil skids may be inside or outside. Unit and distribution switchgear and motor control centers will be indoors.

3.5. WASTE HEAT RECOVERY: Waste heat recovery will be used wherever cost effective. If the turbine unit is to be used only intermittently, the capital cost of heat recovery must be kept down in order to be considered at all. Add-on or side-stream coils might provide a temporary hot water supply for the period of operation—for one example. Care must be exercised due to the high exhaust gas temperature. It may prove feasible to flash steam through the jacket of a small heat exchanger. In the event that a long term operation is indicated, the cost trade off for heat recovery equipment is enhanced, but still must be considered as an auxiliary system. It will take a sizable yearly load to justify an exhaust gas heat recovery boiler. Turbine efficiency loss due to back pressure is also a factor to be considered.

3.6. EQUIPMENT AND AUXILIARY SYSTEMS

A. General: The gas turbine package is a complete power plant requiring only adequate site preparation, foundations, and support facilities including fuel storage and forwarding system, distribution switchgear, step-up transformer, and switchyard.

B. Specifications: Chapter 4 sets forth guidelines for the design of the electrical facilities required for a gas turbine power plant, including the generator, switchgear, switchyard, transformers, relays and controls. Chapter 2 describes the pertinent civil facilities.

C. Scope: The scope of a package gas turbine generator for purchase from the manufacturer will include the following

1. Compressor and turbine with fuel and combustion system, lube oil system, turning gear, governor, and other auxiliaries and accessories.
2. Reduction gear.
3. Generator and excitation system.
4. AC auxiliary power system including switchgear and motor controls.
5. DC power system including battery, charger, and inverter if required.
6. External heat rejection equipment if required.
7. All mechanical and electrical controls.
8. Diesel engine or electric motor starting system.
9. Unit fuel skid (may be purchased separately if desired).
10. Intake and exhaust ducts.
11. Intake air filters.
12. Acoustical treatment for intake and exhaust ducts and for machinery.
13. Weatherproof housing option with appropriate lighting, heating, ventilating, air conditioning and fire protection systems.

CHAPTER FOUR: ELECTRICAL FACILITIES DESIGN

SECTION ONE. TYPICAL VOLTAGE RATINGS AND SYSTEMS

4.1. VOLTAGES

A. General: Refer to ANSI Standard C84. 1 for voltage ratings for 60 Hz electric power systems and equipment. In addition, the standard lists applicable motor and motor control nameplate voltage ranges up to nominal system voltages of 13.8 kV.

B. Generators: Terminal voltage ratings for power plant generators depend on the size of the generators and their application. Generally, the larger the generator, the higher the voltage. Generators for a power plant shall be in the range from 4160 volts to 13.8 kV to suit the size of the unit and primary distribution system voltage. Generators in this size range will be offered by the manufacturer in accordance with its design, and it would be difficult and expensive to get a different voltage rating. Insofar as possible, the generator voltage should match the distribution voltage to avoid the installation of a transformer between the generator and the distribution system.

C. **Power plant station service power systems*.***

1. Voltages for station service power supply within steam electric generating stations are related to motor size and, to a lesser extent, distances of cable runs. Motor sizes for draft fans and boiler feed pumps usually control the selection of the highest station service power voltage level. Rules for selecting motor voltage are not rigid but are based on relative costs. For instance, if there is only one motor larger than 200 hp and it is, say, only 300 hp, it might be a good choice to select this one larger motor for 480 volts so that the entire auxiliary power system can be designed at the lower voltage.

2. Station service power requirements for combustion turbine and internal combustion engine generating plants are such that 208 or 480 volts will be used.

D. Distribution system: The primary distribution system for the installation with central in-house generation should be selected in order to minimize the construction costs of the facility.

4.2. STATION SERVICE POWER SYSTEMS

A. General: Two types of station service power systems are generally in use in electric plants and are discussed herein. They are designated as a common bus system and a unit system. The distinction is based on the relationship between the generating unit and the auxiliary transformer supplying power for its auxiliary equipment.

1. In the common bus system the auxiliary transformer will be connected through a circuit breaker to a bus supplied by a number of units and other sources so that the supply has no relationship to the generating unit whose auxiliary equipment is being served. In the unit system the auxiliary transformer will be connected solidly to the generator leads and is switched with the generator. In either case, the auxiliary equipment for each generating unit usually will be supplied by a separate transformer with appropriate interconnections between the secondary side of the transformers.
2. The unit type system has the disadvantage that its station service power requirements must be supplied by a startup transformer until the generating unit is synchronized with the system. This startup transformer also serves as the backup supply in case of transformer failure. This arrangement requires that the station service power supply be transferred from the startup source to the unit source with the auxiliary equipment in operation as apart of the procedure of starting the unit.
3. The advantages of the unit system are that it reduces the number of breakers required and that its source of energy is the rotating generating unit so that, in case of system trouble, the generating unit and its auxiliaries can easily be isolated from the rest of the system.

B. Common bus system. In this system, generators will be connected to a common bus and the auxiliary transformers for all generating units will be fed from that common bus. This bus may have one or more other power sources to serve for station startup.

1. This type system will be used for diesel generating plants with all station service supplied by two station service transformers with no isolation between auxiliaries for different generating units. It also will be used for steam turbine and gas turbine generating plants. For gas turbine generating plants the auxiliary loads for each unit in the plant will be isolated on a separate bus fed by a separate transformer. A standby transformer is included and it serves the loads common to all units such as building services.
2. The buses supplying the auxiliaries for the several units will be operated isolated to minimize fault current and permit use of lower interrupting rating on the feeder breakers. Provision will be made for the standby transformer to supply any auxiliary bus.

C. Unit type system.

1. The unit type station service power system will be used for a steam electric or combustion turbine generating station serving a utility transmission network. It will not be, as a rule, used for a diesel generating station of any kind since the station service power requirements are minimal.
2. The distinguishing feature of a unit type station power system is that the generator and unit auxiliary transformer are permanently connected together at generator voltage and the station service power requirements for that generating unit,

including boiler and turbine requirements, are normally supplied by the auxiliary transformer connected to the generator leads. If the unit is to be connected to a system voltage that is higher than the generator voltage, the unit concept can be extended to include the step-up transformer by tying its low side solidly to the generator leads and using the high side breaker for synchronizing the generator to the system.

D. Station service switchgear. A station service switchgear lineup will be connected to the low side of the auxiliary transformer; air circuit breakers will be used for control of large auxiliary motors such as boiler feed pumps, fans and circulating water pumps which use the highest station service voltage, and for distribution of power to various unit substations and motor control centers to serve the remaining station service requirements.

If the highest level of auxiliary voltage required is more than 480 volts, say 4.16 kV, the auxiliary switchgear air circuit breakers will only serve motors 250 hp and larger and feeders to unit substations. Each unit substation will include a transformer to reduce voltage from the highest auxiliary power level to 480 volts together with air circuit breakers in a lineup for starting of motors 100 to 200 hp and for' serving 480-volt motor control centers. The motor control centers will include combination starters and feeders breakers to serve motors less than 100 hp and other small auxiliary circuits such as power panels.

E. Startup auxiliary transformer. In addition to the above items, the unit auxiliary type system will incorporate a "common" or "startup" arrangement which will consist of a startup and standby auxiliary transformer connected to the switchyard bus or other reliable source, plus a low voltage switchgear and motor control center arrangement similar to that described above for the unit auxiliary system. The common bus system may have a similar arrangement for the standby transformer.

1. This common system has three principal functions:

a. To provide a source of normal power for power plant equipment and services which are common to all units; e.g., water treating system, coal and ash handling equipment, air compressors, lighting, shops and similar items.

b. To provide backup to each auxiliary power system segment if the transformer supplying that segment fails or is being maintained.

c. In the case of the unit system, to provide startup power to each unit auxiliary power system until the generator is up to speed and voltage and is synchronized with the distribution system.

2. The startup and standby transformer and switchgear will be sized to accomplish the above three functions and, in addition, to allow for possible future additions to the plant. Interconnections will be provided between the common and unit switchgear. Appropriate interlocks will be included so that no more than one auxiliary transformer can feed any switchgear bus at one time.

4.3. GENERATOR TYPES AND STANDARDS

A. Type: Generators for power plant service can be generally grouped according to service and size.

1. Generators for steam turbine service rated 5000-32,000 kVA, are revolving field, non-salient, two-pole, totally enclosed, air cooled with water cooling for air coolers, direct connected, 3600 rpm for 60 Hz frequency (sometimes connected through a gear reducer up to 10,000 kVA or more). Self-ventilation is provided for generators larger than 5000 kVA by some manufacturers, but this is not recommended for steam power plant service.

2. Similar generators rated 5000 kVA and below are revolving field, non-salient or salient pole, self-ventilated, open drip-proof type, sometimes connected through a gear reducer to the turbine which is the result of an economic evaluation by the manufacturer to optimize the best combination of turbine, gear and generator.

3. Generators for gas turbine service are revolving field, non-salient or salient pole, self-ventilated, open drip-proof type, sometimes connected through a gear reducer, depending on manufacturer's gas turbine design speed, to the gas turbine power takeoff shaft. Non-salient pole generators are two-pole, 3600 rpm for 60 Hz, although manufacturers of machines smaller than 1500 kVA may utilize 1800 rpm, four-pole, or 1200 rpm, six-pole, salient pole generators. Generators may be obtained totally enclosed with water cooling if desired because of high ambient temperatures or polluted atmosphere.

4. Generators for diesel service are revolving field, salient pole, air cooled, open type, direct connected, and with amortisseur windings to dampen pulsating engine torque. Number of poles is six or more to match low speeds typical of diesels,

B. Standards: Generators will meet the requirements of ANSI C50. 10, C50. 13 and C50.14 is applicable as well as the requirements of NEMA SM 12 and SM 13.

1. ANSI C84.1 designates standard voltages.

2. Generator kVA rating for steam turbine generating units is standardized as a multiplier of the turbine kW rating. Turbine rating for a condensing steam turbine with controlled extraction for feed-water heating is the kW output at design initial steam conditions, 3.5-inches hg absolute exhaust pressure, three percent cycle makeup, and all feed-water heaters in service. Turbine rating for a non-condensing turbine without controlled or uncontrolled extraction is based on output at design initial steam conditions and design exhaust pressure. Turbine standard ratings for automatic extraction units are based on design initial steam conditions and exhaust pressure with zero extraction while maintaining rated extraction pressure. However, automatic extraction turbine ratings are complicated by the unique steam extraction requirements for each machine specified. For air cooled generators up to 15,625

kVA, the multiplier is 1.25 times the turbine rating, and for 18,750 kVA air cooled and hydrogen cooled generators, 1.20. These ratings are for water cooled generators with 95 “F maximum inlet water to the generator air or hydrogen coolers. Open, self-ventilated generator rating varies with ambient air temperature; standard rating usually is at 104° F ambient.

3. Generator ratings for gas turbine generating units are selected in accordance with ANSI Standards which require the generator rating to be the base capacity which, in turn, must be equal to or greater than the base rating of the turbine over a specified range of inlet temperatures. Non-standard generator ratings can be obtained at an additional price.

4. Power factor ratings of steam turbine driven generators are 0.80 for ratings up to 15,625 kVA and 0.85 for 17,650 kVA air cooled and 25,600 kVA to 32,000 kVA air/water cooled units. Standard power factor ratings for gas turbine driven air cooled generators usually are 0.80 for machines up to 9375 kVA and 0.90 for 12,500 to 32,000 kVA. Changes in air density, however, do not affect the capability of the turbine and generator to the same extent so that kW based on standard conditions and generator kVA ratings show various relationships. Power factors of large hydrogen cooled machines are standardized at 0.90. Power factor for salient pole generators is usually 0.80. Power factor lower than standard, with increased kVA rating, can be obtained at an extra price.

5. Generator short circuit ratio is a rough indication of generator stability; the higher the short circuit ratio, the more stable the generator under transient system load changes or faults. However, fast acting voltage regulation can also assist in achieving generator stability without the heavy expense associated with the high cost of building high short circuit ratios into the generator. Generators have standard short circuit ratios of 0.58 at rated kVA and power factor. If a generator has a fast acting voltage regulator and a high ceiling voltage static excitation system, this standard short circuit ratio should be adequate even under severe system disturbance conditions. Higher short circuit ratios are available at extra cost to provide more stability for unduly fluctuating loads which may be anticipated in the system to be served.

6. Maximum winding temperature, at rated load for standard generators, is predicated on operation at or below a maximum elevation of 3300 feet; this may be upgraded for higher altitudes at an additional price.

4.4. FEATURES AND ACCESSORIES: The following features and accessories are available in accordance with NEMA standards SM 12 and SM 13 and will be specified as applicable for each generator.

A. Voltage variations*.* Unit will operate with voltage variations of plus or minus 5 percent of rated voltage at rated kVA, power factor and frequency, but not necessarily in accordance with the standards of performance established for operation at rated voltage.

B. Thermal variations.

1. Starting from stabilized temperatures and rated conditions, the armature will be capable of operating, with balanced current, at 130 percent of its rated current for 1 minute not more than twice a year; and the field winding will be capable of operating at 125 percent of rated load field voltage for 1 minute not more than twice a year.

2. The generator will be capable of withstanding, without injury, the thermal effects of unbalanced faults at the machine terminals, including the decaying effects of field current and dc component of stator current for times up to 120 seconds, provided the integrated product of generator negative phase sequence current squared and time does not exceed 30. Negative phase sequence current is expressed in per unit of rated stator current, and time in seconds. The thermal effect of unbalanced faults at the machine terminals includes the decaying effects of field current where protection is provided by reducing field current (such as with an exciter field breaker or equivalent) and dc component of the stator current.

C. Mechanical withstand: Generator will be capable of withstanding without mechanical injury any type of short circuit at its terminals for times not exceeding its short time thermal capabilities at rated kVA and power factor with 5 percent over rated voltage, provided that maximum phase current is limited externally to the maximum current obtained from the three-phase fault. Stator windings must withstand a normal high potential test and show no abnormal deformation or damage to the coils and connections.

D. Excitation voltage: Excitation system will be wide range stabilized to permit stable operation down to 25 percent of rated excitation voltage on manual control. Excitation ceiling voltage on manual control will not be less than 120 percent of rated exciter voltage when operating with a load resistance equal to the generator field resistance, and excitation system will be capable of supplying this ceiling voltage for not less than 1 minute. These criteria, as set for manual control, will permit operation when on automatic control. Exciter response ratio as defined in ANSI/IEEE 100 will not be less than 0.50.

E. Wave shape. Deviation factor of the open circuit terminal voltage wave will not exceed 10 percent.

F. Telephone influence factor: The balanced telephone influence factor (TIF) and the residual component TIF will meet the applicable requirements of ANSI C50.13.

4.5. EXITATION SYSTEMS: Rotating commutator exciters as a source of dc power for the ac generator field generally have been replaced by silicon diode power rectifier systems of the static or brushless type.

A. A typical brushless system includes a rotating permanent magnet pilot exciter with the stator connected through the excitation switchgear to the stationary field of an ac exciter with rotating armature and a rotating silicon diode rectifier assembly, which in turn is connected to the rotating field of the generator. This arrangement eliminates both the commutator and the collector rings. Also, part of the system is a solid state automatic voltage regulator, a means of manual voltage regulation, and necessary control devices for mounting on a remote panel. The exciter rotating parts and the diodes are mounted on the generator shaft; viewing during operation must utilize a strobe light.

B. A typical static system includes a three-phase excitation potential transformer, three single- phase current transformers, an excitation cubicle with field breaker and discharge resistor, one automatic and one manual static thyristor type voltage regulators, a full wave static rectifier, necessary devices for mounting on a remote panel, and a collector assembly for connection to the generator field

4.6. GENERATOR LEADS AND SWITCHYARD: The connection of the generating units to the distribution system can take one of the following patterns:

A. With the common bus system, the generators are all connected to the same bus with the distribution feeders. If this bus operates at a voltage of 4.16 kV, this arrangement is suitable up to approximately 10,000 kVA. If the bus operates at a voltage of 13.8 kV, this arrangement is the best for stations up to about 25,000 or 32,000 kVA. For larger stations, the fault duty on the common bus reaches a level that requires more expensive feeder breakers and the bus should be split.

B. The bus and switchgear will be in the form of a factory fabricated metal clad switchgear. For plants with multiple generators and outgoing circuits, the bus will be split for reliability using a bus tie breaker to permit separation of approximately one-half of the generators and lines on each side of the split.

C. A limiting factor of the common type bus system is the interrupting capacity of the switchgear. The switchgear breakers will be capable of interrupting the maximum possible fault current that will flow through them to a fault. In the event of fault current exceeding the interrupting capacity of breakers, a synchronizing bus with current limiting reactors will be required.

Switching arrangement selected will be adequate to handle the maximum calculated short circuit currents which can be developed under any operating routine that can occur. All possible sources of fault current; i.e., generators, motors and outside utility sources, will be considered when calculating short circuit currents. In order to clear a fault, all sources will be disconnected.

The interrupting capacity of the breakers in the switchgear for each set of generators is limited to the contribution to a fault from the generators connected to that bus section plus the contribution from the synchronizing bus and large (load) motors. Since the contribution from generators connected to other bus sections must flow through two reactors in series fault current will be reduced materially.

D. If the plant is 20,000 kVA or larger and the area covered by the distribution system requires distribution feeders in excess of 2 miles, it may be advantageous to connect the generators to a higher voltage bus and feed several distribution substations from that bus with step-down substation transformers at each distribution substation.

E. The configuration of the high voltage bus will be selected for reliability and economy. Alternative bus arrangements include main and transfer bus, ring bus and breaker and a half schemes. The main and transfer arrangement is the lowest cost alternative but is subject to loss of all circuits due to a bus fault. The ring bus arrangement, costs only slightly more than the main and transfer bus arrangement and eliminates the possibility of losing all circuits from a bus fault since each bus section is included in the protected area of its circuit. Normally it will not be used with more than eight bus sections because of the possibility of simultaneous outages resulting in the bus being split.

4.7. GENERATOR LEADS

A. Cable.

1. Connections between the generator and switchgear bus where distribution is at generator voltage, and between generator and step-up transformer where distribution is at 34.5 kV and higher, will be by means of cable or bus duct. In most instances more than one cable per phase will be necessary to handle the current up to a practical maximum of four conductors per phase. Generally, cable installations will be provided for generator capacities up to 25 MVA. For larger units, bus ducts will be evaluated as an alternative.

2. The power cables will be run in a cable tray, separate from the control cable tray; in steel conduit; suspended from ceiling or on wall hangers; or in ducts depending on the installation requirements.

3. Cable terminations will be made by means of potheads where lead covered cable is applied, or by compression lugs where neoprene or similarly jacketed cables are used. Stress cones will be used at 4.16 kV and above.

4. For most applications utilitizing conduit, cross-linked polyethylene with approved type filler or ethylene-propylene cables will be used. For applications where cables will be suspended from hangers or placed in tray, armored cable will be used to provide physical protection. If the cable current rating does not exceed 400 amperes, the three phases will be tri-plexed; i.e., all run in one steel armored enclosure. In the event that single phase cables are required, the armor will be nonmagnetic.

5. In no event should the current carrying capacity of the power cables emanating from the generator be a limiting factor on turbine generator output. As a rule of thumb, the cable current carrying capacity will be at least 1.25 times the current associated with kVA capacity of the generator (not the kW rating of the turbine).

B. Segregated phase bus.

1. For gas turbine generator installations the connections from the generator to the side wall or roof of the gas turbine generator enclosure will have been made by the manufacturer in segregated phase bus configuration. The three phase conductors will be flat copper bus, either in single or multiple conductor per phase pattern. External connection to switchgear or transformer will be by means of segregated phase bus or cable. In the segregated phase bus, the three bare bus-phases will be physically separated by non-magnetic barriers with a single enclosure around the three buses.

2. For applications involving an outdoor gas turbine generator for which a relatively small lineup of outdoor metal clad switchgear is required to handle the distribution system, segregated phase bus will be used. For multiple gas turbine generator installations, the switchgear will be of indoor construction and installed in a control/switchgear building. For these installations, the several generators will be connected to the switchgear via cables.

3. Segregated bus current ratings may follow the rule of thumb set forth above for generator cables but final selection will be based on expected field conditions.

C. Isolated phase bus.

1. For steam turbine generator ratings of 25 MVA and above, the use of isolated phase bus for connection from generator to step-up transformer will be used. At such generator ratings, distribution seldom is made at generator voltage. An isolated phase bus system, utilizing individual phase copper or aluminum, hollow square or round bus on insulators in individual non- magnetic bus enclosures, provides maximum reliability by minimizing the possibility of phase-to- ground or phase-to-phase faults.

2. Isolated phase bus current ratings should follow the rule of thumb set forth above for generator cables.

4.8. SWITCHYARD

A. Outdoor vs. indoor. With normal atmospheric conditions, switchyards will be of the outdoor type. It is possible that a plant will be located on a tropical desert area where alternate sand blasting and corrosion or contamination is a problem or in an arctic area where icing is a problem. In such an event, an indoor switchyard or installation employing totally enclosed metal clad switchgear with SF6 insulation will be provided.

B. Structures and buses.

1. In the event distribution for a large installation is at higher than generator voltage; e.g., 34.5 kV, or in the event an interconnection with a local utility is necessary, a switchyard will be required. The switching structure will be erected to support the bus insulators, disconnecting switches, potential and current transformers, and the terminations for the generator step-up transformer and transmission lines.
2. Structures of galvanized steel or aluminum are most often used. Where the switchyard is located close to an ocean, the salt laden atmosphere may be extremely corrosive to aluminum requiring the use of galvanized steel.
3. Either copper or aluminum, tubular buses will be employed depending upon the atmosphere, with aluminum generally being less expensive. Copper bus connections will be bolted; aluminum connections must be welded. Special procedures are required for aluminum welding, and care should be taken to assure that welders certified for this type of welding are available. For isolated or overseas establishments, only copper buses should be used. A corrosive atmosphere will preclude the use of aluminum.

C. Disconnect switches; insulators

1. Two three-phase disconnect switches will be used for each oil circuit breaker, one on each side of the breaker. If the ring bus arrangement is used, a disconnect switch will also be used in the circuit take-off so the ring can be re-closed with the circuit out for maintenance. If only one bus is used, a disconnect switch will be installed as a by-pass around the circuit breaker so it can be maintained.
2. Line disconnect switches at all voltage ratings will have arcing horns. Above 69 kV, all disconnect switches will have arcing horns.
3. Current carrying capacity of each disconnect switch will be at least 25 percent above that of the line or transformer to which it is connected. The switches are available in 600, 1200 and 2000 ampere ratings.
4. Voltage ratings of switches and bus support insulators will match the system voltage. In particularly polluted atmospheres, the next higher voltage rating than that of the system will be used. In some instances, the manufacturer can furnish current carrying parts designed for the system voltage and will increase phase spacing and insulator stack length to the next higher voltage rating in order to increase the leakage paths in the polluted atmosphere. In such installations, the normal relationship between flashover across the open switch and flashover to ground must be maintained.
5. All disconnect switches will be operable from ground level by means of either a lever or rotating crank mechanism. The crank type mechanism is preferred because it is more positive and takes less strength to operate. Operating mechanisms will be

capable of being locked by padlock in both the open and closed positions. A switch-plate will be provided at each operating mechanism for the operator to stand on when operating the switch. Each plate will be approximately 2 feet, 6 inches wide by 4 feet long, made of galvanized steel, and with two ground lugs permanently attached to the underside of each plate on the side next to the operating mechanism. The switch-plates will be connected to the operating handle and to the switchyard ground grid at two separate points by means of a 2/0 stranded bare copper wire.

D. Oil circuit breakers (OCB):

1. For outdoor service, from nominal 13.8 kV through 69 kV, single tank oil circuit breakers having one operating mechanism attached to the tank will be used. Above 69 kV, three tanks are used, all permanently mounted on a single channel base, with a single operating mechanism attached to one of the end tanks.
2. Operating mechanisms can be spring charged using a motor to charge the spring, pneumatic employing a motor driven compressor in each operating mechanism; or a combination pneumatic and hydraulic mechanism. The 69 kV and below applications utilize the spring charged mechanism because of lower cost while above 69 kV, either of the other two work satisfactorily. Both an ac and a dc auxiliary source must be made available to each breaker operating mechanism.
3. Up to two doughnut type multi-ratio current transformers (600:5, with taps; or 1200:5, with taps) can be obtained on each bushing. These are mounted inside the tanks with all leads brought to terminal blocks in the mechanism cabinets. Since it is a major task to add current transformers, the two will be purchased initially for each bushing.
4. A considerable range of both current carrying and current interrupting capacity is available for each system operating voltage level. Careful study must be made of the continuous load current and fault current requirements before selecting oil circuit breakers. Short circuit calculations must be made for any power system, but for extensive power systems operating in parallel with a utility, a system study will be performed prior to selecting the oil circuit breakers. Power networks analyzers or computer programs will be utilized in such work.

E. Potential and current transformers.

1. For power systems through 69 kV, **potential transformers** (**PT**) are generally used to provide voltages in the 69- and 120-volt ranges for voltmeters, watt-meters, varmeters, watt-hour meters, power factor meters, synchroscopes, various recorders, and for certain protective relays and controls. Above 69 kV, the cost becomes prohibitive and capacitor potential devices are used. The latter do not have as much volt-ampere capacity as potential transformers so care must be taken not

to overload the potential devices by placing too many instruments or devices in the circuit.

2. Both the **potential transformers** (**PT**) and **capacitor potential devices** (**CPD**'s) will be purchased with dual 120 volt secondaries, each tapped at 69 volts for circuit flexibility. All should be for single phase-to-ground application on the high voltage side.

3. Three line-to-ground **PT**t's or **CPD**'s will be employed on each main high voltage bus. Generally, only one pt or cpd is needed on each feeder for synchronizing or hot line indication; but for ties to the outside utility or for special energy metering for billing purposes or other energy accounting, or for relaying, three devices will be necessary.

4. **Current transformers** (**CT**'s) of the through type, where the primary winding is connected in the circuit, will seldom be used. In the usual case, there are sufficient bushing type ct's in the oil circuit breakers and power transformers. Multi-ratio units will be employed, as described under *d* above, for control, indication and protective relaying. Should billing metering be needed, more accurate metering type bushing type ct's will be used.

5. **Current transformer (CT)** ratios do not necessarily have a direct relationship with the continuous current capacity of the circuit breaker or transformer bushing on which they are mounted. The high current portion of the ratio should be selected so that the circuit full load current will beat approximately 70-80 percent of instrument full scale for best accuracy. Ratios for protective relaying will be specially selected to fill the particular relays being applied.

6. Joint use of a particular set of ct's for both instrumentation and protective relaying will be avoided because the two ratio requirements may be different and testing or repair of instrument circuits may require those circuits to be out of service for a time. Power circuits can be operated for extended, periods with a part of the instrumentation and metering out of service; they should not be operated for extended periods without the protective devices.

F. Duct system.

1. Power and control cables will be run in underground conduit in a concrete duct system between the generating station and switchyard; the two types of cable maybe run in the same duct bank but in separate conduits. If in the same duct bank, the manholes will be divided with a concrete barrier between the power and control cable sections. The main power cables will be run in their own duct system and will terminate at the power transformers which are usually placed in a single row.

2. At the point of entrance into the switchyard, the control cable duct system will empty into a concrete cable trench system, either poured in place or assembled from

prefabricated runs. The U-shaped trench will be of sufficient size in width and depth to accommodate control and auxiliary power cables for present transformers, breakers, disconnect switches, power transformers (pt's) and current transformers (ct's), ac and dc auxiliary power cables and lighting circuits, plus provision of at least 25 percent for expansion of the switchyard.

3. Checkered plate or sectionalized prefabricated concrete covers will be placed on the trench, complete with holes or tilt-up recessed handles for assistance in removal of each cover section.
4. Control cables will be run through sleeves from the trench then through galvanized steel conduit buried 18 inches deep to the point of rising to the circuit breaker mechanism housing or other termination. Risers will be attached securely to the terminating device.

G. Ac and dc distribution: One or more 120/208 Vac, 24 or 40 circuit distribution panlboards and one 125 Vdc, 24-circuit distribution panel will be provided in weatherproof enclosures in a central location in the switchyard. Oil circuit breakers require 125 Vdc for closing, tripping and indication. Compressor motors or spring winding motors for the oil circuit breakers will require 120 or 208 volts ac, as will the radiator cooling fans for the power transformers. Strip heaters for the **Oil Circuit Breaker** (ocb) transformer mechanism housings will operate at 208 Vac. Lighting circuits will require 120 Vac. Weatherproof, grounding type convenience outlets at 120 volts and 208 volts will be provided for electrically operated tools and maintenance equipment needed to maintain the switchyard.

H. Grading and fencing:

1. The entire switchyard area will be at the same grade except for enough slope to provide drainage. The concrete pads and foundations for all ocb's and transformers; for all bus, pt and ct supporting structures; and for the switchyard structures will be designed for the same top elevation, and final rough grade will set some 9 inches below top of concrete.
2. Three inches of coarse gravel and 3 inches of fine gravel will be provided on the rough grade which will allow the top of the concrete to be exposed 3 inches above the final crushed rock grade. The rough grade will be sloped at 1 inch per hundred feet to provide drainage, but the final crushed rock course will be dead level. Crushed rock will extend 3 feet outside the fence line.
3. All concrete foundations will have a l-inch, 45-degree chamfer so the edges will not chip.
4. An 8-foot galvanized steel chain link fence with round line and corner posts will enclose the entire substation. The fence will be angle braced in both directions. End

posts for personnel and vehicle gates will be similarly braced. Posts will be mounted in poured concrete footings, having the top cap rounded for drainage.

5. Two 36-inch wide personnel gates will be placed in diagonally opposite locations; one located for convenience for operator and maintenance regular access, and the other to provide an emergency exit. The gate for regular access will be padlock-able. The emergency exit gate will not be padlocked but will be openable only from inside the switchyard by means of removing a drop-in pin; the pin will be so barriered that it cannot be removed from outside the fence. This panic hardware will be designed for instant, easy removal in the event use of the emergency exit is necessary.

6. A double hung, padlockable vehicle gate will be installed; each section will be 8 feet in width to provide adequate room for transformer removal and line truck entrance and egress.

I. Grounding.

1. A grounding grid, buried approximately 2 feet below rough grade level will be installed prior to installation of cable ducts, cable trenches and crushed rock, but simultaneously with the installation of switchyard structure, oil circuit breaker, and transformer footings.

2. The main rectangular grid will be looped around the perimeter of the yard and composed of 500 MCM bare stranded tinned copper cable. From the perimeter, cross- connections from side to side and end to end will be 250 MCM stranded tinned copper cable on 10- to 12-foot spacing. Taps will be made to each vertical bay column of the switchyard structure, to every potential transformer and current transformer and bus support structure, to every oil circuit breaker and transformer, and to every disconnect switch structure with 4/0 stranded tinned copper conductor. Two taps will be run to each circuit breaker and power transformer from different 250 MCM cross-connections.

3. Taps will extend outward from the 500 MCM perimeter cable to a fence rectangular loop with taps at no more than 40-foot centers. This loop will be run parallel to the fence, 2 feet outside the fence line, and the fence loop will be tapped every 20-feet via 2/0 stranded tinned copper taps securely bolted to the fence fabric near the top rail. Flexible tinned copper ground straps will be installed across the hinge point at each swinging gate.

4. At least two 500 MCM bare-stranded, tinned copper cables will be connected via direct burial to the generating station ground grid. Connection will be made to opposite ends of the switchyard 500 MCM loop and to widely separated points at the generating station grid.

5. Ground rods, at least 8 feet long, 3/4-inch diameter, will be driven at each main grid intersection point and at 20-foot centers along the fence loop to a depth of 13 inches above the intersection about 17 inches below rough grade.
6. Every grid intersection and every ground rod connection to both grids will be exothermic welded using appropriate molds.
7. The ground grid system described above will suffice for most sites, except in particularly rocky areas or in the Southwest desert states. Target is to obtain not greater than five ohms ground resistance. In rocky or desert areas, special connections of the switchyard grid to remote grounding pits via drilled holes perhaps 200 feet deep or grids buried in remote stream beds may be necessary.

   The intent of this document is to provide adequate information for the majority of the generating facilities which the Company will be involved with. For (50-1,000 MWe) generating station step-up switchyard which permits connection to a distribution system and interconnection with an outside utility system. The system herein described is a "heavy duty" system.

4.9. GENERATOR STEP-UP TRANSFORMER: The step-up transformer will be in accordance with ANSI Standard C 57.12.10 and will include the following optional features.

A. Rating.

1. The generator step-up transformer kVA rating for frame-turbine-generator "unit type" power plants will depend upon the generator kVA rating which, in turn, is dependent upon the prime mover ratings. In any event, the transformer kVA rating will be selected so that it is not the limiting factor for station output.
2. As a rule of thumb, the top kVA rating will be selected to be approximately 115-120 percent of the KVA rating of the generator. Since the generator unit auxiliary transformer load is tapped off between the generator and step-up transformer and will amount to about 6 percent of the generator rating, the operating margin for the step-up transformer will be on the order of 20-25 percent. This will permit making full use of the margin the turbine generator manufacturer must build in, in order to meet his guarantees.
3. If the load served is expected to be quite constant and the generator will be operating at a high load factor, it should be cost effective to obtain an FOA (forced oil/air cooled) transformer. Pumps and fans are on whenever the transformer is energized. If, on the other hand, a widely varying load is expected, it may be cost effective to obtain a dual rated transformer OA/FA, or even triple rated OA/FA/FA having two increments of fan cooling as well as a self-cooled rating. The top rating would coordinate with the generator rating but fans would shut down when the unit is operating at partial load. The resulting rating of the turbine, generator and stepup

transformer for typical unit might be: Turbine 25,000 kW Generator 31,250 kVA at 0.8 PF Transformer 35,000 kVA at OA/FA/FA rating

4. Voltage of the high side will match the nominal operating voltage desired for the distribution system, such as 34.5 kV; and for the low side will match the generator voltage, such as 13.8 kV. High voltage side will have two 2 1/2 percent full capacity taps above and "below rated voltage.

B. Control.

1. Both the fan and pump systems will operate on 208 volts, 60 Hz, single phase. The control system will provide automatic throw-over from dual 208 volt sources with one being preferred and the other alternate; either may be selected as preferred via a selector switch. Sources will be run from separate auxiliary power sources within the plant.
2. The transformer alarms will be connected to the plant annunciator system and will require 125 Vdc for the alarm system auxiliary relays. Protective devices, which will be mounted in the transformer with control and indication leads run by the transformer manufacturer to the control cabinet, are as follows:
   - **a.** Oil low level gauge with alarm contacts.
   - **b.** Top oil temperature indicator with alarm contacts.
   - **c.** Winding hot spot oil temperature indicator with two or more sets of electrically independent control and alarm contacts, the number depending on whether unit is FOA, O/FA, or OA/FA/FA.
   - **d.** Sudden gas pressure Buchholz type relay with alarm contacts and external reset button.
   - **e.** Pressure relief device with alarm contacts and with operation indicator clearly visible from ground level.
   - **f.** Pressure/vacuum gauge with electrically independent high and low alarm contacts; gauge to be visible from ground level.
   - **g.** Full set of thermally protected molded case circuit breakers and auxiliary control and alarm relays for denoting
     - Loss of preferred fan pump power source.
     - Automatic throw-over of fan and pump sources one or two.
     - Loss of control power.
3. The control compartment will have a dual hinged door readily accessible from finished grade level; bottom of compartment will be about 3 feet above grade. thermostat and heaters will be provided,

C. Miscellaneous: Miscellaneous items that will be included are as follows:

1. Control of the fixed high side winding taps will be accessible to a person standing on the ground. The control device will permit padlocking with the selected tap position clearly visible.
2. Base of transformer will be on I-beams suitable for skidding the transformer in any direction.
3. Two 600-5 or 1200-5 multi-ratio bushing current transformers will be provided on each of the high side and low side bushings with all leads brought to terminal blocks in the control cabinet.
4. One 600-5, or lesser high current rating, bushing current transformer (ct) will be provided on the high side neutral bushing with leads brought to a terminal block in the control compartment.

4.10. AUXILLIARY TRANSFORMERS

A. Rating.

1. As a rule of thumb, the unit auxiliary transformer for a frame type, natural gas, electric station will have a kVA rating on the order of 6 to 10 percent of the generator maximum kVA rating. The percent goes down slightly as generator kVA goes up and coal fired plants have highest auxiliary power requirements while gas fired plants have the least. The actual rating specified for an installation will be determined from the expected station service loads developed by the design. The station startup and standby auxiliary transformer for plants having a unit system will have a kVA rating on the order of 150 percent of a unit auxiliary transformer— say 10 to 12 percent of the maximum generator kVA. The additional capacity is required because the transformer acts as 100 percent spare for the unit auxiliary transformer for each of one or more generators, while also serving a number of common plant loads normally fed from this source. If the auxiliary power system is not on the unit basis; i.e., if two or more auxiliary transformers are fed from the station bus, sizing of the auxiliary transformer will take into account the auxiliary power loads for all units in the station plus all common plant loads. The sizing of auxiliary transformers, in any case, will be subject to an analysis of all loads served under any set of startup, operating, or shutdown conditions with reasonable assumed transformer outages and will include a minimum of 10 percent for future load additions.
2. Auxiliary transformer voltage ratings will be compatible with the switchyard voltage and the auxiliary switchgear voltages. Two 2 1/2 percent taps above and below rated voltage on the high voltage side will be included for each transformer.

B. Control.

1. One step of fan control is commonly provided, resulting in an OA/FA rating. Fan control for auxiliary transformers will be similar to that described for the generator

step-up transformer, except that it is not necessary to provide for dual power sources to the fans. Since the unit auxiliary and the station auxiliary transformers can essentially furnish power for the same services, each transformer serves as a spare for the other. Also, if a fan source fails, the transformer it serves can still be operated continuously at the base self-cooled rating.

2. The protective devices and alarms will be identical to those of the generator step-up transformer.

3. The control compartment will be similar to that of the generator step-up transformer.

C. Miscellaneous: The miscellaneous items will be similar to those for the generator step-up transformer, except that only one set of multi-ratio bushing current transformers need be provided on each of the high and low side bushings.

4.11. UNIT SUBSTATION TRANSFORMER

A. Definition: The phrase “unit substation” is used to denote a unit of equipment comprising a transformer and low-side switchgear designed and factory assembled as a single piece of equipment. It is used herein to denote an intermediate voltage reducing station fed by one or two circuits from the auxiliary switchgear and, in turn, serving a number of large motors or motor control centers. The breakers will have lower ratings than those in the auxiliary switchgear but higher ratings than those in the motor control centers. The transformer in the “unit substation” is referred to as a “unit substation transformer.”

1. The term “unit auxiliary transformer” is used to denote the transformer connected to the generator leads that provides power for the auxiliaries of the unit to which it is connected. It feeds the “auxiliary switchgear” for that unit.

2. The “unit step-up transformer” designates the step-up transformer that is connected permanently to the generator terminals and connects that generator to the distribution system.

B. Rating: For steam electric stations there will be a minimum of two unit substations per turbine installation so that each can be located near an area load center to minimize the lengths of cables serving the various low voltage loads. The kVA rating of the transformer in each unit substation will be sufficient to handle the full kVA of the connected load, including the starting kVA of the largest motor fed from the center, plus approximately 15 percent for future load additions. For diesel engine or gas turbine installations, these unit substations may not be required or one such unit substation may serve more than one generating unit.

C. Control: No fans or pumps are required and thus no control voltage need be brought to the transformer.

D. Alarms: Protective devices will be mounted on the transformer with alarm leads run to an easily accessible terminal board. Devices will include a winding hot spot temperature indicator having two alarm stages for two temperature levels with electrically independent alarm contacts. the unit substation transformer and its physically attached 480-volt switchgear may require the ground indication pt's and their ground indicating lamps to be mounted within and on the transformer ventilated enclosure. In this event, the ground alarm relays will be mounted in a readily accessible portion of the enclosure with leads brought to terminal blocks for external connection to the control room annunicator.

4.12. GENERATOR, STEP-UP TRANSFORMER AND SWITCHYARD RELAYING

A. General:. Selection of relays and coordination of their settings so that the correct circuit breaker trips when it is supposed to, and does not trip when it is not supposed to is a subject too broad to be covered herein. For the purpose of this document the listings below will set forth those protective relay types which will be considered.

B. Generator relaying: Each generator will be provided with the following protective relays:

- Three – Generator differential relays (ANSI Device 87)
- One – Lockout relay, electrical trip, hand reset (ANSI Device 86)
- One – Loss of field relay (ANSI Device 40)
- One – Negative sequence relay (ANSI Device 46)
- One – Reverse power relay (ANSI Device 32)
- One – Generator field ground relay (ANSI Device 64)
- Three – Phase time overcurrent relays, voltage restrained (ANSI Device 51V)
- One – Ground overcurrent relay in the generator neutral (ANSI Device 5 lG)

Although not a part of the ANSI device identification system, generator relay numbers are frequently suffixed with a letter-number sequence.

C. Relay functions.

1. It is usual practice in relay. application to provide two separate relays that will be activated by a fault at any point on the system. In the case of a generating unit with an extended zone of differential protection including generator, feeder, auxiliary transformer, step-up transformer and circuit breaker, it is also common practice to use a dedicated zone of differential protection for the generator as backup protection.
2. The lockout relay (ANSI device 86) is a hand reset device to control equipment when it is desired to have the operator take some positive action before returning the controlled equipment to its normal position.

3. If a unit operating in parallel with other units or a utility system loses its excitation, it will draw excessive reactive kVA from the system, which may cause other difficulties in the system or may cause overloads in the generator. The loss of field relays (ANSI device 40) will sense this situation and initiate a safe shutdown.
4. Negative sequence currents flowing in a generator armature will cause double frequency magnetic flux linkages in the rotor and may cause surface heating of the rotor. The generator is designed to accept a specified amount of this current continually and higher amounts for short periods within a specified integrated time-current square limit. The negative sequence relay (ANSI device 46) is to remove the unit from service if these limits are exceeded..
5. The reverse power relay (ANSI device 32) is used to trip the generator from the system in case it starts drawing power from the system and driving its prime-mover.
6. A ground on the generator field circuits is not serious as long as only one ground exists. However, a second ground could cause destructive vibrations in the unit due to unbalanced magnetic forces. The generator field ground relay (ANSI device 64) is used to detect the first ground so the unit can be shut down or the condition corrected before a second ground occurs.
7. The phase time over-current relays (ANSI device 51) are used for overload protection to protect the generator from faults occurring on the system.
8. The ground over-current relay (ANSI 51G) in the generator neutral is used to confirm that a ground fault exists before other ground relays can operate, thus preventing false trips due to unbalances in transformer circuits.

D. Power transformer relaying. Each step-up transformer will be provided with the following protective relays:

1. Three – Transformer differential relays (ANSI Device 87).
2. One–Transformer neutral time over-current - relay to be used as a ground fault detector relay (ANSI Device 51G)
3. One–Transformer sudden gas pressure relay. This device is specified and furnished as part of the transformer (ANSI Device 63).
4. For application in a “unit system” where the generator, the step-up transformer, and the auxiliary transformer are connected together permanently, an additional differential relay zone is established comprising the three items of equipment and the connections between them. This requires three additional differential relays, one for each phase.

E. Auxiliary transformer relaying: These transformers will each be provided with the following protective relays:

1. Three–Transformer differential relays (ANSI Device 87)
2. One–Lockout relay (ANSI Device 86)

3. One–Transformer neutral time over-current relay to be used as a fault detector relay (ANSI Device 51G)

4. One–Transformer sudden gas pressure relay (ANSI Device 63).

F. Switchyard bus relaying: Each section of the switchyard bus will be provided with bus differential relaying if the size of the installation, say 25,000 kW or more, requires high speed clearing of bus faults.

G. Distribution feeder relaying. Whether feeders emanate from the switchyard bus at, say 34.5kV, or from the generator bus at 13.8 kV, the following relays will be provided for each circuit:

1. Three–Phase time over-current relays with instantaneous element (ANSI Device 50/5 1).

2. One–Residual ground time over-current relay with instantaneous element (ANSI Device 50/51 N).

H. Ties to utility: Relaying of tie lines to the utility company must be coordinated with that utility and the utility will have its own standards which must be met. For short connections, less than 10 miles, pilot wire relaying is often used (ANSI device 87PW). For longer connections, phase directional distance and ground distance relays are often used (ANSI device 21 and 21 G). Various auxiliary relays will also be required. Refer to the utility for these tie line protective relaying requirements.

4.13. SWITCHGEAR AND MCC (Motor Control Center) PROTECTION

A. Medium voltage switchgear (4160 volt system).

1. The incoming line breaker will be provided with: Three-Phase time over-current relays set high enough to provide protection against bus faults on the switchgear bus and not to cause tripping on feeder faults (ANSI Device 50/51).

2. Each transformer feeder will be provided with:

   a. Three-Phase time over-current relays with instantaneous trip attachments (ANSI Device 50/51).

   b. One–Residual ground time over-current relay with instantaneous trip attachment (ANSI Device 50N/51N).

3. Each motor feeder will be provided with:

   a. Three–Phase time over-current relay (ANSI Device 50/51).

   b. One–Replica type over-current relay (ANSI Device 49) (to match motor characteristic heating curves).

4. Each bus tie will be provided with: Three–Phase time over-current relays (ANSI Device 50).

B. Unit substation switchgear protection (480 volt system): Breakers in the 480-volt substations utilize direct acting trip devices. These devices will be provided as follows:

1. Incoming time elements: three–long time and short
2. Motor control center feeders: three–long time and short time elements.
3. Motor feeders: three–long time and instantaneous elements.

C. Motor control center protection (480-volt system): Because of the lower rating, breakers will be molded case type employing thermal/magnetic elements for protection on direct feeders. Combination starters will employ three thermal protective heater type elements in conjunction with the starter.

4.14. INSTRUMENTATION AND METERING: The following instruments will be mounted on the control board in the operating room to provide the operator with information needed for operations:

A. Generator.

1. Ammeter with phase selector switch
2. Voltmeter with phase selector switch
3. Wattmeter
4. Varmeter
5. Power factor meter
6. Frequency meter
7. Temperature meter with selector switch for stator temperature detectors
8. D.C. voltmeter for excitation
9. D.C. ammeter for field current

B. Step-up transformer.

1. Voltmeter on high voltage side with selector switch
2. Ammeter with selector switch
3. Wattmeter
4. Varmeter
5. Power factor meter

C. Auxiliary transformer.

1. Voltmeter on low voltage side with selector
2. Ammeter with selector switch
3. Wattmeter
4. Varmeter
5. Power factor meter

D. Common.

1. Voltmeter with selector switch for each bus
2. Synchroscope

E. Integrating meters: The following integrating meters will be provided but need not be mounted on the control board:

1. Generator output watthour meter
2. Auxiliary transformer watthour meter for each auxiliary transformer.

F. Miscellaneous: For units rated 50,000 kW or larger, a turbine-generator trip recorder will be provided but not necessarily mounted on the control board. This is for use in analyzing equipment failures and shutdowns.

4.15. GENERAL REQUIREMENTS OF STATION SERVICE POWER SYSTEMS

A. Scope: The power plant station service electrical system will consist of the following:

1. For steam turbine plants of about 50MWe or larger, a medium voltage (4.16 kV) distribution system utilizing outdoor oil filled auxiliary power transformers and indoor metal clad draw-out type switchgear assemblies. The 4.16 kV system may be grounded permitting the use of phase and ground protective relays.
2. A low voltage (480-volt and 208/120-volt) distribution system, unit substation assemblies, and also motor control centers containing combination starters and feeder breakers.
3. Station power requirements are smaller for combustion gas turbine units and diesel engine driven generators. For the combustion gas turbine plant, a starting transformer capable of supplying the starting motors is required if the turbine is motor started, but may serve more than one unit. For diesel plants a single 480-volt power supply with appropriate standby provisions is adequate for all units. **Note: The topic of Black start will not be discussed here.**

B. Operating conditions and redundancy: The station service system will be designed to be operational during station startup, normal operation and normal shutdown. Redundancy will be provided to permit operation of the plant at full or reduced output during a component failure of those portions of the system having two or more *similar* equipments.

C. Switchgear and motor control center location*.* Switchgear inside the power plant will be located so as to minimize the requirements for conduit to be embedded in the grade floor slab. In steam electric plants it will generally be convenient to have one or more motor control centers at grade with top entrance of control and power cables. The 4160-volt switchgear and 480-volt unit substation will preferably be located on upper floor levels for maximum convenience in routing power cables; control and power cables can thus enter from either above or below. The 480-volt switchgear in combustion gas turbine or diesel plants will be at ground level.

4.16. AUXILIARY POWER TRANSFORMERS

A. Type: The auxiliary power transformers will be oil filled, outdoor type, having both natural and forced air cooled ratings.

B. Taps. Four full capacity taps for de-energized tap changing will be provided on the high voltage side, in two 2 1/2 percent increments above and below rated voltage.

C. Impedance.

1. Impedance should be selected so that the voltage drop during starting of the largest motor on an otherwise fully loaded bus will not reduce motor terminal voltage below 85 percent of the nominal bus voltage to assure successful motor starting under adverse conditions and so that the symmetrical short circuit current on the low voltage side will not exceed 48 kA using 4160 volt rated switchgear or 41 kA for 4.16 kV system where 2400 volt switchgear is to be used. This permits using breakers having an interrupting rating of 350 MVA for 4160 volts switchgear or 300 MVA for 2400 volt switchgear.

2. Meeting these criteria is possible for units of the size contemplated herein. If the voltage drop when starting the largest motor exceeds the criterion with the fault current limited as indicated, alternative motor designs and reduced voltage starting for the largest motor or alternative drives for that load, will be investigated.

D. Transformer connections.

1. With the unit system, the turbine generator unit auxiliary transformers will be 13.8 kV delta to 4.16 kV wye. If the startup and standby auxiliary transformer is fed from a bus to which the generator is connected through a delta-wye transformation, it must be wye-wye with a delta tertiary. The wye-wye connection is necessary to get the correct phase relationship for the two possible sources to the 4160 volt buses.

Voltage phase relationships must be considered whenever different voltage sources are in parallel. For wye-wye or delta-delta transformer connections, there is no phase shift between the primary and secondary voltages. However, for delta-wye or wye-delta transformer connections, the primary and secondary voltage will be 30 degrees out of phase in either a leading or lagging relationship. With the correct arrangement of transformers it will be possible to establish correct phase angles for paralleling voltages from different sources.

2. Where more than one generator is installed, a single startup and standby auxiliary transformer is sufficient. The low side will be connected through suitable switches to each of the sections of medium voltage switchgear, 4160 volt switchgear

a. Type: The 4160 volt assemblies will be indoor metal clad, drawout type employing breakers having a symmetrical interrupting rating of 48 kA with copper or aluminum buses braced to withstand the corresponding 350 MVA short circuit. Quantity of breakers will be determined to handle incoming transformer, large motors above 200 hp and transformer feeds to the 480 volt unit substations.

b. Cable entrance: Power and control cable entrance from above or below the gear will depend on final locations in the power plant.

c. Relaying: Appropriate protective relaying will be applied to each incoming and outgoing circuit.

4.18. 480 VOLT SUBSTATIONS

A. General arrangement: The unit substation as defined earlier, employ a 4160-480 volt transformer close coupled to a section of 480 volt switchgear. Switchgear portion will utilize drawout breakers and have breakers and buses braced to interrupt and withstand, respectively, a short circuit of 42 kA, symmetrical. Buses may be of aluminum or copper.

B. Loads served: The unit substations will serve as sources for 480-volt auxiliary motor loads between 75 and 200 horsepower, and also serve as supply to the 480-volt motor control centers.

C. Cable entrance: Power and control cable entrance from above or below will depend on final location in the station.

D. Trip devices: Direct acting trip devices will be applied to match the appropriate transformer or motor feeder load and fault characteristics as discussed above.

4.19. 480-VOLT MOTOR CONTROL CENTERS

A. General arrangement: Motor control centers (MCC'S) will utilize plug-in type circuit breakers and combination starters in either a front only or a back-to-back free standing construction, depending on space limitations. Main bus, starters and breakers will be braced to withstand a short circuit of 22 kA, symmetrical. A power panel transformer and feeder breaker, complete with a 120/208 volt power panel and its own main breaker, may be built into the MCC.

B. Current limiting reactors: Dry type three phase reactors, when necessary, will be located in a vertical section of the MCC's to reduce the available short circuit at the 480-volt unit substations to 22 kA at the MCC's. Each system will be investigated to determine the necessity for these current limiting reactors; cable reactance will play an important part in determining the necessity for reactors.

C. Location: The several motor control centers will be strategically located in the power plant to serve most of the plant auxiliary motor loads, lighting transformers, motor operated devices, welding receptacle system and the like. Loads should be grouped in such a manner as to result in relatively short feeder runs from the centers, and also to facilitate alternate power sources to vital services.

D. Cable space: Connection to the MCC's will be via overhead cable tray, and thus the top horizontal section of the MCC will incorporate ample cable training space. Control and power leads will terminate in each compartment. The MCC's can be designed with all external connections brought by the manufacturer to terminal blocks in the top or bottom horizontal compartments, at added expense.

E. Enclosures: *S*tandard MCC enclosures shall be Type 2, drip tight, for all indoor power plant applicants; Type 3, weather resistant, for outdoor service. Other types should only be used when applicable and approved by the turbine manufacturer.

4.20. FOUNDATIONS

A. Transformers: The outdoor auxiliary power transformers will be placed on individual reinforced concrete pads.

B. Medium voltages switchgear: The medium voltage switchgear assemblies will be mounted on flush embedded floor channels furnished by the switchgear manufacturer prior to shipment of the gear.

C. Unit substations and motor control centers. 480-volt unit substation transformers and switchgear, and all MCC's will be mounted on chamfered concrete pads at least 3 inches above finished floor grade. Foundations will be drilled for clinch anchors after the foundation has been poured and set; the anchor placement will be in accordance with the switchgear manufacturer's recommendation.

4.21. GROUNDING: A minimum 1/4-inch by 2-inch copper ground bus will be incorporated within the lower rear of each section of switchgear and MCC. Each ground bus will be connected to the station ground grid with two 4/0 stranded copper cables.

4.22. CONDUIT AND TRAY SYSTEMS

A. Power cables: Power cables will generally be run in galvanized rigid steel conduit to the motor and switchgear terminations, although a ladder type galvanized steel cable tray system having adequate support may be used with conduit run-outs from trays to terminations.

B. Control cables: Control cables will be run in an expanded metal galvanized steel overhead tray system wherever possible. Adequate support will be provided to avoid sagging. Exit from the tray will be via rigid steel conduit.

C. Grounding: Every cable tray length (i.e., each construction section) will be grounded by bolting to a stranded bare copper ground cable which will be run throughout the tray system The tray cable itself will be tapped to the plant ground grid at each building column. Basic tray cable will be 4/0 bare stranded copper with connections to station taps of minimum 2/0 copper.

4.23. DISTRIBUTION OUTSIDE POWER PLANT: Electrical distribution system for the installation outside of the power plant is covered in an auxiliary document and is not attached. Interested parties should contact the Senior Engineer.

4.24. BATTERY AND CHARGER

A. Emergency Power Systems General requirements. The dc system, consisting of a station battery, chargers and dc distribution panels, provides a continuous and reliable source of dc control voltage for system protection during normal operation and for emergency shutdown of the power plant. Battery will be nominal 125 volts, mounted on wooden racks or metal racks with PVC covers on the metal supporting surfaces. Lead calciurn cells having pasted plates or other suitable cells will be considered for use.

B. Duty cycle*.* Required capacity will be calculated on an 8-hour duty cycle basis taking into account all normal and emergency loads. The duty cycle will meet the requirements of the steam generator burner control system, emergency cooling systems, control bench-board, relays and instrument panels, emergency lighting system, and all close/trip functions of the medium voltage and 480-volt circuit breaker systems. In addition, the following emergency functions shall be included in the duty cycle:

1. Simultaneously close all normally open breakers and trip 40 percent of all normally closed breakers during the first minute of the duty cycle; during the last minute, simultaneously trip all main and tie breakers on the medium voltage system.
2. One hour (first hour) running of the turbine generator emergency lube oil pump motor and, for hydrogen cooled units, 3-hour running of the emergency seal oil pump motor.
3. One hour (first hour) running of the backup turning gear motor, if applicable.

C. Battery chargers:

1. Two chargers capable of maintaining the proper float and equalizing voltage on the battery will be provided. Each charger will be capable of restoring the station battery to full charge in 12 hours after emergency service discharge. Also, each unit will be capable of meeting 50 percent of the total dc demand including charging current taken by the discharged battery during normal conditions.

   Note: Equalizing voltage application will subject coils and indicating lamps to voltages above the nominal 125-volt dc system level. These devices, however, will accept 20 percent over-voltage continuously. To assure, however, that the manufacturer of all dc operated devices is aware of the source of dc system voltage, the various equipment specifications will advise that the nominal system voltage will be 125 volts but will have an equalizing charge applied periodically.

2. **Appurtenances:** The following instruments and devices will be supplied for each charger:
   - **a.** Relay to recognize loss of ac supply.
   - **b.** Ac voltage with selector switch.
   - **c.** Dc ground detection system with test device.
   - **d.** Relay to recognize loss of dc output.
   - **e.** Relay to alarm on high dc voltage.
   - **f.** Relay to alarm on low dc voltage.
   - **g.** Dc voltmeter.
   - **h.** Dc ammeter with shunt.

D. Battery room: Only the battery will be located in a ventilated battery room. The chargers may be wall or floor mounted, together with the main dc distribution panel, immediately outside the battery room.

E. DC distribution panel: The distribution panel will utilize molded case circuit breakers or fuses selected to coordinate with dc breakers furnished in control panels and switchgear. The breakers will be equipped with thermal magnetic trip devices, and for 20 kA dc interrupting rating.

4.25. EMERGENCY AC SYSTEM: Those portions of the station service load that must be operable for a safe shutdown of the unit, or that are required for protection of the unit during shutdown, will be fed from a separate 480-volt unit emergency power bus. A suitable emergency diesel engine driven generator will be installed and arranged to start automatically and carry these loads if the normal source of power to this bus is lost. The loads fed from this bus might include such things as emergency lighting, communication system, battery charger, boiler control system, burner control system, control boards, annunciator, recorders and instrumentation. Design of these systems will provide for them to return to operation after a brief power outage.

4-26. MOTOR GENERAL: Motors inside the power plant require drip proof enclosures, while outside the plant totally enclosed fan cooled motors are used. For induced draft and forced draft, and outdoor fan motors in the larger sizes, a weatherproof construction employing labyrinth type enclosures for air circulation will be applied. All motors will be capable of starting at 85 percent nameplate voltage.

4.27. INSULATION

A. **4000-volt motors:** Motors at this voltage will be three phase, 60 Hz, have Class B insulation for 80^{O} C. rise above 40^{O} C. ambient, and with 1.0 service factor.

B. **460-volt motors:** These motors will be three phase, 60 Hz, have Class B insulation for 80^{O} C. rise, or Class F for 95^{O} C. rise, above 40^{O} C. ambient, and with 1.0 service factor.

C. **115-volt motors:** These motors will be one phase, 60 Hz, with Class B insulation for 80^{O} C. rise above 40^{O} C. ambient, and with 1.25 service factor.

4.28. HORSEPOWER: It is seldom necessary to specify motor horsepower if the motor is purchased with the driven equipment. In almost every instance, the load required by the pump, fan, or other driven equipment sets the motor horsepower and characteristics-thus the specification *is* written to require manufacturer of the driven machine to furnish a motor of proper horsepower and characteristics to perform the intended function.

4.29. GROUNDING: Every motor will be connected to the station ground grid via a bolted connection to a stranded copper tap. Single phase motors may be grounded with #6 AWG bare wire; to 75 horsepower, three phase with #2 AWG bare stranded copper cable; and to 200 hp, three phase, with 2/0 bare stranded copper wire. Above 200 horsepower, three phase, 4/0 bare stranded copper wire will be used for the ground connection.

4.30. CONDUIT: Motor power cables will be run in rigid steel galvanized conduit to a point approximately 18 inches from the motor termination or pull box. The last 18 inches, approximately, will be flexible conduit with PVC weatherproof jacket. Firm support will be given the rigid conduit at the point of transition to the flexible conduit.

4.31. CABLE: In selecting motor cable for small motors on a high capacity station service power system, the cable size is seldom set by the motor full load current. Manufacturer's curves showing copper temperature melting values for high short circuit currents for a specific time duration must be consulted; the cable may need to be appreciably larger than required by motor full load current.

4.32. MOTOR DETAILS: It is important to specify enclosure type, special high temperature or other ambient conditions and similar data which is unique to the particular application. Also the type of motor, whether squirrel cage, wound rotor or synchronous, and power supply characteristics including voltage, frequency, and phases must be specified.

4.33. INTRA-PLANT COMMUNICATIONS

A. General requirements: Installation of a high quality voice communication system in the power plant and in the immediate vicinity of the plant is vital to successful and efficient startup, operation and maintenance. The communications system selected will be designed for operation in a noisy environment.

B. Functional description: A description of the features of an intra-plant communication system is given below.

1. A page-talk party line system will be required.
2. If a conversation is in process on the party line when a page is initiated, the paging party will instruct the party paged to respond on the “page” system. This second conversation will be carried on over the page system—that is, both parties will be heard on all speakers, except that the speakers nearest the four or more handsets in use will be muted.
3. If a party wishes to break into a private conversation, all he will do is lift his handset and break into the private conversation already taking place. Any number of parties will be able to participate in the “private conversation” because the private system is a party line system.
4. Additional handsets and speakers can be added to the basic system as the power plant or outdoor areas are expanded.

C. Handsets.

1. Except for handsets at desks in offices or operating rooms, the indoor handsets in the power plant will be hook switch mounted in a metal enclosure having a hinged door. They will be mounted on building columns approximately 5 feet above the floor. In particularly noisy areas, e.g., in the boiler feed pump and draft fan areas, the handsets will be of the noise canceling types.
2. Desk type handsets will be furnished either for table top use or in “wall-mounting” hook switch type for mounting on the side of a desk. The hook switch wall mounting will also be used at various control boards for ease of use by the plant control room operators.
3. Outdoor handsets will be hook switch area configuration but a handset will be readily mounted in a weatherproof enclosure having a available to any operator performing an operating hinged door. They will be mounted on the switch- function. yard structure or other structure five feet above final grade.

D. Speakers.

1. Speakers for general indoor use will be of relatively small trumpet type and will be weather-proof for durability. They will be mounted on building columns about 10 feet above floor level.

2. Speakers for outdoor use will be large trumpet type, weatherproof. They will be mounted on the switchyard structure or other structure about 15 feet above final finished grade.
3. In the control room, two flush mounted speakers will be installed in the ceiling. A wall mounted speaker in wooden enclosure will be provided for the plant superintendent's office, training room or other similar location.

E. Power supply.

1. Power supply will be 120 Vac, 60 Hz, single phase as supplied from the emergency power supply. The single phase conductors will be run in their own conduit system. It is vital to have the plant communication system operable under all normal and emergency conditions.
2. The manufacturer will be consulted regarding type of power supply cable, as well as type, shielding, and routing of the communication pair conductors.

F. Device locations, general: Proper selection and planning for location of components is necessary to ensure adequate coverage. Alignment of speakers is important so as to avoid interference and feedback. It is not necessary to have a speaker and a handset mounted near to one another. Speakers will be positioned to provide "page" coverage; handsets will be placed for convenience of access. For example, a speaker may be mounted outdoors to cover a tank area, while the nearest handset may be conveniently located immediately inside the plant or auxiliary building adjacent to the door giving access to the tanks.

4.34. Telephone communications At least one normal telephone desk set will be provided in the central control room for contact by the operators with the outside world and for contact with the utility company in the event of parallel operation. For those instances when the power plant is connected into a power pool grid, a direct telephone connection between the control room and the pool or connected utility dispatcher will also be provided

CHAPTER 5: GENERAL POWER PLANT FACILITIES DESIGN

SECTION ONE: INSTRUMENTATION AND CONTROL SYSTEMS

5.1. GENERAL: Input adjustments will be designed to be delegated to automatic control systems except during startup, shutdown, and abnormal operating conditions when the operator displaces or overrides automatic control functions.

5.2. CONTROL PANELS

A. Types and selection.

1. **General types:** Control panels used in power plants may be free standing or mounted on a wall or column, as appropriate.
2. **Central control panel selection:** Control panels for use in central control rooms will be enclosed and of the dual switchboard, duplex switchboard, dual bench-board, control bench-board, or control desk type depending upon the size of the plant and complexity of the instruments and controls to be mounted. When control panels have complex wiring (piping and devices mounted in the interior) the vertical panel section will be provided with rear or walk-in access for ease in erection and maintenance. Frequently the floor of the walk-in space is dropped .2 or 3 feet below the raised control room floor to simplify cable and tubing entrance to the panel interior and to increase space for terminals. A dropped floor will be provided for proper access to any bench-board section of a panel. The shape of the panel will be selected using the following criteria:

   a. Space availability in the control room.
   b. Number of controls and instruments to be mounted.
   c. Visibility of the controls and instruments by the plant operators.
   d. Grouping and interrelationship of the controls and instruments for ease of operation and avoidance of operating error.

B. Location of panels.

1. **Control room:** The various panels located in the central control room will be arranged to minimize operator wasted motion. In a unitized power plant (one without a header system), provide a boiler-turbine mechanical panel (or section) for each unit with separate common panel(s) to accommodate compressed air, circulating water, service water and like system which may pertain to more than one unit. If the plant has a header system which is not conducive to boiler-turbine panels, group controls and instruments into a boiler panel for all boilers and a turbine generator panel for all turbines whenever practicable. Usually, a separate electrical panel with mimic bus for the generators and switchgear and switchyard, if applicable, will be provided regardless of whether the mechanical instruments are grouped on a unit basis or a header basis.

2. **Local panels:** These will be mounted as close to the equipment (or process) they are controlling as is practical.

C. Instrument selection and arrangement on panels. Selection and arrangement of the various controls, instruments and devices on the panels will be generally in accordance with the following guidelines:

1. **Items:** Mechanical items will be grouped by basic function (i.e., turbine, boiler, condensate, feed-water, circulating water, service water and like systems), Burner management controls will be obtained as an “insert” or sub-panel which can be incorporated into the boiler grouping of controls and instruments. Such an insert may include remote light-off and startup of burners if desired. Electrical items will be grouped by generator, voltage regulator, switchgear and like equipment items in a manner which is easily incorporated into a mimic bus.

2. **Readability:** Instruments which require operator observation will be located not higher than 6 1/2 feet nor lower than 3 feet above the floor for easy readability.

3. **Controls, switches and devices:** Those controls, switches and other devices which require manipulation by the operators will be easily accessible and will be located on a bench or desk wherever practicable.

4. **Indicators versus recorders:** Indicators will be provided where an instantaneous reading of cycle thermodynamic or physical parameters suffices as a check of proper system operation. When a permanent record of plant parameters is desired for economic or engineering accountability purposes, recorders will be provided.

D. Ventilation: All panels which house heat producing instruments will be ventilated or air conditioned to prevent overheating of the instruments. For panel-in the central control room, this will be accomplished by having a filtered air intake and mechanical exhaust arrangement to circulate cool air from the air conditioned control room through each enclosed panel wherever practicable. Local panels, as a rule, have only gages and other devices which emit little heat and do not require special ventilation.

E. Illumination: In a central control room, the best illumination is a “light ceiling” with diffuser type suspended panels to give a shadowless, even level of lighting throughout the control room. Levels of illumination at bench tops of 75-foot candles, plus or minus 10-foot candles, will be provided. However, caution must be used when designing lighting for control rooms utilizing electronic digital controls with light emitting diode (LED) display as excessive illumination tends to wash out displays. In areas with electronic digital controls with LED displays, the level of general illumination will be maintained at 15- to 25-foot candles. Local panel illumination will be accomplished by means of a canopy built into the top of the panel. Local switch control will be provided at each canopy light.

5.3. AUTOMATIC CONTROL SYSTEMS

A. Types: Control systems and instruments may be pneumatic, ac or dc electronic, electronic digital, combination pneumatic and electronic, or hydraulic, Mechanical-hydraulic and electro-hydraulic systems will be utilized in connection with turbine generator speed governing control systems. Pneumatic controls will be used for power plant units of 30 MW or less. Applications include: combustion control, feed-water regulation, de-superheating and pressure reducing station control, heater drain control, and boiler feed recirculation control. Pneumatic systems are economical, reliable, and provide smooth, modulating type of operation. For plants where the arrangement is dispersed and precision is required, electronic controls and instruments will be provided in lieu of the pneumatic type because of the sluggishness of pneumatic response where long distances are involved. Electronic digital controls have recently become economically competitive with analog pneumatic and electronic controls and offer the advantage of' 'soft-wired" control logic and programmable versatility. With electronic controls it is required to use pneumatically operated valves with transducers to convert the electronic signals to pneumatic at the pneumatic valve operator.

B. Combustion controls: Combustion controls for steam generators will be based on the conventional indirect method of maintaining steam pressure. Systems will be of the fully metering type, designed to hold steam pressure within plus or minus 1 percent of the controller setting with load changes of 5 percent per minute; under the same rate of load change, excess air will be maintained at plus or minus 2 percent of the control setting.

D. feed-water regulator system will be provided for steam power plant service. Such a system balances feed-water input to steam output subject to correction for drum level deviations caused by operating pressure variations (drum swell).

E. Attemperator control system: Each power plant steam generator will have superheat (attemperator) controls to maintain superheat within the limits required for protection of the turbine metal parts against thermal stress and for preventing excessive reduction in part load turbine efficiency. Injection of desuperheating water (which must be high purity water, such as condensate) will be done between stages of the boiler superheater to reduce chances of water carryover to the turbine. An attemperator system having a controller with a fast response, derivative feature will be provided. This type of controller anticipates the magnitude of system deviations from the control set point in accordance with the rate of change of superheat temperature. Automatic positive shutoff valve(s) will be provided in the desuperheating water supply line upstream of the desuperheater control valve to prevent dribbling of water to the desuperheater when the controls are not calling for spray water.

F. Closed heater drain controls: Although it is thermodynamically preferable to pump the drains from each feed-water heater forward into the condensate or feed-water stream exiting from the heater, the expense and general unreliability of the low NPSH pumps required for this type of drain service will normally preclude such a design. Accordingly, the drains from each heater will normally be cascaded to the next lower pressure heater through a level control valve. The valve will be located as closely as possible to the lower pressure heater due to the flashing which occurs because of the pressure reduction at the outlet of the level control valve. Each heater will be provided with two level control valves. The secondary valve only functions on startup, on malfunction of the normal valve, or sometimes during light loads when pressure differential between heaters being cascaded becomes very small. The secondary valve frequently discharges directly to the condenser. Such a complexity of controls for heater drains is necessary to assist in preventing problems and turbine damage caused by turbine water induction. Water induction occurs when feed-water header tubes or level control valves fail, causing water to backup into the turbine through the extraction steam piping.

G. **Boiler feed recirculation controls:** An automatic recirculation system will be installed for each pump to bypass a minimum amount of feed-water back to the de-aerator at low loads for protection against boiler feed pump overheating. A flow signal from the suction of each pump will be used to sense the preset minimum safe pump flow. This low flow signal will open an automatic recirculation valve located in the piping run from the pump discharge to the de-aerator. This recirculation line poses minimum flow through a breakdown orifice for pressure reduction to the de-aerator. The breakdown orifice will be located as closely as possible to the de-aerator because flashing occurs downstream. When pump suction flow increases to a pre-selected amount in excess of pump minimum flow, the recirculation valve closes. The operator will be able to open the recirculation valve manually with a selector switch on the control panel. Designs will be such as to preclude accidental closing of the valve manually. Such an operator error could cause flow to drop below the safe level quickly, destroying high pressure pumps.

H. **Other control systems:** De-superheating, pressure reducing, fuel oil heating, and other miscellaneous power plant control systems will be provided as appropriate. Direct acting valves will not be used. Control valves will be equipped with a matching valve operator for positive opening and closing action.

5.4. MONITORING INSTRUMENTS

A. Types.

1. Control system components will include sensing devices for primary fluids plus transmitters, transducers, relays, controllers, manual-automatic stations, and various special devices. Instruments generally fall into two classifications—direct reading and remote reading.

2. Direct reading instruments (e.g., thermometers, pressure gages, and manometers) will be mounted on local panels, or directly on the process piping or equipment if at an accessible location. Locally mounted thermometers will be of the conventional mercury type. Type selected will depend on accuracy required. Pressure gages for steam or water service will be of the Bourdon tube type.

3. Remote reading instruments (recorders, integrators, indicators and electrical meters) will be mounted on panels in the central control room. These instruments will have pneumatic or electronic transmission circuits. Sometimes the same transmitters utilized for control system service can be utilized for the pertinent remote reading instrument, although for vital services, such as drum level, an independent level transmitter will be used for the remote level indicator.
4. Panel mounted receiver gages for pressure, temperature, level and draft will be of the miniature, vertical indicating type which can be arranged in convenient lineups line-ups on the panel and are easy to read.
5. Recorders will be of the miniature type, except for multi-point electronic dot printing recorders which will be full size.

B. Selection: The monitoring instruments for any control system will be selected to provide the necessary information required for the control room operator to be informed at all times on how the controlled system is functioning, on vital process trends, and on other essential information so that corrective action can be taken as required.

5.5. ALARM AND ANNUNCIATOR SYSTEMS

A. Purpose: The annunciator system supplements the operator's physical senses and notifies him both audibly and visually when trouble occurs so that proper steps can be taken to correct the problem.

B. General: The alarm system will be both audible and visual. The sounding of the alarm will alert the operators that a problem exists and the visual light in the pertinent annunciator window will identify the problem. Annunciator systems shall provide for the visual display to be distinguishable between new alarms and previous alarms already acknowledged by the operator pushing a button provided for this purpose. New alarms will be signified by a flashing light, whereas acknowledged alarms will be signified by a steady light. Alarm windows will be arranged and grouped on vertical, upper panel sections with corresponding control stations and operating switches within easy reach of the operator at all times. Critical or potentially dangerous alarms will be a different color from standard alarms for rapid operator identification and response.

SECTION TWO: HEATING; VENTILATING AND AIR CONDITIONING SYSTEMS

5.6. INTRODUCTION: This section sets forth general criteria for design of space air conditioning systems for a power plant.

5.7. OPERATIONS AREAS

A. Enclosed general operating areas.

1. **Ventilation supply:** Provide mechanical ventilation for fresh air supply to, as well as exhaust from, the main operating areas, A filtered outside air supply, with heating coils and recirculation option for winter use, will be provided. Supply fans will be selected so that indoor temperature does not rise more than 15^{O}F. above the ambient outdoor air design temperature, and to maintain a slight positive inside pressure with all exhaust fans operating at maximum speed. Ventilation system design will take into account any indoor air intakes for boiler forced draft fans, which can be designed to draw warm air from near the roof of the plant. Supply air will be directed through a duct system to the lowest levels of the plant with particular emphasis on furnishing large air quantities to “hot spots.” The turbine room will receive a substantial quantity of fresh air, supplemented by air from lower levels rising through operating floor gratings.

2. **Ventilation exhaust:** Exhaust fans with at least two speeds are switched so that individual fan and fan speed can be selected according to air quantity desired will be provided. Battery rooms will have separate exhaust systems. It may be economical to remove heat from hot spots with local ducted exhaust systems to prevent heat from being carried into other areas. All exhaust and supply openings will be provided with power operated dampers, bird screens, and means for preventing entrance of rain, sleet and snow.

3. **Heating:** As much heating as practicable will be supplied via the central ventilation supply system, which will be designed so that maximum design air flow can be reduced to a minimum required for winter operation. Heat supplied by the ventilation system will be supplemented as required by unit heaters and radiation. Heating system design for ventilation and other space heating equipment will be selected to maintain a minimum plant indoor temperature of 55^{O}F. and an office, control room and laboratory area temperature of 68OF.

B. Control room.

1. The central control room is the operating center of a power plant and will be air conditioned (i.e., temperature control, humidity control and air filtration) for the purpose of human comfort and to protect equipment such as relays, meters and computers. Unattended control rooms may not require comfort conditions but have temperature limits as required by the equipment housed in the room. Control system component manufacturers will be consulted to determine the operating environment required for equipment reliability.

2. Intermediate season cooling using 100 percent outside air for an economizer cycle or enthalpy control will be life cycle cost analyzed.

5.8. SERVICE AREAS

A. Toilets, locker rooms and lunch rooms.

1. Toilets will be exhausted to maintain a negative pressure relative to adjacent areas. All exhaust outlets from a toilet will be a minimum of 15 feet from any supply inlet to prevent short circuiting of air. Toilet exhaust will be combined with a locker room exhaust but not with any other exhaust.

2. Locker rooms will be exhausted according to the applicable codes and supplied by a heated air supply.

3. Lunch rooms will be furnished with recirculation heating systems to meet applicable codes; exhaust will be installed. System will be independent of other systems to prevent recirculation of food odors to other spaces.

4. **Shops and maintenance rooms:** All shops and maintenance rooms will be ventilated according to applicable codes. Welding and painting areas will be exhausted. Heating will be provided by means of unit heaters sized to maintain a maximum of 68 "F. on the coldest winter design day.

B. Offices and laboratories. All offices and laboratories will be air conditioned for human comfort in accordance with TM 5-810-l/AFM 88-8/1. Exhaust will be provided where required for laboratory hoods or other special purposes.

SECTION THREE: POWER AND SERVICE PIPING SYSTEMS

5.9. INTRODUCTION

A. General: Power plant piping systems, designed to transfer a variety of fluids (steam, water, compressed air, fuel oil, lube oil, natural gas) at pressures ranging from full vacuum to thousands of psi, will be engineered for structural integrity and economy of fluid system construction and operation.

B. Design considerations: Piping systems will be designed to conform to the ASME Boiler Pressure Vessel Code Section I governs the design of boiler piping, usually up to the second isolation valve. ANSI B31.1, Code for Pressure Power Piping governs the pressure boundary requirements of most other plant piping (excluding plumbing and drainage piping). Each of these codes provides a detailed description of its scope and limitations.

5.10. PIPING DESIGN FUNDAMENTALS: Design of piping system will conform to the following procedure:

A. Select pipe sizes, materials and wall thickness (pipe schedule). Design for the maximum pressure and temperature the piping will experience during either operation or upset conditions. Follow appropriate sections of ASME Section I and ANSI B31.1. Other requirements for welding qualification and pressure vessel design are set forth in ASME Sections VIII and IX. Specify hydrostatic pressure testing requirements in accordance with the codes. Select flow velocities for overall economy.

B. Select piping components and end connections for equipment.

C. Route piping. Make runs as simple and direct as possible. Allow for maintenance space and access to equipment. Do not allow piping to encroach on aisles and walkways. Inspect for interferences with structures, ductwork, equipment and electric services.

D. Include provisions for drainage and venting of all pipe lines.

E. Design pipe supports, restraints and anchors, using accepted procedures for thermal expansion stress analysis. The stress analysis will consider simultaneous application of seismic loads, where applicable. Computer analysis will be used for major three plane piping systems with multiple anchors.

5.11. SPECIFIC SYSTEM DESIGN CONSIDERATIONS

A. Steam piping: In all steam systems, provisions will be made for draining of condensate before startup, during operation and after shutdown. Steam traps will be connected to low points of the pipelines. Small bore bypass piping will be provided around block valves on large, high pressure lines to permit warming before startup.

B. Circulating water piping. Reinforced plastic piping will be used for salt or brackish water service whenever practicable.

C. Fuel oil piping. Fuel oil piping will be designed with relief valves between all block valves to protect against pipe rupture due to thermal expansion of the oil. Fuel oil piping will be designed in accordance with National Fire Protection Association (NFPA) standards and ANSI B31. Piping subject to vibration (such as engine service) will be socket or butt welded, although flared tubing may be used for small lines under 1/2 inch.

D. Insulation. Insulate all lines containing fluids above 120^{O}F. so that insulation surface temperatures remain below 120^{O}F. at 80^{O}F. still air ambient. Provide anti-sweat insulation for all lines which operate below ambient temperatures. Protect all insulation against weather (or wash down water if indoors) and mechanical abuse.

SECTION FOUR: THERMAL INSULATION AND FREEZE PROTECTION

5.12. INTRODUCTION: Thermal insulations are used for the following purposes:

- **A.** Limit useful heat losses.
- **B.** Personnel burn protection.
- **C.** Limit heat gains where cold is desired.
- **D.** Prevent icing and condensation.
- **E.** Freeze protection.

5.13. INSULATION DESIGN: The principal elements of insulation system design and specification areas follows:

- **A. Selection of surfaces:** Define and list the various surfaces, piping, vessels, ductwork, and machinery for which insulation is needed including lengths, areas and temperatures.
- **B. Insulation systems:** For each class or type of surface select an appropriate insulation system: bulk insulation material and miscellaneous materials, coverings, and like items.
- **C. Economical thickness:** Based on the above data, select the economical or necessary thickness of insulation for each class or type of surface.

5.14. INSULATION MATERIALS

- **A. Bulk material.** Contact the Senior Engineer for nomenclature and characteristics of thermal insulations.
- **B. Restrictions on asbestos***.* Asbestos insulation, or insulations containing loose, fibrous, or free asbestos are not to be used.
- **C. Maximum temperatures***.* Each type of insulation is suitable for use at a specified maximum temperature. Design will be such that those maximums will not be approached closely in ordinary applications. All high temperature insulations are more expensive and more fragile than lower temperature products and, in general, the least expensive material which is suitable for the temperature exposure will be selected. Where substantial total insulation thicknesses of 6 inches or more are required, economics may be realized by using two layers of different materials using high temperature material close to the hot surface with cheaper low temperature material on the cold side.
- **D. Prefabricated insulation***.* A major part of total insulation cost is field labor for cutting, fitting and installation. For large areas or long piping runs, substantial savings may be realized by factory forming, cutting or covering. Valves and pipe fittings, especially large ones, may be economically insulated with factory made prefabricated shapes.

Equipment requiring periodic servicing will be equipped with removable, reusable insulation.

E. Miscellaneous materials. Complete insulation systems include accessory materials such as fasteners, adhesives, reinforcing wire meshes and screens, bandings and binder wires, coverings or laggings, and finishes. All insulations will be sealed or closed at joints and should be arranged to accommodate differential expansions between piping or metal structures and insulations.

F. Cold surface materials*.* Cold surface insulation materials will be selected primarily for high resistance to moisture penetration and damage, and for avoidance of corrosion where wet insulation materials may contact metal surfaces. Foamed plastics or rubber and cellular (or foamed) glass materials will be used wherever practicable.

5.15. CONTROL OF USEFUL HEAT LOSSES

A. General: Control of losses of useful heat is the most important function of insulations. Substantial investments for thermal insulation warrants careful selection and design.

B. Durability and deterioration: Most conventional insulating materials are relatively soft and fragile and are subject to progressive deterioration and loss of effectiveness with the passage of time. Insulation assemblies which must be removed for maintenance or which are subject to frequent contact with tools, operating equipment and personnel, or are subject to shock or vibration, will be designed for maximum resistance to these forces.

5.16. SAFETY INSULATION

A. General: Insulation for personnel protection or safety purposes will be used to cover dangerously hot surfaces to avoid accidental contact, where heat loss is not itself an important criteria.

B. General safety criteria: Safety or burn protection insulations will be selected to insure that outside insulation surfaces do not exceed a reasonably safe maximum, such as *140* “F.

C. Other criteria: Close fitting or sealing of safety insulation is not required. Metal jacketing will be avoided due to its high conductivity in contact with the human body.

5.17. COLD SURFACE INSULATION

A. Applications: Insulations for cold surfaces will be applied to refrigeration equipment, piping and ductwork, cold water piping, and to air ducts bringing outside air into power plants and HVAC systems.

B. Criteria: In most cases, cold surface insulations will be selected to prevent icing or condensation. Extra insulation thickness is not normally economical for heat absorption control.

5.18. ECONOMIC THICKNESS

A. General: Economic thickness of an insulation material (ETI) is a calculated parameter in which the owning costs of greater or lesser thicknesses are compared with the relative values of heat energy which might be saved by such various thicknesses. The method is applicable only to systems which are installed to save useful heat (or refrigeration) and does not apply to safety insulation or anti-sweat (condensation) materials.

B. Economic criteria: The general principle of ETI calculations is that the most economical thickness of a group or set of thicknesses is that one for which the annual sum of owning costs and heat loss costs is a minimum. Generally, thicker insulations will represent higher owning costs and lower heat loss costs. The range of thicknesses selected for calculation will indicate at least one uneconomical thickness on each side of the indicated ETI.

C. Required data: The calculations of ETI for a particular insulation application involves routine calculations of costs for a group of different thicknesses. While calculations are readily performed by computers, the required input data are relatively complex and will include energy or fuel prices with allowance for future changes, relative values of particular heat sources or losses, depreciation and money cost rates, costs of complete installed insulation systems, conductivities, temperatures, air velocities and operating hours. Standard programs are available for routine calculations but must be used with care. The most uncertain data will be the installed costs of alternative insulation systems and thicknesses. Assumptions and estimates of such costs will be as accurate as possible. Refer to the publications and program systems of the Thermal Insulation Manufacturers Association (TIMA) and of leading insulation manufacturers.

5.19. FREEZE PROTECTION

a. Application. Freeze protection systems are combinations of insulation and heat source materials arranged to supply heat to exposed piping or equipment to prevent freezing in cold weather.

b. Insulation materials*.* Conventional insulation materials will be used and selected for general heat loss control purposes in addition to freeze protection. Insulation will be such as not to be damaged by the heat source or by extended exposure to weather and moisture.

c. Design criteria. In general, the insulation will be selected for maximum overall coldest ambient temperatures. Allowance for wind conditions will be made.

d. Heat sources. Electrical heating tape will generally be used to supply the correct heat flow to the protected surface. Steam and hot water tracing may bae used with provisions to avoid loss of steam or water. In either case, the required heat supply will be sufficient to meet the heat loss of the insulation under the combination of design ambient and pipe line surface temperature.

SECTION FIVE: CORROSION PROTECTION

5.20. GENERAL REMARKS

The need for corrosion protection will be investigated. Cycle fluids will be analyzed to determine treatment or if addition of corrosion inhibitors is required. Corrosion protection of items external to the cycle is generally accomplished by more conventional methods such as:

- Selection of corrosion resistant materials
- Protective coatings.
- Cathodic protection.

SECTION SIX: FIRE PROTECTION

5.21. INTRODUCTION: Fire protection will be provided in order to safeguard the equipment and personnel. Various systems will be installed as required to suit the particular type of fire which can occur in the station. This manual discusses various fire protection systems and their general application in power plants. Further details may be found in the National Fire Protection Association (NFPA) Codes and Standards.

5.22. DESIGN CONSIDERATIONS

A. Areas and equipment to be protected: The following are some of the major areas which will be investigated to determine the need for installing fire protection facilities.

1. Main and auxiliary transformers.
2. Turbine lubricating oil system including the oil reservoir, oil, cooler, storage tanks, pumps and the turbine and generator bearings.
3. Generator hydrogen cooling system including control panels, seal oil unit, hydrogen bottles and the purification unit.
4. Coal storage bunkers, fuel oil storage tanks and the burner front of the steam generator.
5. Emergency diesel generator and its oil storage tank.
6. Office and records rooms.
7. Control room.
8. Relay, computer, switchgear and battery rooms.
9. Shops, warehouses, garages and laboratories.
10. Personnel locker rooms, lunch rooms and toilets.

B. Types of systems: The following is a brief description of the various types of systems and their general application.

1. **Water spray and deluge system**. This type of system consists of open type sprinkler heads attached to a network of dry (not water filled) piping which is automatically controlled by a fully supervised fire detection system which also serves as a fire alarm system. When a fire is detected, an automatic deluge valve is tripped open, admitting water to the system to discharge through all of the sprinkler heads. The system may be subdivided into separately controlled headers, depending on the area to be covered and the number of sprinkler heads required. The usual pressure required at the sprinkler heads is about 175 psi and the piping should be properly sized accordingly. A water spray deluge sprinkler system will be provided where required in open areas and areas requiring the protection of the piping from freezing, such as the steam generator burner fronts; the generator hydrogen system; the main and auxiliary transformers; and unheated shops, garages, warehouses and laboratories.

2. **Water spray pre-action and deluge system.** This type of system is similar to the above water spray deluge system, except that it contains closed type sprinkler heads which only discharges water through those sprinklers whose fixed temperature elements have been opened by the heat from a fire. This system will be utilized for the turbine and generator bearings and for the above water spray deluge sprinkler system areas where more localized control is desired.

3. **Wet pipe sprinkler systems**. This wet pipe system utilizes a water filled piping system connected to a water supply and is equipped with sprinklers having fixed temperature elements which each open individually when exposed to a high temperature due to a fire. The areas where wet pipe sprinkler systems will be used are heated shops, garages, warehouses, laboratories, offices, record rooms, locker rooms, lunch rooms and toilets.

4. **Foam extinguishing systems**. Foam fire extinguishing systems utilize a foam producing solution which is distributed by pipes equipped with spray nozzles or a fuel tank foam entry chamber for discharging the foam and spreading it over the area to be protected. It is principally used to form a coherent floating blanket over flammable and combustible liquids which extinguish (or prevent) a fire by excluding air and cooling the fuel. The foam is usually generated by mixing proportionate amounts of 3% double strength, low expansion standard foam concentrate using either a suitably arranged induction device with (or without) a foam storage proportioning tank to mix the foam concentrate with a water stream from a fire water header. A specially designed hand play pipe, tank foam chamber or open sprinklers aspirate the air to form the foam to blanket the area to be protected. The deluge water entry valve to the system may be manually or automatically opened. Foam systems will be installed

in power plants to protect fuel oil areas, lubricating oil systems, and hydrogen seal oil systems.

5. **Carbon dioxide extinguishing systems**. This type of system usually consists of a truck filled low pressure refrigerated liquid carbon dioxide storage tank with temperature sensing controls to permit the automatic injection of permanently pipe carbon dioxide into areas to be protected. The system usually includes warning alarms to alert personnel whenever carbon dioxide is being injected into an actuated area. Carbon dioxide extinguishing systems of this total flooding type will be utilized to extinguish coal bunker fires and for electrical hazard areas such as in battery rooms, electrical relay rooms, switchgear rooms, computer rooms and within electrical cabinets.

6. **Halogenated fire extinguishing systems:** This type of system utilizes specially designed removable and rechargeable storage containers containing liquid HaIon at ambient temperature which is super-pressurized with dry nitrogen up to 600 psig pressure. These manifolded containers are located as closely as possible to the hazards they protect and include connecting piping and discharge nozzles. There are two types of systems. The total flooding system is arranged to discharge into, and fill to the proper concentration, an enclosed space or an enclosure about the hazard. The local application system is arranged to discharge directly onto the burning material. Either system may be arranged to protect one or more hazards or groups of hazards by so arranging the piping and valves and may be manually or automatically actuated. The principal application of Halon extinguishing systems is where an electrically nonconductive medium is essential or desired or where the cleanup of other media presents a problem, such as in control rooms, computer rooms, chemical laboratories and within electrical panels.

C. **Automatic fire detectors:** All fire protection systems will normally be automatically alarmed and actuated; however, some special conditions may require manual actuation on an alarm indication. The primary element of any fire protection system is the fire detection sensing device which is actuated by heat detectors which detect abnormally high temperature or rate-of-temperature rise, or smoke detectors which are sensitive to the visible or invisible particles of combustion. The ionization type of smoke detector belongs in this category.

5.23. SUPPORT FACILITIES

To support the fire protection water systems, an assured supply of water at an appropriate pressure is necessary. This water supply will be provided from an underground fire water hydrant system main if one is available in the area and/or by means of an elevated head storage tank or by fire pumps which take their suction from a low level storage tank. For cases where the water supply pressure is inadequate to fill the tank, fill pumps will be provided. Fire pumps will be electric motor driven, except that at least one should be of the engine driven or of the dual drive type.