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.

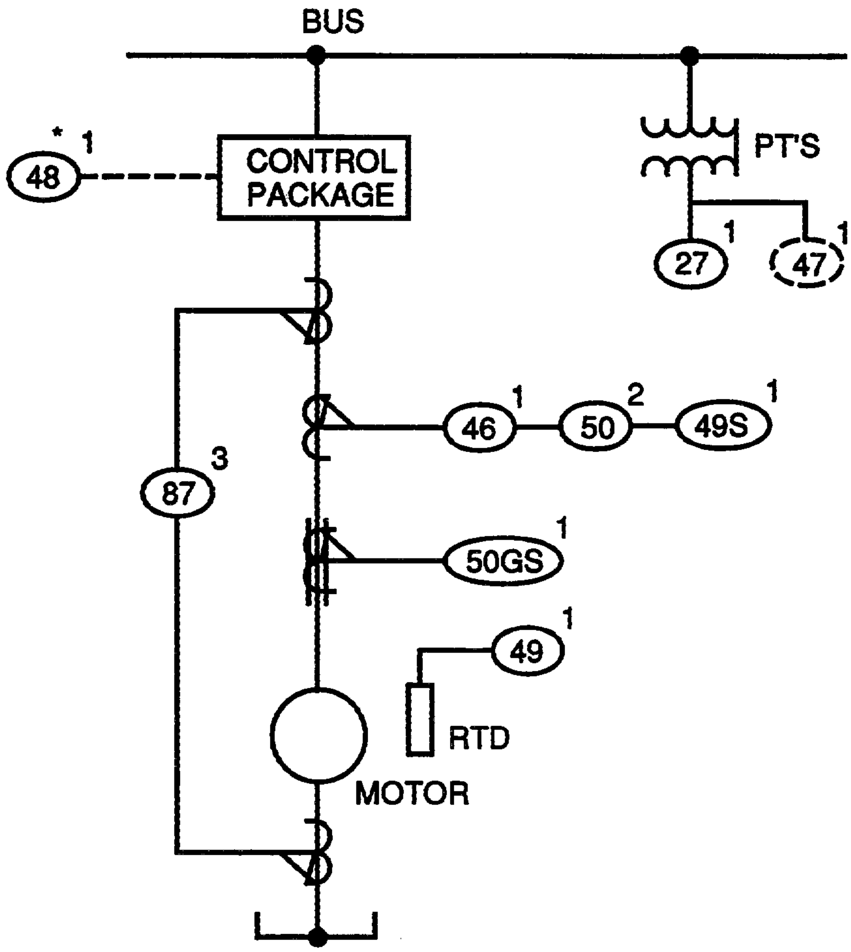
(2) Induction motor protection. It is logical that more extensive protection be considered for larger motors than for smaller motors, since they represent a larger capital investment. Therefore, minimum recommended protective relaying is divided into two groups: one for motors rated below 375 kW (500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

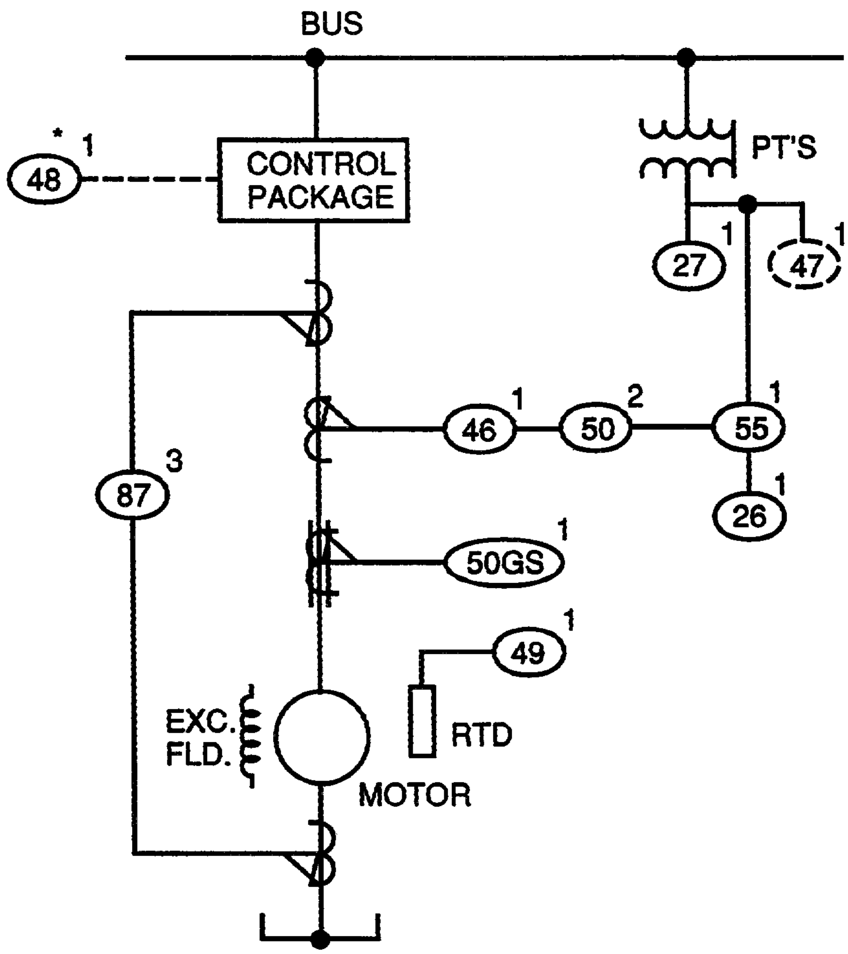
(3) Medium-voltage brushless synchronous motor protection. Figure 15-2 covers the recommended minimum protection for brushless synchronous motors. Device 26 has been included to provide stalled-rotor protection. It is a stator-current operated device. The characteristic and rating of this device is provided 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▲3Ø 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▲3ø 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.