NOTES & REFERENCES

Module 5

ELECTRIC MOTOR PROTECTION

OBJECTIVES:

After completing this module you will be able to:

5.1 Explain how each of the following protection schemes could be used to provide protection of an electric motor:

Pages 2–6 ⇔ a) Timed overload,

Pages 6–8 ⇔ b) Stalling (Locked rotor),

Page 9 ⇔ c) Open circuit or single phasing,

Page 9 ⇔ d) Phase unbalance,

Page 12 ⇔ e) Instantaneous overcurrent,

Page 13 ⇔ f) Ground fault,

Page 14 ⇔ g) Undervoltage.

Pages 2–14 ⇔ 5.2 For each of the schemes listed in 5.1, give an example of a fault requiring the protection scheme to operate and the consequence to the electric motor if the protection scheme failed to operate.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

This module concentrates on the protection schemes used for the protection of electrical motors and consequences of failure to operate. A brief discussion will also be given on **the operation of the various types of protective relays, but you will not be required to memorize this information.**

One note to make here is that the protection schemes that will be discussed, have some similarities and overlap. This is advantageous, since not all motors have the all of the protection schemes listed in this module. In fact, there are many protection schemes available, and only the more common ones are discussed in this module.

NOTES & REFERENCES

TIMED OVERLOAD PROTECTION

Obj. 5.2 ⇔

Continuous operation of an electric motor at currents marginally above its rated value can **result in thermal damage to the motor**. The insulation can be degraded, resulting in reduced motor life through eventual internal motor faults. Typically, an electric motor has a service factor rating listed on its nameplate. This number represents the **continuous allowable load limit that can be maintained without sustaining damage to the motor***. To protect against motor damage, we must ensure that this condition is not reached, hence we must trip the motor before the overload limit (service factor) is reached.

Obj. 5.1 a) ⇔

A common type of relay used for timed overload protection is a thermal overload relay. In this type of relay, the motor current, or a fraction of the current through a current transformer, is connected to an in–line heater. Figure 5.1 shows a simplified thermal overload relay.

The heater (heated by I^2R action) is used to heat a bimetallic strip**, which causes the displacement of a relay contact. **Normal operating currents, or short duration overload conditions, will not cause the bimetallic element to bend enough to change the relay contact positions.** Excessive currents will cause increased heating of the bimetallic strip, which will cause relay contacts to open and/or close, tripping the motor. This type of relay has an inherent reaction time ***, since the heater and bimetallic element take time to heat up. Protection against **causes of excessive motor currents such as:** short circuits, mechanical problems causing overload, high resistance ground faults, will be provided by this scheme.

Obj. 5.2 ⇔

Another type of relay that can be used is an electromagnetic relay. This type of relay uses a current in a coil to operate a plunger or armature. This relay type is almost instantaneous, since an increase in current will change the magnetic force on the plunger or armature. Time delay for overload protection can be achieved by the use of timers or dashpots (oil or air). Figure 5.2 shows a simplified electromagnetic relay with an oil dashpot.

As current increases in the relay shown in Figure 5.2, the plunger will immediately want to move to operate the contact due to the magnetic forces produced.

* *For example, a typical electric motor is designed to withstand a continuous overload of about 15% without sustaining damage, and has a service factor = 1.15. Continuous operation above this value will result in thermal damage.*

** *A bimetallic strip consists of two different materials bonded together, each having different thermal expansion properties. As the materials are heated, one side will lengthen more than the other, causing bending.*

*** *If the reaction time is not matched to current–heating characteristics of a motor, the motor could be damaged during start conditions, when large currents are drawn. This will be discussed in the next section.*

NOTES & REFERENCES

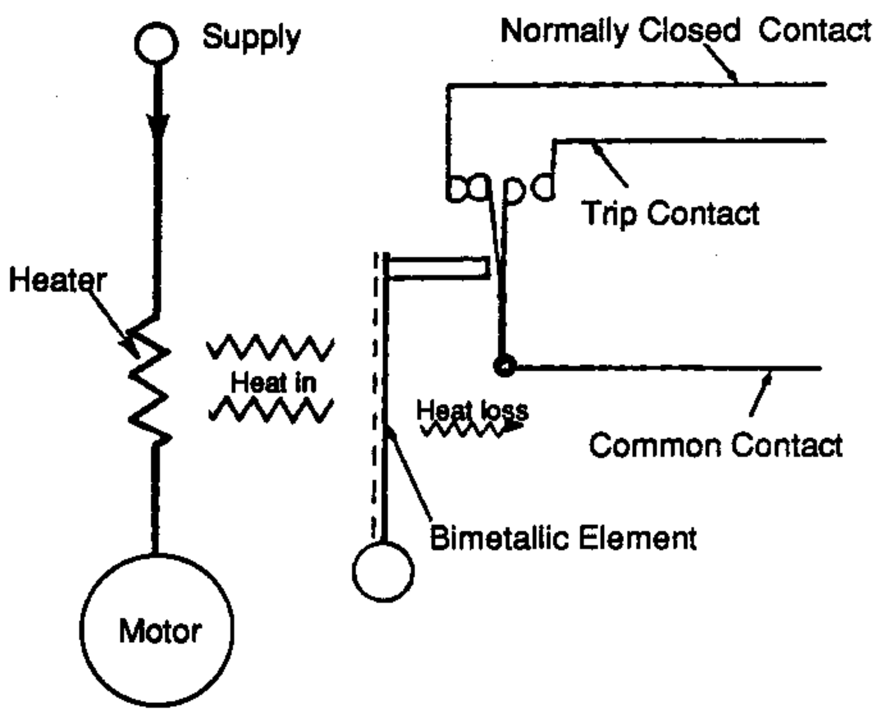

Figure 5.1: Operating Principle of a Thermal Overload Relay

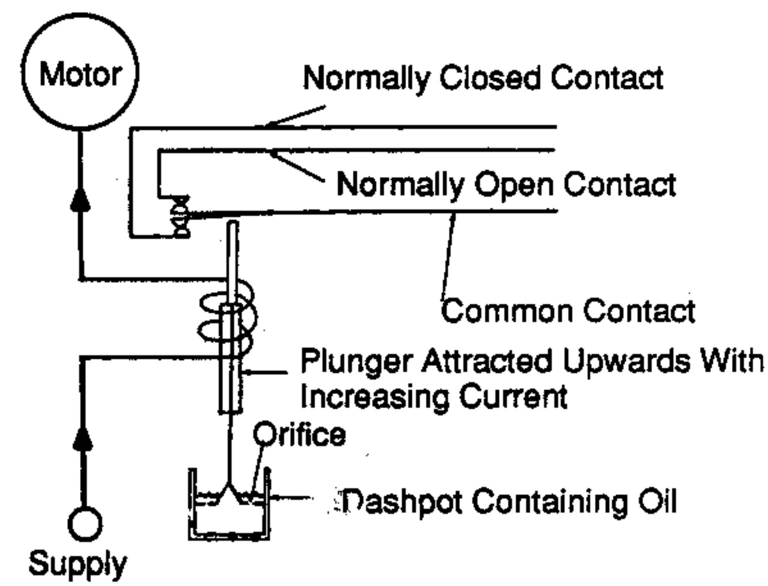

Figure 5.2: Electromagnetic Relay with Time Delay

But, movement is slowed by the viscosity of the oil, and the size of the orifice in the dashpot. Hence the time delay is controlled by the size of the orifice and the viscosity of the oil. This **time delay will allow for short increases in current demand, but will trip the motor for sustained overload**. During heavy overload conditions, this type of relay will trip somewhat faster due to the large magnetic forces produced.

The time delays of both relays considered thus far are governed by inverse current/time characteristics. Recall that fuses also have inverse current/time relationships*. For currents that are several times the normal rating of the fuse, it has a fast operating time, but for currents close to its normal rating the operating time is slow. Figure 5.3 (a fold–out drawing at the end of the module) is a simplified inverse current/time graph showing the characteristics of a fuse, an electromagnetic relay with oil dashpot and a thermal relay. Using the example of an induction motor with a normal running current of 8 amps and a starting time of 5 seconds at 48 amps, these characteristics show the range of overcurrent protection offered by each device. The figure also shows the motor thermal damage curve allowing you to assess the merits of each protective device.

Notice from Figure 5.3 that the 16A fuse will only protect against the stall condition (or problems during starting that lead to the motor drawing starting current for longer than about 25 seconds). It will blow before the motor suffers thermal damage at 48 amps (about 45 seconds). The thermal relay protects against long duration operation at overload just below the service factor (at about 8.8 amps, in this case) but will not alleviate a stall situation before serious damage occurs. The electromagnetic relay with oil dashpot combines the advantages of both other devices and gives complete protection for start, stall and continuous overload conditions.

Another type of electromagnetic relay with a time delay is the induction–type relay. Induction–type relays are the most widely used protective relaying where ac quantities are involved. One such relay is the induction disc relay. A simplified sketch of an induction disc relay is shown in Figure 5.4. In this relay, two coils producing opposing magnetic fluxes create a torque on a disc (a current proportional to the load current flows in the operating coil. Its magnetic circuit induces a current and hence, an out of phase flux, in the opposing coil. The two fluxes together produce a torque on the disc). A spring provides reverse torque on the disc to counteract the magnetically produced torque. A third smaller magnet is used to produce a damping effect to control the disc speed, and also to prevent the disc from overshooting when the current returns to normal.

* *Fuse ratings and characteristics were discussed in your 426.0–12 Electricity course.*

NOTES & REFERENCES

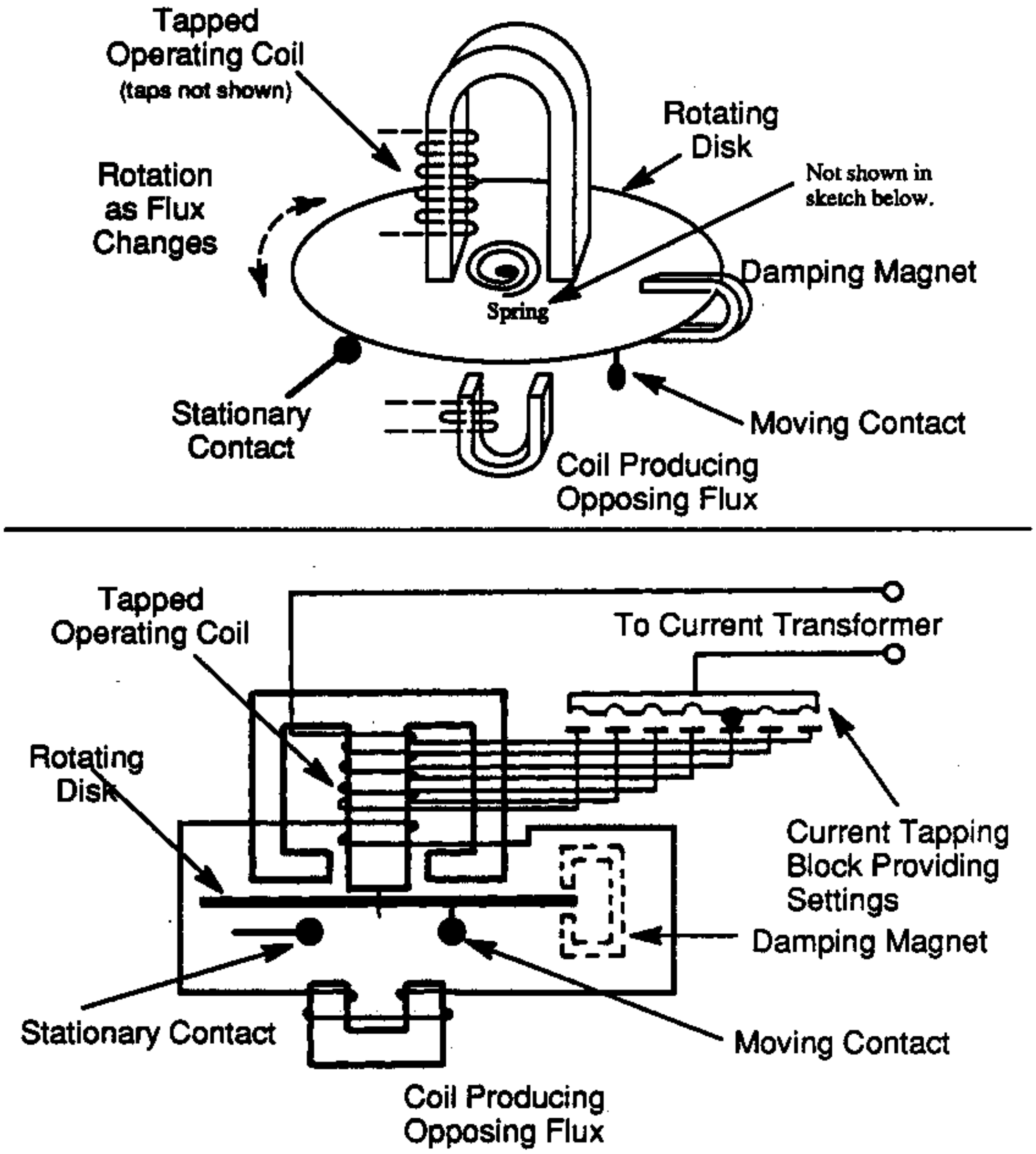

Figure 5.4 : Induction Disc Relay

As the current in the operating coil increases, so does the torque on the disc. When the torque overcomes the spring torque, the disc begins to rotate. When the moving contact meets the stationary contact on the disc, the trip will operate.

Tap settings and time characteristic adjustments can be made to alter the time delay of the relay (the current/time characteristic is not shown in Figure 5.3 but can be shaped to match those devices shown).

NOTES & REFERENCES

Note that the time delay in all of the above relays is beneficial when system loads *temporarily* fluctuate to the overload limits. It allows continued operation of the motor without a trip. Short term overloading will not cause damage to the motor's insulation.

Our stations also employ small dc motors for special applications such as the drives for the emergency stator cooling pump, emergency generator seal oil pump and emergency turbine generator lubricating oil pump. Overload protection methods for these motors are similar to the thermal and electromagnetic plunger devices described above for ac motors (see Figures 5.1 and 5.2).

Thermal overload relays, typically using in–line heaters that act on bimetallic strips, are used to provide an alarm in the case of continuous overload. This is an alarm and not a trip because these emergency pumps are the last resort for the safe shutdown of affected plant equipment. Unannounced shutdown could have disasterous consequences.

Magnetic overload protection is provided to trip the dc motor in the event of a short circuit. Again, time delay may be provided by using dashpots or thermal elements.

STALLING (LOCKED ROTOR) PROTECTION

Obj. 5.2 ⇔

Stalling, or locking the rotor, is a situation in which the circuits of a motor are energized but the rotor is not turning. It can occur during motor starting or operation. **For example, mechanical faults such as a seized bearing, heavy loading, or some type of foreign object caught in a pump could be possible causes of motor stalling.** The **loss of a single phase** while the motor is not rotating, or under high load, is another situation in which a motor may stall.

The typical starting time of a motor is less than ten seconds. As long as this **start time is not exceeded, no damage to a motor will occur** due to overheating from the high currents. During operation, a **motor could typically stall for twenty seconds without resulting in excessive insulation deterioration**. Since these two stall conditions have different characteristics, either two types of stalling protection are needed, or start protection can be used to cover both cases.

Motors are especially susceptible to overheating during starts, due to high currents combined with low cooling air flows (due to the low speed of the motor, cooling fans are delivering only small amounts of air). This is also why some larger motors have a limit on the number of attempted motor starts before a cooling off period is required.

NOTES & REFERENCES

Obj. 5.1 b) ⇔

We use a "stalling relay" to protect motors **during starts**, since a standard thermal relay has too much time delay. A stalling relay **will allow the motor to draw normal starting currents** (which are several times normal load current*) **for a short time, but will trip the motor for excessive time at high currents.** A stalling relay uses the operating principle of a thermal overload relay, but operates faster than a standard thermal relay.

Figures 5.5 a & b) show a typical stalling relay. By passing the motor current directly through the bimetallic elements in this relay, the heating is immediate, just as would be experienced within the windings of the motor.

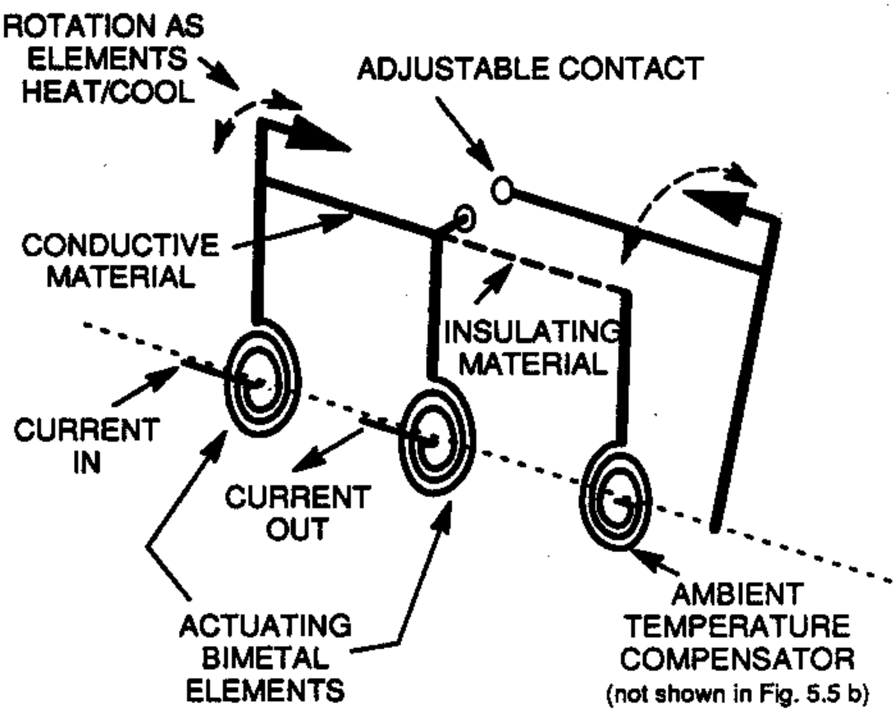

Figure 5.5 a): Stalling Relay

This type of relay is usually operational only when the motor current is above 3 times the normal operating current, and is switched out when the current is below 2 times the normal operating current. This switching in/out is achieved by the use of an additional contact. These **high currents are only typical of stall and fault conditions** (faults will usually be detected by other relays, which will operate faster than stalling relays).

When the motor is operating normally, the current in this protection scheme passes through the resistor and bypasses the bimetallic elements, going through the closed contact (as per the configuration in Figure 5.5 b))**.

* *This was discussed in the 426.0–14 Electricity Course.*

** *A small amount of current will also flow through the remaining parallel circuit. But since the resistance of the closed contact is much less than the remaining circuit, the current flow in the circuit parallel to the contact will be insignificant.*

NOTES & REFERENCES

The resistor will limit the current in this circuit (which controls the contactor operation). When the current reaches 3 times normal current, the relay contacts shown reverse their positions by the action of the control contactor. The current then bypasses the resistor through the closed contact, and passes directly through the bimetallic elements. When the current reduces to 2 times the normal operating current, the circuit will return to the normal position.

Another popular method of providing this protection is by using a speed detection probe. This probe detects the speed of the shaft, and sends a signal to the protection circuit. If the speed signal is below a certain value for a specified time duration (or after a specified amount of time during a start), the stall protection will trip the motor.

Electromagnetic relays, such as those described in the previous section can also be used for stalling protection at startup. The time delay of the dashpot or induction disc may be set to accommodate the startup surge of current in the motor without causing an unnecessary trip.

If protection for stalling encountered during operation is required, a standard thermal overload relay can usually be matched to the motor stalling current–time–heating curve to provide protection.

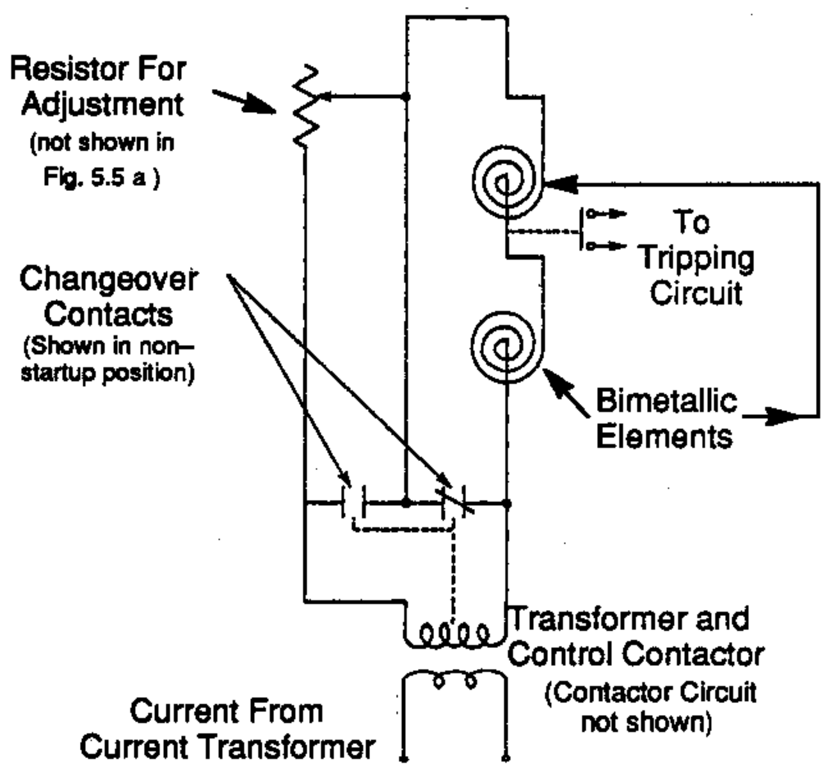

Figure 5.5 b): Stalling Relay

NOTES & REFERENCES

OPEN CIRCUIT/SINGLE PHASING PROTECTION AND PHASE UNBALANCE PROTECTION

If a supply line to a three phase motor opens, it **results in the motor operating as a single phase motor.** This type of fault can be caused by a fuse failure in a single phase (possibly due to the inrush current during a startup), or a damaged motor terminal, etc..

Obj. 5.2 ⇔

If the motor continues to operate with an open supply line, **it will result in currents in the winding between the remaining two healthy leads to exceed two times the current normally seen for a given load** (caused by induced circulating currents)*. This will **result in rapid, uneven heating within the motor. This will result in damage to insulation, windings, reduced machine life, and thermal distortion.**

It is also possible that the load torque exceeds the amount of torque produced, causing the motor to stall. The motor will draw locked rotor current ratings, which are, on average, 3–6 times full load current. This will lead to **excessive heating of the windings,** and will cause the insulation to be damaged. If the open circuit is present before the motor start is attempted, it is unlikely that the motor will be able to start rotating.

In the above case of the operating motor, the **unbalanced magnetic forces within the motor will also cause excessive vibration, resulting in bearing wear/damage and reduced machine life.**

For imbalances in phase currents/voltages, the above effects will still be present, but less severe. **Causes of phase imbalance include voltage regulation or transformer tap changer problems, and faults causing individual windings to draw excessive currents.**

Obj. 5.1 c) & d) ⇔

Figures 5.6 a) & b) show sketches of a relay arrangement that is used to protect against a phase imbalance. If any one of the phases in the motor loses power, the heater will cool down. The bimetallic strip will turn, causing the unbalance contacts to close, and the motor to be tripped. This relay will also protect against thermal overload, as the heaters cause the bimetallic strips to close the overload trip contact**. You will also see a compensating bimetal element, which will compensate for ambient temperature changes, thus preventing unnecessary trips.

---

* *How these currents are formed is beyond the scope of this course. You need only know that these currents circulating in the motor will cause additional heating due to I^2R losses.*

** *Phase imbalance will be limited to about 20% at full load, after which the trip will occur.*

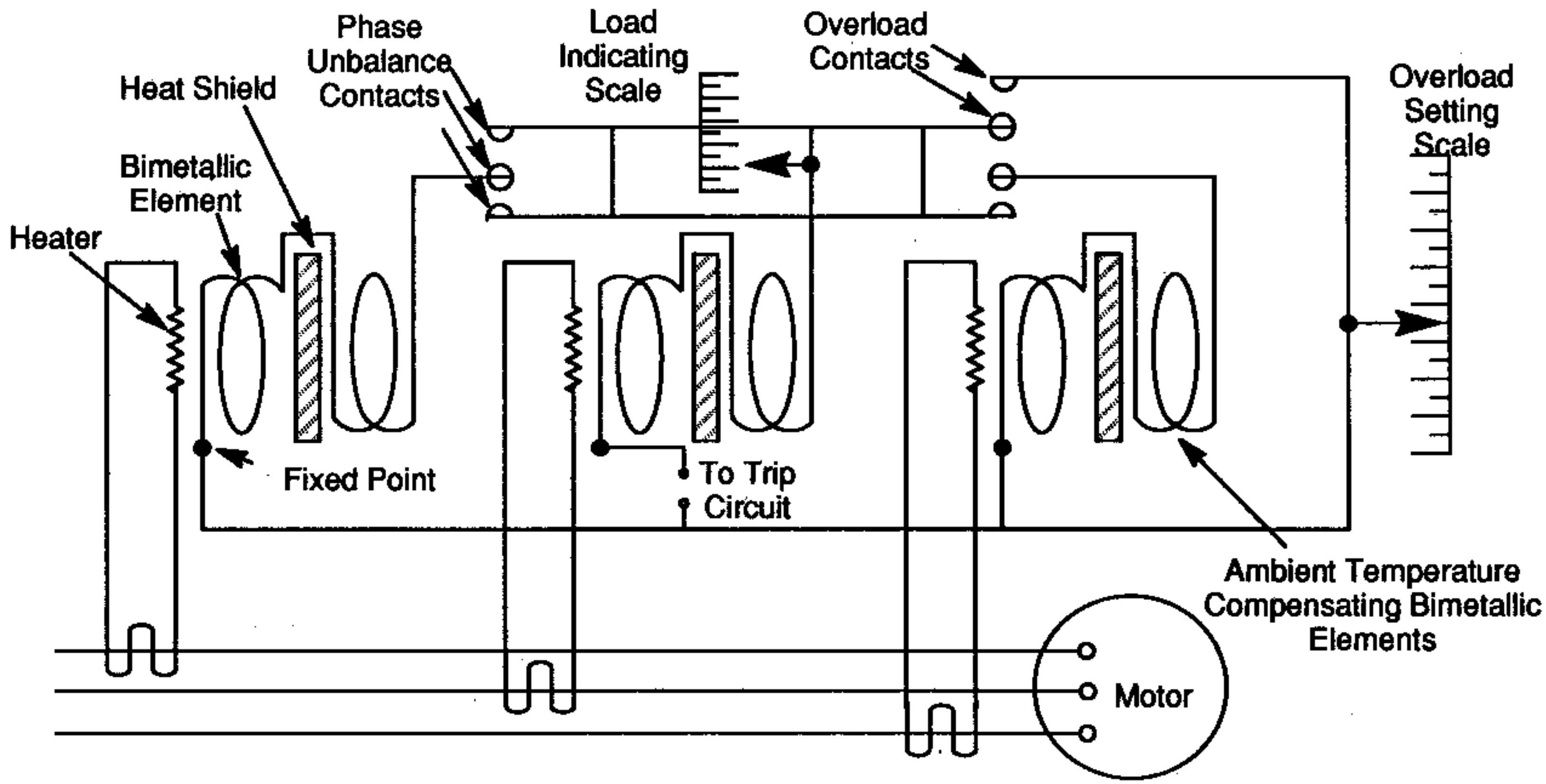

Figure 5.6 a): Phase Unbalance & Overload Protection

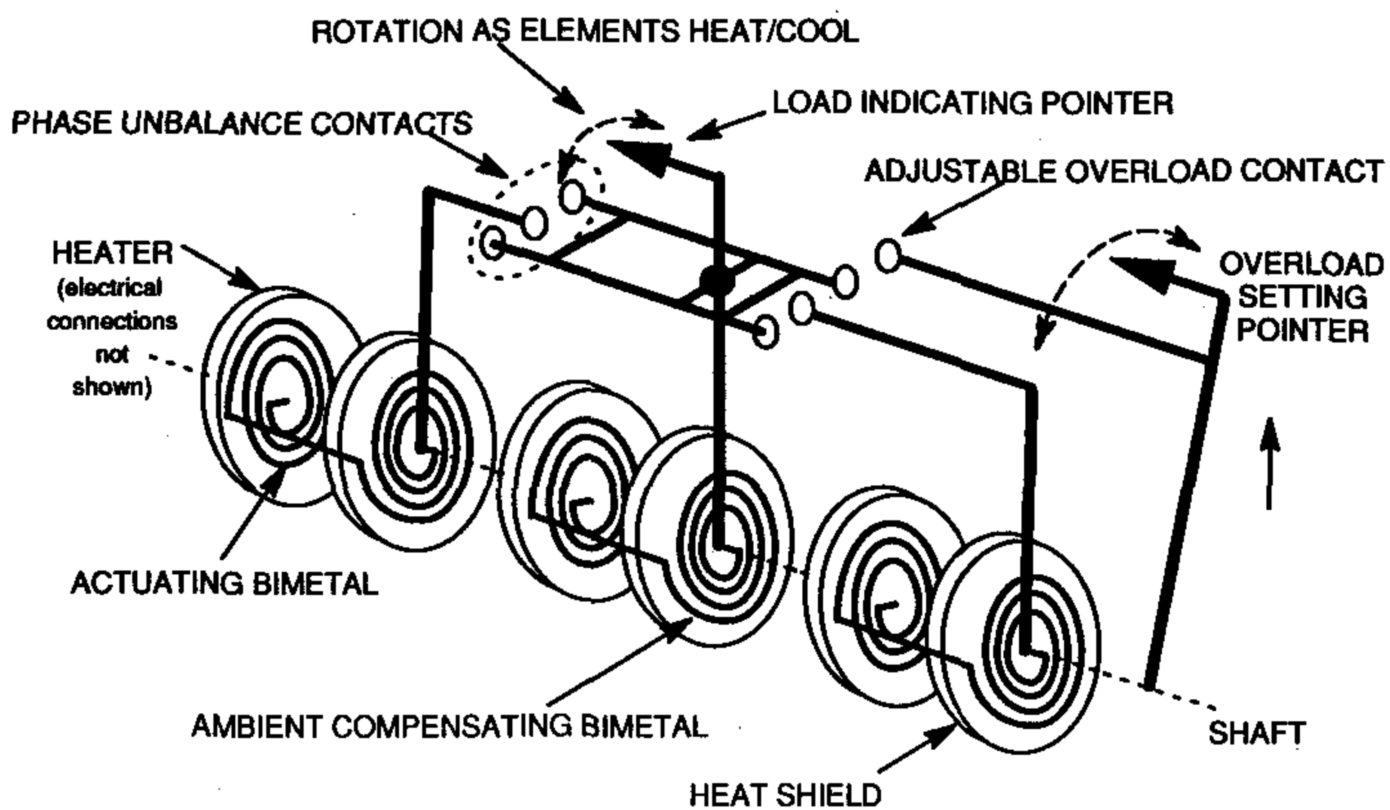

Figure 5.6 b): Phase Unbalance & Overload Protection

NOTES & REFERENCES

SUMMARY OF THE KEY CONCEPTS

- Timed overload protection protects electric motors from sustained higher than normal operating currents by tripping the motor before the overload limit is reached. Excessive currents (from motor overload, mechanical problems causing overload, high resistance ground faults, and winding short circuits) cause heating, which results in insulation damage. Insulation damage will reduce the life of the motor.
- Stall (locked rotor) of an electric motor can occur during startup and operation. During stalls, excessive currents are drawn by the motor, resulting in excessive heating and insulation damage. Special protective relays are used to trip the motor if operation at high currents occurs for excessive time .
- Single phasing due to the loss of a single supply line will result in the motor operating as a single phase motor. The winding between the healthy phases will have currents in excess of two times that expected for a given load. Protective relays detect the loss of power in any phase and trip the motor.
- Phase unbalance will cause unbalanced currents, with the effects similar to those seen in single phasing, but less severe. Protection is similar to that for single phasing.

Pages 16–17 ⇔

You can now do **assignment questions 1–6.**

INSTANTANEOUS OVERCURRENT PROTECTION

Obj. 5.2 ⇔

Instantaneous overcurrent is usually the **result of fault conditions** (phase to phase, phase to ground), in which **current flow will greatly exceed normal.** Damage due to **winding overheating and burning damage** associated with large fault currents can occur without this type of protection.

Obj. 5.1 e) ⇔

These types of **faults** can be **rapidly detected by differential protection schemes,** as were discussed in Module 3, and cleared before major damage results. In these situations, fast acting electromagnetic relays will be used to trip the affected motor*.

GROUND FAULT PROTECTION

In the detection of ground faults, as with the detection of instantaneous overcurrents, it is extremely important that the fault be detected and cleared quickly to prevent equipment damage. **Insulation damaged** by heat (from extended overload operation), brittleness of insulation (due to aging), wet insulation or mechanically damaged insulation can cause ground faults.

* *Electromagnetic relays were discussed earlier in this module.*

NOTES & REFERENCES

Obj. 5.1 f) ⇔

Ground fault protection schemes also use **differential protection schemes** to detect and clear the faulted equipment (these protection schemes were discussed in an earlier module). Figure 5.7 shows a protection scheme that will detect an **imbalance of current between the three phases.** If no ground fault is present, no current imbalance is present, hence no current will flow in the protection circuit.

Obj. 5.2 ⇔

If a ground fault develops, a current imbalance will be present, and a current will flow in the protection circuit, causing it to operate. Figure 5.8 shows a similar protection scheme, with each of the windings of the motor protected individually (this scheme is not normally installed in small motors, but may appear in the protection of very large motors).

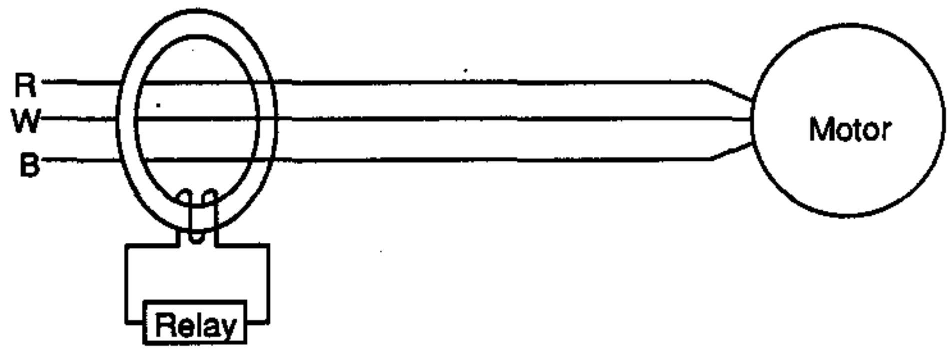

Figure 5.7: Ground Fault Protection

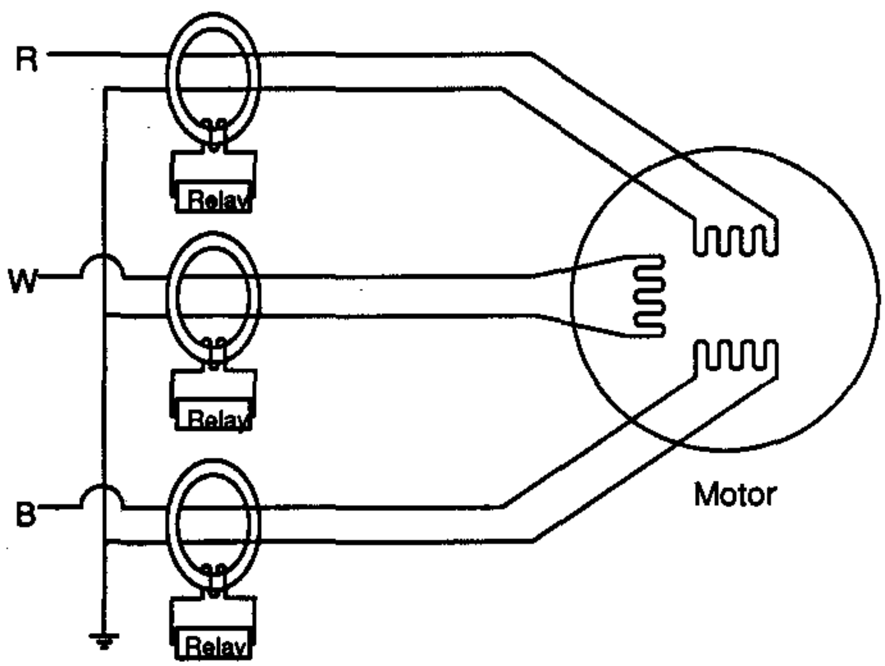

Figure 5.8: Ground Fault Protection

NOTES & REFERENCES

UNDERVOLTAGE PROTECTION

Obj. 5.2 ⇔

As the **voltage supply to a motor drops**, the motor will attempt to deliver the same amount of torque for a given load, and **will draw higher currents** to do this. This will result in **excessive heating of the motor windings**, resulting in insulation damage and reduced machine life. To prevent this type of damage, undervoltage protection is utilized. Undervoltage protection will trip the supply/loads from a bus, if the voltage on that bus reduces to levels that could cause problems.

Another benefit of this type of protection is to **prevent all loads from automatically restarting at the same time**, when voltage to a system is restored. Loads are usually introduced slowly to allow the generator to stabilize its power production before more loads are placed on the generator (there are thermal limits on rates of loading/unloading of turbine–generators anyway, which help in this situation). If the loads are all automatically reconnected at once to a re–energized bus, the voltage on that bus will likely drop, and the loads **will likely trip again on undervoltage**. Another danger of automatic re–loading if the voltage is quickly restored is that the supply and load currents **will be out of phase, resulting in current surges and mechanical stresses on the machine.**

Obj. 5.1 g) ⇔

Undervoltage protection can be achieved by an electromagnetic relay (an example is shown in Figure 5.9). This relay holds the armature to the coil as long as the voltage remains above the desired amount, keeping the normally open contacts of the relay closed. If voltage drops, the coil can no longer hold the armature, and the relay contacts will open. In this type of protection, there will also be a time delay built in (usually by a timer) to prevent operation during voltage transients (ie. if the voltage is quickly restored, the trip will not occur). The voltage drop and time delay are chosen such that re–energizing the load will not result in excessive demands on the system.

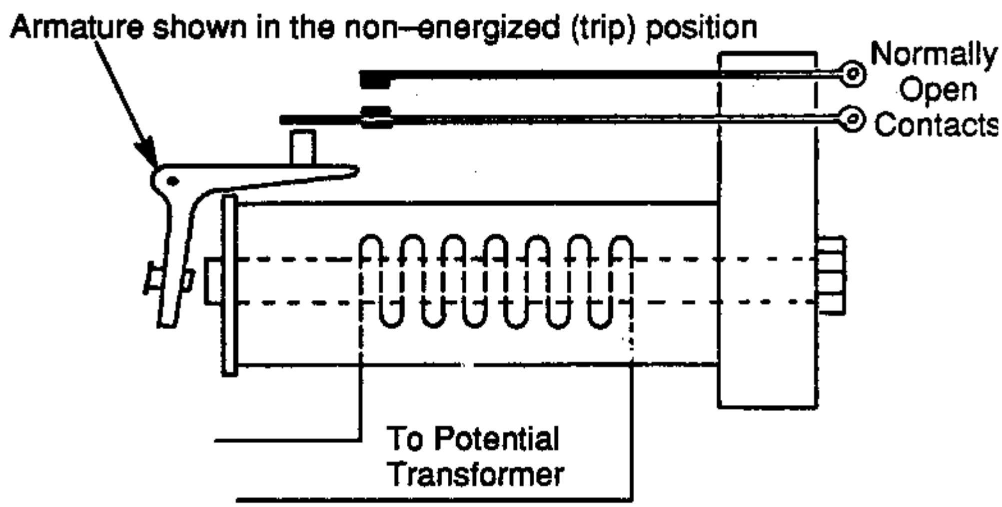

Figure 5.9: Undervoltage Relay Operation

SUMMARY OF THE KEY CONCEPTS

- Instantaneous overcurrent protection is achieved via differential schemes employing fast–acting electromagnetic relays. This will prevent damage to winding insulation due to overheating and the burning damage associated with large electrical faults. Ground and winding faults could be causes of instantaneous overcurrents.
- Ground faults are detected and cleared quickly by differential protection schemes to prevent damage to winding insulation due to overheating. Deteriorated insulation, wet insulation or mechanically damaged insulation can cause ground faults.
- Undervoltage protection, via electromagnetic relays, is used to prevent motors from drawing excessive currents to maintain torque output with reduced supply voltages. These excessive currents cause greater than normal heating, which will result in insulation damage, and reduce the life of the motor.
- Undervoltage protection will also prevent all loads from re–loading at the same time if bus voltage drops too low. Re–synchronizing with currents out of phase will cause current surges and mechanical stresses on the machine.

Pages 17–19 ⇔

You can now do **assignment questions 7–11.**

NOTES & REFERENCES

ASSIGNMENT

1. Explain how timed overload protection is used to protect an electric motor:

   Causes of overload are:

2. If timed overload protection did not work, the consequence to an electric motor is as follows:

3. Explain how stalling (locked rotor) protection is used to protect an electric motor:

   Causes of stalling (locked rotor) are:

4. If stalling protection did not work, the consequence to an electric motor is as follows:

NOTES & REFERENCES

5. Explain how single phasing or phase imbalance protection is used to protect an electric motor:

   ____

   ____

   ____

   ____

   ____

   Causes of single phasing are:

   ____

   ____

   Causes of phase unbalance are:

   ____

   ____

6. If phase unbalance protection did not work, the consequences to an electric motor are as follows:

   a) ______________________________

   ____

   b) ______________________________

   ____

7. Explain how instantaneous overcurrent protection is used to protect an electric motor:

   ____

   ____

   ____

   ____

   ____

   Causes of instantaneous overcurrent are:

   a) ______________________________

   ____

   b) ______________________________

   ____

NOTES & REFERENCES

8. If instantaneous overcurrent protection did not work, the consequences to an electric motor are as follows:

   a) ____

   ____

   b) ____

   ____

9. Explain how ground fault protection is used to protect an electric motor:

   ____

   ____

   ____

   ____

   ____

   Causes of ground faults could be:

   a) ____

   ____

   b) ____

   ____

10. Explain how undervoltage protection is used to protect an electric motor:

   ____

   ____

   ____

   ____

   ____

11. If undervoltage protection did not work, the consequences to an electric motor are as follows:

    a) ______________________________

    ____

    b) ______________________________

    ____

    c) ______________________________

    ____

Before you move on to the next module, **review the objectives** and make sure that you can meet their requirements.

Prepared by: Nick Ritter, WNTD

Revised by: Paul Bird, WNTD

Revision date: July, 1992

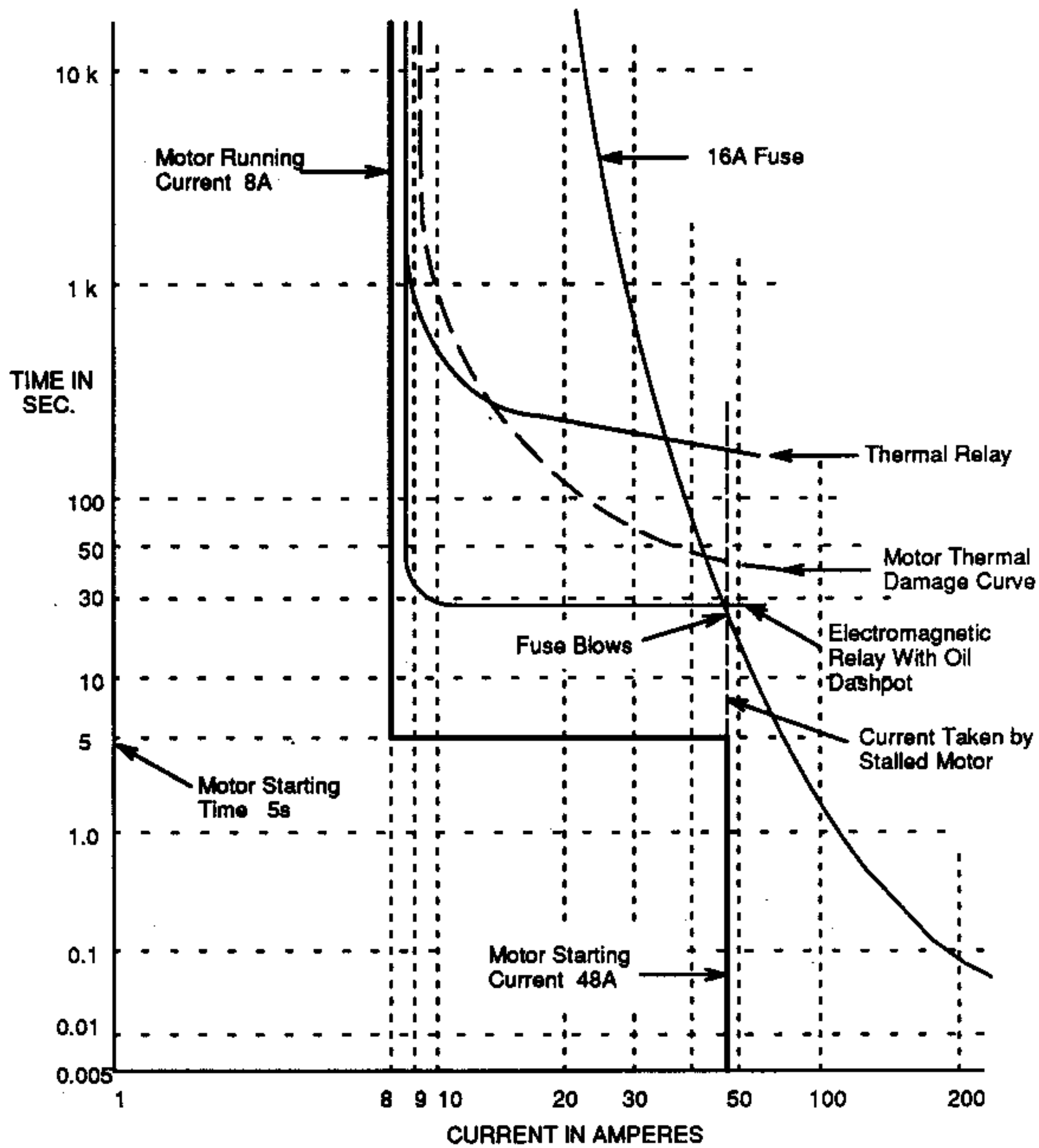

Figure 5.3: Current/Time Characteristics for a Fuse and Protective Relays