

Figure 7.9.2(A) — Transfer trip DC circuit

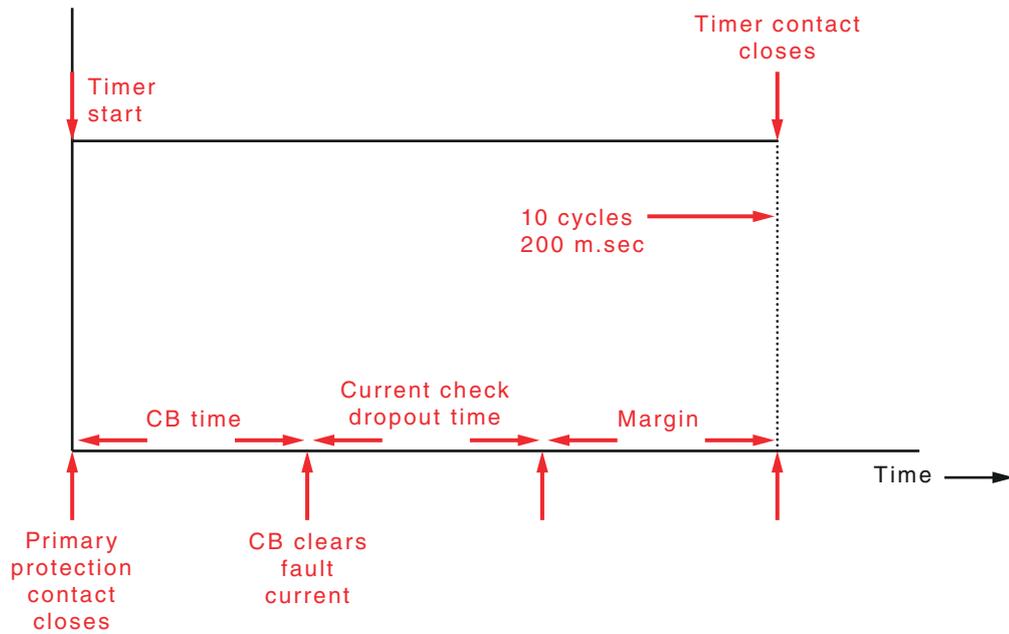


Figure 7.9.2(B) — Transfer trip timing sequence

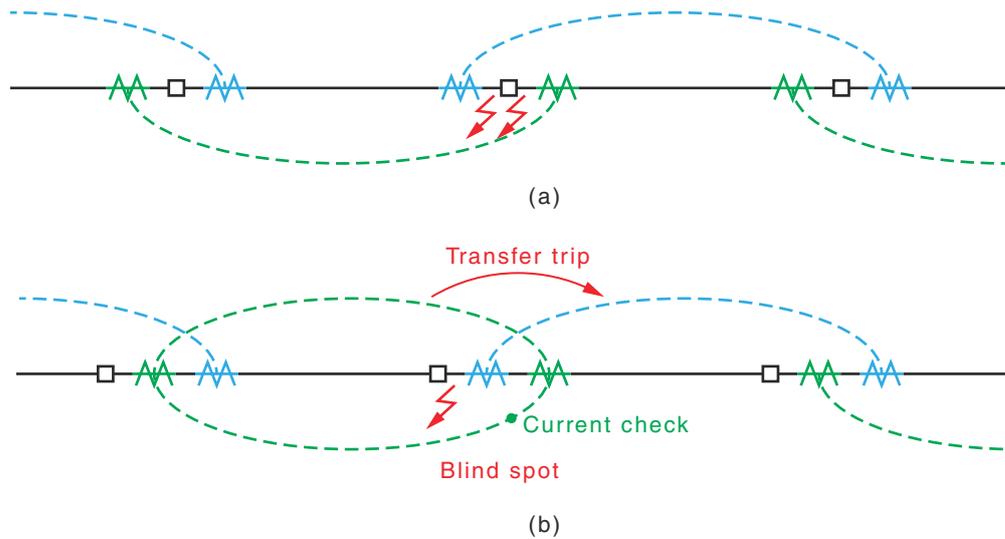


Figure 7.9.2(C) — Blind-spot protection and transfer trip

7.9.3 Feeder intertrip

Where the circuit-breaker concerned is an incoming feeder breaker, a fault on the busbar will cause the busbar protection to trip this breaker. If the breaker fails to trip, the transfer trip function is still needed, but has to be transferred to the other end of the feeder by intertrip or protection communications. Depending on primary system topology, it may be acceptable to send this intertrip directly to the other end without using the transfer trip circuit, thereby avoiding the 0.2 s delay.

7.9.4 Independence of No. 1 and No. 2 protection schemes

It is necessary that the duplicated schemes be fully independent so as to be immune from both being disabled by any failure or event.

To this end it is important that the No. 1 and No. 2 schemes do not use the same relays. This may take the form of requiring different makes of relay for each of the two schemes, so that common mode failures are avoided, particularly in the domain of firmware and software.

In the case of feeder protection, it is good practice to use different relaying principles for the No. 1 and No. 2 schemes, such as line differential for one and distance for the other.

7.9.5 Advantages of LBU

The five main advantages of LBU are as follows:

- (a) High speed as is necessary for the higher levels of the system.
- (b) Makes use of unit protection schemes which usually have good sensitivity because they do not have to be set above load current like overcurrent schemes.
- (c) Full coverage of the system is achieved in high speed zones.
- (d) Makes use of unit protection schemes which may be required anyway for other reasons.
- (e) Provides the means of covering blind spots.

7.9.6 Disadvantages of LBU

The two main disadvantages of LBU are as follows:

- (a) Cost impact mainly due to the duplication.
- (b) Extreme care is needed to avoid common factors, either electrical or physical, which could disable both protection schemes.

7.10 Fuses and back-up

It is generally accepted that fuses do not require back-up protection. This is because they are simple thermal devices with no moving parts or electronics like relays. However, this depends very much on the correct application of the fuse.

Although fuses are apparently simple, replaceable devices, their design is anything but simple, and the application of them in a safely engineered manner is not simple.

There are multiple factors to consider when choosing the correct fuse for a particular application, including the following:

- (a) Fuses are a source of heat.
- (b) Applicable time-current characteristic.
- (c) Interrupting rating.
- (d) Voltage rating.
- (e) Heating and de-rating.
- (f) Minimum breaking current.
- (g) Voltage transients generated.

Ongoing control is also an issue. It is all too easy to replace a fuse that has blown with a bigger one, or with whatever type may be at hand rather than with the intended type. There is therefore a strong case for strict management of fuse policy, practices and procurement.

Fuses are a crude form of overcurrent protection compared with relays. They do not provide the equivalent of earth fault protection and are therefore unsuitable for mining situations where heavy restriction of earth fault current is used. See [Section 6](#) for more detailed information on HV and LV fuses.

Section 8 Application of protection schemes

8.1 General

This Section describes the various combinations of individual protection schemes, as applied to different equipment within the power system.

8.2 Feeder protection

8.2.1 General

Feeder protection does not fall into a single or simple category because there is such a variety of different feeder types and arrangements.

Feeders are defined as any overhead line, underground cable, circuit, or final sub circuit, of any voltage used to connect to or from substations, switchboards, or equipment.

HV feeders are generally three-phase, three wire. LV feeders are generally three-phase, four wire. Individual LV circuits may be single-phase, two wire.

Specifically, feeders fall into the following categories:

- (a) HV overhead lines.
- (b) HV underground cables.
- (c) LV overhead lines.
- (d) LV circuits using underground cables or enclosed wiring.
- (e) LV circuits to final equipment such as motors.

[Clauses 8.2.2 to 8.2.6](#) provide typical examples of common feeder arrangements and protection.

8.2.2 HV overhead lines — Radial (11 kV and 22 kV)

Where overhead lines of these voltages are radial fed (not operating in parallel with other feeders and not capable of being backfed), it is common to provide the following protection at the source substation:

- (a) Three-phase overcurrent (inverse type characteristic).
- (b) Three-phase instantaneous overcurrent.
- (c) Earth fault (inverse type characteristic).
- (d) Sensitive earth fault.
- (e) Back-up protection.

This protection provides for connection of a number of small, HV fuse or relay/circuit breaker protected distribution transformers to the feeder.

The feeder may have 1, 2, or 3 additional stages of the same protection at intervals downstream at intermediate substations or by means of reclosers. All these stages have to be time graded and pick-up graded. The grading of even 1 or 2 stages quickly leads to unacceptably long settings on the upstream protection. Care is needed to minimize fault clearance times.

This protection is not ideal from the safety point of view because of long clearing times. Every opportunity should be taken to keep settings to a minimum and not allow grading considerations to drive settings up.

Earth fault settings have to be very sensitive in the context of restricted earth fault currents by NERs in mine situations.

Reclosing should not be used in mine situations for safety reasons.

8.2.3 HV overhead lines in rings or closed networks (33 kV, 66 kV and 132 kV)

HV overhead lines in rings or closed networks need protection that can discriminate so as to determine which feeder has the fault, and trip only that feeder at both ends, while leaving the other feeders in service to maintain supply.

Where feeders are overhead, the sensitivity of earth fault protection should be high for the following two reasons:

- (a) Overhead conductors in contact with the ground, trees, vehicles, or cranes draw very little fault current.
- (b) Mine installations will generally have earth fault current limited by neutral-earth impedance at the source transformer.

Protection schemes that can be used are as follows:

- (i) *Combination three-phase overcurrent and earth fault protection* — With directional overcurrent and directional earth fault.
- (ii) *Distance protection* — At each end of each feeder. Additional earth fault or directional earth fault at each end to provide the necessary earth fault sensitivity. The distance protection has the advantage of instantaneous operation for Zone 1 faults, as compared to the slower overcurrent protection.

The distance protection coverage and functionality can be improved if a copper or fibre communications channel can be provided and used to give permissive overreach or permissive underreach distance schemes.

Distance protection also has the benefit of being able to provide Zone 2 or Zone 3 backup to the remote substation or the next feeder.

- (iii) *Line differential protection* — Between the ends of each feeder in the closed network. This necessitates a copper pilot cable or fibre communications link between the ends. Differential schemes provide 100 % coverage of the feeder (between the CTs) in a nominally instantaneous zone. Differential inherently provides discrimination for faults not on the feeder.

Sensitivity of the differential is not sufficient to detect earth faults restricted by neutral-earth impedance or contact resistance, and it therefore has to be supplemented by earth fault and directional earth fault protection.

Differential protection inherently cannot provide back-up to downstream protection zones, and additional types of protection have to be used in conjunction with differential to provide back-up.

A network of feeders should never rely on differential protection alone, and should be used in conjunction with overcurrent, earth fault, and/or distance. Differential protection does not readily allow for tee off loads within the differential zone.

8.2.4 HV underground cables — Radial (11 kV and 22 kV)

This Clause covers buried cables, trailing cables, and cables in underground mines.

Where underground cables at these voltages are radial fed (not operating in parallel with other feeders and not capable of being backfed) it is common to provide the following protection at the source substation:

- (a) Three-phase overcurrent (inverse type characteristic).
- (b) Three-phase instantaneous overcurrent.
- (c) Earth fault (inverse type characteristic).
- (d) Back-up protection.

This protection provides for connection of a number of small, HV fuse or relay/circuit breaker protected distribution transformers to the feeder.

The feeder may have 1, 2, or 3 additional stages of the same protection at intervals downstream at intermediate substations. All these stages have to be time graded and pick-up graded. The grading of even 1 or 2 stages quickly leads to unacceptably long settings on the upstream protection. Care is needed to minimize fault clearance times.

This protection is not ideal from the safety point of view because of long clearing times. Every opportunity should be taken to keep settings to a minimum and not allow grading considerations to drive settings up.

Earth fault settings have to be very sensitive in the context of restricted earth fault currents by NERs in mine situations.

Reclosing should not be used on underground cables and should not be used in mine situations.

8.2.5 HV underground cables in rings or closed networks (33 kV and 66 kV)

8.2.5.1 General

Similar concepts and schemes apply as for overhead line feeders in closed networks with the following exceptions:

- (a) Distance protection may be difficult to apply if the feeders are short and feeder impedances are low.
- (b) Earth fault sensitivity is not an issue from the point of view of phase-to-earth faults being restricted by high-contact resistance, but is still needed for mine installations with severely restricted earth fault levels.

The following two schemes are examples of commonly used feeder differential schemes using electromechanical relays and copper pilots, which have been extensively used in the past, with many still in service.

However, modern digital/numeric line differential relays using fibre communication links are now used.

8.2.5.2 Translay protection

Translay protection is a typical biased, electromechanical balanced voltage system which gives useful service on distribution systems (see [Figure 8.2.5.2](#)).

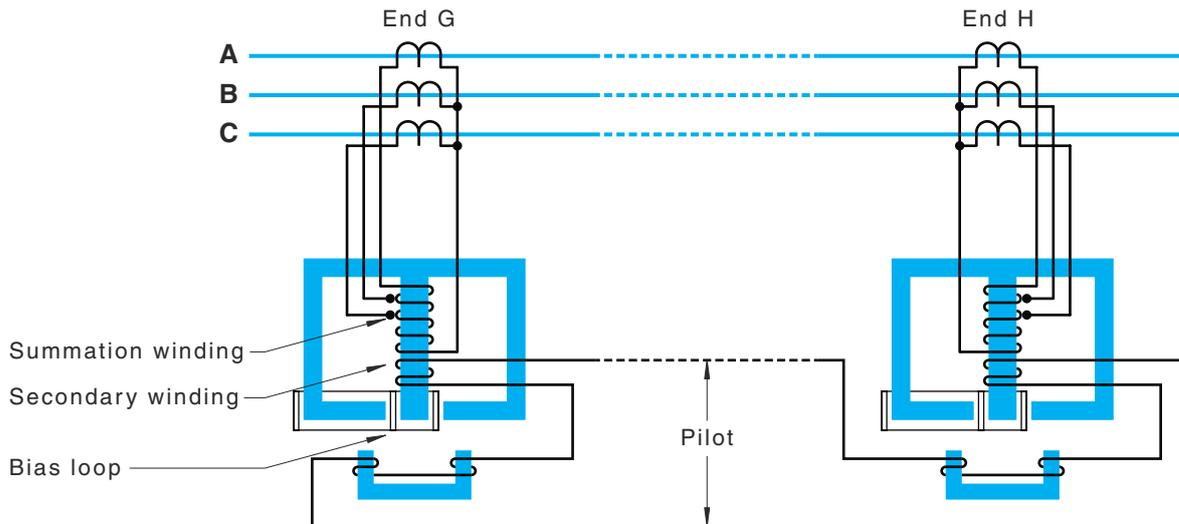


Figure 8.2.5.2 — Electromechanical balanced voltage system

While the feeder is healthy, the line CTs at each end carry equal currents. Equal and opposite voltages are induced in the secondary windings and no current flows in the pilots. No magnetic flux is set up in the bottom magnets, so the relays do not operate. Under heavy through-fault conditions there may be a small circulating current due to line CT mismatch. A restraint torque is produced by bias loop, which also stabilizes the relay against pilot capacitance currents. A fault fed from one end causes current to circulate in the pilots and the relay at that end will operate to trip. A fault fed from both ends will cause a current reversal in the remote CTs, making the circulating current additive so that both ends operate to trip.

8.2.5.3 Solkor protection

Solkor unit protection is used where solid metallic pilot wires are available. Optional equipment includes pilot wire supervision and injection intertripping systems.

8.2.6 LV overhead lines

Low voltage overhead lines are difficult to protect because the fault current drops rapidly along the line due to the impedance and low driving voltage. Also, conductor clashing or contact results in arcing which severely restricts the fault current (at low voltage) and further makes detection by overcurrent devices difficult. Furthermore, LV circuits are usually 4 wire so as to supply single-phase loads, which makes the application of simple earth fault protection impracticable.

It is common to use fuse protection of LV overhead lines, but this should not be used for earth fault limited networks in mine situations for the following reasons:

- (a) Fuses cannot provide earth fault protection. Earth faults would never be seen by fuse protection in mine situations which have the earth fault level restricted to 5 A or 10 A.
- (b) Fuse size would have to be kept very small to have any chance of detecting faults at the extremities or when arcing is involved.

Where LV overhead lines are used on mine sites, they should be protected by circuit breakers having both overcurrent and earth fault protection.

Where lightning strikes are likely to affect mine/quarry plant, such as in overhead LV areas, consideration of the desirability of mitigating the effects of lightning strikes by installing surge arrestors on switchboards and/or close to their sensitive equipment. Similarly, it is usual to place surge arrestors adjacent to critical electrical equipment. Such arrestors will not totally protect the mine/quarry installation, but may provide relief, especially from indirect lightning strikes.

8.3 Capacitor protection

8.3.1 General

Capacitors are sensitive to power frequency overvoltage, harmonic voltage stress, voltage transients, excessive ambient temperature, inrush currents.

Protection of shunt capacitor banks covers the following fault and abnormal conditions:

- (a) Faults internal to the bank but outside the capacitor cans.
- (b) Phase current unbalance due to individual capacitor failure.
- (c) Harmonic overvoltage.
- (d) Voltage unbalance.
- (e) Faults internal to the capacitor cans.
- (f) Power frequency overvoltage.
- (g) Overtemperature.

The type of protection chosen and how it is implemented depends on the voltage rating, the kVAR size and the configuration of the capacitor bank.

Capacitor protection presents some difficulties and complications as follows:

- (i) Be aware that there are both internally fused capacitor cans and non-fused capacitor cans requiring external fusing.
- (ii) Discharge resistors internal to the can, or external means of discharge, need to be provided to remove stored energy on disconnection of the bank. There are time constraints on switching and earthing capacitor banks due to discharge requirements.
- (iii) Capacitor faults can result in significant outrush current. It is important to limit the energy that can be released in such an event. This outrush current can create problems for adjacent circuit breakers not rated for capacitive switching duty.

8.3.2 Typical protection

The typical protection arrangement for capacitor protection is as follows:

- (a) Overcurrent on the whole bank.
- (b) Star point unbalance protection to detect individual can or element loss.
- (c) Fusing of individual cans either externally or internally.

8.4 Motor protection

8.4.1 General

The frequency of motor damage differs since it depends on the specific operating conditions. Statistics show that annual down times of 0.5 % to 4 % have to be expected. Most breakdowns are caused by an overload. Insulation faults leading to earth faults, turn-to-turn or winding short circuits are caused by excess voltage or contamination by dampness, oil, grease, dust or chemicals.

The approximate percentages of these individual faults are as follows:

- (a) Overload — 30 %.

- (b) Insulation damage — 20 %.
- (c) Phase failure — 14 %.
- (d) Bearing damage — 13 %.
- (e) Ageing — 10 %.
- (f) Rotor damage — 5 %.
- (g) Others — 8 %.

Therefore, the following points have to be observed to guarantee fault-free operation of an electrical drive:

- (i) *Correct design* — A suitable motor has to be selected for each application.
- (ii) *Professional operation* — Professional installation and regular maintenance are preconditions for fault-free operation.
- (iii) *Good motor protection* — This has to cover all possible problem areas such as the following:
 - (A) It should not trip unless the motor is put at risk.
 - (B) If the motor is put at risk, the protection device has to operate before any damage occurs.
 - (C) If damage cannot be prevented, the protection device has to operate quickly in order to restrict the extent of the damage as much as possible.

These are the arrangements implemented in order to avoid operation of motors in abnormal conditions which could result in negative events such as —

- (1) overheating;
- (2) premature ageing;
- (3) destruction of electrical windings;
- (4) damage to coupling; or
- (5) damage to gear box.

8.4.2 Levels of protection schemes

Four levels of protection scheme are commonly proposed, and can be adopted depending on the sophistication and power of the driven machine as follows:

- (a) “Conventional” protection functions apply for every type of motor or application.
- (b) “Advanced” protection functions apply to more sophisticated machines requiring special attention.
- (c) “Advanced plus” and “high performance” protection functions are justified for high-power motors, demanding applications, or motors in critical processes or whenever ground current has to be measured with high accuracy (~ 0.01 A) (see [Figure 8.4.2](#)).

NOTE “High performance” protections are not based only on current but also on voltage.

Protection	Conventional	Advanced	Advanced plus	High performance
Short-circuit/Instantaneous overcurrent				
Thermal overload				
Phase current imbalance				
Phase current loss				
Over-current/Instantaneous and temporised)				
Ground current/Instantaneous earth fault				
Long start (stall)/Incomplete sequence				
Jam (locked rotor)				
Under-current				
Phase current reversal				
Motor temperature (by sensors)				
Rapid cycle lock-out/Locking out				
Load shedding				
Notching or jogging/Number of stats				
Phase voltage imbalance				
Phase voltage loss				
Phase voltage reversal				
Under-voltage				
Over-voltage				
Under-power				
Over-power				
Under power factor				
Over power factor				
Motor reclosing				

Figure 8.4.2 — Classification of motor protection functions

8.4.3 Motor protection functions

The following is a list of motor protection functions and the result of activation:

- (a) *Short-circuit* — Disconnection in case of a short-circuit at the motor terminals or inside the motor windings.
- (b) *Thermal overload* — Disconnection of motor in case of sustained operation with a torque exceeding the nominal value. Overload is detected by measurement of excessive stator current or by using positive temperature coefficient (PTC) probes.
- (c) *Phase current imbalance* — Disconnection of the motor in case of high current imbalance, responsible for increased power losses and overheating.
- (d) *Phase current loss* — Disconnection of the motor if one phase current is zero, as this is revealing of cable or connection breaking.
- (e) *Overcurrent* — Alarm or disconnection of the motor in case of high phase current, revealing a shaft over-torque.
- (f) *Ground fault* — Disconnection in case of a fault between a motor terminal and ground. Even if the fault current is limited, a fast action could avoid a complete destruction of the motor. It can