MULTILIN

PROTECT4A®

MOTOR PROTECTION RELAY

INSTRUCTION MANUAL

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PROTECT 4A

MOTOR PROTECTION RELAY

PATENTS U.S. 4,241,336 4,224,651
CANADA 1,130,383

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1. INTRODUCTION

1.1 MOTOR PROTECTION REQUIREMENTS

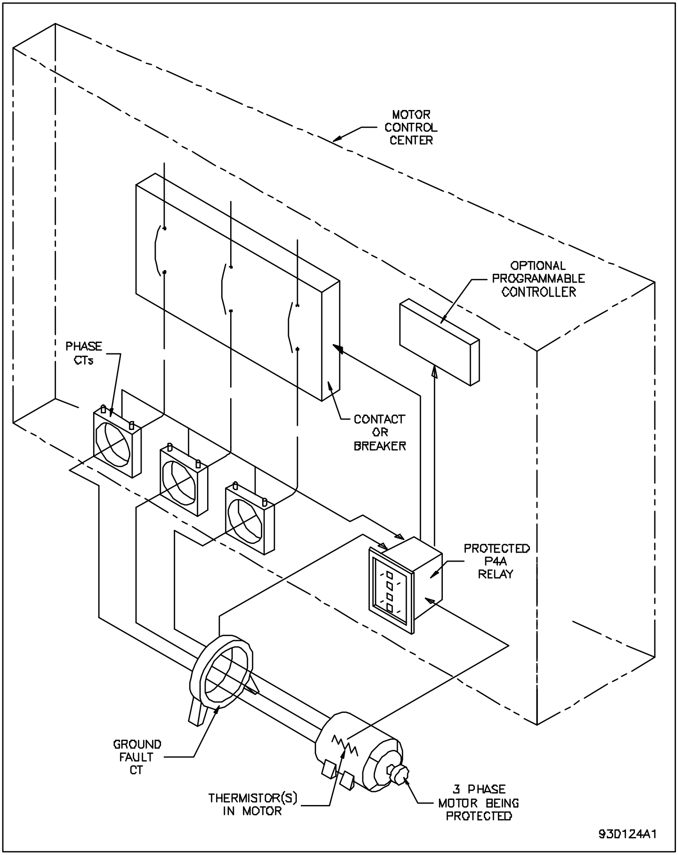
Three phase AC motors have become the workhorse of modern industry. Although motors are generally reliable devices, many different causes ranging from abnormal conditions to operator abuse can result in premature failure. Newer motors also tend to be designed much closer to the normal operation limits allowing less margin for abuse.

Sophisticated electronic relays are now normally used on large high voltage motors to protect against a wide range of possible fault conditions. High cost has precluded the use of these relays on less expensive motors. In these applications, a simple thermal overload is usually used. While inexpensive, these devices only give limited protection under one type of fault condition — overloads.

The PROTECT 4A relay is designed to provide protection against the four main causes of motor failure: overloads, single phasing, ground faults (earth leakage) and overheating (thermistor sensing). The Protect 4A relay is economical enough in price that it can be used with low and medium voltage motors, bridging the gap between expensive, sophisticated relays and economical thermal overloads which are of limited effectiveness. While no relay can prevent normal wear on the motor, the Protect 4A has been optimized to give maximum motor life without unnecessary production shutdown from overprotection. Controls are simple and self explanatory for ease of use.

Current sensing is achieved through the use of separate phase and ground fault CTs connected directly to the PROTECT 4A relay. Three 5 amp or 1 amp secondary CTs are used to sense motor phase currents. The three phase current wires pass through the window of a 2000:1 CT for ground fault sensing.

FIGURE1-1 PROTECT 4A TYPICAL SYSTEM CONNECTION



1.2 PROTECT 4A FEATURES

A microcomputer housed in a rugged, industrial package allows the Protect 4A to provide accurate, economical protection in a unit that will outlast the life of the motor. Since many new factories are using programmable controllers as automation increases, a 4-20mA output of motor current is also provided eliminating the need for an additional transducer. This output gives a direct reading of motor current.

Fault diagnosis after a trip is displayed on front panel indicators. This will allow operators and electricians to rapidly isolate and correct problems. It is possible to verify correct operation of an installed Protect 4A relay to ensure that the motor protection is functioning properly.

One Protect 4A relay is required per motor. Phase and ground fault currents are monitored through current transformers so that motors of any line voltage can be protected. The relay is used as a pilot device to cause a contactor or breaker to open under fault conditions; that is, it does not carry the primary motor current. Figure 1-1 shows how the Protect 4A is connected into a system for complete motor protection.

TABLE 1-1 PROTECT 4A FEATURES

PROTECTION	FEATURES
• Overloads (8 Time Curves) • Locked Rotor/Stall • Mechanical Jam • Multiple Starts • Single Phasing • Ground Fault/Earth Leakage (Trip or indication only) • Overheating (Thermistor Sensing)	• Fault Diagnosis • 4–20mA Output of Motor Current • Overload Status Indicator • Economical • Compact — Plug In • Universal Models Simplify Spares

1.3 TYPICAL APPLICATIONS

Versatile features make the Protect 4A an ideal choice in a wide range of motor applications. It should be considered for these and other typical uses:

1) Basic protection on low and medium voltage motors. The lowest horsepower selected for protection in an installation will depend on frequency of motor failure.

2) Protection of motors and equipment from operator abuse

3) Personnel safety from shock hazard using sensitive ground fault settings to detect winding shorts or leakage current from moisture in mines.

4) Fault indication of ground fault without shutdown to warn that corrective maintenance is required.

5) Mechanical protection of gears, pumps, fans, saw mills, cutters and compressors against mechanical jam.

6) Simplified spare parts stocking using one universal model to cover all motor sizes and settings.

7) Output of motor current suitable for programmable controller interface (4–20mA).

The motor phase currents are sensed by 3 conventional 1 amp or 5 amp secondary current transformers (CTs). If ground fault sensing is required then a separate zero sequence ground fault CT, through which all 3 phase conductors pass, is required. This CT is available in 2 sizes: HGF-3 (3½" diameter window) or HGF-5 (5½" diameter window).

Note: Ground fault sensing only works on systems that are solid or resistance grounded. Ungrounded systems require an artificial ground, through the use of a zigzig transformer, for ground fault sensing to work.

1.4 ORDER CODE

TABLE 1-2 RELAY ORDER CODE

RELAY

PROTECT 4A — 120

PART NO.	DESCRIPTION
PROTECT 4A	Standard relay
— 120	120 VAC control voltage
— 240	240 VAC control voltage

PHASE SENSING CURRENT TRANSFORMERS

Any standard 5 amp secondary 5 VA or greater CT can be used. 3 phase CTs per PROTECT 4A are required. 1 amp CT operation available on special order.

PART NO.	DESCRIPTION
CT-100:5	100:5
CT-150:5	150:5
CT-200:5	200:5
CT-250:5	250:5
CT-300:5	300:5
CT-500:5	500:5
CT-1000:5	1000:5

GROUND FAULT CURRENT TRANSFORMERS

1 required for ground fault sensing:

PART NO.	DESCRIPTION
HGF3	3½" Window 2000:1
HGF5	5½" Window 2000:1

1.5 TECHNICAL SPECIFICATIONS

TABLE 1-3 TECHNICAL SPECIFICATIONS

FULL LOAD CURRENT

50-100% PHASE CT RATING	
INPUT:	0-8 TIMES MAXIMUM RANGE CURRENT
FREQUENCY:	48-62 Hz, 3 PHASE SINUSOID
MAXIMUM INPUT:	8 TIMES FULL LOAD 25 SECONDS 12 TIMES FULL LOAD 2 SECONDS

FULL LOAD CONTROL — AMPS

RANGE:	50-100% PHASE CT RATING
CALIBRATED VALUE:	3 PHASE SINEWAVE-RMS EQUIVALENT
PICKUP ACCURACY:	±5% FULL SCALE
OVERLOAD TIMES:	±10% CURVE VALUE
MECHANICAL JAM:	ACTIVATED AT 3 TIMES FULL LOAD SETTING IF ENABLED. NOMINAL DELAY — 1 SECOND

SINGLE PHASE

ACTIVATION:	SEVERE UNBALANCE/SINGLE PHASE DEFEATED IF MOTOR AVERAGE CURRENT < 40% FULL LOAD SETTING
TRIP DELAY:	5 SECONDS ±2 SECONDS

THERMISTOR INPUT

HOT TRIP RESISTANCE:	2800-3300 OHMS
COLD RESET RESISTANCE:	250 OHMS MAX
TRIP DELAY:	3 SECONDS ±1 SECOND

THERMISTOR MEMORY MODEL

ACTIVE:	MOTOR RUNNING/STOPPED WITH CONTROL POWER
CLEAR:	POWER ON OR RESET AFTER TRIP
COOL RATE:	5 MINUTES TO CLEAR MEMORY @10 SEC STALL SETTING
RESET:	NO LOCKOUT ON TRIP

GROUND FAULT/EARTH LEAKAGE

TRIP LEVEL:	1-10A ±15% PRIMARY CURRENT FULL SCALE (0.5A MAX WITH CONTROL FULLY ANTI-CLOCKWISE)
TRIP DELAY:	TIMES AT < 25% PICKUP THRESHOLD 30ms 7-30ms TYPICAL 30ms MAX 50, 100ms: ±15ms 200, 300, 500, 750, 100ms: ±15%

MOTOR AMPS OUTPUT

OUTPUT CURRENCY:	4 mA = 0 AMPS 20 mA = PHASE CT RATING
ACCURACY:	LINEAR ±5% FULL SCALE
MAXIMUM LOAD RESISTANCE:	350 OHMS
SATURATION OUTPUT:	30 mA MAX

OUTPUT CONTACTS

TYPE:	SINGLE FORM C NO/NC SILVER CADMIUM OXIDE
RATINGS:	STANDARD PILOT DUTY 120/240 VAC 10 AMPS @ 80% PF. 360VA 28 VDC 10 AMPS

CONTROL POWER

120VAC INPUT RANGE:	85-140 VAC
240VAC INPUT RANGE:	170-280 VAC
FREQUENCY:	48-62 Hz
POWER:	5VA

PHYSICAL

PRODUCT	SHIP WEIGHT	CARTON DIMENSIONS
PROTECT 4A	4 lbs 8.8 kg	5¼" × 5¼" × 7½" 133mm × 133mm × 191mm
HGF3	2.2 lbs 1 kg	2½" × 6½" × 6½" 64mm × 165mm × 165mm
HGF5	3.8 lbs 1.5 kg	3" × 8" × 9" 76mm × 204mm × 228mm

ENVIRONMENT

TEMPERATURE RANGE
–10°C — +60°C

CERTIFICATION: CSA

2. INSTALLATION

2.1 PHYSICAL DIMENSIONS

Dimensions of the Protect 4A relay and mounting components are shown in fig. 2-1. Both the clear cover and the terminal board are detachable from the relay. The case is made of rugged plastic with a clear cover for viewing indicators and control settings.

Phase CTs with 1 amp or 5 amp secondaries should be used. These can be standard CTs which are user supplied. Dimensions for CTs available from Multilin are shown in figure 2.2. If zero sequence ground fault detection is required, the appropriate ground fault CT shown in figure 2-3 must be installed.

FIGURE 2-1 RELAY DIMENSIONS

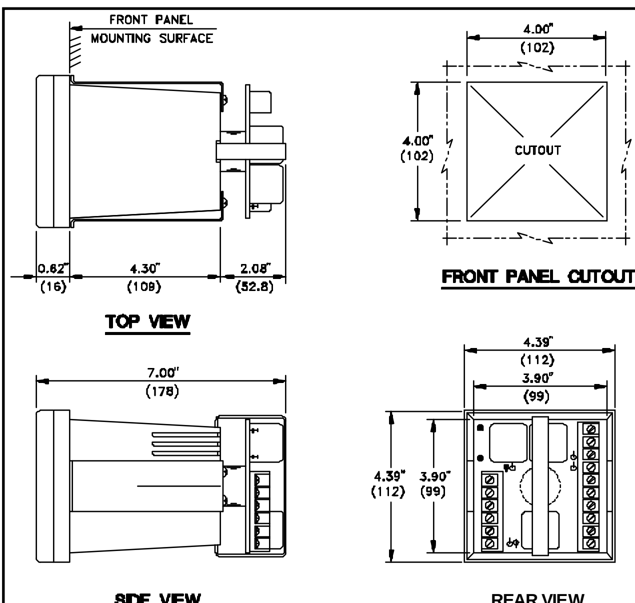


FIGURE 2-2 PHASE CT DIMENSIONS

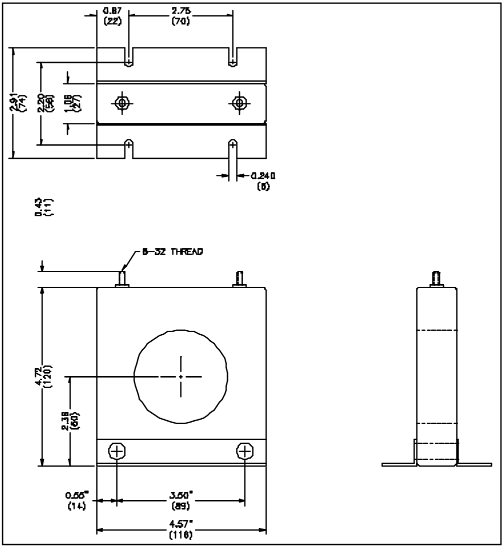
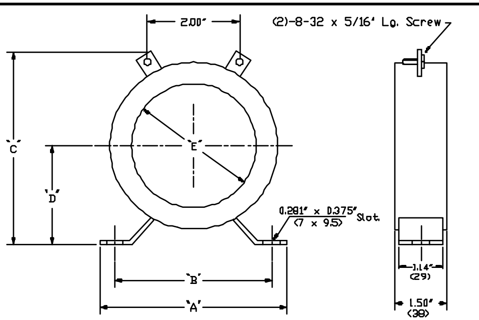


FIGURE 2-3 GROUND FAULT CT DIMENSIONS



PART NO.	DIMENSIONS																	
	A		B		C						D		E					
					Min.		Nom.		Max.				Min.		Nom.		Max.	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
CT-HGF5	7.80	198	7.05	179	8.09	205	8.15	207	8.21	209	3.94	100	5.25	134	5.50	140	5.50	140
CT-HGF3	6.06	154	5.28	134	6.12	155	6.18	157	6.24	159	3.15	80	3.29	84	3.54	90	3.54	90

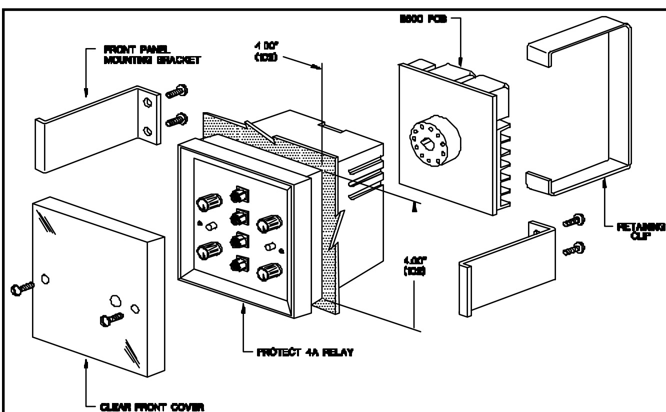
Inches
(mm)

2.2 MOUNTING

Normally the Protect 4A relay will be mounted on a panel or motor control center door so that the indicators can be viewed and the reset button is directly accessible. A square cutout is made in the door as shown in fig. 2-1. The relay is then placed in the cutout and two mounting brackets are installed to hold it in place as shown in fig 2-4. The terminal board socket is wired and plugged into the back of the relay. A spring retaining clip that goes into slots on the back of the relay is provided with the relay. This should be installed to prevent the terminal board from working loose.

If it is desirable to let operators reset a tripped Protect 4A relay, the cover plate should be mounted with the reset hole plug over the reset switch. If it is in inconvenient to remove the plug when resetting the unit is necessary, an extender shaft can be obtained that protrudes through the front cover hole and fits over the reset button. Tamper proof screws are also available for attaching the cover to prevent access to the controls or the reset switch by unqualified personnel.

FIGURE 2-4 RELAY MOUNTING

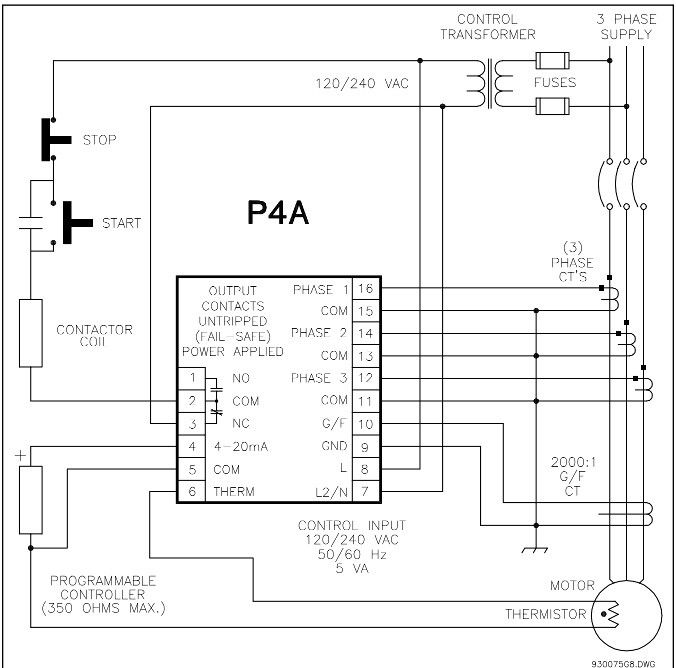


2.3 EXTERNAL WIRING

A typical wiring diagram for the Protect 4A relay is shown in figure 2-5. Connections are made to the terminal board provided which is then plugged onto the Protect 4A relay. Protect 4A relays are interchangeable and can be quickly replaced by a standard spare unit regardless of the motor current range.

Separate phase and ground fault CTs are wired directly to the back of the Protect 4A. It is recommended that the ground fault CT wires be twisted together to minimize noise pickup.

FIGURE 2-5 TYPICAL WIRING DIAGRAM



2.4 CONTROL POWER

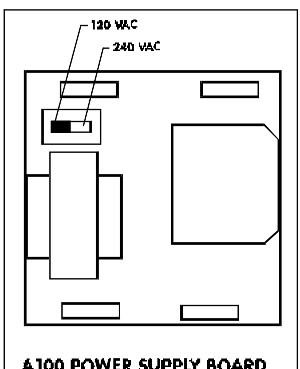
Control power must be applied to the Protect 4A relay before energizing the motor for correct operation. Supply voltage can be selected as 120VAC or 240VAC by a selector switch on the power supply board.

The supply voltage for which the relay is set will be clearly marked on the wiring diagram label attached to the outside of the relay. If the supply voltage is to be changed, the cover must be removed and the selector switch shown in fig. 2-6 set accordingly. When changing the supply voltage be sure to mark the new voltage on the terminal label for future reference.

Full accuracy of the Protect 4A relay will be maintained over a wide range of supply voltages which are typically found in industrial environments (85-140VAC) or (170-275VAC) 48-62Hz. When the control voltage drops below the minimum voltage, the PROTECT 4A output contacts go into the trip condition to provide fail-safe operation. Whenever control power is applied to the Protect 4A, it will come on in the state present at loss of power.

Since the reset for the Protect 4A relay is electrical, control power must be applied when the relay reset button is pushed.

FIGURE 2-6 CONTROL VOLTAGE SELECTION



2.5 TRIP CONTACTS

One set of form C normally open/normally closed contacts are provided for switching up to 240VAC, 10 amps, 360VA which should be adequate for most loads. Silver cadmium oxide contacts are provided because of their ability to withstand high inrush inductive loads. Connection of the trip contacts to the motor contactor or breaker is shown in the typical wiring diagram figure 2-5.

When the relay is ready for motor starting, the contacts for terminals 1, 2, 3 will be as shown in figure 2-5. When the relay trips, or if control power is lost, the contacts will change to the opposite condition. However, if this change occurred from lost control power, the main relay will return to its normal operating state when power is re-applied, without having to reset the relay.

The output contacts can be returned to the untripped state by pressing the reset button or by selecting the auto reset option (section 2.9.1.).

2.6 THERMISTOR INPUT

In order to use the thermistor sensing feature the motor being protected must have a suitable thermistor sensor embedded in the stator winding. This is normally fitted when the motor is built or rewound although it may be possible to retrofit a thermistor into the end turns of some motors. Thermistors exhibit a non-linear characteristic and the Protect 4A is designed to match a characteristic similar to that shown in figure 2-7. The actual trip temperature of the thermistor is specified when it is ordered. Consult the factory for recommended thermistor types that will work with the Protect 4A relay.

If three thermistors are installed in the motor connect them in series as shown in figure 2-8. When combining several thermistors in series, care should be taken to ensure that the maximum cold resistance including wiring resistance does not exceed the trip temperature resistance. If any thermistor overheats in this configuration the relay will trip. Should no thermistor be installed in the motor it is not necessary to make any connection to terminals 5 and 6. A no sensor detector will prevent the relay from tripping. Alternately, a jumper can be placed across these two terminals. The Protect 4A relay is not suitable for use with RTDs (resistance temperature detectors).

If no thermistor is used, put a jumper between terminals 5 and 6 to prevent nuisance tripping from noise. Shielded wire should be used for the thermistor input especially if the wiring is near high current conductors or if the motor is remotely situated. Maximum shield effectiveness is obtained if the shield is grounded at one end only.

FIGURE 2-7 THERMISTOR CHARACTERISTIC

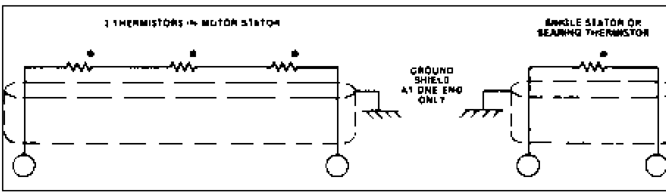
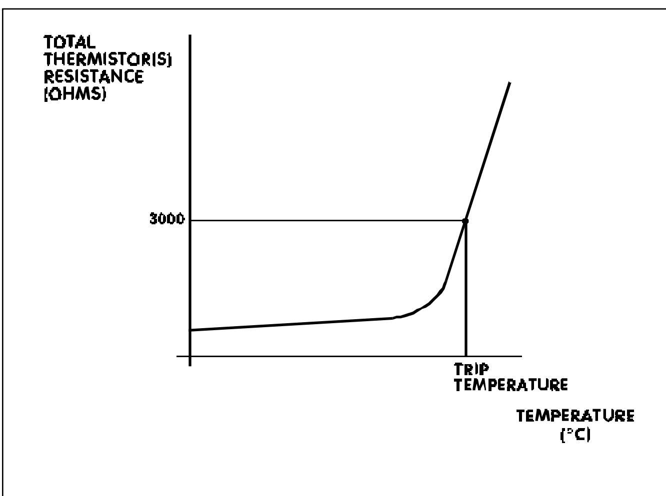


FIGURE 2-8 THERMISTOR CONNECTION



2.7 PROGRAMMABLE CONTROLLER OUTPUT

In many installations an output of motor current into a programmable controller is desirable. Terminals 4 (+ VE) and 5 (-VE) provide a DC output of 4-20mA proportional to motor current. The 20mA output is obtained at the rated CT ratio. For example, if a 600:5 CT is used, at 600 Amps the output would be 20mA. The output saturates below 30mA during overloads to prevent damage to the programmable control.

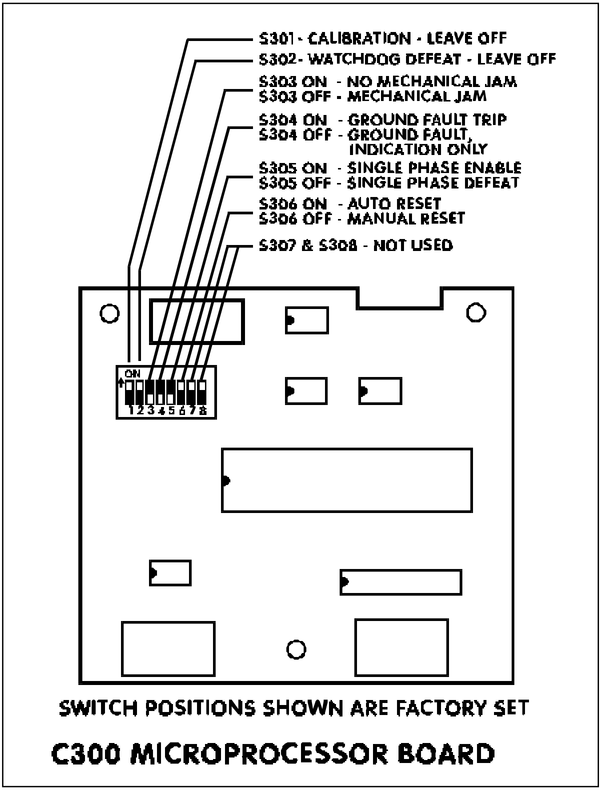
2.8 TAMPER PROOF COVER

If limited access to the Protect 4A controls is desired to prevent settings from being altered by operators, tamper proof screws and a special installation tool can be ordered. The normal cover screws are replaced with these special screws so that the cover cannot be removed without the tool. The cover can also be rotated 180 degrees and a plug placed over the reset button hole. This prevents access to the reset button so that only qualified personnel can reset the relay once it has tripped.

2.9 FIELD OPTIONS

It is possible to change some features on the relay in the field for specific applications. Refer to the internal switch setting location diagram fig. 2.9 to set the field options.

FIGURE 2-9 FIELD PROGRAMMABLE OPTIONS



2.9.1 AUTO RESET

Normally a Protect 4A relay will only reset after a trip by pushing the reset button. If it is required to automatically reset whenever a trip occurs, set switch S306 on. The relay will automatically reset about 5 seconds after tripping. Note that the indicators will also reset so that the cause of the trip will not be apparent. If auto reset is used, ensure that the motor can only be restarted by an operator once the fault has been cleared.

2.9.2 MECHANICAL JAM

Overloads will normally cause a trip according to the overload curves of fig. 3-2. In some situations it may be desirable to protect associated mechanical equipment against a jam while running. Setting switch S303 off will cause the relay to trip whenever the current rises above 3 times the FULL LOAD—AMPS control setting for one second while the motor is running

The Protect 4A automatically defeats mechanical jam during the high starting inrush current but enables this option (if switch S303 is off) as soon as the inrush current drops below the FULL LOAD AMPS setting. This feature is especially useful in applications such as pumps and fans where overloads are not part of normal operation. Mechanical jam will activate the overload indicator.

2.9.3 GROUND FAULT INDICATION ONLY

In some resistance grounded systems a single ground fault detector is used to monitor a complete bus feeding numerous motors. If one of the motors develops a ground fault, an alarm condition is registered on the central ground fault monitor but the motors may be allowed to continue running to prevent a production shut down. This is possible since the ground fault current is resistance limited, however the faulty motor should be repaired as soon as possible because a second ground fault on another phase could cause a phase to phase short circuit resulting in extensive damage. If the motors don’t have individual ground fault protection, the whole bus must be scheduled for a convenient shutdown and each motor checked until the faulty one is found.

A ground fault above the trip settings will normally cause the Protect 4A to trip with a ground fault indication. Setting switch S304 off will cause the ground fault indicator to activate but will inhibit a trip due to a ground fault. If each motor is equipped with a Protect 4A and this feature is selected, when the central monitor registers a ground fault, it is only necessary to look at each Protect 4A to locate the faulty motor. The defective motor can then be shut down and repaired when convenient without shutting down the rest of the bus and testing every motor.

This scheme is not suitable for solidly grounded systems since any motor which develops a ground fault should be shut down immediately due to the high current that can flow.

Once the ground fault indicator is set it can only be reset by pressing the reset button. This makes it particularly useful for detecting momentary ground faults due to initial insulation breakdown and arcing or excessive moisture in mines,

2.9.4 SINGLE PHASE DEFEAT

Systems such as variable speed controllers may produce non-sinusoidal waveforms that may cause nuisance tripping of the single phase detection. If this is a problem, the single phase protection may be defeated by setting switch S305 off.

2.9.5 FACTORY SERVICE

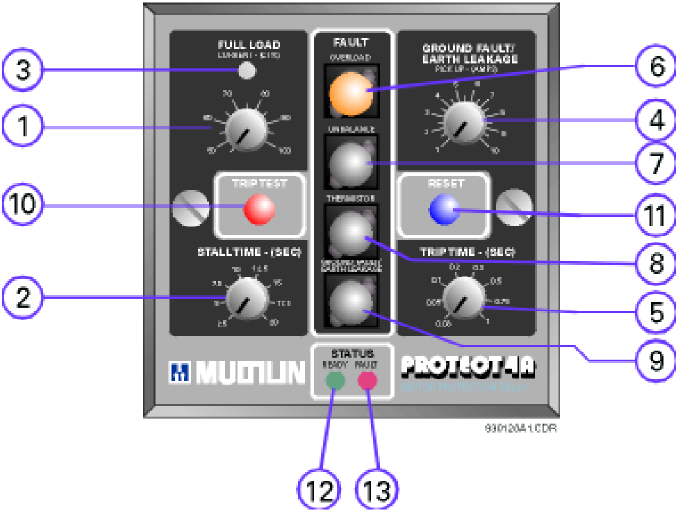
Switches S301/S302 are used for factory calibration. They should be left off for correct operation.

2.10 ENVIRONMENT

Precision components and rugged industrial packaging are used to ensure that Protect 4A relays will perform accurately and reliably over a wide range of conditions typical of industrial environments around the world. Some of the features incorporated into the Protect 4A design to ensure trouble free operation and useful life longer than the motor being protected are listed in table 2-1.

TABLE 2-1 PROTECT 4A ENVIRONMENTAL FEATURES
• Transient protection/filtering on inputs and outputs • Crystal controlled time delays for accuracy with temperature/aging • Precision IC voltage references for stable accuracy • Wide temperature range –10°C to +60°C

FIGURE 3-1 FRONT PANEL LAYOUT



3. SETUP AND USE

3.1 CONTROL AND INDICATORS

NO.	NAME	FUNCTION
1	FULL LOAD CONTROL	Sets the maximum average RMS motor current at which overload pickup occurs. Calibrated in % CT rated amps.
2	STALL TIME	Selects one of eight overload time curves based on stall times at 6 times inrush current.
3	OVERLOAD INDICATOR	Flashing - motor current exceeds full load setting (overloads or starting).
4	GROUND FAULT (EARTH LEAKAGE) TIME DELAY CONTROL	Sets level of ground fault current necessary to cause a trip. Calibrated in amps.
5	GROUND FAULT (EARTH LEAKAGE) TIME DELAY CONTROL	Sets time ground fault current must exceed level setting before a trip. Calibrated in seconds.
6	OVERLOAD INDICATOR	Set whenever overload or mechanical jam trip occurs.
7	UNBALANCE INDICATOR	Set whenever single phase trip occurs.
8	THERMISTOR INDICATOR	Set when thermistor senses an overtemperature and relay trips.
9	GROUND FAULT/ EARTH LEAKAGE INDICATOR	Set when ground fault trip or ground fault alarm occurs.
10	TEST TRIP	Activates trip indicators (6-9) and the trip relay when pressed.
11	RESET	Resets all fault indicators and trip relay.
12	READY INDICATOR	Indicates the output contacts are untripped ready for motor starting.
13	FAULT INDICATOR	Indicates the output contacts are tripped due to a fault condition. Motor cannot be started.

3.2 FULL LOAD CONTROL

The full load control is calibrated in % of phase CT rated amps. It should be set to the maximum load rating of the motor being protected. For example, a setting of 75% with 100:5 phase CTs corresponds to a motor full load current of 75 amps. In the time/overload curves of figures 3-2 the value of a multiple of one full load is represented by the current set on this control. When the current exceeds the full load control setting, the overload indicator light will flash to indicate an overload and the relay will begin to time the overload according to the time/overload curves of fig. 3-2. If the condition persists the relay will eventually trip.

When the motor is in a normal run state the internal memory begins to discharge to simulate motor cooling. Overload trip time will be reduced by the cumulative effect of previous overloads and starting inrush unless the motor has not been overloaded for a period of time in which case the memory is empty to simulate a cool motor.

Multiple start protection is provided by the memory which integrates the heating effect of each start. If power is lost and reapplied or if the reset button is pressed after a trip, the memory will be empty. Figures 3-3 shows how the thermal memory modelling operates for typical motor operation.

FIGURE 3-2 TIME/OVERLOAD CURVES

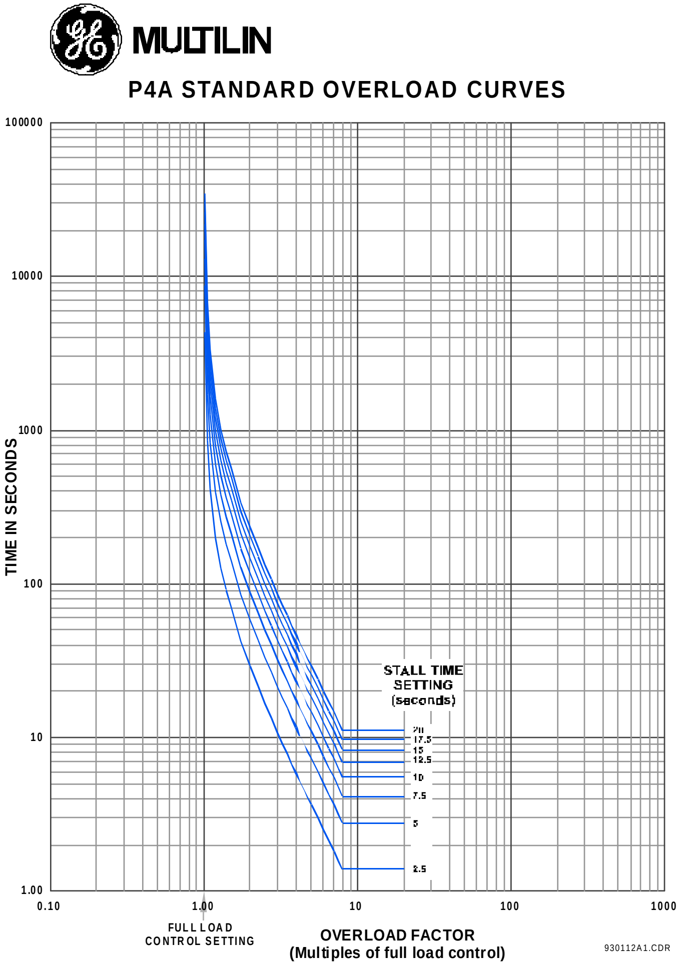
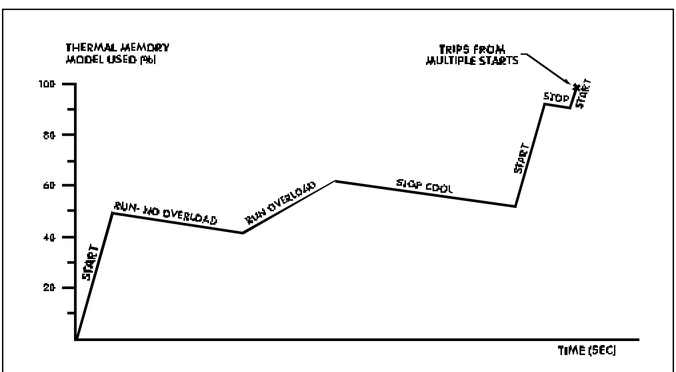


TABLE 3-2 TIME/OVERLOAD CHARACTERISTIC

TRIP TIME VS. OVERLOAD (SECONDS)								
Stall Time Setting	Multiples of Full Load							
	7	6	5	4	3	2	1.5	1.25
2.5	1.8	2.5	3.6	5.8	10.9	29.2	70	156
5	3.6	5	7.9	11.7	21.9	58.4	140	311
7.5	5.5	7.5	10.9	17.5	32.8	87.6	210	467
10	7.3	10	14.6	23.3	43.7	116	280	622
12.5	9.1	12.5	18.2	29.2	54.7	146	350	778
15	10.9	15	21.8	35.0	65.6	175	420	934
17.5	12.7	17.5	25.5	40.8	76.5	204	490	1089
20	14.6	20	29.1	46.7	87.4	234	560	1245

FIGURE 3-3 THERMAL MEMORY MODELLING



3.3 STALL TIME CONTROL

One of eight different time/overload curves can be selected by the stall time control to closely match the thermal characteristics of the motor. If curve data is available from the motor manufacturer the next lowest curve from fig. 3-2 should be selected and the stall time control set accordingly.

Each of the curves represents an I^2t characteristic of a motor having the specified stall time set by the control at an inrush current of 6 times the motor full load rating which is fairly typical. If no motor curve data is available, this control should be set to the next lowest stall time from that specified for the motor. Thus for a motor with a rated stall time of 9 seconds at 6 times full load, the STALL TIME control would be set to 7.5 seconds. If the stall time is specified at some other inrush current, the point can be plotted on the time/overload curves of fig. 3-2 and the next lowest curve selected.

Table 3-2 lists the curve points in tabular form. Points for a selected curve can be plotted directly on curves for associated equipment to facilitate a coordination study with systems that use the Protect 4 relay.

3.4 GROUND FAULT (EARTH LEAKAGE) LEVEL CONTROL

Aging or overheating may cause the insulation of the stator windings to degrade until a point of the stator winding touches the metal stator slot or the insulation becomes carbonized. This provides a low impedance path from the supply to ground and back to the source resulting in very high currents on a solidly grounded system. It is necessary to shut down the motor immediately if this ground fault occurs. Many systems have a resistance in series with the ground at the supply source to limit this fault current and allow the system to continue running. However the problem should be identified and fixed as soon as possible because a second fault occurring on another phase would cause a very high current to flow.

It will usually be necessary to rewind a motor which develops a fault to earth due to insulation breakdown. If no ground fault protection were used, however, the high fault current could cause severe structural damage to the motor stator or result in the shutdown of the complete bus on which the faulty motor is located.

Environmental conditions can result in ground faults even on a sound motor. Moisture or conductive dust which are often present in mines may provide an electrical path to ground. By shutting down the motor immediately using ground fault (earth leakage) protection the motor can be dried or cleaned then restarted without any damage. To use the ground fault feature a separate ground fault sensing CT must be used. Each of the 3 motor current conductors passes through this zero sequence (core balance) current transformer.

3.5 GROUND FAULT (EARTH LEAKAGE) TIME DELAY CONTROL

In systems with several levels of ground fault (earth leakage) detection, time coordination is required for satisfactory operation. If ground fault protection is used on a bus, each motor must have a shorter time delay than the bus fault detector or a fault in any motor will shut down the whole bus. In a solidly grounded system, short time delays should be used to prevent system damage unless the contactor is not capable of breaking the fault current in which case a backup detection system of sufficient interrupt capacity should be allowed to operate first.

On resistance grounded systems where the fault is limited to safe levels longer time delays can be used if there are no coordination constraints. Short time delays may cause nuisance tripping due to transients or capacitive charging currents and should be avoided if possible.

3.6 SINGLE PHASE DETECTION

Under normal balanced conditions the stator current in each of the three motor phases is equal and the rotor current is just sufficient to provide the turning torque. When the stator currents are unbalanced, a much higher current is induced in the rotor because it has a much lower impedance to this negative sequence current component. Usually the increase in stator current is small (125-200%) so that conventional thermal overloads do not trip, however the much higher induced rotor current can cause extensive rotor damage.

Motors can tolerate different levels of current unbalance depending on the rotor design. The most common and serious case called single phasing is the complete loss of one phase. Typically this is caused by a blown fuse or malfunction in the utility supply. If this condition is allowed to persist, extensive rotor damage is likely. The Protect 4A is internally set to respond to the large phase current unbalance that occurs under a single phase condition and to trip if this condition persists for five seconds consecutively. If an unbalance trip occurs check for a blown fuse, loose wiring connections and the incoming supply. To prevent nuisance trips on lightly loaded motors when a much larger unbalance level will not damage the rotor, the single phase detection will automatically be defeated if the average motor current is less than 40% of the full load control setting.

Some starting schemes switch in a reactor in only two phases to limit the inrush current. If this creates a severe enough unbalance to trip the relay, a third reactor should be added to create a balanced condition on starting. Before applying the Protect 4A to motors which do not operate from a conventional three phase supply such as electronic speed controllers, consult the factory, as the unbalance detector may give nuisance tripping due to the unusual waveforms present. For these conditions, it is possible to defeat the single phase protection as described in section 2.9.4.

3.7 THERMISTOR TRIP DETECTION

Insulation breakdown of the stator windings due to overheating is the main cause of motor failure under overload conditions. Heat buildup in the rotor can be very rapid but the large thermal mass of the motor prevents direct detection by temperature sensors embedded in the stator slots soon enough to prevent damage. It may take several minutes for the temperature sensor to reach its trip temperature. Consequently, a predictive model is required to accurately determine heat buildup within the motor. The Protect 4A relay uses an accurate electronic memory method based on motor currents. Thermal overloads rely on using motor current to heat an element with a much smaller time constant than the motor itself to predict overheating within the motor but these devices, although inexpensive, are subject to many limitations.

Overheating from causes other than resistive heating due to current cannot be detected by modelling methods that only sense current. To detect the effects of motor overheating due to blocked ventilation, high ambient temperature or other unforeseen causes, direct temperature sensing is necessary. Since temperature rise under these conditions is much slower, the temperature detector will accurately sense the actual temperature within the motor which would not be true under a rapid heat buildup situation such as locked rotor, for example.

Linear sensing elements such as RTDs and thermocouples can give an output of actual temperature but these are expensive and unnecessary for basic motor protection. Thermistors are available which give a rapid change of resistance at a specific temperature which is determined at the time of installation. The Protect 4A accepts a thermistor input and will provide a trip within 3 seconds of the thermistor threshold temperature being exceeded. Several thermistors can be connected in series to protect each of the stator phases. Any one of the thermistors exceeding its threshold temperature will cause the Protect 4A to trip. In addition, if the motor is still overheated, the thermistor signal will prevent restarting of the motor by tripping the Protect 4A immediate after reset.

3.8 RESET/TEST BUTTON

When a fault condition causes the Protect 4A relay to trip, the red fault light will come on and the fault condition will remain latched. If control power is lost or re-applied the relay will retain the state and fault indications present when control power was removed. Pressing the reset button will clear all fault indications and restore the output contacts to a condition ready for motor starting. There is no lockout of the relay after a trip. Reset is possible after a five second delay which is provided to ensure contactor opening on a fault when using auto reset.

In many smaller motor applications where the Protect 4A is applied, down time is more expensive than motor protection. In these situations, maintenance staff will correct the fault and put the motor back on line. Consequently, no lockout after trip is provided since it would be a nuisance. When the reset button is pressed after a trip, the motor is considered to be cold making it possible to damage a motor by starting, tripping and resetting several times. Heat build up in this situation would be detected by a thermistor in the motor which would prevent starting if the motor were hot. If a thermistor is not installed in the motor and unskilled operators are using the equipment, the reset button should be made tamper proof (Section 2.8). Pressing the reset button when the Protect 4A is not tripped will have no effect.

Pushing the TEST button when the relay is not tripped will cause all fault indicators to be set and the output to go to a tripped state. This is useful for verifying correct operation of the internal circuitry and the contactor wiring.

3.9 MOTOR AMPS OUTPUT

An output of the average RMS current in the three motor phases is provided for connecting to a programmable controller. Unlike conventional schemes which give an indication of only one phase current, the Protect 4A relay can monitor all 3 phase currents simultaneously without the need for additional current transformers. The output of 4-20 mA corresponds to motor current from 0 amps to the full load current of the CT, For example, if 100:5 phase CTs were used, the linear output of 4-20 mA would correspond to phase currents of 0-100 amps. Under overload conditions the current is limited to 30 mA maximum.

For online monitoring the output can be used to drive a programmable controller or chart recorder with a linear 4-20 mA input range. Useful applications include load studies and computer control of loads.

3.10 FAULT DIAGNOSIS

Four fault indicators as well as READY/FAULT status lights are provided to display the relay state and cause of fault after trip. Table 3-3 lists probable causes of trip and corrective measures required for various fault indicators.

TABLE 3-3 PROTECT 4 FAULT FINDER

FAULT INDICATION	● OVERLOAD ○ UNBALANCE ○ THERMISTOR ○ GROUND FAULT/ EARTH LEAKAGE	○ OVERLOAD ● UNBALANCE ○ THERMISTOR ○ GROUND FAULT/ EARTH LEAKAGE	○ OVERLOAD ○ UNBALANCE ● THERMISTOR ○ GROUND FAULT/ EARTH LEAKAGE	○ OVERLOAD ○ UNBALANCE ○ THERMISTOR ● GROUND FAULT/ EARTH LEAKAGE
CONDITION	OVERLOAD/JAM	SINGLE PHASE	HOT THERMISTOR	GROUND FAULT/ EARTH LEAKAGE
PROBABLE CAUSE	- excessive overloads during running - multiple starts - mechanical jam (if enabled) - locked rotor start - incorrect run curve	- loss of phase by utility - blown fuse - loose wiring connection - worn contactor - short between motor windings	- buildup of material on cooling fins - blocked ventilation to motor - high ambient temperature - too many starts/ overloads	- motor winding to case short - wiring touching metal ground - moisture in motor - conductor particles in motor - level/time settings too sensitive - intermittent fault to ground
CORRECTIVE ACTION	- allow motor to cool - investigate cause of overloads - operator training - disable jam feature running overloads normal	- check incoming supply - check fuses - monitor each phase current - tighten mechanical connections	- allow motor to cool - clean external motor housing - check airflow to motor	- static testing of winding to ground resistance - dry motor with hot blower - clean motor - increase level/time settings to prevent nuisance trips

4. RELAY TESTING

4.1 COMMISSIONING TESTS

Prior to applying power at a new installation, system operation can be verified by injecting current through the phase CTs. If a 3 phase current injection set is available it would be connected as shown in figure 2-5 in place of the 3 phase supply and using a short between the 3 phases in place of the motor. A short must be placed across the ground fault CT terminals when doing current tests or nuisance ground fault trips will occur.

When a single phase injection set is used, the sensing circuitry sees an unbalance condition as shown in figure 5-2 and explained in the theory of operation section 5. To make the single phase input appear to the Protect 4A like a 3 phase input, it is necessary to temporarily connect a capacitor (observe capacitor polarity) across the two test points on the terminal board as shown in figure 4.1. Larger capacitors may be substituted. The actual value is not critical. This shifts the measured values so that all current readings should be multiplied by a factor of 1.5 to set the equivalent 3 phase current.

Figure 4-1 shows a suitable setup for single phase testing. Figure 4-2 shows how to build a 100 amp current source if a commercial unit is not available. All current values can be increased by winding n turns in place of the single turn shown and multiplying current readings by n.

To verify that the internal relay circuitry is operating press the front panel test button. When the test button is pressed, the fault indicators operate and the motor contactor should trip, Tests for each protection mode are outlined in the sections that follow.

FIGURE 4-1 SINGLE PHASE INJECTION TESTING

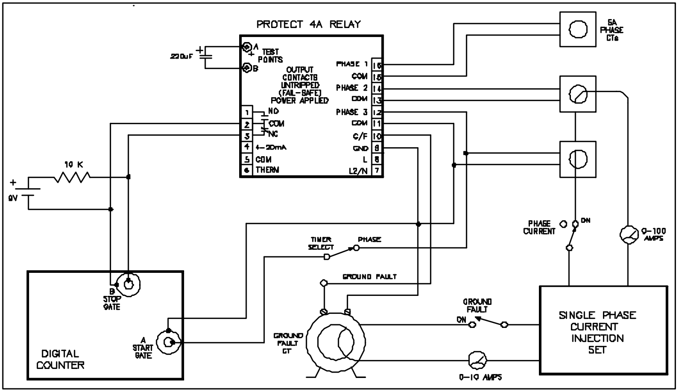
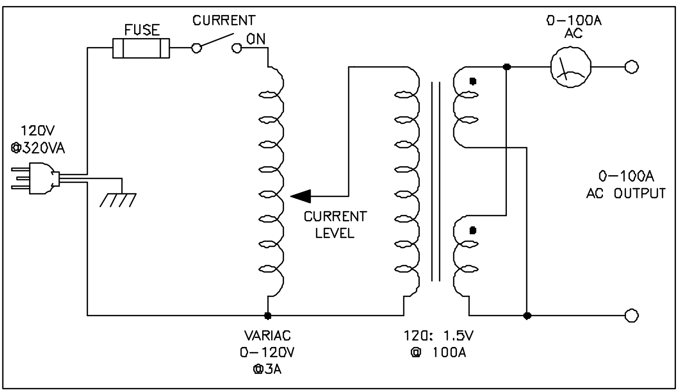


FIGURE 4-2 100 AMP CURRENT SOURCE



4.2 OVERLOADS

Set the FULL LOAD — AMPS control to the desired pickup current and gradually increase the phase current through the phase CTs. With current applied below the full load pickup point the overload indicator light will be off. When the pickup current is reached the light will flash.

At the point where the light just begins to flash, the control setting and actual three phase RMS current of simulated current (multiplied by the overload factor) using a single phase source should agree.

Example: Verify 3 times overload trip time for a stall setting of 2.5 seconds using 100:5 CTs with single phase injection (figure 4-1).

1) Set the Protect 4A FULL LOAD control to 50% for a 50 amp pickup level and stall time to 5 seconds.

2) Pass 1 turn from the current source (or n turns and multiply the current by n) through two of the 100:5 CTs shown in figure 4-1 wiring diagram. (Pass the current source through the two CTs in opposite direction.)

3) Connect 220 uF/25V capacitor (nominal) to Protect 4A test points A (+ ve) and B (- ve) on the terminal board. Observe polarity.

4) a) Slowly increase the current until the overload indicator starts to flash. This is the pickup level. The injected current should be 50A × 1.5 (multiplier factor) = 75A for correct calibration.

   b) Increase the current to 3 × 75A = 225A.

   c) Turn off the current. Press front panel TEST and then RESET buttons. This clears the internal thermal memory ready for timing tests.

   d) Apply the full 225A immediately while timing. From the overload curves of figure 3-2, the relay should trip in 21.9 seconds. Other overload levels and stall times can also be verified this way. Note that the times will only be as accurate as the current multiples of pickup level injected.

5) Repeat steps 2-4 for the 3rd 5 amp phase CT.

When checking the time/over current curves for accuracy, it must be remembered that previous overloads will shorten the time available since the internal memory is partially full to simulate motor heating. Before performing timing tests, ensure that full memory capacity is available by:

a) removing and re-applying control power.
or b) tripping and resetting relay.
or c) applying no overloads for a ten minute period.

If the mechanical jam feature has been selected (section 2.9.2) apply current to the motor below the full load setting and wait several seconds for the PROTECT 4A to internally determine that the simulated motor is in a normal run state. Gradually increase the current until the relay trips. This should occur at approximately three times the full load pickup point. Since there is a one second delay between sensing the threshold and actually tripping, the current must be increased slowly.

Use the maximum stall time setting and clear the memory before doing this test to prevent the overload memory from tripping before mechanical jam.

4.3 SINGLE PHASING

Set the FULL LOAD—(AMPS) control to a suitable pickup setting and apply slightly less than one full load of three phase input current. Create a single phase by removing the capacitor across test posts A and B for a single phase injection setup. After approximately 5 seconds the relay should trip with an unbalance indication.

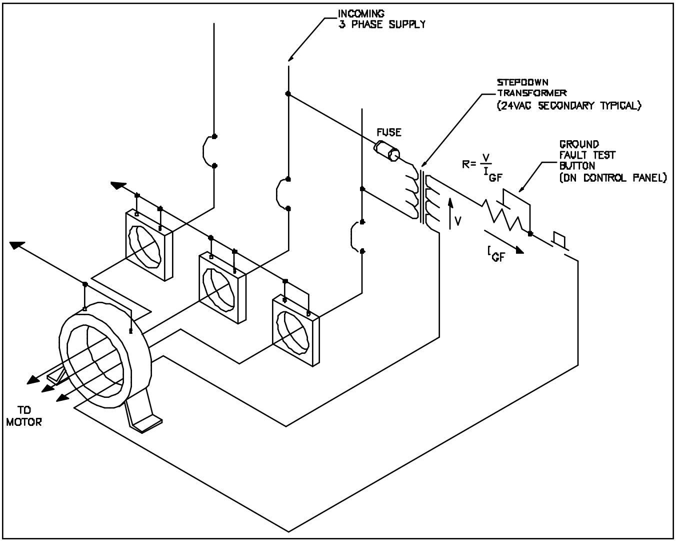
If the current applied is below 40% of the full load setting, the single phase protection is automatically deactivated to prevent nuisance tripping on lightly loaded motors where a large unbalance will not cause damage.

4.4 GROUND FAULT/EARTH LEAKAGE

When a ground fault occurs on a three phase system, the core balance CT will pick up a sine wave current at the system frequency. Consequently, to test this protection feature, pass a wire through the separate ground fault CT and apply a single phase current. When the current through this wire reaches the ground fault pickup level selected, the relay will trip. Some mine specifications require a permanent ground fault test system installed in the switchgear. Fig. 4-3 shows a typical scheme that can be used with the Protect 4A relay.

Ground fault time delays are controlled by an accurate crystal reference and should be drift free. Time delays can be checked using a frequency counter or mechanical cycle timer. The scheme will depend upon the equipment used, however it will be necessary to use the ground fault current signal to trigger the timer on and the closure of the output contacts to stop the timer. A typical setup is shown in figure 4-1. Time delay measurements should be made with applied currents of 25% or greater than the PICKUP — AMPS control setting.

FIGURE 4-3 GROUND FAULT/EARTH LEAKAGE TEST

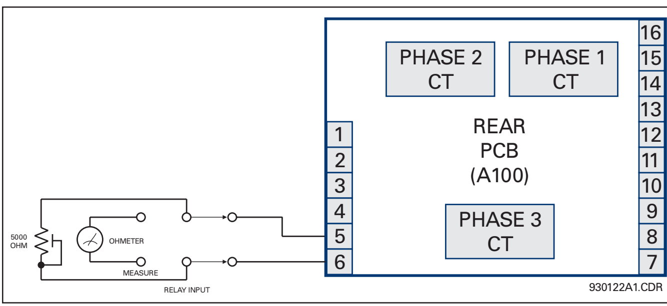


4.5 THERMISTOR

A simple 5000 ohm variable resistor connected across terminals 5 and 6 can be used to check the operation of the thermistor circuit as shown in Fig. 4-4. For low resistance values the PROTECT 4A remains untripped. At approximately 3000 ohms the relay will trip. Since there is a 3 second delay after sensing a hot thermistor, the control should be increased slowly.

With the thermistor connected or with very high resistances, the relay will not trip because a no sensor hold off circuit is activated. If an actual thermistor similar to the type used in the motor is available it can be connected instead of the variable resistance. When gently heated with a match or heat gun, it should cause the relay to trip.

FIGURE 4-4 THERMISTOR TEST



4.6 4-20 mA OUTPUT

Connect a DC milliammeter to terminals 4 (+ ve) and 5 (- ve). With no input current the meter should read zero. Apply a balanced three phase signal through the current transformers equal to the rated CT current (e.g. 100 amps into 100:5 CTs should give a current reading of 20 mA). The meter should now read 20 mA and this reading will be independent of the FULL LOAD — AMPS control setting

Intermediate current values will result in a meter reading of:

$$\text{meter mA} = \frac{\text{actual current}}{\text{full load current}} \times 16 + 4$$

For example, 75 amps into a 100:5 CT will result in a meter reading of:

$$\frac{75}{100} \times 16 + 4 = 16 \text{ mA}$$

Use the setup of fig. 4-1 if single phase injection is to be used. Multiply all current values by 1.5 and calculate the output as above. For example: if 200:5 CTs are used, apply a current of 200 x 1.5 = 300 amps through one CT to set an effective input current of 200 amps.

The output is a current source with a maximum drive voltage of about 8 volts. Consequently the programmable controller load or sensing resistance used for these tests must be less than 350 ohms or saturation will occur. For loads in this range, the output current will be independent of the load resistance.

It is possible to recalibrate the PROTECT 4A to give a linear output over a range of 0-20 mA for use with standard current loop interfaces. Consult factory if this is required.

4.7 ROUTINE MAINTENANCE VERIFICATION

A front panel self test feature is provided so that proper operation of the relay and its indicators can be verified. If this test button is pushed while a motor is running the motor should shut down with the 4 fault indicators set. Although this indicates that the internal circuitry is operating, further tests are needed to check calibration accuracy.

Periodic checks of the overload pickup calibration are possible by turning the FULL LOAD — AMPS control counter-clockwise when the motor is running until the overload light just begins to flash. The dial value at this setting should correspond to the actual average current measured in the motor using a separate ammeter. To simulate an overload, set the FULL LOAD —AMPS control to a value less than the actual motor current and note the trip time from the run curves of figure 3-2. Calculate the amount of overload from:

$$\text{period multiple} = \frac{\text{actual current}}{\text{pickup setting}}$$

Read the trip time from the overcurrent curves of figure 3-2 using the curve selected by the STALL TIME — (SEC) control.

For example: if 100:5 CTs are used and the motor is drawing 75 amps, set the FULL LOAD — AMPS control to 50 amps to simulate and overload of:

$$\frac{75}{50} = 15 \text{ times}$$

Note that any previous overloads or starting inrush currents in the previous 10 minutes will reduce the total trip time.

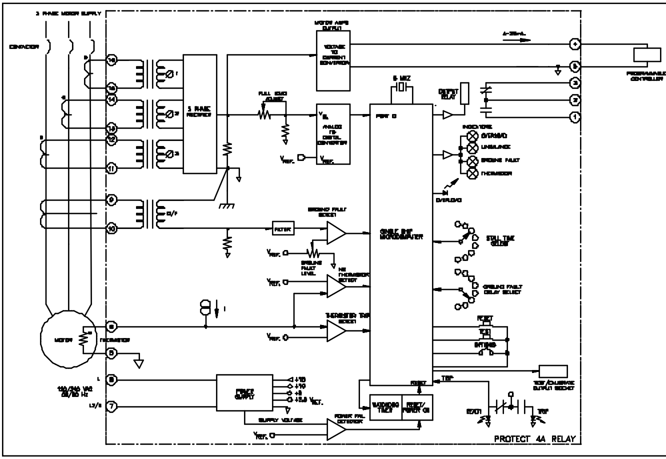
It is difficult to simulate other fault conditions directly. The test methods outlined in the previous sections will be required if these checks are to be performed on a routine basis.

4.8 PROBLEM TROUBLESHOOTING

TABLE 4-1 PROBLEM TROUBLESHOOTING

SYMPTOM	PROBABLE CAUSE	ACTION
Periodic Overload Tripping	– Overload surges during running. – Incorrect run curve.	– Defeat mechanical jam. – Use run curve with longer trip time (higher stall setting).
Overload Trip Time Too Short	– Previous overloads affect values. – Jam enabled (1 second trip).	– Trip test/reset relay before doing time tests. – Defeat jam feature
Ground Fault Nuisance Trip	– Capacive motor inrush currents give ground fault signal. – CT wiring too close to high noise source.	– Increase ground fault level/time settings. – Twist CT wires together and route away from high current cables or use shielded cable.
Nuisance Unbalance Trip	– Non-sinusoidal waveform.	– May not be suitable for variable speed drive application. – Check load distribution.
Cannot Reset	– No control power.	– Status light will be on if control power applied. – Push test/reset or power off/on then reset.
4-20 mA Output Low	– Meter or programmable controller too high.	– Maximum load 350 ohms.

FIGURE 5-1 HARDWARE BLOCK DIAGRAM



5. THEORY OF OPERATION

5.1 HARDWARE

The Protect 4A is able to provide many protection features at low cost through the use of a powerful single chip microcomputer as shown in block diagram of figure 5-1 and the schematic insert. Phase currents are sensed by three current transformers with 1 amp or 5 amp secondaries. A three phase bridge rectifier is used to provide a rectified output signal into a fixed burden which is shown for balanced and unbalanced conditions in fig. 5-2. Under microcomputer control an analog to digital convertor continuously samples this signal and generates both the three phase average for overload curve timing and the phase minimum for unbalance detection. The burden voltage proportional to the three phase average current is also connected to a voltage to current convertor to provide a 4-20 mA output for a programmable controller.

Ground fault/earth leakage sensing is provided by a fourth current transformer in the current sensing module which encircles the three motor conductors and senses ground faults by the reliable core balance (zero sequence) method. Only if a ground fault is present will this CT give an output which is rectified, filtered and compared against a preset value set by the front panel ground fault/earth leakage level control. Time delays for both the ground fault and overload curves are provided by accurate crystal controlled time counters under program control. This eliminates inaccuracies and time/temperature drift associated with resistor/capacitor time constant circuits.

A voltage divider circuit using the remote thermistor as one resistance element is used to detect if the thermistor resistance has exceeded the preset threshold point. The voltage across the thermistor is compared to two fixed reference values; the lower reference is the trip resistance point and the higher reference is used to determine if no thermistor is connected to prevent nuisance tripping.

FIGURE 5-2 SINGLE PHASE DETECTION

FIGURE 5-2a 3 PHASES, BALANCED CONDITION

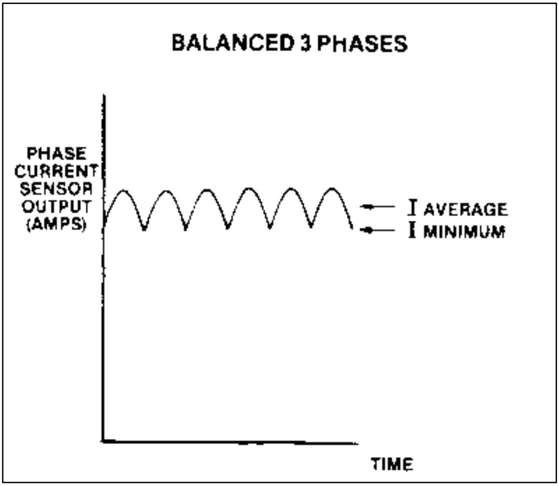
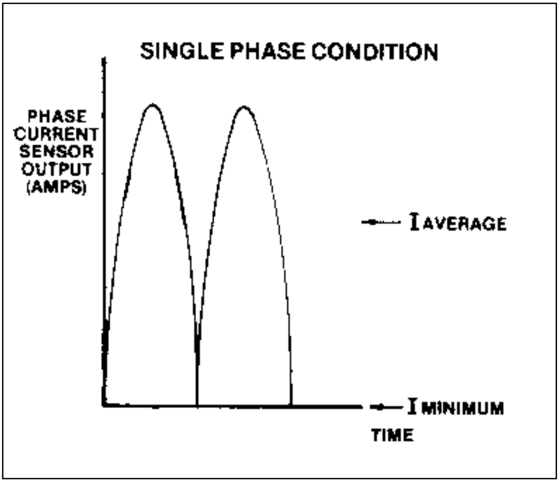


FIGURE 5-2b SINGLE PHASE CONDITION



All front panel and option switches are monitored and stored in the microprocessor for use by various parts of the program. Indicators and the output relay are strobed under program control as required. Since these are activated by pulse action, power is conserved and the relay returns to the state before loss of power whenever power is reapplied

Reliable operation of the microprocessor under erratic or transient supply conditions is obtained through the use of a power fail detector which resets the microprocessor to a start up state whenever control power is out of range.

In case a transient or system malfunction should cause erratic program execution a watchdog timer, consisting of independent circuitry, will reset the microprocessor. The correct strobe signals which are only present during normal program execution must be received or the watchdog timer will be activated

A switch is used to select 120/240 VAC 50/60 Hz for the dual primary power transformer. This transformer is designed to accept a wide range of input voltages commonly encountered in industrial applications and is of split bobbin design to minimize control line transients. In addition to voltage regulators for the circuitry, reference voltages are derived from a temperature compensated precision voltage reference to provide stable long term performance.

5.2 FIRMWARE

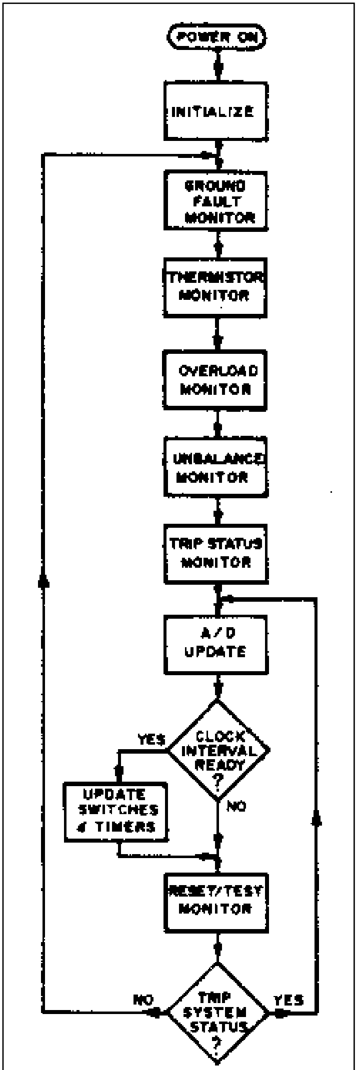
All mathematical computations and logical operations are performed by a program stored in the microcomputer. Execution flow of the routines is shown in the firmware block diagram of fig. 5-3.

An initialize routine ensures that the system always comes up in the same state when first powered on. Ground fault and thermistor input signals, if present, are used to update delay counters to determine if there is a trip condition. The unbalance routine compares the average and minimum phase current difference to the average. If this difference exceeds the threshold representative of a single phase condition for a specific time period an unbalance trip condition occurs.

In order to generate an inverse curve the three phase average current is squared and integrated over time. If the integrated value, which represents the thermal heat buildup in the motor, exceeds a threshold determined by the stall time setting the relay trips on overload. When the motor is stopped or not overloaded the integrated value is reduced with time proportional to motor cooling.

Other housekeeping features include analog to digital convertor sampling, updating all timers using programmed timers, reading switches and sampling internal status. When the relay is tripped, the internal program continuously scans for a reset signal and ignores all fault inputs.

FIGURE 5-3 FIRMWARE BLOCK DIAGRAM



MULTILIN RELAY WARRANTY

Multilin warrants each relay it manufactures to be free from defects in material and workmanship under normal use and service for a period of 24 months from date of shipment from factory.

In the event of a failure covered by this warranty, Multilin will undertake to repair or replace the relay providing the warrantor determined that it is defective and it is returned with all transportation charges prepaid to and from an authorized service centre or the factory. Repairs or replacement under this warranty will be made without charge.

This warranty shall not apply to any relay which has been subject to misuse, negligence, accident, incorrect installation or use not in accordance with instructions nor any unit that has been altered outside a Multilin authorized factory outlet.

Multilin is not liable for contingent or consequential damages or expenses sustained as a result of a relay malfunction, incorrect application or adjustment.

PROTECT 4A

MOTOR PROTECTION

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