Electrical Design of Pumping Stations

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of Engineers

ENGINEERING AND DESIGN

Mechanical and Electrical Design of Pumping Stations

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Engineering and Design
MECHANICAL AND ELECTRICAL DESIGN OF PUMPING STATIONS

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Chapter 10
Pump Drive Selection

10-1. General

Several options are available to the designer when considering the selection of a pump drive for flood-protection pumping stations. The two factors that must be investigated when making this selection are reliability and cost. Alternative studies should be made considering these two factors. The two types of drives to be considered are electric motors and internal combustion engines. Gear drives are required as part of the drive system when using engines. Gear drives can also be used with electric motors permitting the use of a less expensive higher speed motor and allowing a greater variation of the pump speed than permitted with direct drive.

10-2. Reliability

The primary consideration in the selection of any pump drive is reliability under the worst conditions likely to prevail during the time the station will be required to operate. The reliability of the electrical power source should be determined from power company records of power outages in that area and their capability to repair any outages. Consideration of power from two different power grids within a company may be advisable for large pumping stations. The reliability of the various different types of equipment must also be studied. Electric motors and engines are usually very reliable while the necessary accessories to operate these units are less reliable. The complexity to operate and repair the piece of equipment by the operating personnel should also be considered. Equipment repair requiring specialized service personnel may require much greater time to put it back into service.

10-3. Cost Considerations

a. General. Unless reliability considerations are important enough to decide what type of drive to use, annual cost comparisons should be made of all systems under study. The annual costs should include the installed, operating, maintenance and replacement costs. After all costs have been established, a life-cycle cost analysis can be performed.

b. Installed costs. The installed costs include the construction costs of all the equipment and the electric power supply costs, which usually would include the cost of the substation plus the power line to the station. These costs should be figured on an annualized basis using the number of years determined for the project life.

c. Operating costs. The operating costs would include the cost for energy and manpower expenses. To accurately estimate the total energy costs, an estimate of the amount of pumping required for each month of the year must be obtained. The source of pumping time should be obtained from hydrology period-of-record routing studies. The current price schedule for electric power from the supplying utility or the market price of engine fuel can be used to determine the costs for all stations except for large stations. For large stations, a study of future energy costs over the life of the project is justified. In determining the total cost of electricity, it is important to include both the cost for the energy used (kilowatt hours) plus any demand (capacity) charges. Demand charges by some power companies may be a major part of the energy costs.

d. Maintenance costs. Maintenance costs include manpower and materials for both preventative and major repairs. Unless the station has specialized equipment, these costs are usually estimated using the following percentages of the installed equipment costs:

Station Size	Percentage (%)
25 ℓ/s (1.0 cfs)	0.5
15 m^3/s (530 cfs)	5.0

Percentages for intermediate station sizes are determined proportionally with the above values. The maintenance cost of unusual or specialized equipment would be determined separately and would be an additional amount.

e. Rehabilitation and replacement costs. Rehabilitation and replacement costs include those costs required to keep the station operable for the project life. For a normal 50-year station life, most of the equipment would be rehabilitated or replaced at least once, except for very large pumping stations. The periods between the rehabilitation/replacement could be shorter if the operating time were great. Major items such as pumps, drivers, and switchgear are figured to be rehabilitated or replaced once during the 50-year life. This major equipment rehabilitation or replacement is usually estimated to occur between 20 and 40 years after placing the station into operation. Rehabilitation costs for major equipment can be estimated to be 35 to 45 percent of replacement costs depending on the condition of the equipment. Other items of equipment may be replaced several times during the project life depending on their use or may require only partial replacement. It is most likely that equipment, except for the pump and motor, may not be replaced in kind. Therefore, the replacement cost should include all engineering and structural modification costs as well as the equipment costs. In any event, the equipment removal costs including the cost of all rental equipment plus the installation cost of all new equipment should be included.

Chapter 11
Pump and Station Hydraulic Tests

11-1. General

Two types of tests are generally performed in connection with a pumping station and its pumping equipment before the station is built. Tests are run on pumps, either full size or model, to determine their performance and to demonstrate that the performance of the pump complies with specification requirements. Physical hydraulic model tests of the pumping station substructure may also be conducted to assess its hydraulic performance.

11-2. Pump Tests

a. General. The pump performance tests are conducted at the pump manufacturer's facility. Field testing to prove performance at the completed station is more difficult and costly if not impossible in many cases. All pumps should be factory tested to determine their capacity, total head, efficiency, and horsepower requirements. Pumps normally should also have a cavitation test performed. This test is usually performed on a model. Model testing specifications and parameters can be found in Guide Specification CW 15160, Vertical Pumps, Axial and Mixed Flow Impeller Type.

b. Description. Factory pump tests are either performed on full-size pumps or performed on a model pump of the full-size pump. If a model pump is used, it should be geometrically similar to that of the full-size pump and of the same specific speed. Either type of test is acceptable to check the ratings of the pump; however, because of size limitations, most manufacturers limit full-size tests to pumps of less than 2 m^3/s (75 cfs) capacity. A pump test consists of determining the total head, efficiency, and brake horsepower for a range of capacities. All testing should be witnessed by the District office design personnel performing the station design. The dimensions of the model and prototype impellers should be made by using drawings, measurements, and scaling factors. The performance factors measured include capacity, pressure head, horsepower, and suction pressure when cavitation performance is to be determined.

c. Performance tests. All pumps for flood-control pumping stations should have their performance verified by tests. For installation of identical pumps in a station, only one of the pumps needs to be tested. Tests on similar pumps used for another station will not be acceptable as equivalent tests. The test setup should permit, and the specifications require, the pump to be tested over a range of heads starting at least 600 millimeters (2 feet) greater than the highest total head requirement or at shut-off and extending down to the lowest head permitted by the test setup. The test should, if an unstable range ("dog leg" in the head curve) exists. Sufficient test points should be run to adequately define the unstable range. This allows the pump manufacturer to demonstrate that their pump does not operate in the unstable range. The lowest head tested should be at least equal to the total head that occurs for 95 percent of the operation time during low head pumping conditions. For pumps with capacities greater than 11 m^3/s (400 cfs), the model tests should be required to cover the complete head range required by the specifications including down to the lowest total head specified. All performance tests should be run at the same head at which the pumps will operate during actual duty. The readings of capacity and brake horsepower along with the total head will be used to determine the pump efficiency. For model tests, no correction factor for efficiency due to size differences will be allowed. Tests will be performed at water levels similar to that which will occur during actual operating conditions. An actual scale model of the station's inlet and discharge systems is not warranted except for pumps over 14 m^3/s (500 cfs). This requirement should also be used when the sump is not designed by the Government and is a part of the pump contract or has some complicated flow passage which has not had a sump model test. The pump test is used to ascertain the performance of the pumps, not how it reacts in the prototype sump except in the cases listed below. It is expected that the factory sump would be free of vortexes and adverse flows so that good results are obtained. Manufacturers are responsible for furnishing a pump that conforms to the specifications and meets the performance in the sump to be provided by the Government. The pump manufacturer should be held responsible for poor sump design, evidenced by vortexing and bad flow conditions within the sump, when the contract specifications require the sump to be designed by the pump manufacturer. Except for this special case, the pump manufacturer warrants performance of the pumps only, not the sump, and the activity within the sump would be the responsibility of the Government. Duplicate model pump sumps should include the sump from the inside of the trashrack. Any pump using a formed suction intake should be tested with this formed suction intake. Vertical pumps should be tested only in the vertical position.

d. Cavitation tests. Cavitation tests are performed to indicate the operating conditions in which the pump will start cavitating. For purposes of design, it is assumed that cavitation starts when the pump performance starts to decrease as the effective sump level is reduced. The inception of cavitation definition has not been agreed upon by all the pump suppliers and users. A typical pump test consists of operating the pump at a fixed capacity while reducing the pressure on the suction side of the pump. As the suction pressure is reduced, a point is reached where a plot of the head-capacity curves deviates from a straight line. The Corps specifies the start of cavitation at a point where the curve starts to deviate from the straight line. Others use as the start of cavitation, a point where a 1- or 3-percent deviation in performance from the straight line occurs. Submergence requirements, as used in this manual, are based on the Corps criterion of zero deviations from the straight line portion. In most cases, some cavitation has already started at either point; therefore, a design allowance of extra submergence should be provided in addition to that indicated by the tests results. The submergence allowance is based on the estimated number of operating hours expected annually. The amounts of allowance are indicated in Appendix B. In all cases, the cavitation tests should be performed in a test setup that uses a variation of water levels on the suction side of the pump.

11-3. Station Tests

a. General. Hydraulic model tests of pumping station sumps and discharge systems should be performed by WES for stations with unique or unusual layouts. The procedure in ER 1110-2-1403 should be followed when requesting model tests. A decision should be made on the requirement for model testing during the General Design Memorandum stage so that the results of any testing are available during the design of the station. Test results are usually not available until 6 to 9 months after forwarding a work order to the test agency.

b. Sump model tests. The primary purpose for performing a model test of a pumping station sump is to develop a sump design that is free of adverse flow distribution to the pump. Optimal flow into a pump impeller should be uniform without any swirl and have a steady, evenly distributed flow across the impeller entrance. However, it is usually not possible to obtain the optimal flow conditions without considerable added expense. Acceptable pump operation will occur when a deviation in the ratio of the average measured velocity to the average computed velocity is 10 percent or less and when the swirl angle is 3 degrees or less. Swirl in the pump column is indicated by a vortimeter (free wheeling propeller with zero pitch blade) located inside the column. Swirl angle is defined as the arc tangent of the ratio of the blade speed at the tip of the vortimeter blade to the average velocity for the cross section of the pump column. There should not be any vortex formations allowing entrance of air into the pump. In order to accurately simulate the field conditions, the model should include sufficient distance upstream of the station to a location where changes in geometry will not affect flow conditions in the sump. The prototype-to-model ratio is usually determined by the testing agency, but it should not be so large that adverse conditions cannot be readily observed. Normally the model should be sized to ensure that the Reynold's number in the model pump column is equal to or exceeds a value of 1×10^5. Reynold's number is defined by the following equation:

$$R = dV/r \qquad (11\text{-}1)$$

where

R = Reynold's number
d = column diameter
V = velocity
r = viscosity of water

c. Discharge model tests.

(1) General. These tests are performed to evaluate the performance of a discharge system. Usually two types of systems are investigated, discharges which form a siphon and/or through the protection discharges for large stations where the friction head loss would be a substantial portion of the total head of the pump.

(2) Siphon tests. The siphon tests are run to determine that a siphon will prime the system in the required time. This test is recommended when the down leg of the siphon system is long or it contains irregular flow lines and for pumps of 20 m^3/s (750 cfs) or greater having a siphon built into the station structure.

(3) Discharge tests. A head loss test should be considered only for pump discharges with capacities of 20 m^3/s (750 cfs) or greater and where the accuracy deviation for estimating the total head exceeds 20 percent of the total head. Other considerations would be the sizing of the pump and its driver. In some cases, a safety factor of 10 to 20 percent of the total head may not change the pump unit selection, and therefore the expense of a discharge test may not be warranted. For those stations where the size of the driver is close to its rating, a test may be in order to ensure that the driver would not be overloaded due to error in head determination.

(4) Other tests. Additional tests may also be required to fully prove the station acceptable. These could include energy dissipation tests of a saxophone outlet and a stilling basin or apron. Tests can also be made on models of existing pumping station sumps where operating difficulties have been experienced.

Chapter 12
Earthquake Considerations

Seismic investigation of the pumping station, as specified in EM 1110-2-3104, will indicate if required measures are necessary for the pumping station. If the forementioned investigation shows that damage from earthquakes is possible, the design of anchorages and support for the mechanical and electrical equipment shall be in accordance with TM 5-809-10. If the seismic investigation indicates that seismic design is not required, design methods as indicated in TM 5-809-10 should be followed where the additional cost is minimal.

Chapter 13
Power Supply

13-1. General

When the power requirements for the pumping station have been tentatively established, the adequacy of the intended source of electrical power and any limitations of that source must be determined before proceeding with station design (Plate 10). The design investigations should disclose the optimum system operating voltage, capacities, and location of existing utility facilities which may be involved in the supply of power to the pumping station, supply system reliability, voltage regulation, inrush current limitations, power factor restrictions, and short circuit characteristics. The Electric Power System Data Sheet in Appendix G is a convenient means to organize the information received.

13-2. Station Operating Voltage

It is extremely important that the proper operating voltage for the motors be selected, if the minimum overall installed cost of equipment is to be realized. Most flood-control pump stations operate at either 480 or 4,160 volts. As a general rule-of-thumb, motors of 150 kW (200 HP) and below are usually most economically operated at 480 volts. Above 150 kW (200 HP), 2,300- or 4,000-volt motors should be considered. Once the station capacity has been determined, the utility should be contacted to determine what utilization voltages are available. The utility rate structure and discounts such as untransformed service credit must also be obtained and analyzed. Determination of the most economical operating voltage requires accurate estimation and comparison of the complete electrical installation costs required for each operating voltage considered. Costs which must be considered include line construction, substation installation, motors, controls, conduit/cable sizes, and floor space required.

13-3. Power Supply Reliability and Availability

a. General. The first step in assuring an adequate power supply to a pumping station is to define the degree of reliability needed. This is not an easy task that results in the assignment of a numerical value. It is, instead, an evaluation of the tolerable power outages versus the additional costs to reduce the probability of outages. Some factors to consider in determining the degree of reliability needed in the power supply are:

(1) The type of property being protected. Is it cropland, industrial plants, or urban areas?

(2) The consequences if the pumping station fails to operate when required. Would an industrial plant be inundated causing immediate damage or could crops planted in a rural area tolerate submergence for a short time? Is ponding available? Would residential areas be flooded? Could there be potential human injury?

(3) The frequency and duration of outages that are acceptable to prevent any of the above.

(4) The time of year flooding is likely to occur. Does that pose any special problems such as overloading total utility capabilities?

Once the designer has established a feel for the need of continuity of service, contact with the utility is necessary to establish a system to meet that need. Several meetings or correspondences may be required to work out final details of the system. Chart G-1 of Appendix G is a flowchart for interfacing with the power company.

b. Availability. Availability could be defined as the long-term average that the electric service is expected to be energized. Outage data, given over a 5-year period, are usually available from the utility. The number of outages and duration of those outages over the 5-year period for the substation which will supply the pumping station can be used to calculate the availability.

c. Distribution system alternatives. Plate 11A depicts the functional components of a typical electric power system. The pumping station designer will primarily be concerned with subtransmission and distribution systems when discussing reliability considerations with the utility. Basically, there are two types of distribution systems:

(1) Radial.

(2) Network.

A radial system has only one simultaneous path of power flow to the load; a network has more than one simultaneous path of power flow to the load. A complete listing of the variations of these two broad groups falls outside the scope of this document. For an in-depth description of the various configurations, consult *Electric Utility Engineering Reference Book--Distribution Systems* by the Westinghouse Electric Corporation (1980). Plate 11B indicates some of the more commonly used distribution system configurations. Beginning at the top left of the drawing with the network primary feeder, the system's reliability increases as one moves clockwise around the loop. In general, the usage of a radial feed should be limited to projects where either the economics or characteristics of the protected property do not justify or require a more expensive network. Not all of the network schemes shown will be available from every utility. Consultation with each utility will be necessary to provide the appropriate system for the particular application.

13-4. Pumping Station Distribution Substation

a. Layout and design. Normally the Government contracts with the local utility to design, construct, operate, and maintain the power supply to the pump station. In some cases, the electric utility will ask the Government to provide the transformer pad as part of the pumping station contract. In such cases, close coordination between the utility, the Government, and the contractor will be necessary to ensure pad sizes, and mounting bolt locations are as required by the utility's transformers or other substation equipment. The substation should be located as close to the pumping station as possible. Further guidance on rights-of-way, ownership, operation, etc., of the transmission line and substation may be found in TM 5-811-1, Electric Power Supply and Distribution.

b. Transformers. The type of transformer used, i.e., whether single-phase or three-phase, should generally be determined by the availability of replacements from the local power company stock. Most utilities keep an inventory of replacement transformers of the various sizes necessary to provide quick replacement. The designer should inquire as to the location of transformer storage and the length of time required to transport and install it in an emergency. All transformers used must be non-PCB to comply with all Federal, State, and local laws. It is common in rural areas to employ three single-phase transformers connected either wye-delta or delta-delta so that, in the event of a transformer failure, they can remain in operation when connected in an open-delta configuration. However, this configuration should be used with caution since it prohibits the application of ground fault relaying as well as producing inherent unbalanced voltages which could result in the overloading of motors. Another, more attractive, option would be the furnishing of a fourth single-phase transformer or a second three-phase transformer as a spare.

13-5. Supply System Characteristics

An interchange of information between the designer and the utility is necessary if the pumping station electrical system is to be compatible with the power supply furnished. The designer should obtain the data requested in Appendix G from the local utility supplying power to the proposed pump station. To prepare the short-circuit studies indicated in Paragraph 23-3, the designer will need to obtain the maximum fault current available from the utility as well as information concerning the distribution substation transformer impedance. The designer should transmit station loads and motor starting requirements to the local utility as soon as they become available so that the utility can prepare an analysis of the impact upon their system. The utility can then advise the designer of power factor and motor inrush current limitations. After details of the electrical system have been coordinated, the designer should request time-current curves of the substation primary side protective devices so that a coordination study as described in Paragraph 23-2 can be prepared.

13-6. Pumping Station Main Disconnecting Equipment

For guidance on selection of the pumping station main disconnecting equipment, see Paragraph 15-2.

Chapter 14
Motors

14-1. General

a. Motor types. Constant-speed motors of either the squirrel-cage induction or synchronous type are the preferred drives for pumps installed in flood-protection pumping stations. Both squirrel-cage and synchronous motors are available in speed ranges and sizes that embrace most requirements.

b. Vertical-type motor construction. Usually, the vertical-type motor construction is preferred since it requires a minimum of floor space, which contributes significantly to an economical pumping station layout. The simplicity of the vertical motor construction also contributes to station reliability. Horizontal motors with gear drives have been used in some applications, but any first cost advantages must be weighed against increased operation and maintenance costs as well as decreased reliability over the life of the project. The gear reducer and its associated auxiliary equipment are additional components that are subject to failure. Comparative costs should include installation and maintenance costs for gear lubricating pumps, cooling water pumps, associated piping, monitoring equipment, etc.

c. Full-voltage starting. All motors should be designed for full-voltage starting, even if incoming power limitations indicate that some form of reduced-voltage starting is required. For installations having siphonic discharge lines, the power required to establish prime should not exceed the motor rating plus any additional service factors. This is necessary to assure successful operation in case siphon action is not established.

d. Contractual requirements. The contractual requirements for the majority of induction and synchronous motors used in flood-control pumping stations are described in Guide Specifications CW 15170, Electric Motors 3-Phase Vertical Induction Type (for Flood-Control Pumping Stations) and CW 15171, Electric Motors 3-Phase Vertical Synchronous Type 1500 Horsepower and Above (for Flood-Control Pumping Stations).

14-2. Induction Motors

a. Squirrel-cage. The squirrel-cage induction motor has a stator winding which produces a rotating magnetic field that induces currents in a squirrel-cage rotor. The squirrel-cage consists of a number of metal bars connected at each end to supporting metal rings. Current flow within the squirrel-cage winding produces the torque necessary for rotor rotation. Squirrel-cage induction motors have very simple construction, with no electrical connections to the rotor, and hence they possess a very high degree of reliability. However, the squirrel-cage rotor does not rotate as fast as the revolving magnetic field setup by the stator winding. This difference in speed is called "slip." Because of this inherent feature, squirrel-cage motors are not as efficient as synchronous motors, whose rotors rotate in synchronization with the magnetic field. There are three basic variables that classify motor performance types. These are:

(1) Starting torque.

(2) Starting current.

(3) Slip.

Motors can have high or low starting torques, starting currents, and slip. However, these six variables are not produced in every combination. For example, high resistance rotors produce higher values of starting torque than low resistance rotors. But high resistance in the rotor also produces a "high slip" motor. A high slip motor, by definition, has higher slip losses, hence lower efficiency, than an equivalent low slip motor.

b. Wound-rotor. The wound-rotor induction motor has coils instead of conducting bars in the rotor circuit. These coils are insulated and grouped into poles of the same number as the stator poles. The coil winding leads are attached to slip-rings. The brushes that travel along the slip-rings are connected to variable external resistances. High starting torques with relatively low starting current can be obtained by adding external resistance to the rotor circuit. As the motor comes up to speed, the resistance is gradually reduced until, at full speed, the rotor is short-circuited. Within certain limits, the motor speed can be regulated by varying resistance in the rotor circuit. It is not commonly used in flood-control pumping stations.

14-3. Synchronous Motors

a. Operating principle. The synchronous motor starts and accelerates its load utilizing the induction principles common to a squirrel-cage motor. However, as the rotor approaches synchronous speed (approximately 95 to 97 percent of synchronous speed), a second set of windings located on the rotor is energized with direct current. These field coil windings are responsible for providing the additional torque necessary to "pull" the rotor into synchronism with the revolving magnetic field established by the stator windings. The time at which direct current is applied to the field coil windings is critical and usually takes place when the rotor is revolving at approximately 95 to 97 percent of synchronous speed.

b. Field coil winding excitation. There are several methods commonly employed to achieve field coil winding excitation. Generally, brushless field control is the preferred method of field application. In a brushless motor, solid state technology permits the field control and field excitation systems to be mounted on the rotor. The motor, its exciter, and field control system are a self-contained package. Application and removal of field excitation are automatic and without moving parts. The brushes, commutator collector rings, electromagnetic relay, and field contactor are eliminated. Thus, the extra maintenance and reliability problems usually associated with older brush-type synchronous motors are greatly reduced.

c. Load commutated inverter. A recent development that may have limited application in pumping station design is the load commutated inverter (LCI). It is a promising adjustable-frequency drive for variable-speed high-voltage, high-power applications utilizing synchronous motors. Because of the internal counter electromotive force generated in a synchronous motor, the design of inverter circuits is greatly simplified. This device provides continuously variable speed regulation of from 10 to 100 percent of synchronous speed. It also limits inrush currents to approximately rated full-load current. Being a solid state device, however, the LCI may cause harmonic currents in the neutral conductors. Neutrals should be sized to 1.732 times the phase current. Further guidance can be found in CEGS 16415, Electric Work Interior.

d. Flow- or propeller-type pumps. Synchronous motors find their application as pump drives in the large capacity, low rpm mixed flow- or propeller-type pumps. In general, their usage should be limited to pumps of at least 375 kW (500 HP) and above, and at speeds of 500 rpm and below. Careful attention must be given to available pull-in torque to "pull" the rotor into synchronism with the revolving magnetic field. At this point, the motor must momentarily overspeed the pump past the moving column of water. Knowledge of the pump speed torque curve, voltage drop at the motor terminals, and the ability of the motor field application control to provide the best electrical angle for synchronism must all be considered.

14-4. Submersible Motors

Submersible motors have been used very effectively in smaller stations where economy of design is paramount. Where the possibility exists that combustible gases or flammable liquids may be present, the motor should be rated for explosion-proof duty. Thermal sensors should be provided to monitor the winding temperature for each stator phase winding. A leakage sensor should be provided to detect the presence of water in the stator chamber. If the possibility exists that rodents may enter the sump, special protection should be provided to protect the pump cable(s).

14-5. Common Features

Guide Specifications CW 15170 and CW 15171 give detailed requirements for common motor features such as enclosures, winding insulation, overspeed design, or anti-reversing device and core construction.

14-6. Shaft Type

Motors can be furnished with either a hollow or solid shaft. Commonly, however, hollow shaft motors are available only up to about 750 kW (1,000 HP). The hollow shaft motor provides a convenient means to adjust the impeller height. Other factors such as station ceiling height and the ability of the crane to remove the longer pump column must be considered in the decision of the type of shaft to employ.

14-7. Starting Current Limitations

Guide Specifications CW 15170 and CW 15171 limit the locked rotor current to 600 percent of rated (full-load) current. However, when utility requirements necessitate, lower inrush current induction motors may be specified not to exceed 500 percent of the rated full-load current. (Note: Starting inrush varies with efficiency; therefore, specifying reduced inrush will result in a somewhat lower efficiency.) The motor manufacturer should be contacted before specifying a reduction of inrush current for a synchronous motor. If 500 percent is not acceptable, reduced-voltage starting of the closed-transition autotransformer type should generally be used. Autotransformer starters provide three taps giving 50, 65, and 80 percent of full-line voltage. Caution must be exercised in the application of reduced voltage starting, however, since the motor torque is reduced as the square of the impressed voltage, i.e., the 50-percent tap will provide 25-percent starting torque. Connections should be made at the lowest tap that will give the required starting torque. Reactor-type starters should also be given consideration for medium voltage motors. Solid state motor starters employing phase-controlled thyristors are an option to reduce inrush currents for 460-volt motor applications. However, the reliability, price, availability of qualified maintenance personnel, and space considerations should all be studied carefully before electing to use solid state starters.

14-8. Duty Cycle

Care should be taken in the selection of the number and size of pumps to avoid excessive duty cycles. Mechanical stresses to the motor bracing and rotor configuration as well as rotor heating are problems with frequently started motors. The number of starts permissible for an induction motor should conform to the limitations given in MG-1-20.43 and MG-1-12.50 of NEMA MG-1, as applicable. Synchronous motors should conform to MG-1-21.43 of NEMA MG-1. The motor manufacturer should be consulted concerning the frequency of starting requirements if other than those prescribed above. Economic comparisons of different pumping configurations should include the reduction in motor life as a function of increased motor starting frequency.

14-9. Starting Torque

a. General. Most stations use medium or high specific speed propeller-type pumps with starting torques in the range of 20 to 40 percent of full-load torque. The motor must be designed with sufficient torque to start the pump to which it is connected under the maximum conditions specified, but in no case should the starting torque of the motor be less than 60 percent of full load. For a more detailed discussion of torque values, see the particular motor type below.

b. Squirrel-cage induction motors. Normally, motors specified in CW 15170 will have normal or low starting torque, low starting current. Each application should be checked to ensure that the motor has sufficient starting torque to accelerate the load over the complete starting cycle. CW 15170 requires a minimum starting torque of 60 percent of full load. Breakdown torque should not be less than 200 percent of full load unless inrush is reduced to 500 percent of full load. If 500 percent is specified, the breakdown torque must be reduced to 150 percent of full load.

c. Synchronous motors. Synchronous motors must usually be specially designed for pumping applications. The load torques and WK^3, so called "normal" values, on which NEMA MG-1 requirements are based are generally for unloaded starts and are therefore relatively low. Starting and accelerating torque shall be sufficient to start the pump and accelerate it against all torque experienced in passing to the pull-in speed under maximum head conditions and with a terminal voltage equal to 90 percent of rated. The minimum design for a loaded pump starting cycle should be: 60-percent starting torque, 100-percent pull-in torque, and 150-percent pull-out torque for 1 minute minimum with a terminal voltage equal to 90 percent of rated. This would produce inrush currents of 550 to 600 percent of full load.

d. Amortisseur windings. Double-cage amortisseur windings may be required to generate the uniformly high torque from starting to pull-in that is required by loaded pump starting. They consist of one set of shallow high-resistance bars and one set of deeper low-resistance bars.

14-10. Selection

a. General. The choice between a squirrel-cage induction and synchronous motor is usually determined by first cost, including controls, and wiring. In general, the seasonal operation of flood-control pump stations results in a fairly low annual load factor, which, in turn, diminishes the advantage of the increased efficiency of synchronous motors. A life-cycle cost analysis should be performed that includes first costs, energy costs, and maintenance costs. Another factor that should be considered is the quality of maintenance available since the synchronous motor and controls are more complex than the induction motor. The additional cost of providing power factor correction capacitors to squirrel-cage induction motors, when required, should be included in cost comparisons with synchronous motors. Also, the extra cost to provide torque and load WK^2 values higher than normal for a synchronous motor because of loaded pump starting characteristics must be taken into account.

b. Annual Load Factor (ALF): The ALF can be estimated from data obtained from a period-of-record routing (PORR) study or from the electric billing history of a similar pumping station. If a PORR or billing history is used, ALF would be defined as

$$ALF = We/(Pd \times 8,760) \qquad (14\text{-}1)$$

where

We = total amount of energy consumed during year

Pd = maximum of 12 peak demands occurring during year

8,760 = number of hours in a year

14-11. Power Factor Correction

a. General. Power factor is the ratio of total watts to the total root-mean-square (rms) volt-amperes. Utility companies may meter the reactive or out-of-phase component (kvar) of apparent power (kva) as well as total energy (kwh). They may charge additionally for higher capacity requirements driven by peak loads and low power factor. A rule of thumb is that about 12 to 14 percent of line loss can be saved by improving the power factor 10 percent.

b. Flood-control pumping stations. In flood-control pumping stations, the power factor for induction motors will vary according to size and rpm. The power factor should be corrected to 92 to 95 percent at full load through the addition of power factor correction capacitors. The power factor correction capacitors are usually located either within or on top of the motor control center. The capacitors should be switched in and out of the circuit with the motor.

14-12. Noise Level

The Department of Defense considers hazardous noise exposure of personnel as equivalent to 85 decibels or greater A-weighted sound pressure level for 8 hours in any one 24-hour period. The guide specifications provide requirements to obtain motors that meet this limitation. The designer, however, should evaluate the advantages and disadvantages of providing either the more expensive motors that meet these requirements or a room to isolate the operating personnel from the noise exposure. American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) Standard No. 85, Test Procedures for Airborne Sound Measurements on Rotating Machinery, and NEMA MG-1 provide more information on the subject.

14-13. Variable Speed Drives

a. General. Variable speed pump drives are not normally required in flood-control pump stations. Normally, if base flows are anticipated, a smaller constant speed vertical or submersible pump is furnished to avoid excessive cycling of larger stormwater pump motors. Variable speed drives are more frequently employed in sewage stations where the ability to match flow is more critical. If it has been determined, however, that a variable speed drive is necessary, the designer should determine the most efficient and economical method that meets the needs of the application. Two common methods of speed control are discussed below:

b. Variable frequency. Adjustable speed is obtained by converting the fixed-frequency alternating current (AC) line voltage into an adjustable voltage and frequency output that controls the speed of a squirrel-cage motor. A rectifier converts power from 60-Hz AC to direct current (DC). An inverter, then, reconverts the DC power back to AC power, which is adjustable in frequency and voltage. Drives are available in sizes up to 600 kW (800 HP) with variable frequency operation from 2 to 120 Hz. Inrush currents can be reduced to 50 to 150 percent of rated. Variable frequency drives are very efficient and provide a wide range of speed adjustment.

c. Wound-rotor motors. The speed of a wound-rotor motor is varied by removing power from the rotor windings. This is usually accomplished by switching resistance into the rotor circuit via the use of slip-rings and brushes. As resistance is added, the speed of the motor decreases. This method is not efficient, however, because of the loss in the resistors. Starting torques of the wound-rotor induction motor can be varied from a fraction of rated full-load torque to breakdown torque by proper selection of the external resistance value. The motor is capable of producing rated full-load torque at standstill with rated full-load current. The motor has low starting current, high starting torque, and smooth acceleration. In general, however, speed stability below 50 percent of rated is unsatisfactory. Additional maintenance is required because of the slip-rings and brushes required to access the rotor windings.

Chapter 15
Power Distribution Equipment

15-1. General

The power distribution equipment for motors used in flood-protection pumping stations must be as simple as possible, compact, and reliable, and since the equipment will stand idle for long periods and be subject to wide temperature variations, provisions must be made to prevent condensation within control enclosures (Plates 12-19). See Chapter 20, "Electrical Equipment Environmental Protection," for recommended protective requirements.

15-2. Main Disconnection Device

a. General. The main pumping station disconnecting device should be located within the station as part of the motor control center (for low-voltage stations) or the motor controller line-up (for medium-voltage stations). The main for the motor control center could be a molded case circuit breaker, power air or vacuum circuit breaker, or a quick-make, quick-break fusible interrupter switch. Similarly, the medium-voltage motor controller line-ups can utilize high-voltage load interrupter switches or power circuit breakers of the air or vacuum type.

b. Design decision. The design decision between a fusible interrupter switch and a circuit breaker ultimately depends upon the specific application. In some cases, continuous current requirements or interrupting capacities will dictate. Below 600 volts, circuit breakers and fuses are generally available in all continuous current ratings and interrupter ratings likely to be encountered. At the medium-voltage level, however, fuses are usually limited to 720 amperes continuous with 270 mVA maximum interrupting capacity. Additionally, at this continuous current level, the slow interrupting characteristics of the fuse often presents coordination problems with the utility's overcurrent protective relaying. A new product, current limiting electronic fuses, improves the fuse reaction time by electronic sensing of the rate of change of current. It should be considered when coordination is a problem. In any event, the utility should be advised of the choice of main disconnect in order to ensure compliance with their standards and to prevent coordination problems. If a fusible interrupter switch is selected, protection from single phasing should also be provided.

c. Fusible interrupter switch. Some general advantages and disadvantages of a fusible interrupter switch include:

Advantages	Disadvantages
Simple and foolproof	Requires spares
Constant characteristics	Self-destructive
Initial economy (3:1 or 4:1 versus medium-voltage breakers)	Nonadjustable
No maintenance	No remote control

d. Circuit breaker. Some general advantages and disadvantages of a circuit breaker:

Advantages	Disadvantages
Remote control	Periodic maintenance
Multipole	Higher initial cost
Smaller, convenient (at low voltage)	Complex construction (at medium voltage)
Resettable	
Adjustable	

15-3. Low-Voltage Stations

a. General. In general, motor control centers are preferred over "metal enclosed low-voltage power circuit breaker switchgear" for control of motors 480 volts and below in pumping station design. While metal-enclosed switchgear is a high quality product, its application is found more in feeder protection and starting and stopping of infrequently cycled motors and generators.

b. Maintenance. Experience has shown that frequent operation of power circuit breakers requires additional maintenance of the various mechanical linkages that comprise the operating mechanisms. Since maintenance of pumping station equipment is usually a local levee or sewer district responsibility, every effort should be made to reduce system maintenance and optimize station reliability. Magnetic starters provide a simple, reliable, and less expensive alternative to the usage of power circuit breakers. Combination magnetic starters are available in either the circuit breaker or fusible type.

c. Motor protection. Protection of the motor is provided by thermal overload relays, which are normally built into the starter itself. The relays contain high-wattage electric heaters, in each phase, which are heated by the passage of motor current. The heat generated either bends a bi-metallic strip or melts a low temperature (eutectic) fusible alloy. The bent bi-metallic strip opens contacts that interrupt the current to the contactor-operating coil. The melted alloy frees a spring-loaded shaft that rotates and breaks contacts in the operating coil circuit. The bi-metallic relay has two advantages not found in the fusible-alloy type: it can reset itself automatically and can compensate for varying ambient-temperature conditions if the motor is located in a constant temperature and the starter is not. The heaters must be sized to accept the starting current of the motor for the expected starting time without causing the contactor to open. To achieve this with a variety of connected loads, conventional starters are available with a range of standard heaters, which can be selected according to the application.

d. Undervoltage protection. Undervoltage protection is supplied inherently by the action of the operating coil. An abnormally low supply voltage causes the motor to run well below synchronous speed, drawing a current which, even though not as high as the starting current, quickly overheats the motor. A low supply voltage, however, also means a low current to the holding coil and causes the contactor to drop out and isolate the motor. If more protection from undervoltage is required, an undervoltage relay can be added for increased protection.

e. Combination motor controllers. Combination duplex or triplex motor controllers are sometimes provided by the pump manufacturer as part of a pump, motor, controller package. This is often the case for smaller stations employing submersible motors. This is a viable option, where applicable, and assures one manufacturer responsibility should problems arise.

15-4. Medium-Voltage Stations

a. General. The designer must choose between a medium-voltage motor controller (incorporating a magnetic contactor) and an air-magnetic or vacuum circuit breaker. While "metal-clad" switchgear is the highest quality equipment produced by the industry, motor controllers are still preferred. Circuit breakers in metal-clad switchgear are used as motor starters primarily by utilities, where a motor, once started, may run a week or more without stopping. In industry, circuit breakers find their application as main or feeder breakers that are not frequently opened or closed.

(1) Circuit breaker benefits. The benefit of circuit breakers is that although the contact mechanism is not designed for a large number of operations, it is designed to interrupt short-circuit currents of high magnitude and be returned to service immediately. While vacuum bottle technology increases the number of operations possible, contactors are still the preferred mechanism for frequently started motors.

(2) Cost. Another consideration in the choice between the two is the relative cost. Metal-clad switchgear is approximately three times as expensive as an equivalent line-up of motor controllers. Where required, air or vacuum circuit breakers can be used as mains with transition sections to accommodate the motor controller line-up.

b. Medium-voltage motor controllers. The medium-voltage controllers should comply with NEMA ICS 2-324, "A-C General-Purpose High-Voltage Class E Controllers" and UL Standard 347 (Underwriters Laboratories, Inc. 1985). They may be described as metal-enclosed high-interrupting capacity, drawout, magnetic-contactor type starter equipments with manual isolation. Medium-voltage motor controllers are available for reduced-voltage and full-voltage starting of non-reversing squirrel-cage and full-voltage starting of synchronous motors typically used in pumping stations.

(1) High- and low-voltage sections. Each motor controller enclosure is divided into a high- and low-voltage section. The high-voltage section contains the magnetic contactor and its protective fuses. The low-voltage section contains the controls and protective relaying. Contingent upon motor size and relaying requirements, one, two, or three starters can be located in one vertical section. Power for control relays is usually 115 volts but may be 230-volt AC or 48-, 125-, or 250-volt DC.

(2) Fuses. The contactor itself is not capable of interrupting a short circuit and must be protected by silver-sand type current limiting fuses. Fuses are generally mounted on the contactor itself and can be drawn out of the cabinet for replacement by withdrawing the contactor. One limitation of such fuses is that, should a short-circuit occur on one phase only, only that fuse will blow, and the motor will continue to operate on the single phase between the remaining two lines. Current drawn in that phase is twice full-load current and will rapidly overheat the motor. This can be avoided by the addition of suitable relaying, as described later, but, in

some cases, the contactor may also incorporate a trip mechanism that is actuated by the blown fuse itself. The trip mechanism causes the contactor to open immediately when the fuse is blown, isolating the motor. Either protective relaying or a mechanical trip mechanism should be provided.

c. Motor protection.

(1) General. The following gives general guidance for protection of medium-voltage motors. For further information on motor protection, refer to ANSI/IEEE 242, "Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems." For motor protection against lightning and switching surges, refer to Chapter 19.

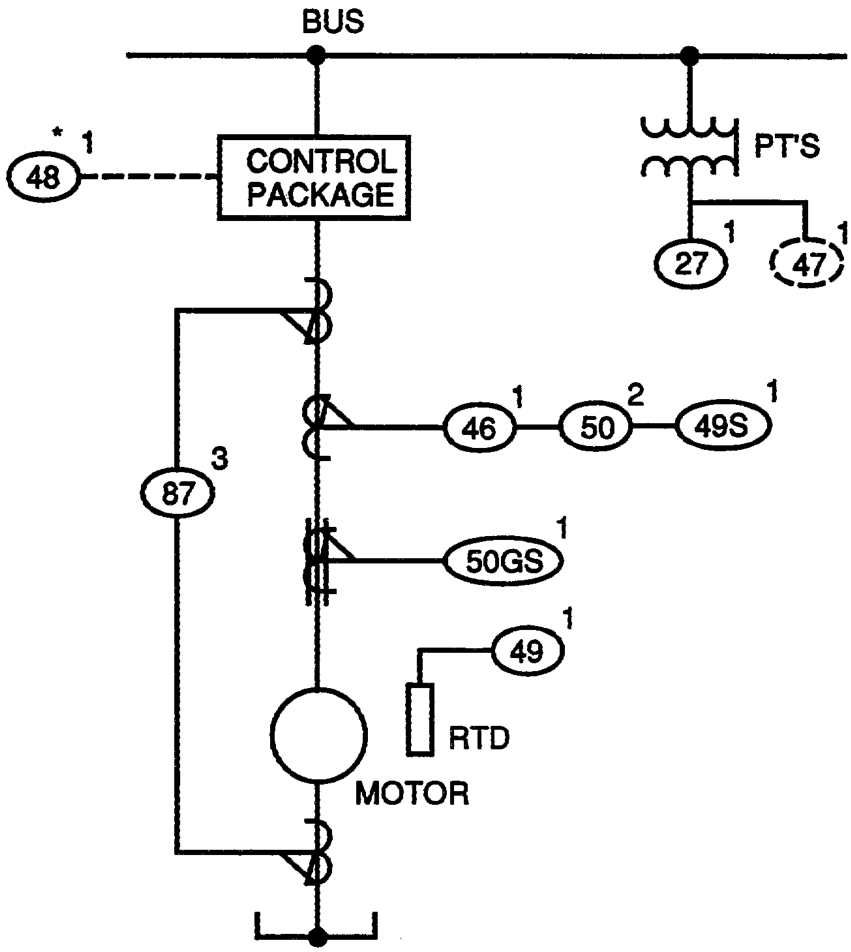
(2) Induction motor protection. It is logical that more extensive protection be considered for larger motors than for smaller motors, since they represent a larger capital investment. Therefore, minimum recommended protective relaying is divided into two groups: one for motors rated below 375 kW (500 HP), and the other for those rated 375 kW (500 HP) and above.

(a) Motors below 375 kW (500 HP). Referring to Figure 15-1, for motors rated below 375 kW (500 HP), protection against loss of voltage or low voltage is generally provided by the single-phase time-delay undervoltage relay, Device 27. Where it is desired to secure three-phase undervoltage protection, such as when the motor is fed through fuses or from an overhead open line wire, Device 47 would be used in place of Device 27. In addition, Device 47 would provide protection against phase sequence reversal should it occur between the source and the motor's associated switchgear. The Device 49/50 provides short-circuit, stalled-rotor, and running overload protection; this relay has a thermally operated time-overcurrent characteristic. It is therefore generally to be preferred for this application over an inverse time-overcurrent relay such as the Device 51 relay. The instantaneous device on the Device 49/50 relay is normally set at 1.6 to 2 times locked-rotor current. Sensitive and fast ground-fault protection is provided by the instantaneous ground-sensor equipment, Device 50GS. Device 49 operates from a resistance-temperature detector embedded in the machine stator winding. This type of running overload protection is to be preferred over the stator-current-operated device, since it responds to actual motor temperature. The Device 40S provides protection against stalled rotor conditions. This device is necessary since the resistance-temperature detector used with Device 49 will not respond immediately to fast changes in the stator conductor temperature as would be the case under stalled conditions. The Device 49S relay includes a special high-drop-out instantaneous-overcurrent unit which is arranged to prevent its time-overcurrent unit from tripping except when the magnitude of stator current is approximately equal to that occurring during stalled conditions. Device 48, the incomplete sequence timer, would be included where the control package is of the reduced-voltage type. It provides protection for the motor and control package against continued operation at reduced voltage which could result from a control sequence failure. For wound-rotor motors where the starting inrush current is limited, more sensitive short-circuit protection can be provided with the addition of the Device 51 time over-current relays. With the motor inrush current limited, these relays can generally be set to operate at full-voltage locked-rotor current with all secondary resistance shorted.

(b) Motors rated 375 kW (500 HP) or above. For the larger motors rated 375 kW (500 HP) and above, a current-balance relay, Device 46, is included to provide protection against single-phase operation. Differential protection for larger motors is provided by Device 87. This device provides sensitive and fast protection for phase-to-phase and phase-to-ground faults.

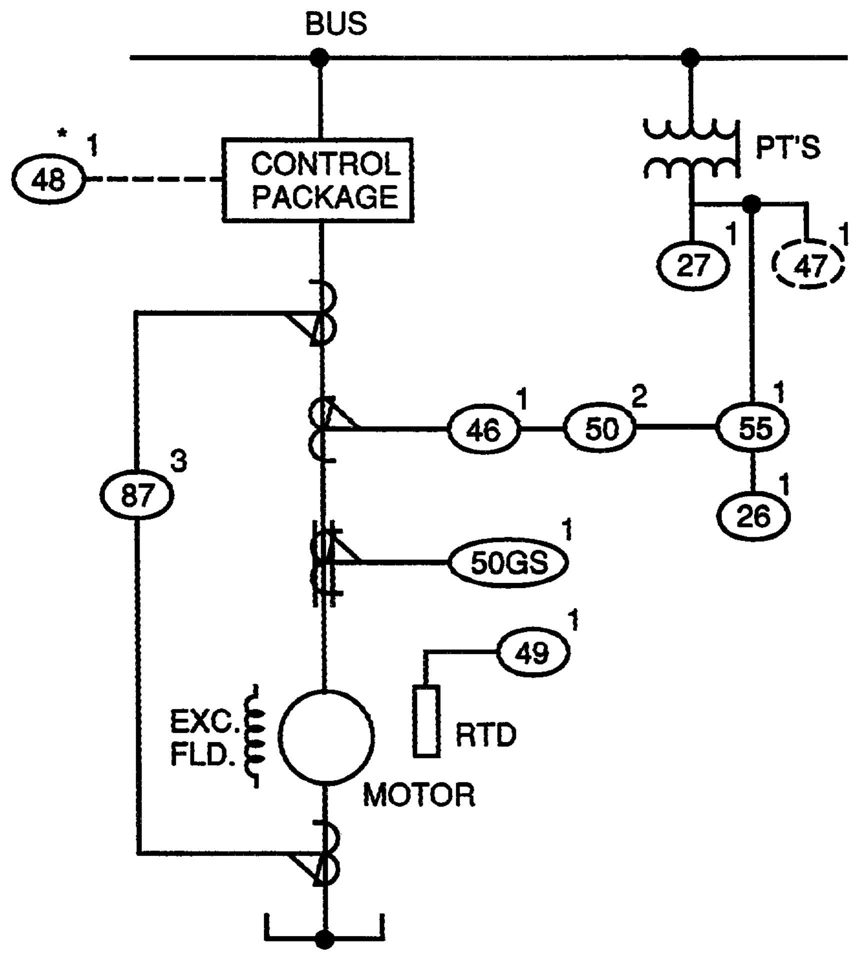
(3) Medium-voltage brushless synchronous motor protection. Figure 15-2 covers the recommended minimum protection for brushless synchronous motors. Device 26 has been included to provide stalled-rotor protection. It is a stator-current operated device. The characteristic and rating of this device is provided by the equipment manufacturer and must be closely coordinated with the starting and operating characteristics of the individual motor being protected. The power factor relay Device 55 has also been included to protect the motor from operating at sub-synchronous speed with its field applied. This commonly called out-of-step operation will produce oscillations in the motor stator current, causing them to pass through the "lagging" quadrature. The power factor relay is connected to sense this current and will operate when it becomes abnormally lagging. Upon operation, excitation is immediately removed from the motor, allowing it to run as an induction machine. After excitation has been removed, the control is arranged to shut down the motor.

(4) Microprocessor-based motor protection systems. Microprocessor-controlled motor protective systems are a relatively recent development that combines control, monitoring, and protection functions in one assembly.



DEV.
27▲UNDERVOLTAGE
46-CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
49-THERMAL
49S-THERMAL (STALLED)
50-INST. SHORT CIRCUIT
50GS-INSTANTANEOUS GROUND SENSOR
87-DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW (3000 HP))
47▲3∅UNDERVOLTAGE & REVERSE PHASE ROTATION
48-INCOMPLETE SEQUENCE-TIMER FOR WOUND ROTOR MOTORS ADD 2-DEV. 51
IF 87 IS SELF-BALANCING PRIMARY CURRENT ADD 2 DEV. 51
*INCLUDE IF CONTROL PACKAGE IS REDUCED VOLT. START
▲OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 15-1. Recommended minimum protection for medium-voltage induction motors (all horsepowers except as noted)



DEV.
26-APPARATUS THERMAL DEVICE
27▲UNDERVOLTAGE
46-CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
47▲3∅UNDERVOLTAGE & REVERSE PHASE ROTATION
48-INCOMPLETE SEQUENCE-TIMER
49-THERMAL
50-INST. SHORT CIRCUIT
50GS-INSTANTANEOUS GROUND SENSOR
55-POWER FACTOR RELAY
87-DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW 3000 HP))
IF 87 IS SELF-BALANCING PRIMARY CURRENT ADD 2 DEV. 51
*INCLUDE IF CONTROL PACKAGE IS REDUCED VOLT. START
▲OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 15-2. Recommended minimum protection for medium-voltage brushless synchronous motors (all horsepowers except as noted)

Most protection packages provide complete motor protection for any size motor. The packages usually include motor overload protection, overtemperature, instantaneous overcurrent, ground fault, phase loss/phase reversal/phase unbalance (voltage), phase loss and unbalance (current), overvoltage, undervoltage, and motor bearing temperature protection. The monitoring features include current, voltage, watts, frequency, power factor, and elapsed time. Some units can tabulate the number of starts per programmed unit of time and lock out the starting sequence, preventing inadvertent excessive cycling. The control features replace discrete relay logic for prestart, poststart, prestop, and poststop timing functions and various enabling signals. Programmable logic under the control of the processor performs these functions. The units can be programmed for simple, across-the-line starting or more complex starting sequences such as reduced-voltage autotransformer starting. Also included are adjustable alarm and trip parameters and self-diagnostics including contractor report-back status to enhance system reliability. In instances where motor conditions exceed the programmed setpoint values, an alarm and/or trip condition is automatically initiated. One of the advantages to these systems is that there are few options making it less likely that a desired protective feature will be overlooked in the specification process.

(5) Considerations. Microprocessor-controlled protection packages are a viable option when precise and thorough motor protection is required. After the designer has decided upon the minimum required protective features, as described above, an economic comparison should be made between standard methods of relay protection versus the microprocessor-based systems. Consideration should be given to the microprocessor system's added features such as the built-in logic capabilities, expanded motor protection, and monitoring and alarm functions when making the cost comparison. As with all solid state devices, careful consideration must be given to their operating environment. The typical operating range of the processor is -20 to 70 degrees centigrade. However, the operating temperature of the external face of the operator panel is limited to 0 to 55 degrees centigrade. Special coating of the circuit boards is, also, required to provide protection from the extremely humid environment of the typical pumping station. The applications department of the manufacturer should be consulted for each application.

Chapter 16
Control Equipment

16-1. Control Rooms and Consoles

In larger pumping stations, the complexity of the pumping system and the trend toward reducing the number of operating personnel will usually require the formation of a centralized monitoring and control room. Controls, alarms, and devices to indicate system status should be grouped on a control console so that one operator can conveniently initiate control sequences and observe the system response (Plate 20). Care should be taken to include a monitoring capability for all essential pumping system parameters. Some alarms that may be required include motor and pump bearing temperatures, motor winding temperature, motor trip and lockout relays, motor or gear cooling water failure, excessive pump discharge piping pressures or flow rates, lubrication system failures, abnormal water levels, trashrake malfunction, etc. A graphic display is an effective means of grouping alarm and status information.

16-2. Programmable Controllers

A programmable controller (PLC) should be considered for usage when the controls or monitoring requirements of the station become complex. When appropriately applied, this device provides the processing power and flexibility necessary to efficiently control a complicated system.

a. Advantages. Advantages of the programmable controller include:

(1) The flexibility to reprogram or modify the control sequence.

(2) The ability to manipulate, compare, or perform arithmetic functions on data stored at various memory locations.

(3) A high degree of reliability when operated within their ratings.

(4) The ability to accept a wide variety of input and output devices.

(5) The capability to force inputs and outputs "on" or "off" to aid in troubleshooting.

b. Operator interfaces. Operator interfaces can range from simple pushbuttons and indicating lights to personal computers (PCs). The PC offers increased computing power, data logging, and graphics capabilities.

c. Cautions.

(1) Personnel. Some caution should be exercised, however, in applying PLCs and PCs to pump station applications. Most pumping stations are operated and maintained by local interests. The local levee or sewer district may not have the experience or expertise to maintain the PLC system. An evaluation should be made of the availability of qualified repair services and the competency level of the anticipated operating and maintenance personnel.

(2) Environment. Also, while PLCs are rugged devices which can normally be applied to pumping station environments with little concern for exceeding their environmental ratings, the designer should evaluate the need for any special provisions to ensure that the PLC will be operated within its temperature and humidity ratings. If the use of a PC is desired, it should be an industrially hardened version and should be kept in a conditioned environment.

d. Temperature and humidity ratings. Typical ambient operational temperature ratings are 0 to 60 degrees centigrade and -40 to 85 degrees centigrade during storage. Typical humidity ratings are from 5 to 95 percent without condensation. Operation or storage in ambients exceeding these values is not recommended without special consultation with the manufacturer.

e. Interposing relays. The output contacts of programmable controllers have limited current carrying capacity. Electrical devices which require significant amounts of current for operation, such as large solenoid devices, may require the addition of interposing relays to the system. However, to minimize complexity, the use of interposing relays should be avoided wherever possible.

16-3. Water Level Sensors

a. General. A variety of sensors are available for use in sensing water levels, including float-actuated mercury switches, float-actuated angle encoders, bubbler systems, bulb-type floats, etc. The use of float-actuated mercury switches is discouraged due to environmental concerns. A comparison should be made of the particular pumping station requirements in relation to the various level sensor capabilities before deciding upon the system to be employed. In more sophisticated stations, it may be desirable to utilize an angle encoder. With its associated electronic packages, very accurate level comparisons and alarm functions are possible. Also, its output may be convenient for inputting to programmable controllers or computers. The selection of a sophisticated water level sensing system, however, must always be made with consideration of the quality of maintenance and repair services available to the station after construction.

b. Bubbler systems. Bubbler systems when used are usually of the air-purged type. The nitrogen gas purged type is usually employed at remote sensing areas where power to run the air compressor of an air-purged system is difficult to obtain. The air-purged system operates by purging air into a channel, sump, etc., through a tube and measuring the back pressure which varies in proportion to the variation in liquid level. A linear variable differential transformer is usually used to convert pressure readings to low voltage or current signals. When used in sufficient number, this system may be cheaper than an equivalent float-actuated system. However, it is more complex and is subject to clogging in highly siltatious waters.

c. Angle encoders. The transducer should be of the electromagnetic resolver type and nonvolatile. Each shaft position should be a unique output that varies as a function of the angular rotation of the shaft. If power is lost, the correct output should immediately be restored upon restoration of power. Units are available in single or multiturn construction.

16-4. Elapsed Time Meters and Alternators

To ensure even wear on pumping units as well as reducing the frequency of motor starting, it is recommended that elapsed time meters and alternators (where pumps are started automatically) be installed to provide a record of pump usage.

16-5. Timing Relays

Several timing relays are commonly employed in pump control circuits. If siphon breakers are required, an on-delay timer delays closing of the siphon breaker solenoids until the siphon system is fully primed. This feature reduces motor horsepower requirements to establish prime. The other is an off-delay timer which prevents the motor from being restarted until any reverse spinning of the pump has stopped.

16-6. Miscellaneous Circuits

The miscellaneous small power circuits commonly required in installations for the control transformers, potential transformers, lighting transformers, and control power should either be protected by standard circuit breakers or fuses of adequate rating.

Chapter 17
Station Wiring

17-1. General

The reliability of the entire electrical installation will be only as good as that of the wiring by which the various items of power supply, power distribution, control, and utilization equipment are interconnected. Selection of proper materials and methods of construction for the wiring system are therefore a matter of prime importance. The following basic principles should be observed in design of pump station wiring systems.

17-2. Conduit

For the mechanical protection of wiring and for the safety of operating personnel, all station wiring should be enclosed. Rigid galvanized steel conduit is the most commonly used material for raceways and is suitable for all locations where wiring is required within a pumping station. If it is necessary to run conduits exposed below the operating floor, consideration should be given to polyvinyl chloride (PVC) coated rigid galvanized steel or PVC conduit. All ferrous conduit fittings should be zinc-coated or otherwise suitably plated to resist corrosion due to moisture and fumes common to pumping stations. In large stations where extensive cabling is required, the usage of cable trays should be considered. If conduits are to be embedded, the use of nonmetallic conduits should be considered.

17-3. Conductors

Wire and cable for pumping stations should be furnished with moisture- and heat-resisting insulation. Details of cable construction and insulation can be found in CW 16120, Insulated Wire and Cable (for Hydraulic Structures). Sizes of conductors should be in accordance with the National Electrical Code (NFPA-70) for motor feeders and branch circuits.

17-4. Conductor Joints

The most common causes of trouble in completed wiring installations are imperfect joints and terminations of conductors that permit entrance of moisture under protective sheaths. The procedures to be followed in terminating conductors should be made a part of the installation contract specifications. No splicing of circuits of 480 volts or greater should be allowed in the contract specifications. This important detail of electrical construction should receive proper consideration by both designers and field inspectors.

Chapter 18
Station and Equipment Grounding

18-1. General

Following are the recommended practices for system and equipment grounding in pumping stations. However, special applications may require variations to the recommended practices. A thorough discussion of grounding principles can be found in ANSI/IEEE 142, Recommended Practices for Grounding of Industrial and Commercial Power Systems. Installations should also comply with the applicable provisions of Article 250 - Grounding of the National Electric Code (NFPA-70). Typical grounding plans are shown on Plates 21 and 22.

18-2. Station and Equipment Grounding

a. General. An effective grounding system is an essential part of a pump station electrical system. In general, 19-millimeter (3/4-inch) by 6-meter (20-foot) ground rods should be driven at the corners of the structure and exothermically joined to a ground bus run completely around the periphery of the pumping station. The ground bus should be installed a minimum of 0.5 meter (18 inches) outside the building wall and a minimum of 0.8 meter (30 inches) below the finished grade. Additional lengths or numbers of ground rods should be added as required to achieve a maximum resistance to ground of 25 ohms. In rocky ground where driven rods are impractical, it is sometimes more economical and desirable to use a grid system with cable spacings of approximately 3 meters (10 feet) being common. The cables should be placed 150 millimeters (6 inches) to 300 millimeters (1 foot) deep and encased in concrete.

b. Grounding conductors. At least four grounding conductors should be run from the ground bus or grid and exothermically welded to a ground loop embedded in the operating floor. All connections to either the ground loop or ground bus should be by exothermic welds.

c. Ground bus. The ground bus should be exothermically connected to the sump floor rebars, any steel columns of the structure, and metallic underground water piping where present.

d. Sizing of grounding bus and loop conductors. Sizing of grounding bus and loop conductors should be made in accordance with the applicable requirements of the National Electrical Code (NFPA-70). For mechanical strength, however, the grounding conductors should not be smaller than No. 2/0-AWG conductor. However, it may be desirable to exceed these values where exceptional precaution is required or where extremely high ground-fault currents are expected.

e. Frames and enclosures. The frames of stationary or permanently located motors, and the frames and enclosures of static equipment such as transformers should be grounded by direct connection to the operating floor ground loop through an equipment grounding conductor equal in size to the largest conductor in the line connected to the equipment, but in general not less than No. 6 AWG. The equipment grounding conductors shall be connected to the equipment through the use of a clamp-type connector.

f. Switchgear. To provide a convenient method of grounding switchgear, a ground bus should be provided as part of the equipment. The switchgear ground bus must not be smaller in current-carrying capacity than 25 percent of the highest continuous-current rating of any piece of primary apparatus to which it is connected. The switchgear ground bus should, in turn, be connected to the operating floor ground loop by conductors having a current-carrying capacity equal to that of the switchgear ground bus.

g. Other noncurrent carrying metal. All other noncurrent carrying metal such as ladders, fences, fuel-storage tanks, etc., shall be connected to either the ground bus or operating floor ground loop. All neutral conductors of grounded power supplies shall be solidly grounded to the station ground system.

h. Utility power. The utility furnishing power to the station should be contacted to determine if any interconnections are required between the pumping station ground grid and the substation ground grid.

18-3. System Grounding

a. General. The basic reasons for system grounding are the following:

(1) To limit the difference of electric potential between all uninsulated conducting objects in a local area.

(2) To provide for isolation of faulted equipment and circuits when a fault occurs.

(3) To limit overvoltage appearing on the system under various conditions.

b. Low-voltage systems. It is recommended that pumping stations with electrical systems of 1,000 volts and below be solidly grounded. Solid grounding is the least expensive way to detect and selectively isolate ground fault through the usage of fast-acting ground-fault relaying. However, use of a solidly grounded low-voltage distribution system increases the probability of damage from arcing ground faults. The driving voltage of these systems tends to sustain arcs rather than clear them through the standard phase overcurrent protective devices. High impedances associated with the arc may limit fault current to levels too low for detection by conventional over-current protective devices. For this reason, sensitive ground-fault relaying should be provided on the feeders and the main of all solidly grounded systems. Ungrounded operation of low-voltage systems is not recommended because of the potential over-voltage problems.

c. Medium-voltage systems. Modern power systems in this range of voltages are usually low-resistance grounded to limit the damage due to ground faults in the windings of rotating machines and yet permit sufficient fault current for the detection and selective isolation of individually faulted circuits. The lowest ground-fault current (highest resistance) consistent with adequate ground relay sensitivity should be used. High-resistance grounding is not recommended for medium-voltage systems.

Chapter 19
Surge Protection

19-1. General

a. Lightning-induced voltage surges. Pumping stations are particularly vulnerable to lightning-induced voltage surges on incoming power lines, since it is characteristic of their operation to be in use during thunderstorms. Therefore, special care should be taken to reduce the magnitude of these voltage surges to avoid major damage to the electrical equipment contained within. A relatively small investment can greatly reduce the voltage stresses imposed on rotating machinery and switchgear by lightning-induced surges.

b. Protective equipment. There are two transient elements of a voltage surge that require different protective equipment. The protection of the major insulation to ground is accomplished by station surge arresters which limit the amplitude or reflections of the applied impulse waves within the motor windings. The protection of turn insulation by reducing the steepness of wave fronts applied to or reflected within the motor windings is accomplished by protective capacitors.

19-2. Medium-Voltage Motors

To obtain the most reliable protection of the motor's major and turn insulation systems, a set of arresters and capacitors should be installed as close as possible to the motor terminals. The arresters should be valve-type, Station-Class designed for rotating machine protection. The capacitors should be of the non-PCB type. The leads from the phase conductor to the capacitor and from the capacitor to ground should be as short as possible. (If solid state motor controllers are used, the addition of capacitors at the motor terminals may not be recommended. Chopped-wave equipment such as SCR controlled motor starters can generate surges and harmonics. The capacitors can contribute to the problem by increasing resonance effects. The manufacturer should be consulted for the particular application.)

19-3. Low-Voltage Motors

Motors of 600 volts and below have relatively higher dielectric strength than medium-voltage machines. Normally, when higher speed motors of this voltage class are connected through a transformer protected by Station-Class arresters on the primary side, no additional protection is warranted. However, due to the more expensive slower speed motors employed in pump stations, plus the critical nature of these motors, the minimal additional cost of lightning protection is justified. A three-phase valve-type low voltage arrester should be provided at the service entrance to the station and a three-phase capacitor should be provided at each motor terminal.

19-4. Substation

The utility should be requested to supply valve-type Station-Class surge arresters on the primary side of the substation transformer.

Chapter 20
Electrical Equipment Environmental Protection

20-1. General

Since the electrical equipment will stand idle for long periods of time, special attention must be given to corrosion protection. Guide Specifications CW 15170 and CW 15171 provide recommended corrosion-protection requirements for induction and synchronous motors, respectively. The standard manufacturer's treatments of the medium-voltage motor controller line-ups and motor control centers consist generally of one undercoat of a phosphatizing rust inhibitor followed by one finish coat applied to both internal and external surfaces. In many stations where humidity is especially high or other conditions merit special consideration, two undercoats of the rust-inhibiting primer should be specified. In addition, all major items of electrical equipment including motors, control centers, controller line-ups, control consoles, wall-mounted combination starters, gate operator controllers, trashrake controllers, etc., should be equipped with space heaters sized per the manufacturer's recommendations. Heaters in motors and controllers should be interlocked with the motor starters to ensure de-energization when the equipment is in operation. Heaters are generally fed from the lighting panels, and as such pose a shock hazard. Therefore, all items of equipment containing space heaters should be clearly marked indicating the source of the space heater power. These heaters will require 120 VAC, single-phase service year-round.

20-2. Formulas

Standard formulas used to estimate the output ratings of equipment heaters to give a temperature rise above ambient are as follows:

$$Ph = 0.6 \times A \times dT \qquad (20\text{-}1)$$

where

Ph = panel heater output rating (watt)

A = panel external surface area (square feet)

dT = designed temperature rise above ambient (degrees Fahrenheit)

For motor-winding heaters giving a 10-degree-Fahrenheit rise above ambient,

$$Ph = D \times L / 2.52 \qquad (20\text{-}2)$$

where

Ph = motor winding heater output rating (watt)

D = end bell diameter (inches)
= "2D" (frame dimension from NEMA MG1)

L = motor length (inches)
= "2F + 2BA" (frame dimensions from NEMA MG1)

Chapter 21
Station Service Electrical System

21-1. Auxiliary Power Distribution

a. Low-voltage stations. In low-voltage stations, auxiliary loads of 480 volts and below are most conveniently distributed by means of a power panel(s) either mounted in a vertical section of the motor control center or in a strategic location along a station wall. This power panel(s) should be fed from a circuit breaker or fusible disconnect switch in the motor control center. A separate auxiliary or lighting service may be required to obtain the optimum rate schedule from the utility.

b. Medium-voltage stations. In medium-voltage stations, packaged unit substations are available that conveniently incorporate a high-voltage load interrupter switch, a 4160/480-volt transformer section, and a power panel section. It is not necessary to provide a main breaker on the power panel since the high-voltage interrupter switch provides a disconnecting means. Three-phase voltmeters should be provided to monitor the 480-volt service. A separate auxiliary or lighting service may be required to obtain the optimum rate schedule from the utility.

21-2. Lighting System

In general, 208/120-volt, three-phase, four-wire systems are recommended for lighting loads. A minimum of 20-percent spare circuits should be provided for future expansion. Operating floor lights, floodlights, and other lights that may be used for considerable periods of time should usually be of the high-pressure sodium-type due to their efficiency. Where possible, several operating floor fixtures should be furnished with quartz restrike lamps, automatically switched so that light is available immediately upon energization or during restrike. If selected fixtures do not have quartz restrike as an option, several incandescent fixtures should be provided for this purpose. Following are typical foot-candle levels for various pumping station areas:

Location	LUX	(Foot-candles)
Operating Floor	325	30
Control Room	540	50
Lavatory	215	20
Sump Catwalk	215	20
Forebay	55	5
Roadway	10	1

Chapter 22
Station Service Diesel Generator

In stations utilizing engine-driven pumps, it may be more economical to furnish a diesel-generator unit to furnish station auxiliary power requirements (if three-phase is required) than to provide a separate service from a local utility. However, a single-phase service to meet minimal space heating and lighting needs may still be necessary. Economic comparisons should be made to determine the most cost-effective method of supplying auxiliary power. The unit should be rated for continuous service, not for standby or emergency service.

Chapter 23
Station Studies

23-1. Voltage Drop Studies

a. General. A preliminary voltage drop study for motor start-up as well as for motor-running conditions should be made during the initial design phase. The final study should be made during the approval drawing and data review phase of the project. The voltage drop study must be updated whenever the electrical system is revised. Computer programs are available to calculate the system's voltage dips and currents from motor starting to full load speed. For further information on voltage studies, refer to ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants and ANSI/IEEE 339, Power System Analysis.

b. Motor start-up. Motor start-up voltage drop depends on the motor inrush current. Depending upon the method of motor start-up, the inrush current ranges from two to six times the motor full-load current. Excessive starting voltage drop can result in problems such as motor stalling, nuisance tripping of undervoltage relays, motor overload devices, and temporary dips in lighting system brightness or restriking of high-intensity discharge lamps. During motor starting, the voltage level at the motor terminals should be maintained at approximately 80 percent of rated voltage or higher as recommended by the motor manufacturer.

c. Motor running. Undervoltage during the motor running condition may produce excessive heating in the motor windings, nuisance tripping of undervoltage relays and motor-overload devices, dim lighting, and reduced output of electric space heating equipment. Approximately 5-percent voltage drop from the transformer secondary terminals to the load terminals is acceptable.

23-2. System Protection and Coordination Studies

a. General. When a short circuit occurs in the electrical system, overcurrent protective devices such as circuit breakers, fuses, and relays must operate in a predetermined, coordinated manner to protect the faulted portion of the circuit while not affecting the power flow to the rest of the system.

(1) Isolation of faulted section. Isolation of the faulted section protects the electrical system from severe damage. It also results in efficient trouble shooting since the faulted section is downstream of the tripped protective device. Efficient troubleshooting results in reduction of costly repair time and system downtime.

(2) One-line diagram of electrical system. A one-line drawing of the electrical system is an important element of the protection and coordination study. The one-line diagram is discussed in detail in paragraph 23-3*c*.

b. Procedures. The coordination study is accomplished by overlaying protective device characteristic curves over equipment damage curves. This method is applicable in the range of fault clearing times greater than approximately 0.016 seconds (1 cycle) on a 60-Hz basis. For clearing times faster than this, as is the case for protecting solid state inverters, protection and coordination studies are achieved by comparing let-through energy (I-squared-t) values of current-limiting fuses (CLFs) to withstand energy values of the equipment being protected. Similarly, coordination between CLFs is achieved by comparing values of let-through energy of upstream fuses with the values of the melting energy of the downstream fuses.

(1) Protection and coordination study. A protection and coordination study may be performed manually or with the aid of a computer. Computer software is available with pre-programmed time-current characteristic curves. The result of the computer study can be automatically drawn onto standard time-current characteristic paper by the computer printer.

(2) Additional information. For further information on protection and coordination studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. Main disconnecting device. The utility supplying the power to the facility should be consulted regarding the type of protective device it recommends on the load side of the supply line which best coordinates with the source side protective device furnished by the utility.

d. Motors. Protective device characteristics must be coordinated with motor start-up characteristics. The devices must be insensitive enough to allow motors to start up without nuisance tripping caused by the relatively high magnitude of motor start-up current. The devices must be sensitive enough, however, to operate during overload or short-circuit conditions.

e. Transformers. Transformer protection is similar to that of motor protection as discussed above. The protective device must be insensitive to the transformer magnetizing in-rush current, but sensitive enough to operate for a short circuit condition. Note, the new ANSI standard on transformer protection (ANSI/IEEE C57.109) could be used as an alternative to the classic method of transformer protection. Transformer magnetizing inrush should be specified as 8 X full-load current for transformers rated less than 3 MVA, and 12 X full-load current, otherwise.

f. Cables. Cable protection requires coordinating the protective device characteristics with the insulation smolder characteristics of the power cable. The insulation smolder characteristics of the cable are the same as the "short-circuit withstand" and "short-circuit heating limits" of the cable.

g. Specification requirements. The pump station construction specifications should require the contractor to furnish the completed protection and coordination study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clearly stated in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to produce a complete and accurate protection and coordination study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The construction specifications should require the contractor to submit the following items as one complete submittal:

(1) Full-size reproducibles of protective device characteristic curves.

(2) The motor-starting characteristics in the form of time versus current curves or data points.

(3) Data indicating the short-circuit withstand capability of motor control centers, panelboards, switchgear, safety switches, motor starters, and bus bar and interrupting capacities of circuit breakers and fuses.

(4) Transformer impedance data. These data should be submitted in one of three forms: percent IR and percent IX, percent IZ with X/R ratio, or percent IZ with no load and total watt losses.

(5) Cable insulation smolder temperature.

(6) Completed time-current coordination curves indicating equipment damage curves and device protection characteristics.

(7) A marked-up one-line diagram indicating ratings and trip sizing of all equipment.

23-3. Short-Circuit Studies

a. General. Short-circuit calculations are necessary in order to specify equipment withstand ratings and for use in conjunction with the protective device coordination study. Switchgear, motor control centers, safety switches, panelboards, motor starters, and bus bar must be capable of withstanding available fault currents. After the available fault current has been calculated at each bus in the electrical network, the available fault current withstand ratings are specified.

(1) Circuit breakers. Circuit breakers must be capable of withstanding the mechanical and thermal stresses caused by the available fault currents. They must be able to remain closed even though tremendous forces are present in such a direction as to try to force the breaker contacts open. The ability of circuit breakers to remain closed is indicated by their momentary ratings. The momentary rating is a function of the circuit breakers interrupting rating, which is the ability to interrupt a fault current without incurring excessive damage to the breaker.

(2) Fuses. Fuses must also be capable of safely interrupting fault current and are rated in terms of interrupting capacity.

(3) Motor starters. Motor starters furnished with motor circuit protectors are available with short-circuit withstand ratings up to 100,000 amperes. Starters furnished with fusible switches are available with withstand ratings up to 200,000 amperes.

b. Procedures. The basic elements of a short-circuit study are the short-circuit calculations and the one-line diagram of the electrical system. For pumping stations the three-phase bolted fault is usually the only fault condition that is studied. Utility systems line-to-ground faults can possibly range to 125 percent of the three-phase value, but in pumping plants line-to-ground fault currents of greater magnitude than the three-phase value are rare. Line-to-line fault currents are approximately 87 percent of the three-phase fault current.

(1) Preliminary short-circuit study. A preliminary short-circuit study should be prepared during the design phase of the project. The final study should be prepared by the pump station construction contractor as described below.

(2) Calculations. The magnitude of the fault currents can be calculated using long-hand methods. However, software is available to reduce preparation time and simplify the task for large complex systems.

(3) Additional information. For further information on short circuit studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. One-line diagram. Plate 13 indicates the format of the one-line diagram developed as part of the preliminary and final protection and coordination and short-circuit studies. Plates 15 and 16 are typical of one-line diagrams to be issued with the plans and specifications.

(1) Standard symbols. Standard symbols for use on the one-line diagram are listed in ANSI Y32.2. Any nonstandard symbols that are used to show special features or equipment should be explained in the drawing legend to make their meaning entirely clear.

(2) Check list. The following is a check list of items that should be included on the study one-line diagram:

(a) Fault current. This is the available three-phase fault current of the utility supply at the pumping station metering point. This information can be presented in amperes, MVA, or as an impedance to the utility infinite bus (impedance in ohms or per unit on a specified base). The designer should also request the utility to provide an estimate of future three-phase fault levels. The estimate provides an indication of utility system changes which may affect the future short-circuit interrupting capability and withstand ratings of installed electrical equipment.

(b) Bus voltage.

(c) Transformers. The diagram should show winding connections, KVA rating, percent impedance, the X/R ratio, neutral grounding, if any, including the neutral ground impedance value, if not solidly grounded.

(d) Power cables. The diagram should show size, length, conductor material, whether single or multi-conductor, and whether the cable is carried in a magnetic or nonmagnetic duct.

(e) Circuit breakers. The diagram should show type by appropriate symbol (for example, molded case or draw-out) and the following ampere ratings: interrupting rating, frame size, thermal trip setting, and magnetic trip setting. It should show also the range of adjustment of the magnetic trip, if adjustable, as well as the recommended setting as determined by a protective device coordination study.

(f) Switches and fuses. The diagram should show type of fuse or switch and the continuous and interrupting rating in amperes.

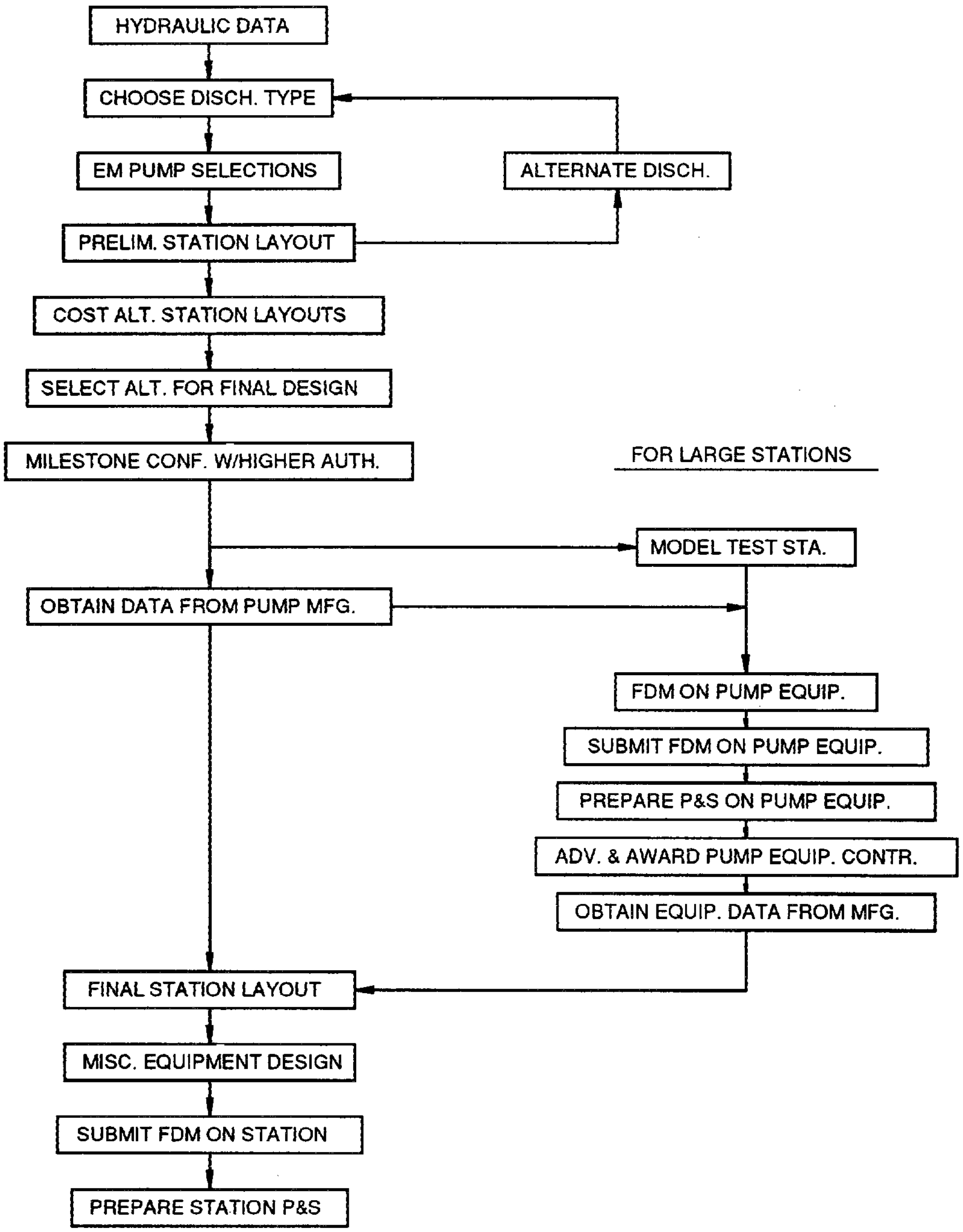
(g) Motors. The following should be given: horsepower or kilowatt rating, power factor, synchronous or induction type, mechanical speed (revolutions per minute), and subtransient reactance. The following additional data are required for synchronous machines: transient reactance, synchronous reactance, and the impedance of any grounding resistor.

(h) Location(s) where power purchased from a utility company is metered.

(i) The following information is required for preparation of the protection and coordination study: locations of potential and current transformers and relays and metering. Show location, quantity, and types of relays by standard IEEE device numbers, such as 51 for overcurrent relays, 67 for directional overcurrent relays. Device numbers are listed in ANSI/IEEE C37.2.

d. Specification requirements. The pump station construction specifications should require the contractor to furnish the final short-circuit study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clear in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to produce a complete and accurate short-circuit study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The specifications must state that the cable sizes, ampere ratings of the protective devices, and the short-circuit withstand ratings of the equipment shown on the one-line diagram are preliminary and that the contractor shall furnish a complete and final one-line diagram upon completion of the coordination and protection and short-circuit studies.

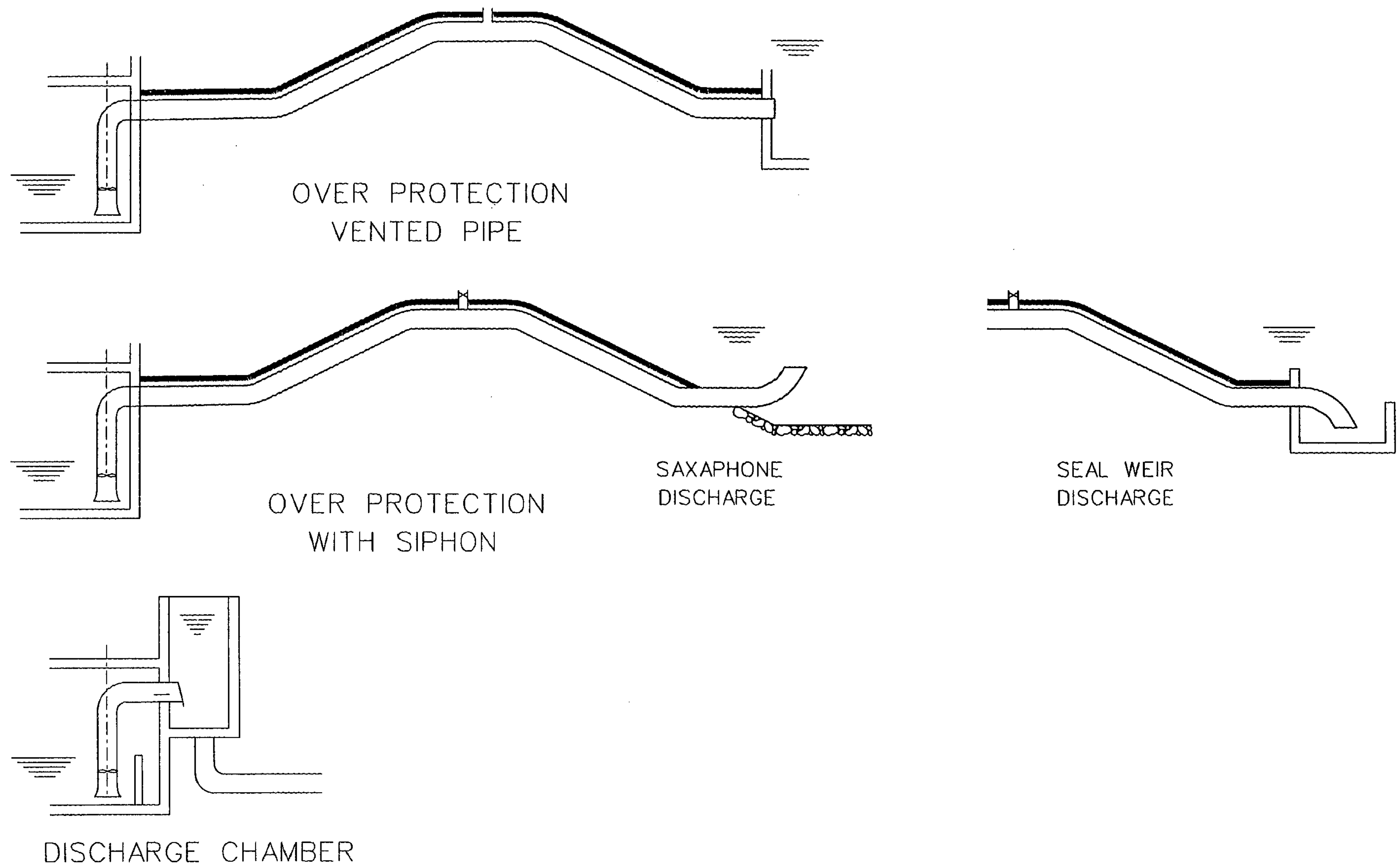
Chapter 24
List of Plates

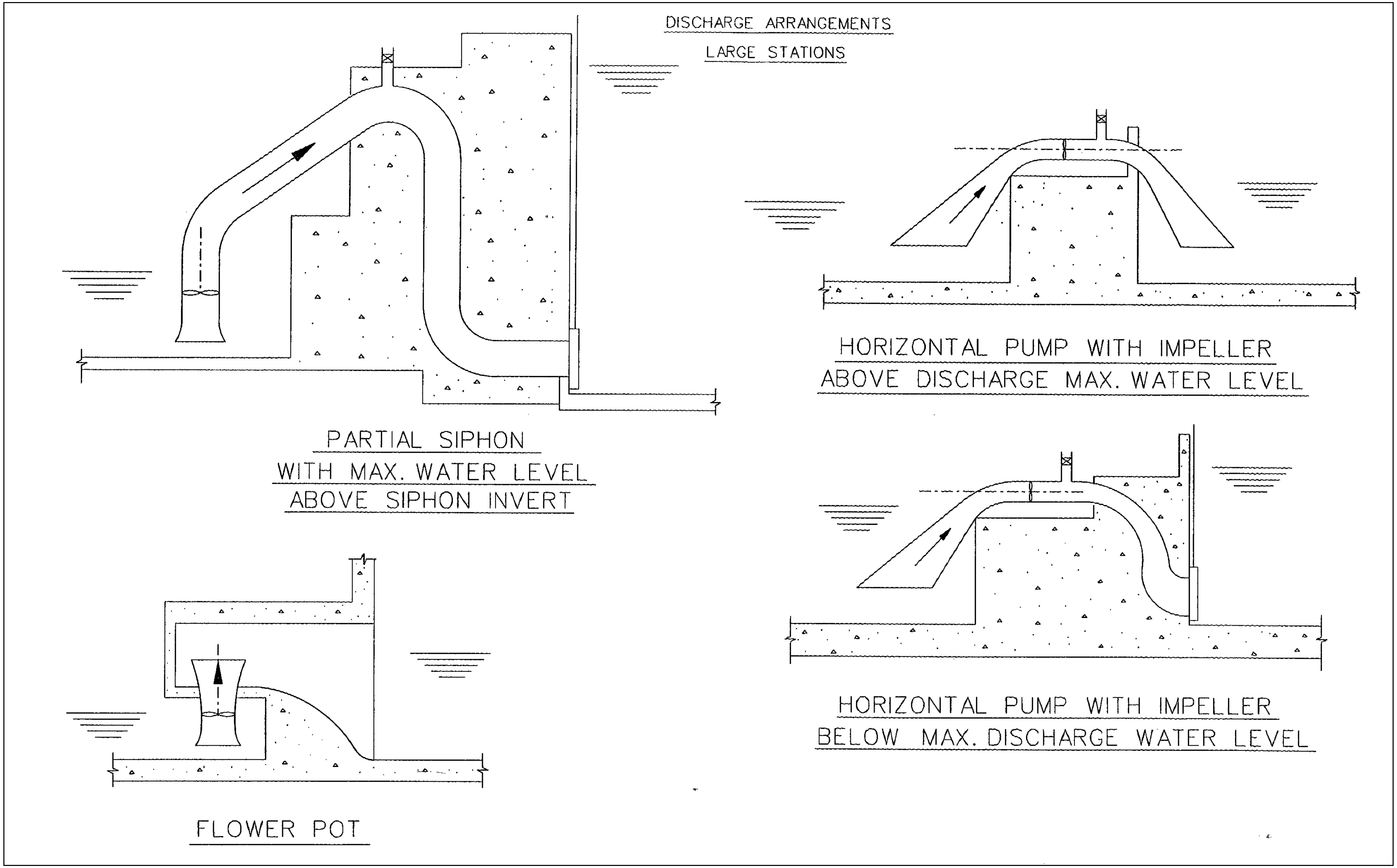


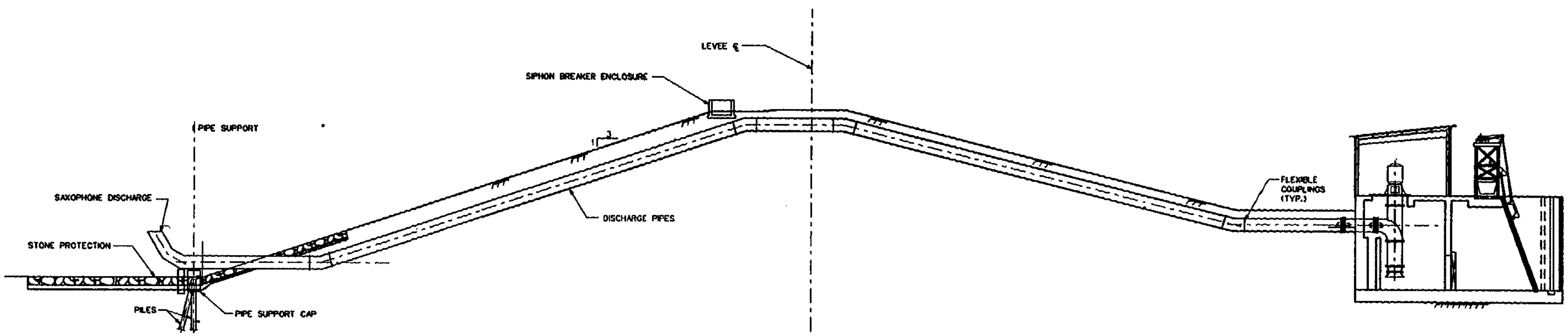
DESIGN PROCEDURES

DISCHARGE ARRANGEMENTS

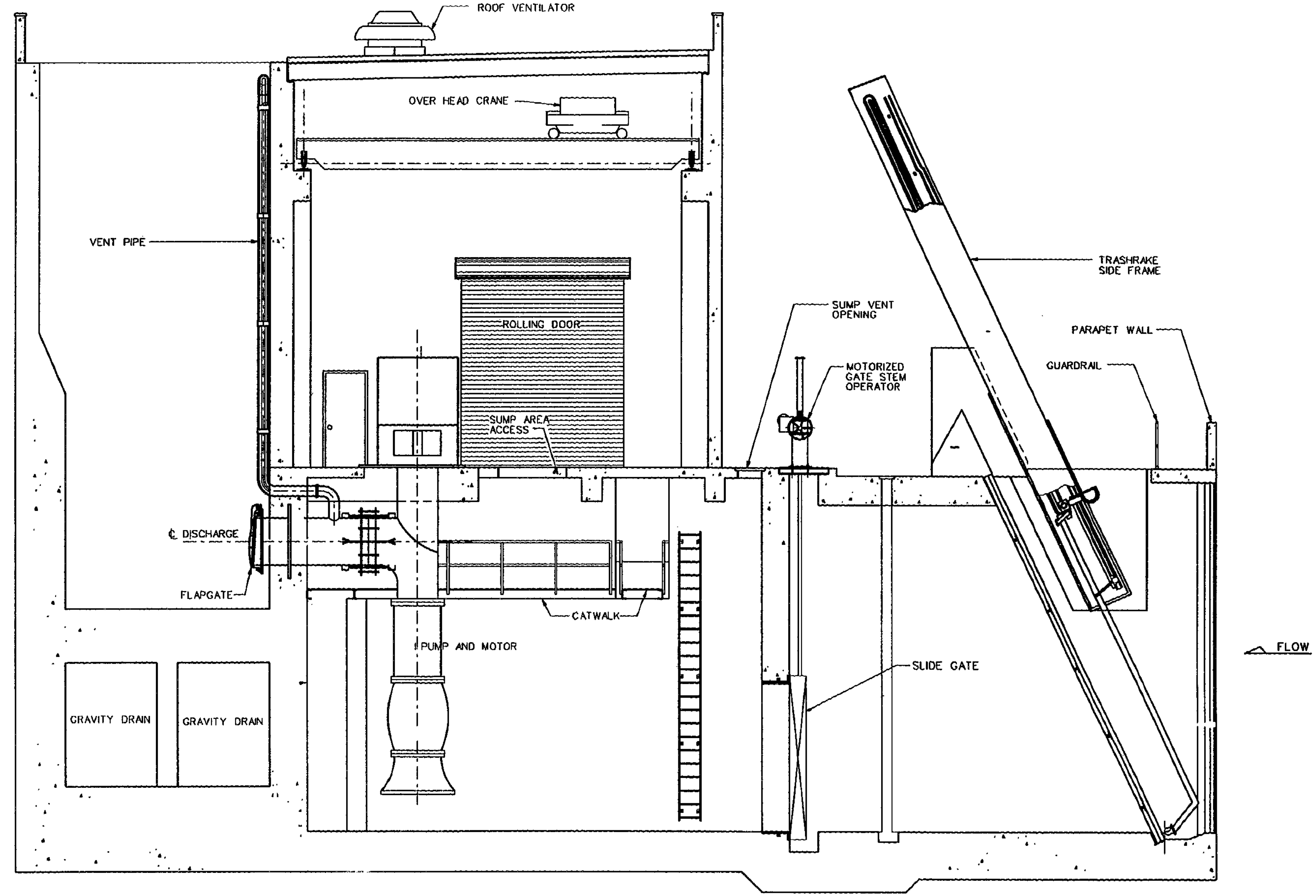
CONVENTIONAL STATIONS



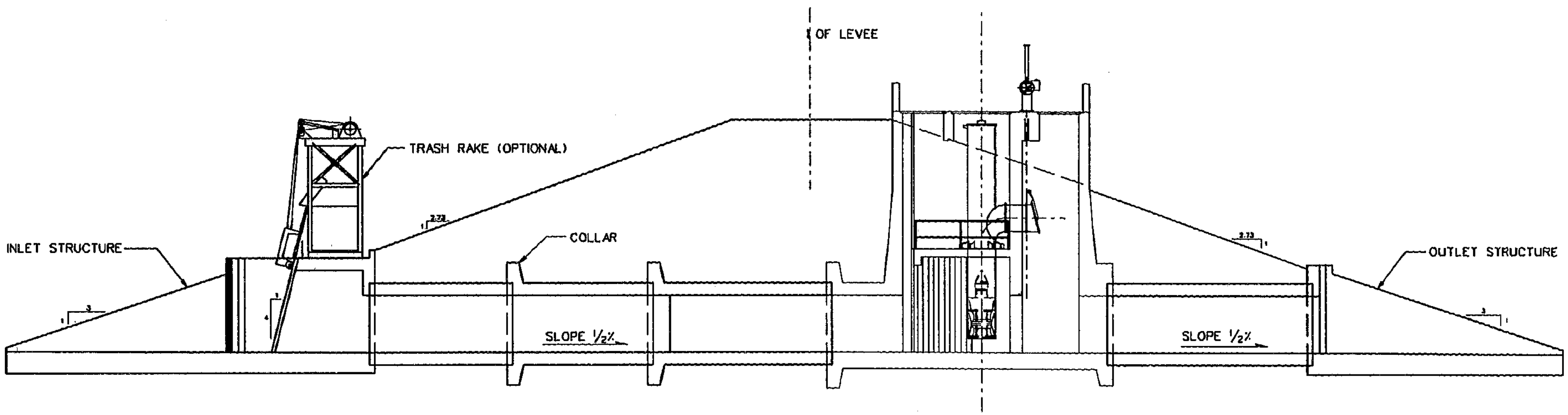

DISCHARGE ARRANGEMENTS
LARGE STATIONS
PARTIAL SIPHON
WITH MAX. WATER LEVEL
ABOVE SIPHON INVERT
HORIZONTAL PUMP WITH IMPELLER
ABOVE DISCHARGE MAX. WATER LEVEL
HORIZONTAL PUMP WITH IMPELLER
BELOW MAX. DISCHARGE WATER LEVEL
FLOWER POT



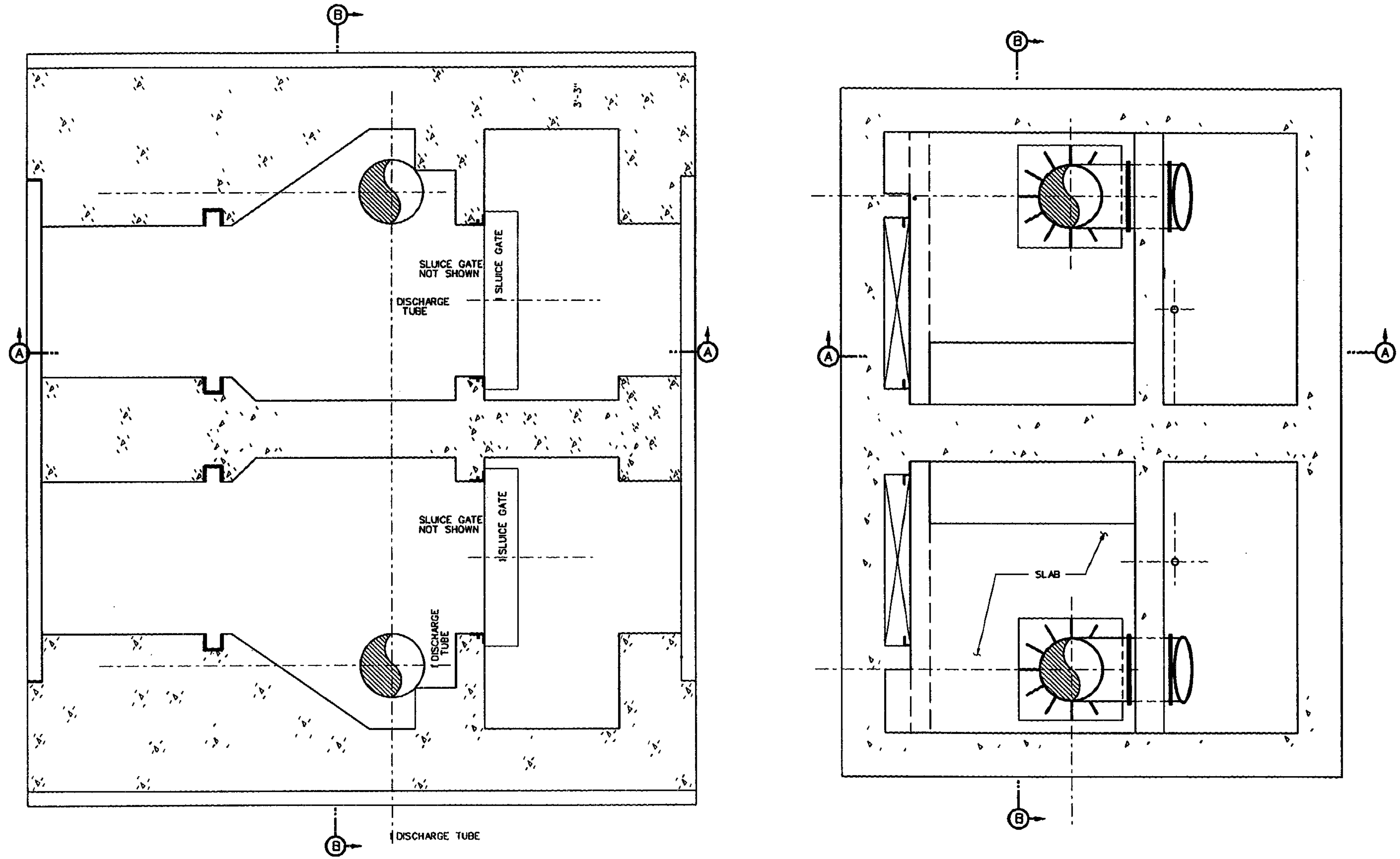
PUMP STATION WITH OVER THE PROTECTION DISCHARGE



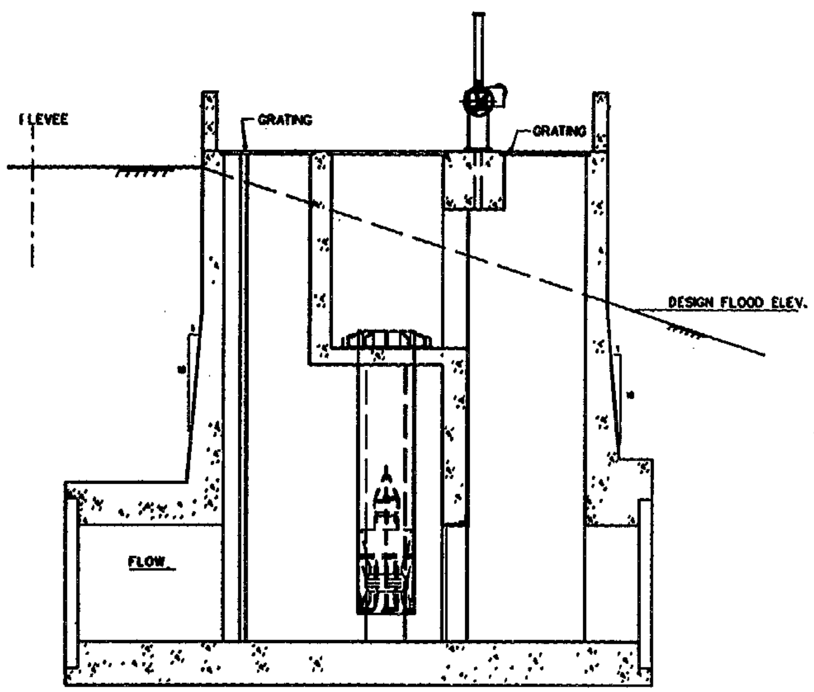
DISCHARGE CHAMBER PUMP STATION



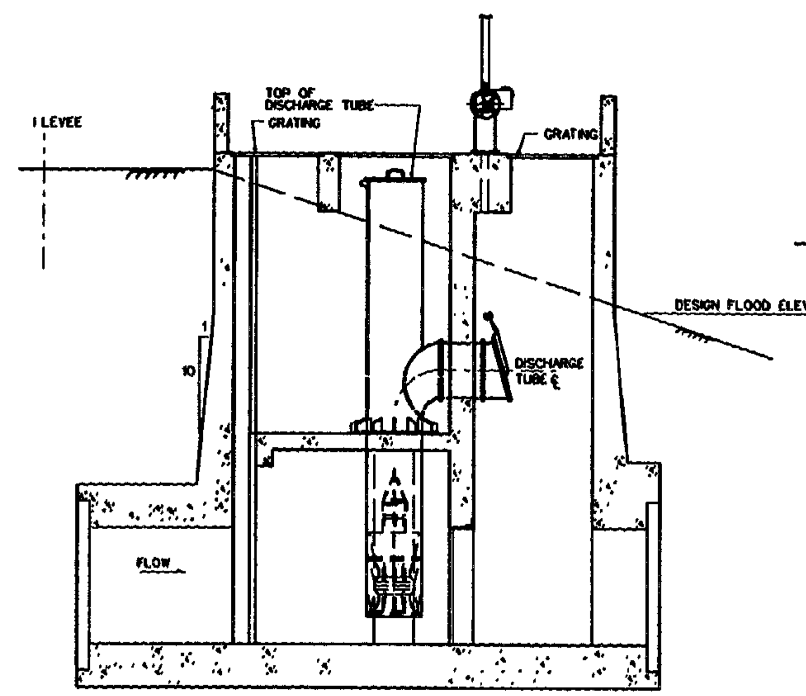
COMBINATION GATEWELL/PUMP STATION USING SUBMERSIBLE PUMPS



PLAN VIEWS: COMBINED GATEWELL/PUMP STATIONS

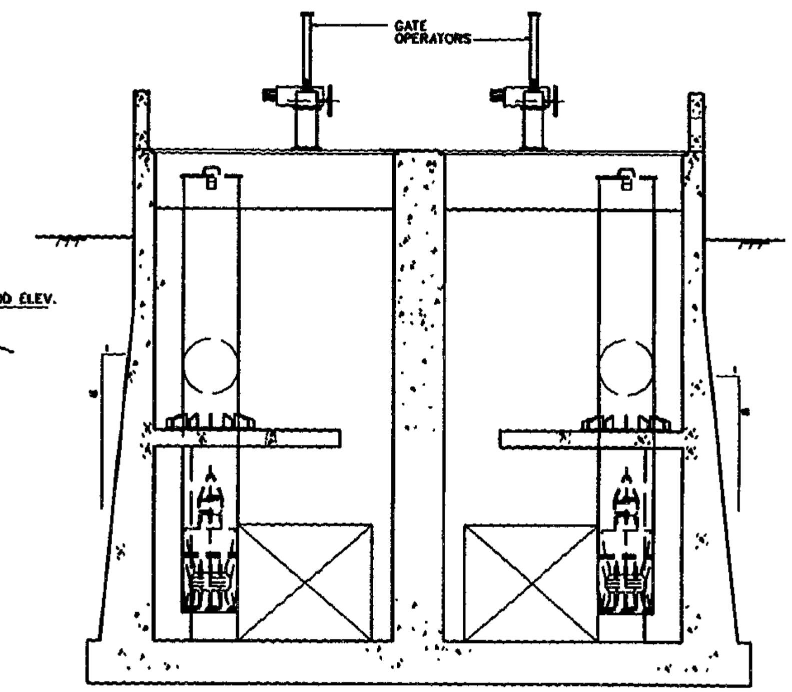


"FREE-FALL" DISCHARGE



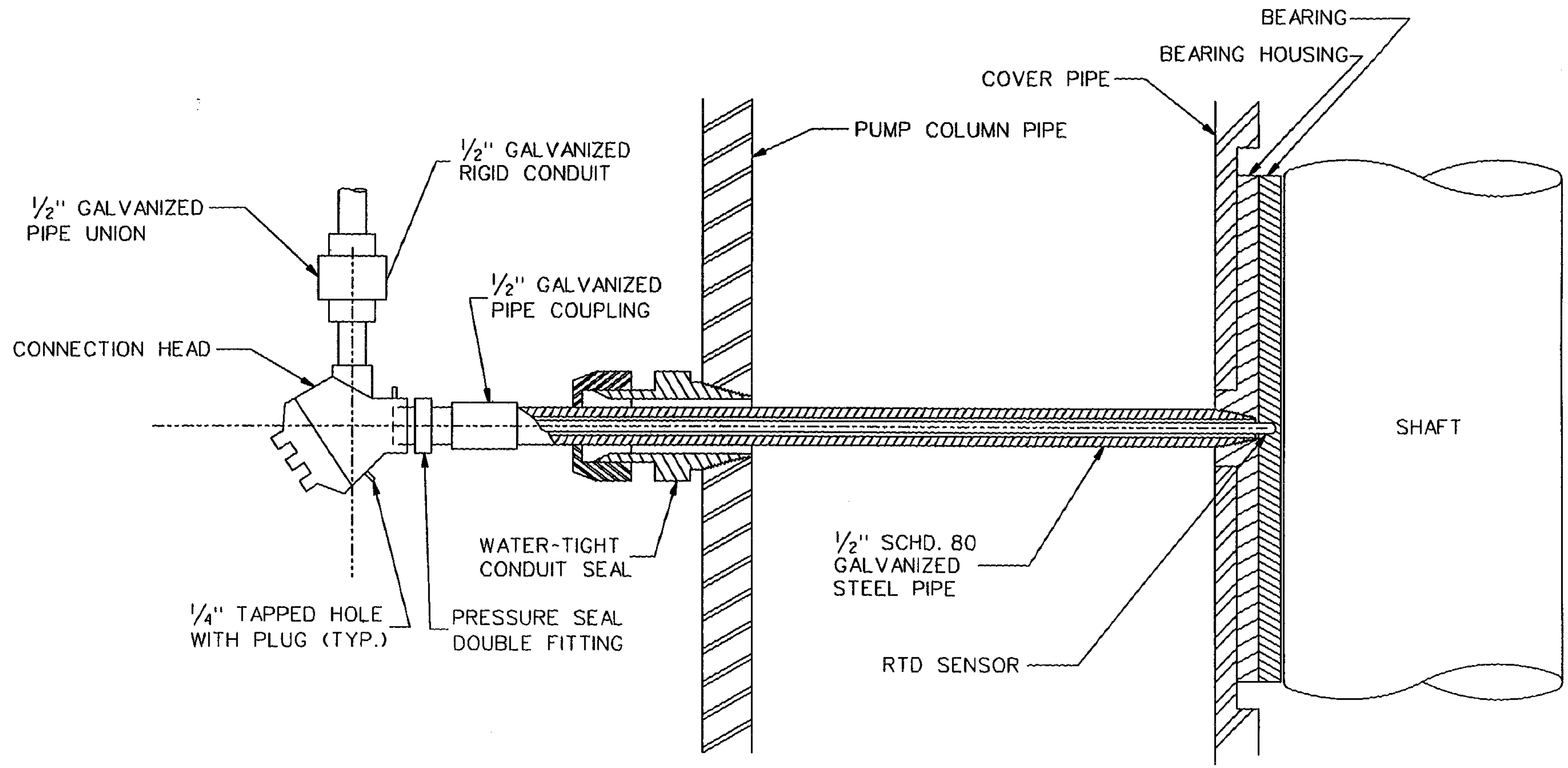
"FLAP GATE" DISCHARGE

SECTION A-A FROM PLATE G-7

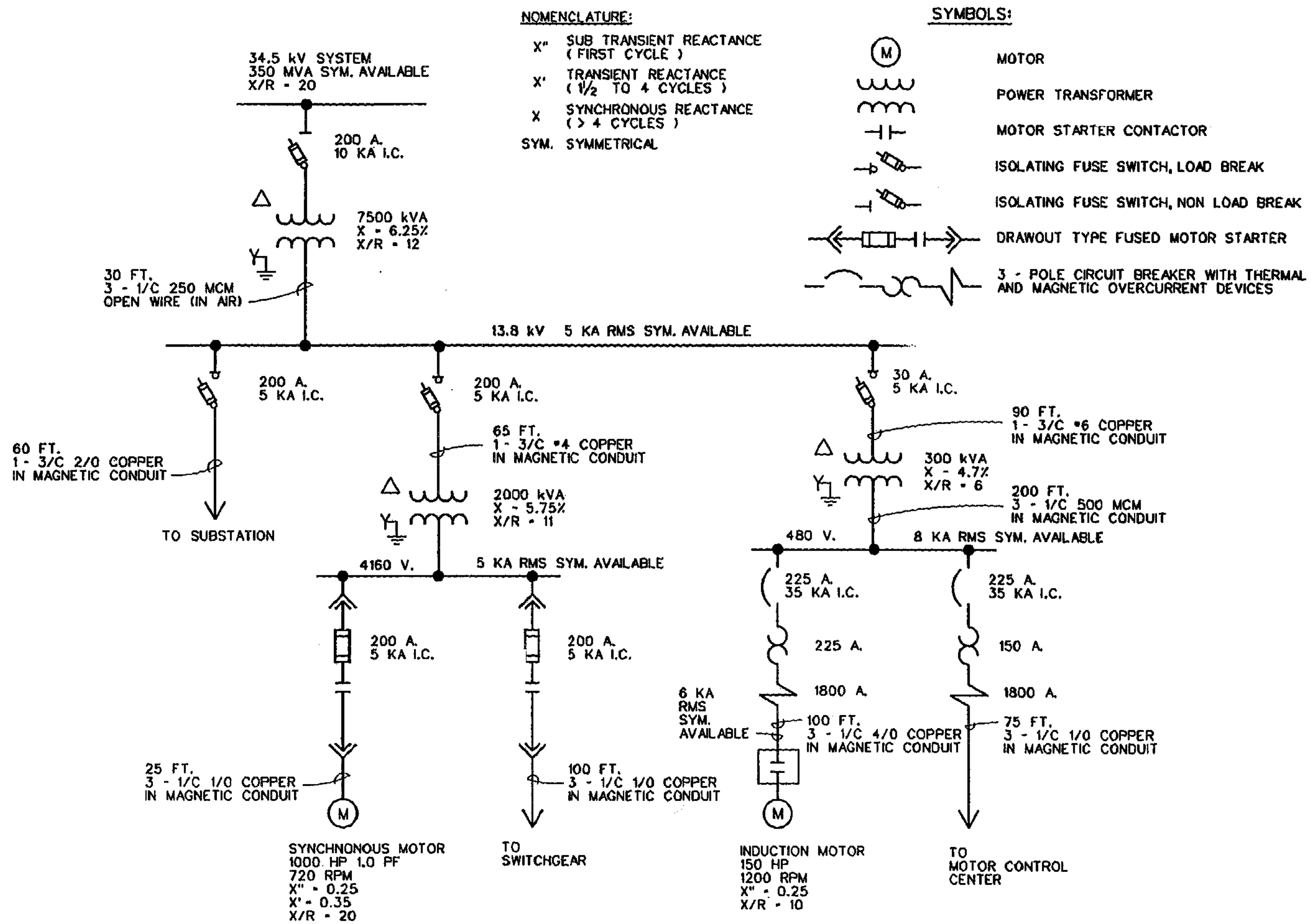


SECTION B-B FROM PLATE G-7

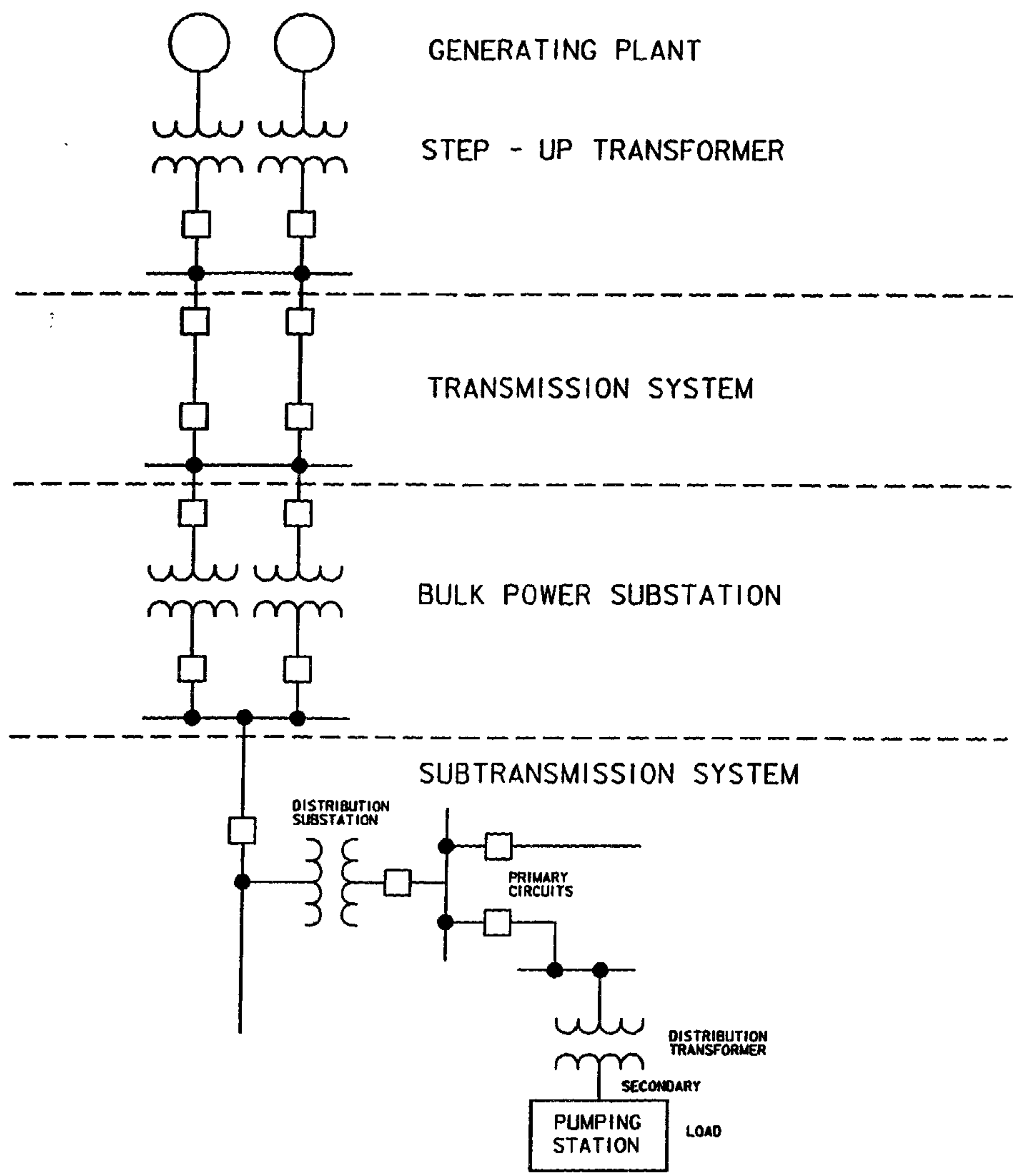
PROFILES: COMBINED GATEWELL/PUMP STATIONS



RTD INSTALLATION FOR VERTICAL WET PIT PUMPS



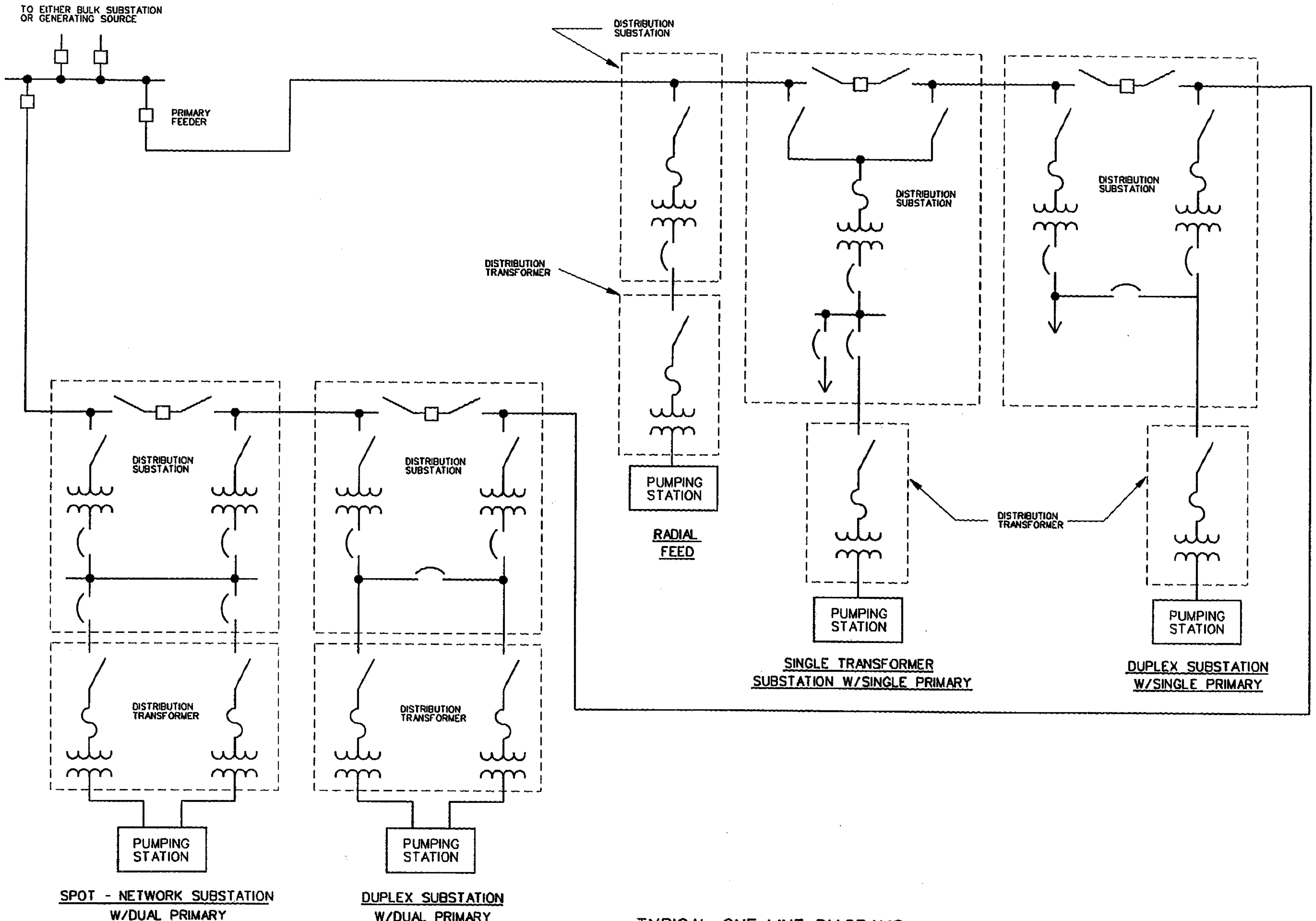
PUMPING STATION
ONE LINE DIAGRAM
FOR ELECTRICAL SYSTEM STUDIES



COMPONENTS OF AN ELECTRIC POWER SYSTEM

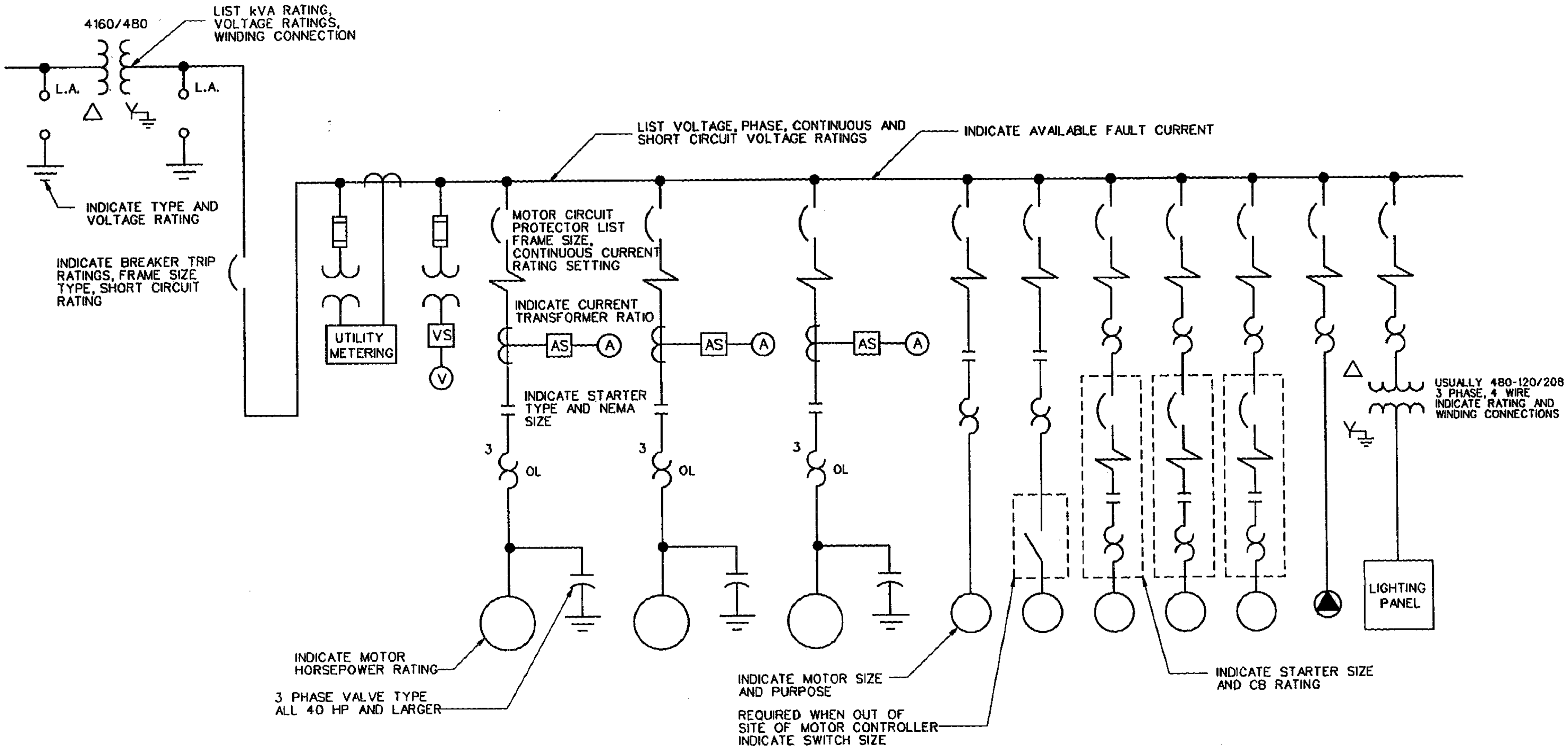
PUMPING STATION

POWER SUPPLY SYSTEM CONFIGURATIONS



TYPICAL ONE-LINE DIAGRAMS FOR DISTRIBUTION TYPE–SUBSTATIONS

PUMPING STATION
POWER SUPPLY SYSTEM CONFIGURATIONS

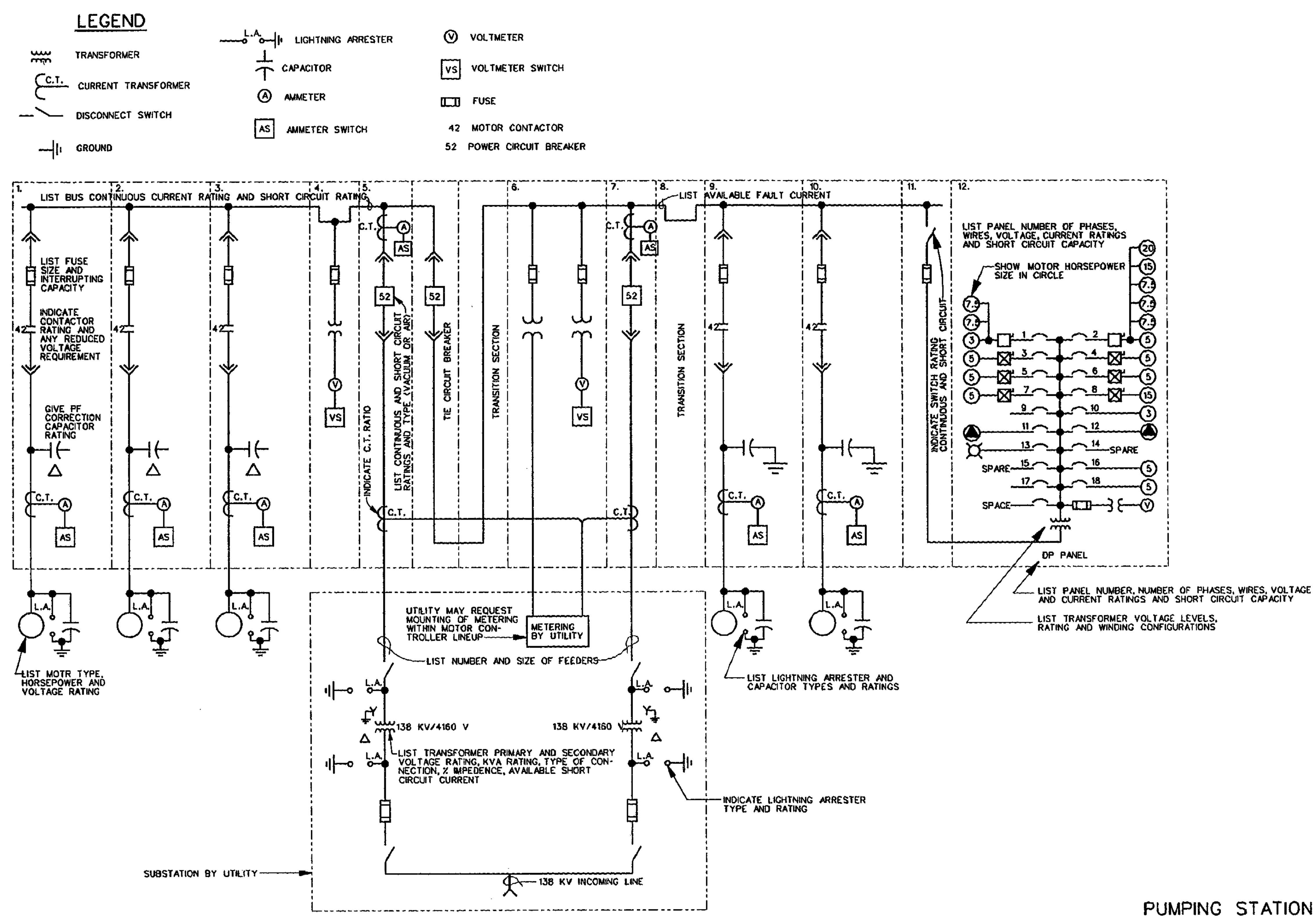


ONE LINE DIAGRAM

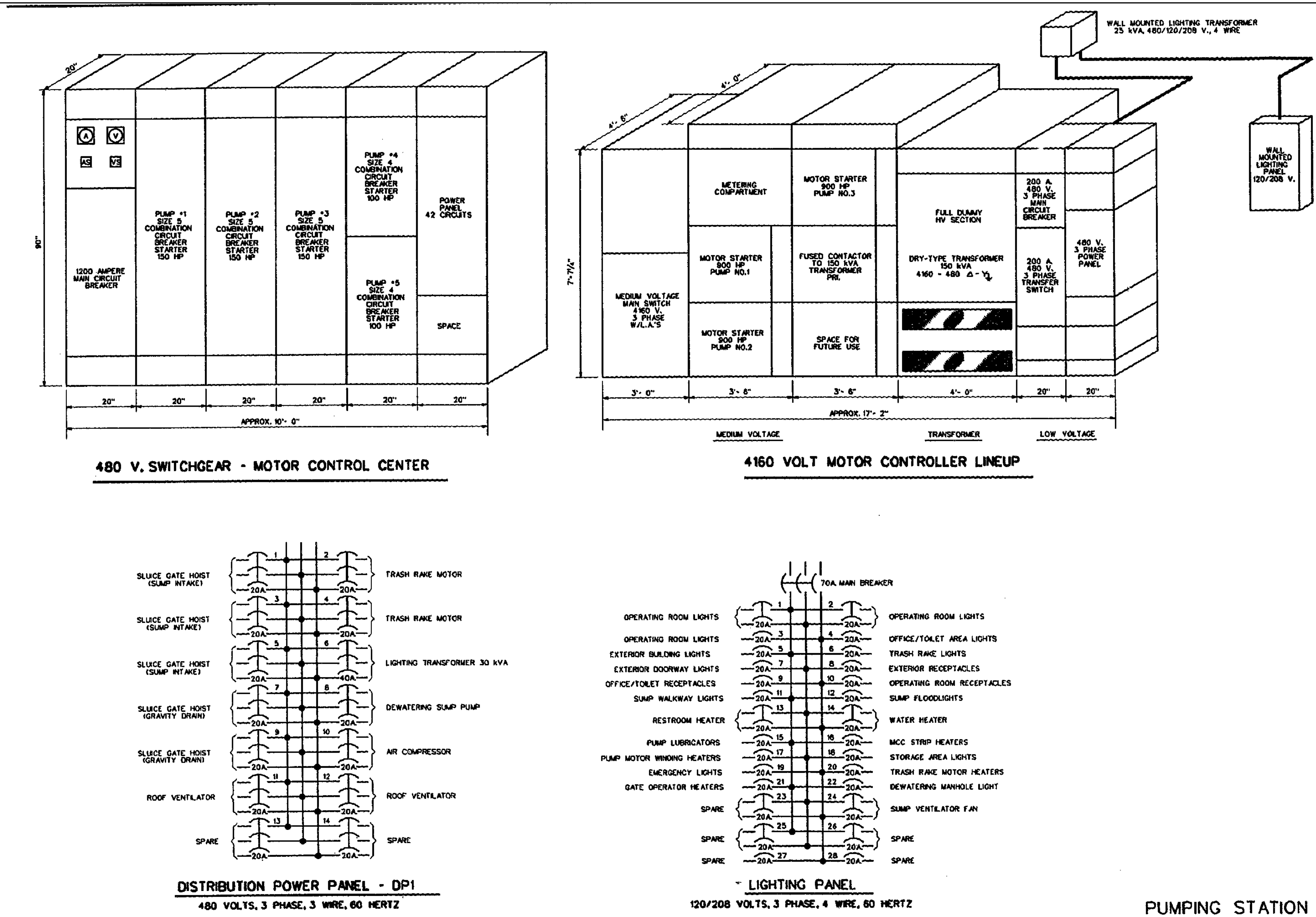
NO SCALE

PUMPING STATION

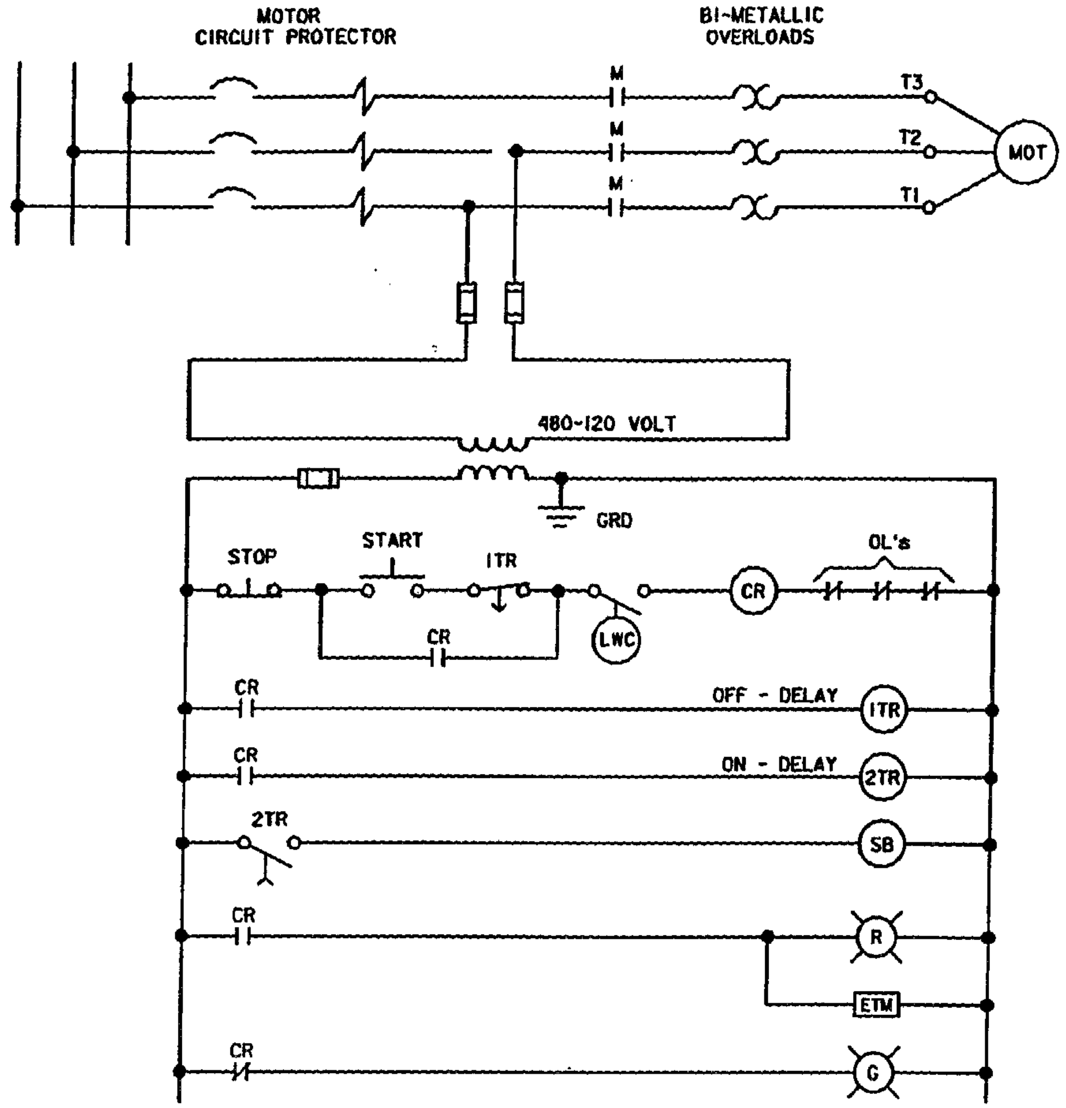
TYPICAL LOW VOLTAGE STATION ONE-LINE



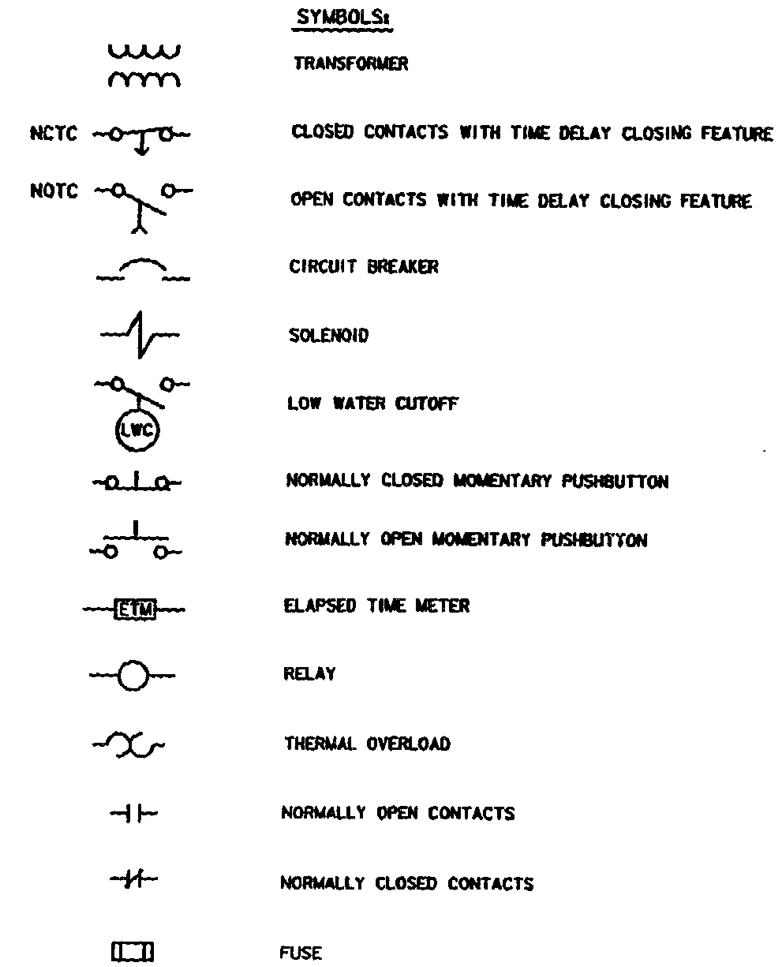
PUMPING STATION
TYPICAL MEDIUM VOLTAGE STATION ONE-LINE



PUMPING STATION
TYPICAL CONTROLLER LINEUP
AND POWER & LIGHTING PANEL LAYOUTS



FULL VOLTAGE NON-REVERSING CIRCUIT BREAKER TYPE



NOMENCLATURE:

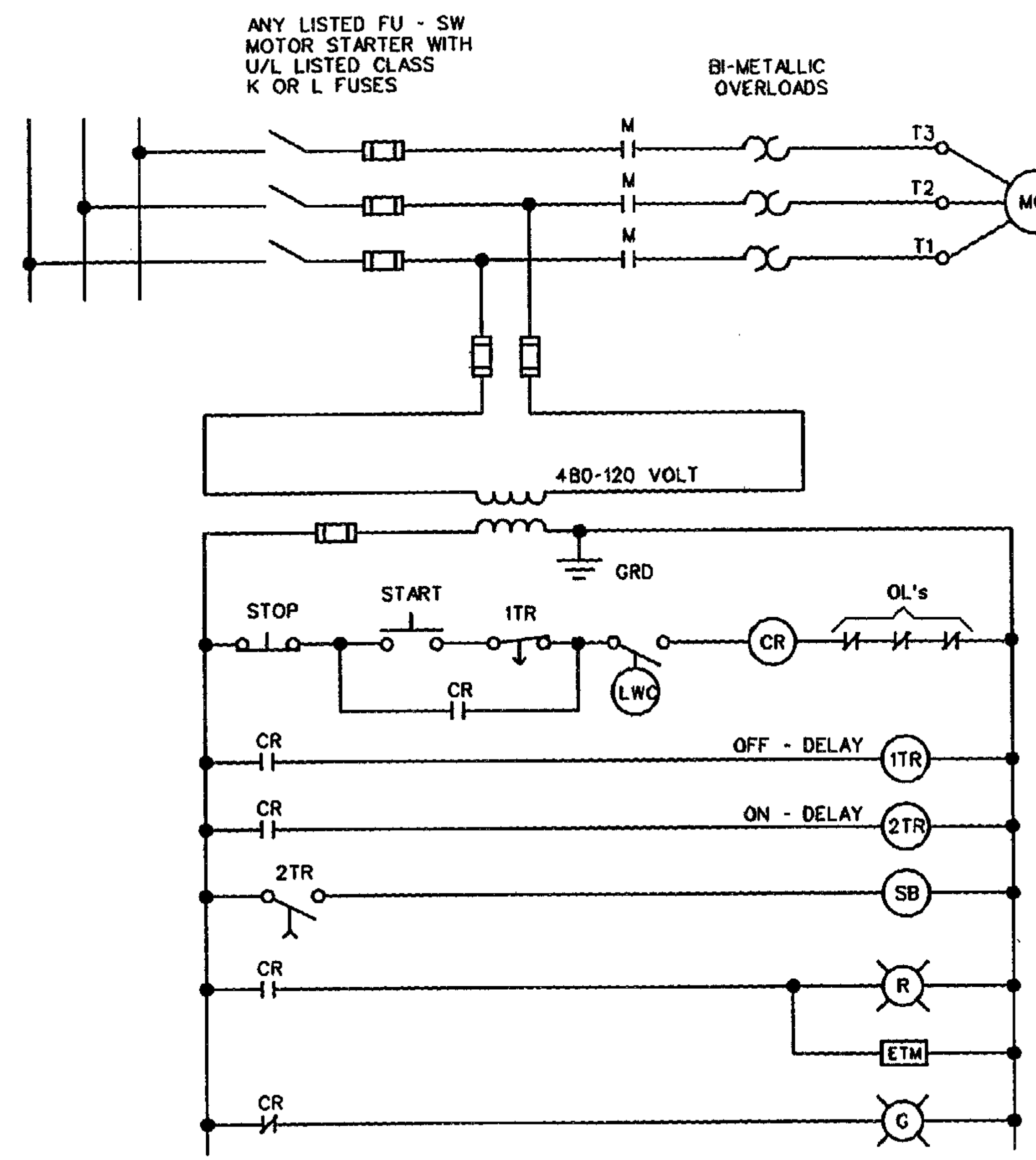
AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD,GND	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS ON STARTER OR MOTOR
SB	SIPHON BREAKER
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
TR	TIMING RELAY
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)

NOTE:

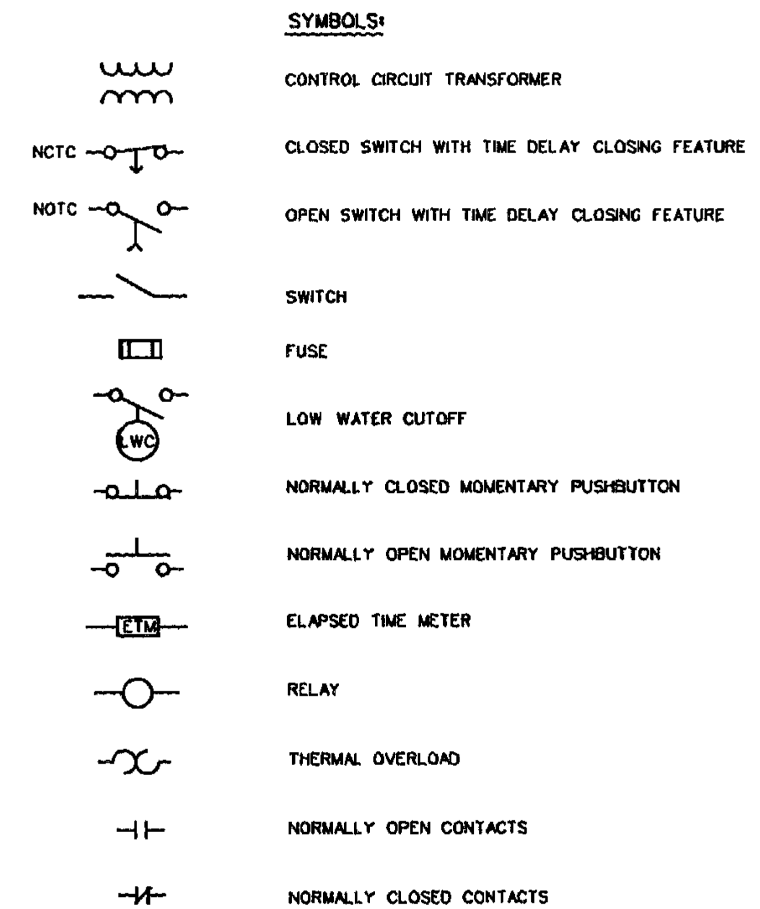
1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION

TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



FULL VOLTAGE NON-REVERSING FUSIBLE SWITCH TYPE



NOMENCLATURE:

AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS
SB	SIPHON BREAKER
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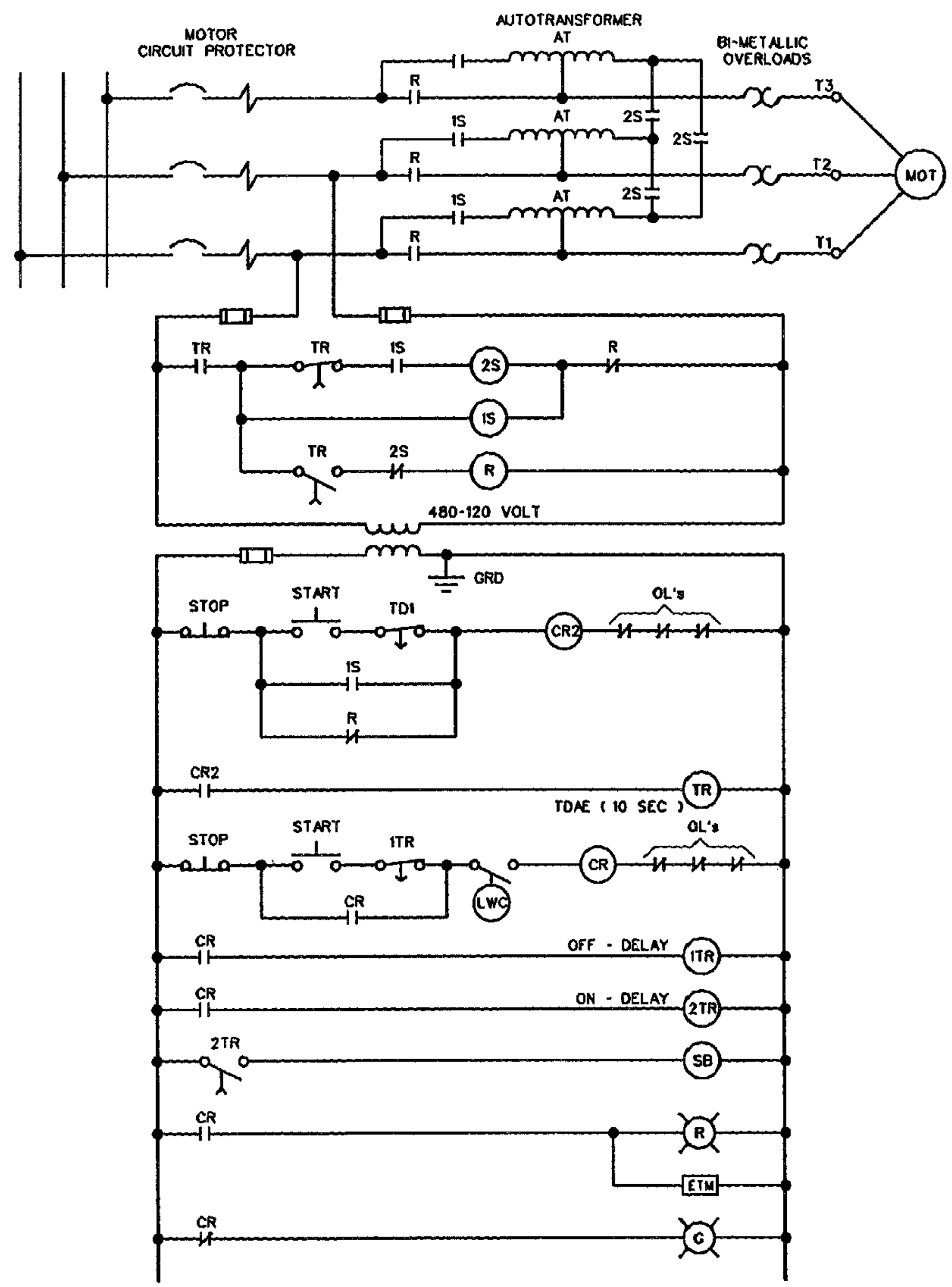
NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

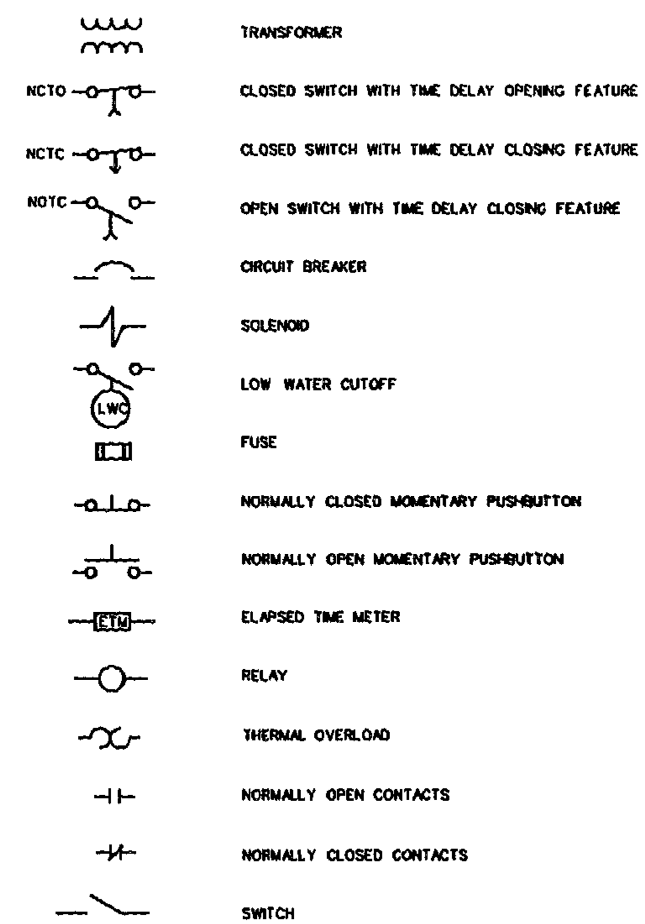
PUMPING STATION

TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



REDUCED-VOLTAGE NON-REVERSING
AUTOTRANSFORMER TYPE (CLOSED TRANSITION)

SYMBOLS:



NOMENCLATURE:

AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS
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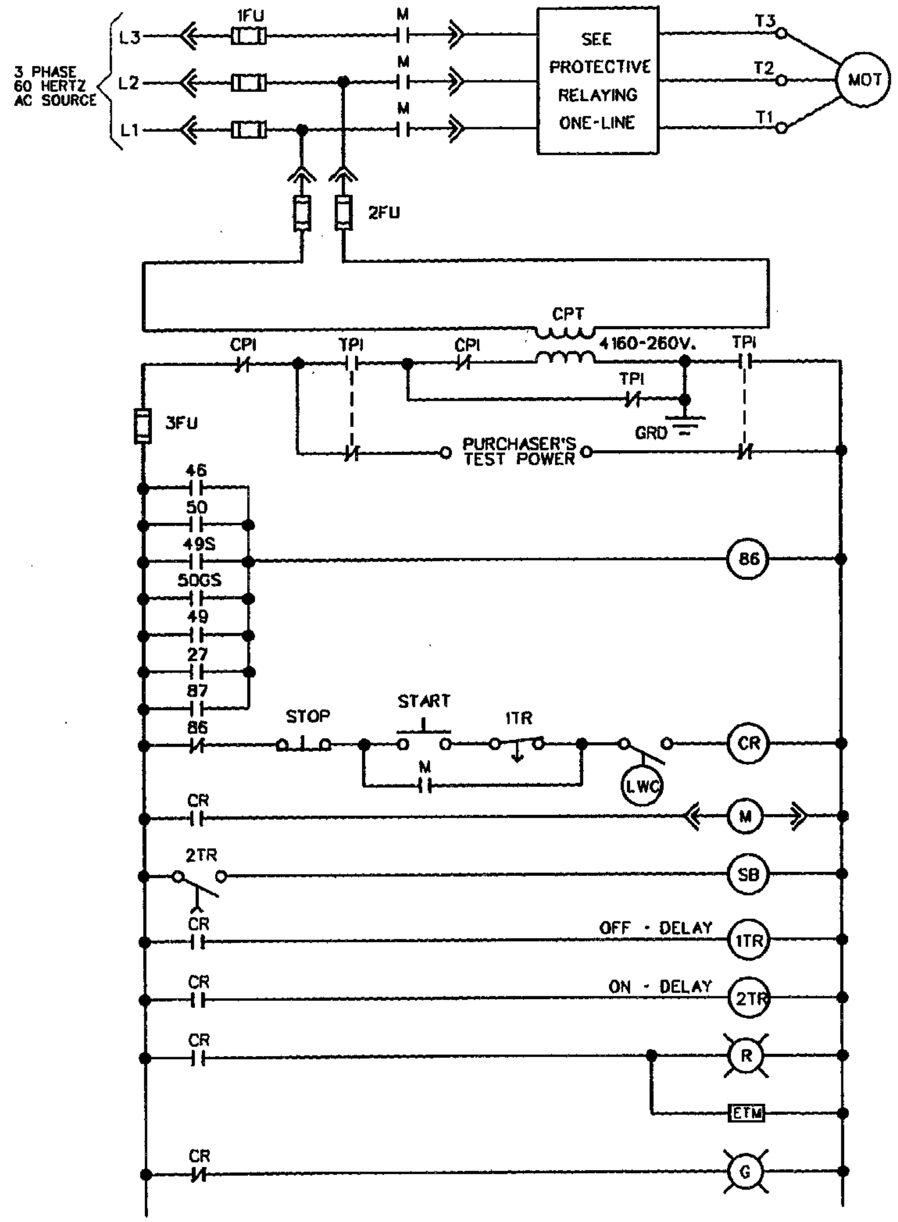
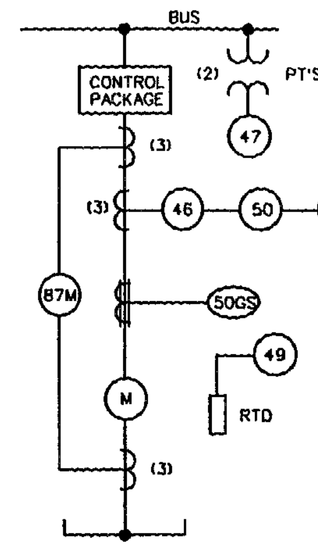
NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION
TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



TYPICAL INDUCTION - MOTOR CONTROL FULL VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING FULL-VOLTAGE NON-REVERSING INDUCTION MOTOR

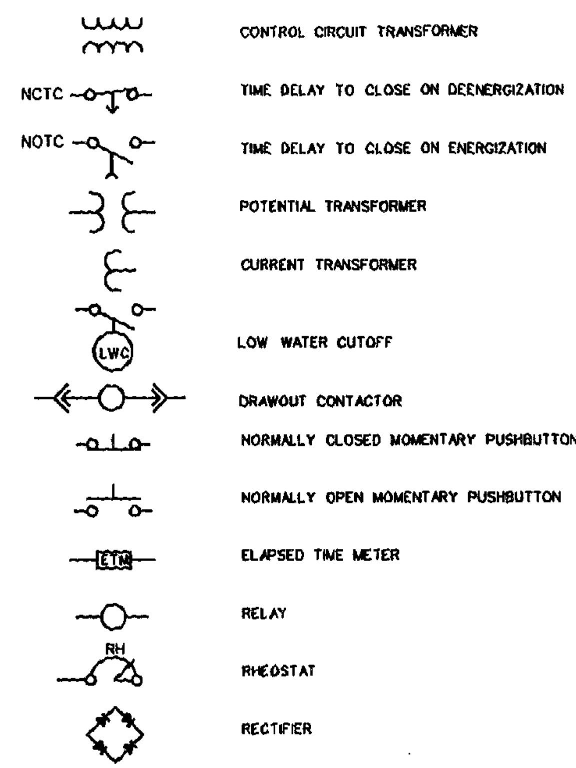
NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK
1,2,3, CT	CURRENT TRANSFORMER
1,2,3, FU	FUSE
GRD	GROUND
M	LINE CONTACTOR
MOT	MOTOR
CPT	CONTROL POWER TRANSFORMER
TPI	TEST POWER INTERLOCK
L1,L2,L3	INCOMING TERMINALS
T1,T2,T3	OUTGOING TERMINALS
A	AMMETER
SB	SIPHON BREAKER
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
ETM	ELAPSED TIME METER
CR	CONTROL RELAY

DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

SYMBOLS:

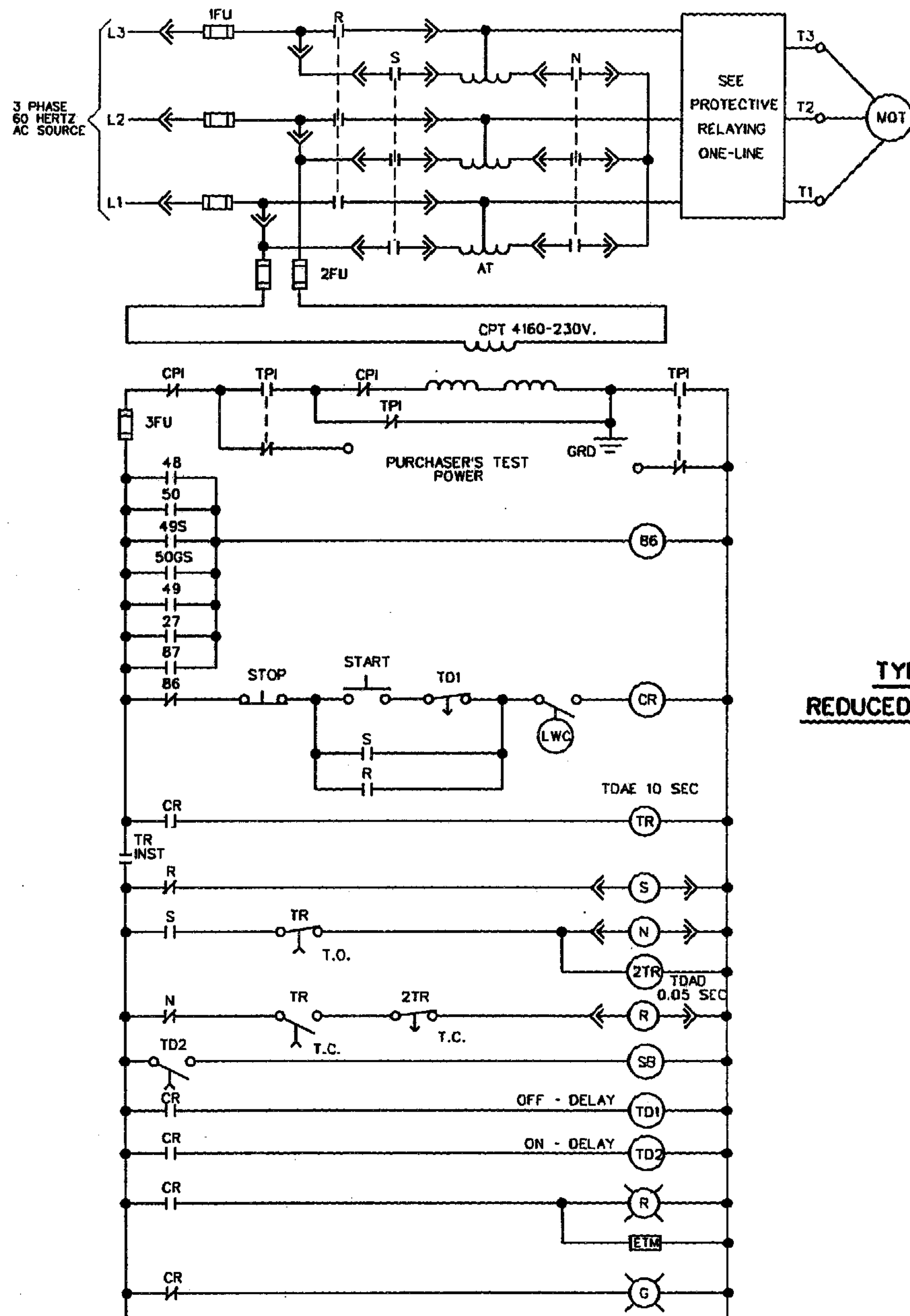


NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

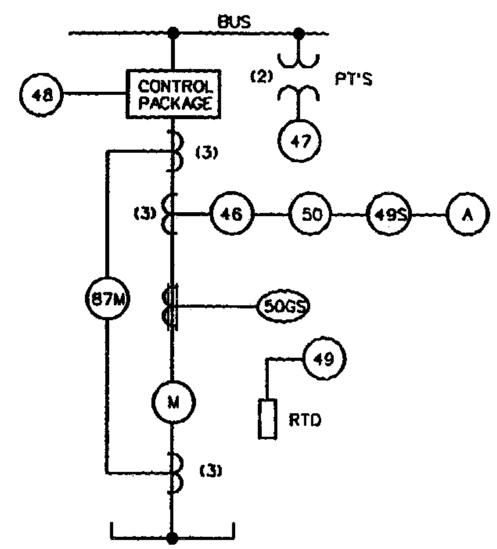
PUMPING STATION

TYPICAL MEDIUM VOLTAGE FULL - VOLTAGE
INDUCTION NON - REVERSING CONTROL SCHEMATIC
RELAY LOGIC



TYPICAL INDUCTION - MOTOR CONTROL

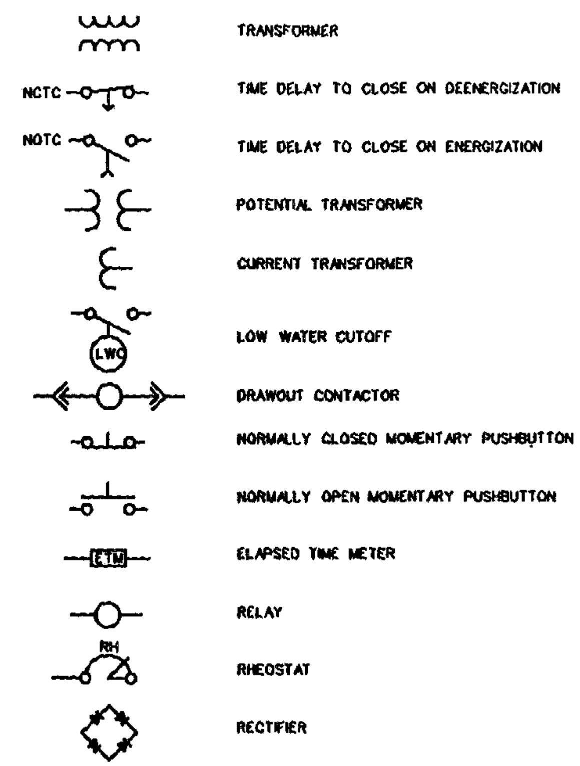
AUTOTRANSFORMER REDUCED-VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING

REDUCED-VOLTAGE NON-REVERSING INDUCTION MOTOR

SYMBOLS:



NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK
1,2,3, CT	CURRENT TRANSFORMER
1,2,3, FU	FUSE
GRD	GROUND
M	LINE CONTACTOR
MOT	MOTOR
CPT	CONTROL POWER TRANSFORMER
TPI	TEST POWER INTERLOCK
L1,L2,L3	INCOMING TERMINALS
T1,T2,T3	OUTGOING TERMINALS
A	AMMETER
SB	SIPHON BREAKER
TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
S	STARTING CONTACTOR
R	RUN CONTACTOR
N	NEUTRAL
TR	TIMING RELAY FOR REDUCED VOLTAGE
2TR	TRANSITION TIMER

DEVICE NUMBERS:

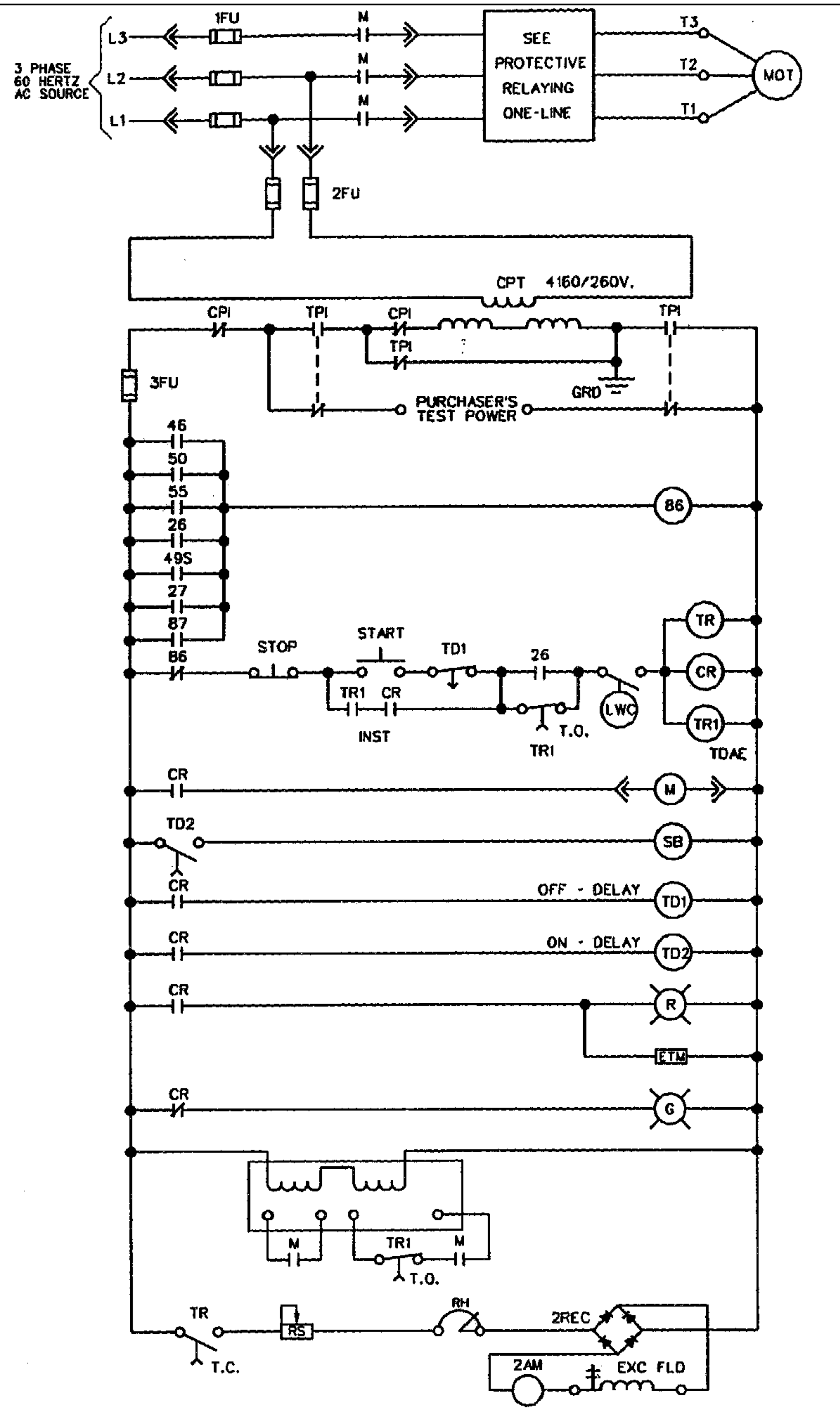
26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

NOTE:

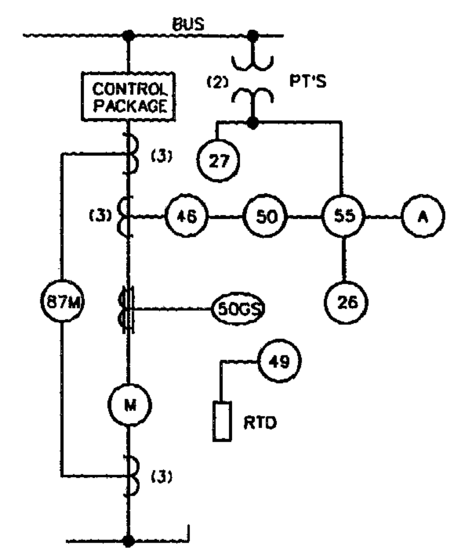
1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION

TYPICAL MEDIUM VOLTAGE REDUCED - VOLTAGE INDUCTION NON - REVERSING CONTROL SCHEMATIC RELAY LOGIC

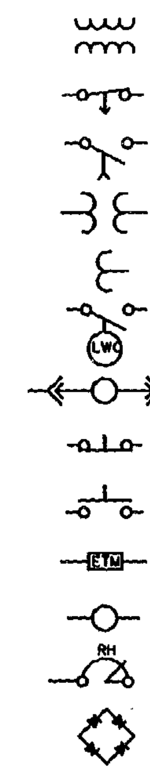


TYPICAL BRUSHLESS SYNCHRONOUS - MOTOR CONTROL
FULL VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING
FULL-VOLTAGE NON-REVERSING SYNCHRONOUS MOTOR

SYMBOLS:



TRANSFORMER
TIME DELAY TO CLOSE ON DEENERGIZATION
TIME DELAY TO CLOSE ON ENERGIZATION
POTENTIAL TRANSFORMER
CURRENT TRANSFORMER
LOW WATER CUTOFF
DRAWOUT CONTACTOR
NORMALLY CLOSED PUSHBUTTON
NORMALLY OPEN PUSHBUTTON
ELAPSED TIME METER
RELAY
RHEOSTAT
RECTIFIER

NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK	TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
1,2,3, CT	CURRENT TRANSFORMER	TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
1,2,3, FU	FUSE	ETM	ELAPSED TIME METER
GRD	GROUND	CR	CONTROL RELAY
M	LINE CONTACTOR	2AM	Dc AMMETER
MOT	MOTOR	EXC FLD	EXCITER FIELD
CPT	CONTROL POWER TRANSFORMER	TR	FIELD - APPLYING TIMER
TPI	TEST POWER INTERLOCK	RH	EXCITER FIELD RHEOSTAT
L1,L2,L3	INCOMING TERMINALS	TR1	PULLOUT PROTECTION APPLYING TIMER
T1,T2,T3	OUTGOING TERMINALS		
A	AMMETER		
SB	SIPHON BREAKER		

DEVICE NUMBERS:

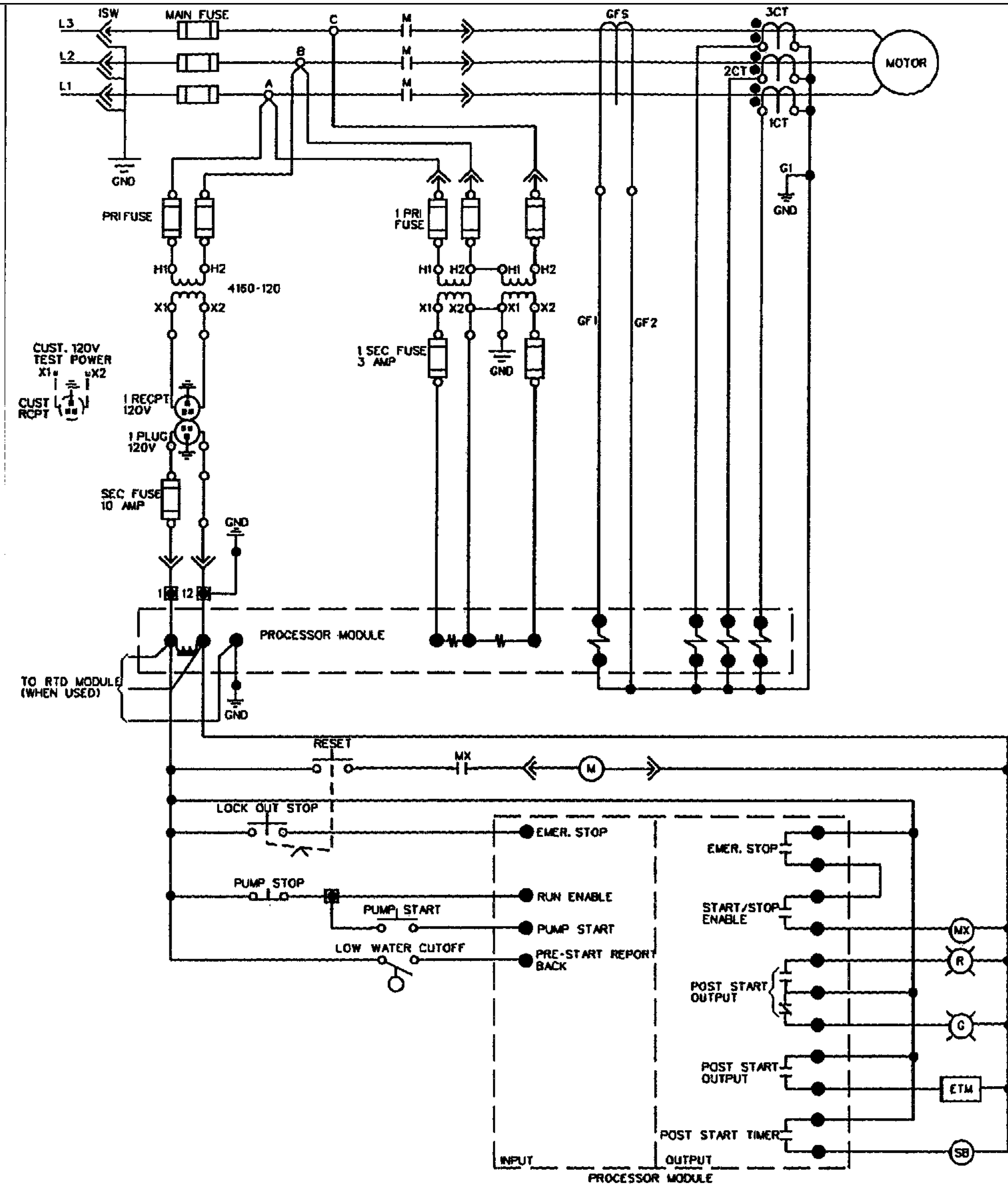
26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

NOTE:

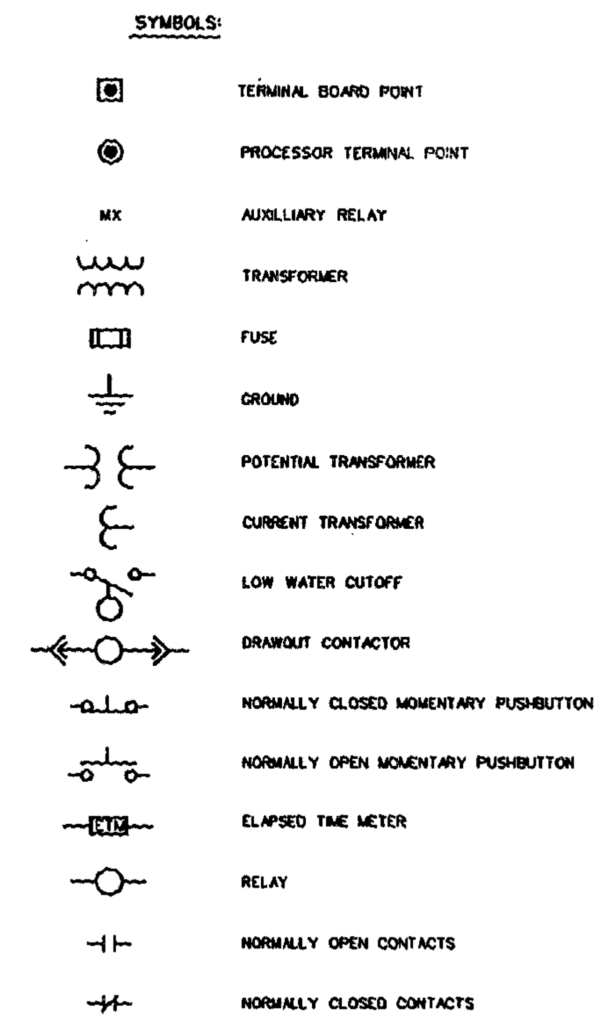
1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION

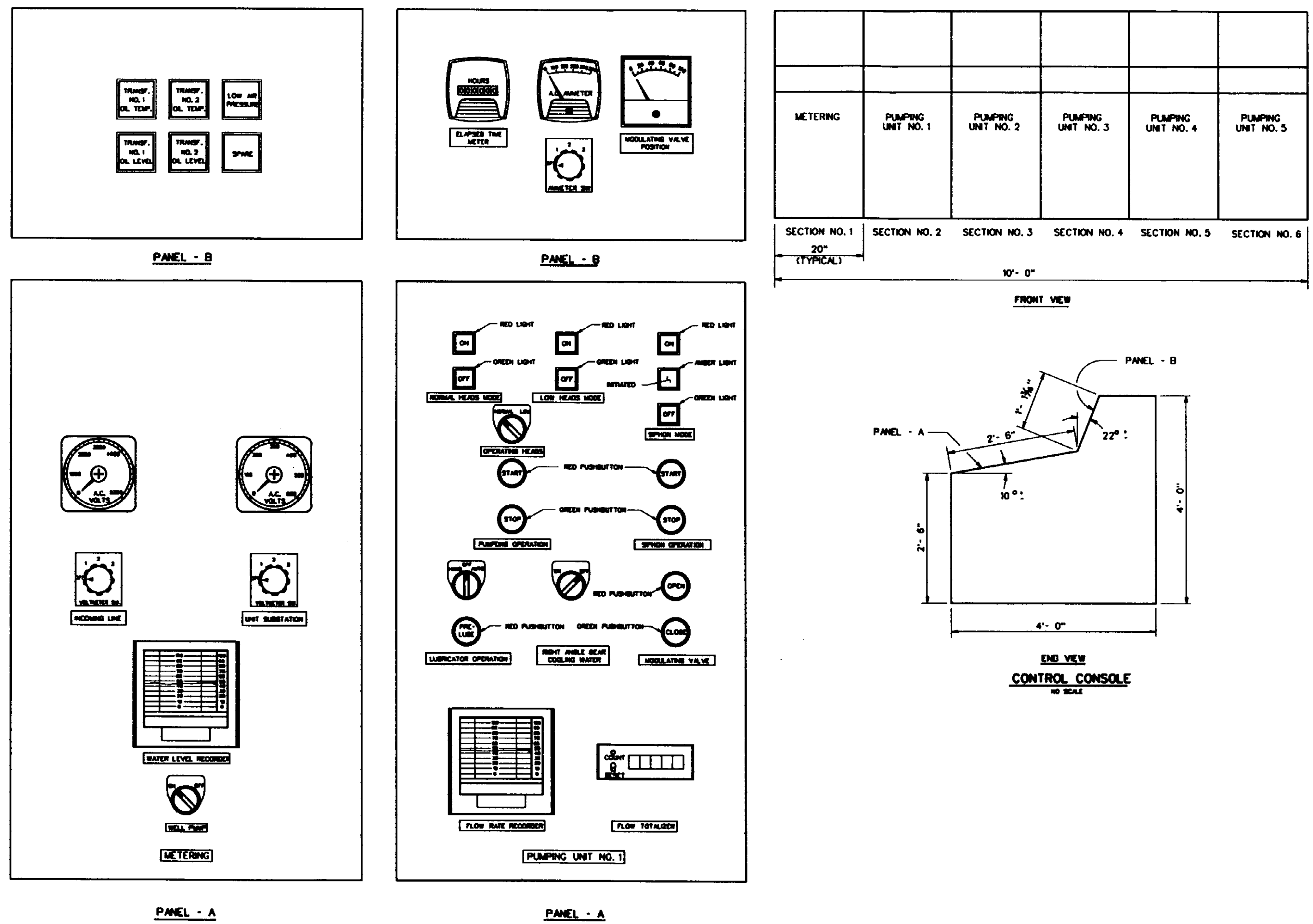
TYPICAL MEDIUM VOLTAGE FULL - VOLTAGE
BRUSHLESS SYNCHRONOUS NON - REVERSING
CONTROL SCHEMATIC RELAY LOGIC



TYPICAL REVERSING MOTOR CONTROL FULL VOLTAGE NON-REVERSING
MICROPROCESSOR PROTECTION PACKAGE

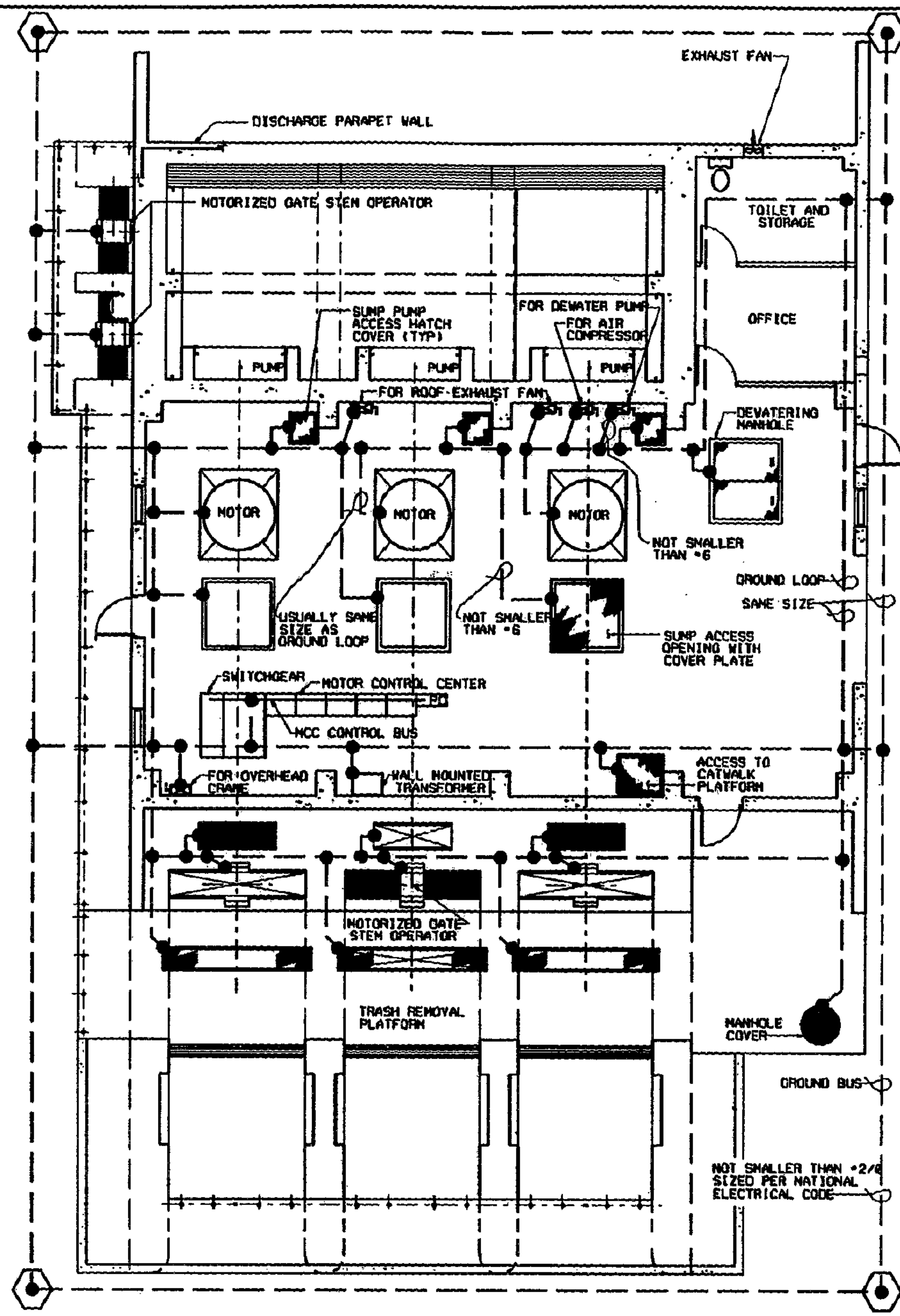


PUMPING STATION
TYPICAL MEDIUM VOLTAGE FULL VOLTAGE INDUCTION NON-REVERSING CONTROL SCHEMATIC MICROPROCESSOR -BASED PROTECTIVE LOGIC

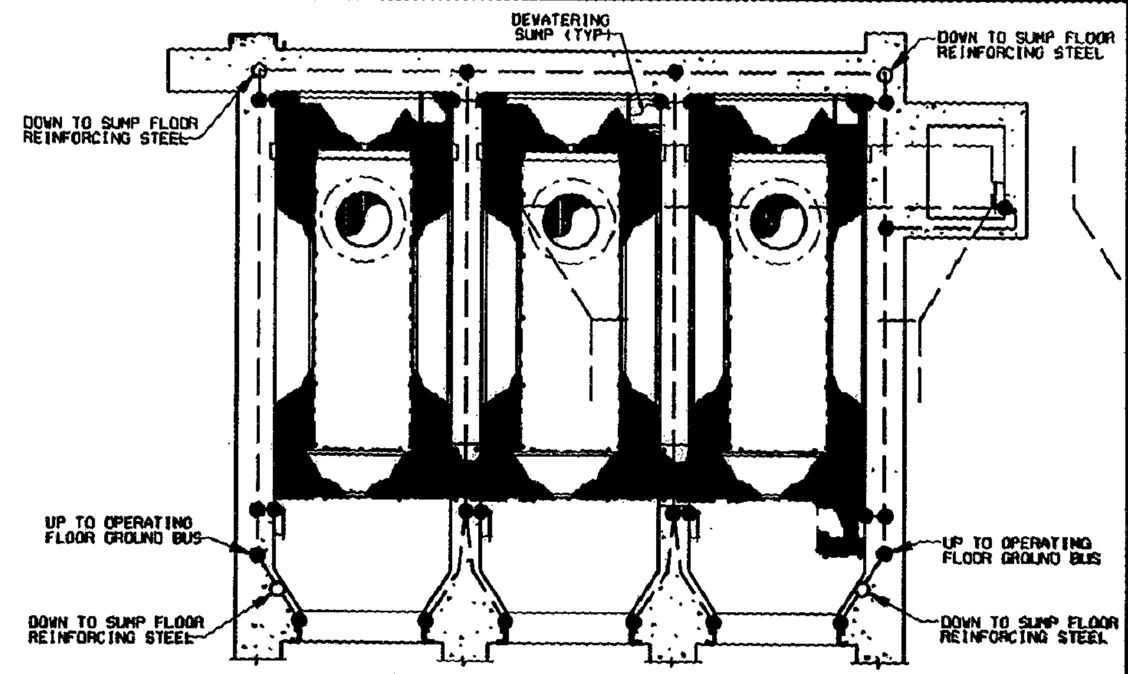


PUMPING STATION

TYPICAL REMOTE CONTROL CONSOLE



OPERATING FLOOR GROUNDING PLAN



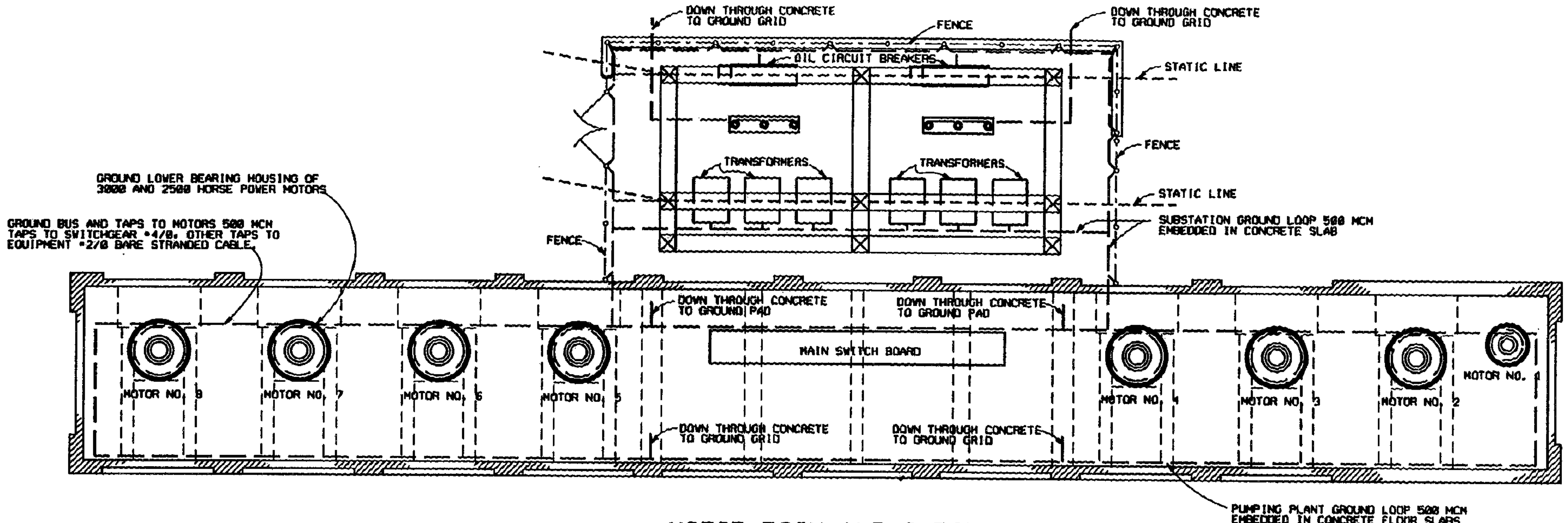
SUMP GROUNDING PLAN

TYPICAL NOTES:

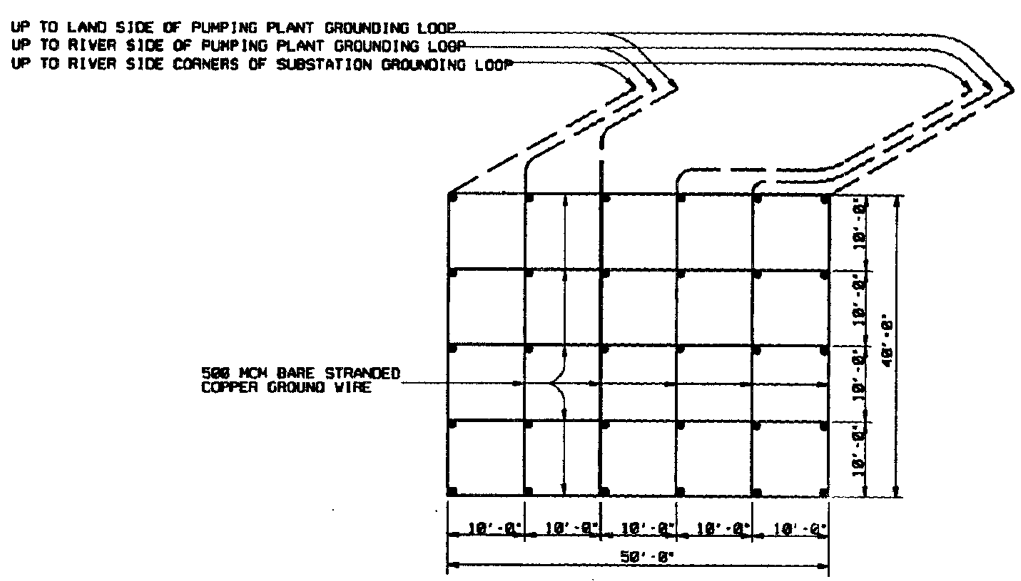
1. ADDITIONAL LENGHTS OR NUMBERS OF GROUND RODS SHALL BE ADDED AS REQUIRED TO ACHIEVE A MAXIMUM RESISTANCE TO GROUND OF 25 OHMS.
2. GROUND BUS SHALL BE EXOTHERMICALLY WELDED TO THE SUMP FLOOR REBARS, ANY METAL FRAMEWORK OF THE BUILDING AND METALLIC UNDERGROUND WATER PIPE IF PRESENT.
3. THE FRAMES OF ALL STATIONARY OR PERMANENTLY LOCATED MOTORS, STATIC EQUIPMENT OR MOTOR CONTROLLERS SHALL BE GROUNDED BY CONNECTION TO THE GROUND LOOP BY AN EQUIPMENT GROUNDING CODUCTOR EQUAL IN SIZE TO THE LARGEST CONDUCTOR IN THE LINE CONNECTED TO THE EQUIPMENT BUT NOT LESSTHAN NO. 6 AWG.

PUMPING STATION

TYPICAL GROUNDING PLAN
UTILIZING DRIVEN ELECTRODES



MOTOR ROOM AND SUBSTATION GROUND LOOPS



GROUNDING PAD

NOTE: BECAUSE OF SPACE LIMITATIONS 10'- 0" SPACING OF RODS WAS USED. A 20'- 0" SPACING WOULD GIVE MAXIMUM EFFECTIVENESS.

GENERAL NOTES:

1. LOCATE GROUND GRID IN AREA OF PERMANENTLY MOIST SOIL. PADS SHOULD HAVE A MINIMUM OF 12 INCHES OF CONCRETE COVER. THE GROUND GRID BOUNDARY SHOULD BE INDICATED BY ABOVE GROUND MARKERS AND PROTECTED AGAINST WASHOUTS OR DISTURBANCES RESULTING FROM FUTURE CONSTRUCTION.
2. ALL EQUIPMENT FRAMES AND HOUSINGS, METAL CABINETS INCLOSING ELECTRICAL EQUIPMENT AND METAL CONDUITS SHOULD BE CONNECTED TO GROUNDING SYSTEM.
3. THE CONTACT AREA OF ALL JOINTS IN GROUNDING CIRCUIT SHOULD PROVIDE A CURRENT CARRYING CAPACITY AT LEAST EQUAL TO THAT OF THE CONNECTING WIRE OR CABLE. ALL TERMINAL LUGS SHOULD BE OF THE SOLDERLESS TYPE AND SECURELY CONNECTED TO THE EQUIPMENT.
4. IN ADDITION TO SOLDERLESS CONNECTORS, GROUND CONNECTIONS AND SPLICES, WHICH WILL BE CONCEALED UPON COMPLETION OF WORK, SHOULD BE EXOTHERMICALLY WELDED.
5. GROUND CABLE WHERE EMBEDDED IN CONCRETE SHOULD BE COVERED WITH WATERPROOF CORRUGATED PAPER OR SIMILAR MATERIAL TO PROTECT THE CABLE DURING PLACEMENT AND VIBRATING OF THE CONCRETE.
6. MAXIMUM RESISTANCE TO GROUND NOT TO EXCEED 25 OHMS.

PUMPING STATION

TYPICAL GROUNDING PLAN UTILIZING GROUND GRID