Distance Protection

Schemes

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12.1 INTRODUCTION

Conventional time-stepped distance protection is illustrated in Figure 12.1. One of the main disadvantages of this scheme is that the instantaneous Zone 1 protection at each end of the protected line cannot be set to cover the whole of the feeder length and is usually set to about 80%. This leaves two 'end zones', each being about 20% of the protected feeder length. Faults in these zones are cleared in Zone 1 time by the protection at one end of the feeder and in Zone 2 time (typically 0.25 to 0.4 seconds) by the protection at the other end of the feeder.

This situation cannot be tolerated in some applications, for two main reasons:

a. faults remaining on the feeder for Zone 2 time may cause the system to become unstable
b. where high-speed auto-reclosing is used, the non-simultaneous opening of the circuit breakers at both ends of the faulted section results in no 'dead time' during the auto-reclose cycle for the fault to be extinguished and for ionised gases to clear. This results in the possibility that a transient fault will cause permanent lockout of the circuit breakers at each end of the line section.
Even where instability does not occur, the increased duration of the disturbance may give rise to power quality problems, and may result in increased plant damage.

Unit schemes of protection that compare the conditions at the two ends of the feeder simultaneously positively identify whether the fault is internal or external to the protected section and provide high-speed protection for the whole feeder length. This advantage is balanced by the fact that the unit scheme does not provide the back up protection for adjacent feeders given by a distance scheme. The most desirable scheme is obviously a combination of the best features of both arrangements, that is, instantaneous tripping over the whole feeder length plus back-up protection to adjacent feeders. This can be achieved by interconnecting the distance protection relays at each end of the protected feeder by a communications channel. Communication techniques described in detail in Chapter 8.

The purpose of the communications channel is to transmit information about the system conditions from one end of the protected line to the other, including requests to initiate or prevent tripping of the remote circuit breaker. The former arrangement is generally known as a 'transfer tripping scheme' while the latter is generally known as a 'blocking scheme'. However, the terminology of the various schemes varies widely, according to local custom and practice.

12.2 ZONE 1 EXTENSION SCHEME (Z1X SCHEME)

This scheme is intended for use with an auto-reclose facility, or where no communications channel is available, or the channel has failed. Thus it may be used on radial distribution feeders, or on interconnected lines as a fallback when no communications channel is available, e.g. due to maintenance or temporary fault. The scheme is shown in Figure 12.2.

The Zone 1 elements of the distance relay have two settings. One is set to cover 80% of the protected line length as in the basic distance scheme. The other, known as 'Extended Zone 1' or 'Z1X', is set to overreach the protected line, a setting of 120% of the protected line being common. The Zone 1 reach is normally controlled by the Z1X setting and is reset to the basic Zone 1 setting when a command from the auto-reclose relay is received.

On occurrence of a fault at any point within the Z1X reach, the relay operates in Zone 1 time, trips the circuit breaker and initiates auto-reclosure. The Zone 1 reach of the distance relay is also reset to the basic value of 80%, prior to the auto-reclose closing pulse being applied to the breaker. This should also occur when the auto-reclose facility is out of service. Reversion to the Z1X reach setting occurs only at the end of the reclaim time. For interconnected lines, the Z1X scheme is established (automatically or manually) upon loss of the communications channel by selection of the appropriate relay setting (setting group in a numerical relay). If the fault is transient, the tripped circuit breakers will reclose successfully, but otherwise further tripping during the reclaim time is subject to the discrimination obtained with normal Zone 1 and Zone 2 settings.

The disadvantage of the Zone 1 extension scheme is that external faults within the Z1X reach of the relay result in tripping of circuit breakers external to the faulted section, increasing the amount of breaker maintenance needed and needless transient loss of supply to some consumers. This is illustrated in Figure 12.3(a) for a single circuit line where three circuit breakers operate and in Figure 12.3(b) for a double circuit line, where five circuit breakers operate.
12.3 TRANSFER TRIPPING SCHEMES

A number of these schemes are available, as described below. Selection of an appropriate scheme depends on the requirements of the system being protected.

12.3.1 Direct Under-reach Transfer Tripping Scheme

The simplest way of reducing the fault clearance time at the terminal that clears an end zone fault in Zone 2 time is to adopt a direct transfer trip or intertrip technique, the logic of which is shown in Figure 12.4.

A contact operated by the Zone 1 relay element is arranged to send a signal to the remote relay requesting a trip. The scheme may be called a 'direct under-reach transfer tripping scheme', 'transfer trip under-reaching scheme', or 'intertripping under-reach distance protection scheme', as the Zone 1 relay elements do not cover the whole of the line.

A fault $F$ in the end zone at end $B$ in Figure 12.1(a) results in operation of the Zone 1 relay and tripping of the circuit breaker at end $B$. A request to trip is also sent to the relay at end $A$. The receipt of a signal at $A$ initiates tripping immediately because the receive relay contact is connected directly to the trip relay. The disadvantage of this scheme is the possibility of undesired tripping by accidental operation or maloperation of signalling equipment, or interference on the communications channel. As a result, it is not commonly used.

12.3.2 Permissive Under-reach Transfer Tripping (PUP) Scheme

The direct under-reach transfer tripping scheme described above is made more secure by supervising the received signal with the operation of the Zone 2 relay element before allowing an instantaneous trip, as shown in Figure 12.5. The scheme is then known as a 'permissive under-reach transfer tripping scheme' (sometimes abbreviated as PUP Z2 scheme) or 'permissive under-reach distance protection', as both relays must detect a fault before the remote end relay is permitted to trip in Zone 1 time.
A variant of this scheme, found on some relays, allows tripping by Zone 3 element operation as well as Zone 2, provided the fault is in the forward direction. This is sometimes called the PUP-Fwd scheme.

Time delayed resetting of the ‘signal received’ element is required to ensure that the relays at both ends of a single-end fed faulted line of a parallel feeder circuit have time to trip when the fault is close to one end. Consider a fault F in a double circuit line, as shown in Figure 12.6. The fault is close to end A, so there is negligible infeed from end B when the fault at F occurs. The protection at B detects a Zone 2 fault only after the breaker at end A has tripped. It is possible for the Zone 1 element at A to reset, thus removing the permissive signal to B and causing the ‘signal received’ element at B to reset before the Zone 2 unit at end B operates. It is therefore necessary to delay the resetting of the ‘signal received’ element to ensure high speed tripping at end B.

The PUP schemes require only a single communications channel for two-way signalling between the line ends, as the channel is keyed by the under-reaching Zone 1 elements.

When the circuit breaker at one end is open, or there is a weak infeed such that the relevant relay element does not operate, instantaneous clearance cannot be achieved for end-zone faults near the ‘breaker open’ terminal unless special features are included, as detailed in section 12.3.5.

12.3.3 Permissive Under-reaching Acceleration Scheme

This scheme is applicable only to zone switched distance relays that share the same measuring elements for both Zone 1 and Zone 2. In these relays, the reach of the measuring elements is extended from Zone 1 to Zone 2 by means of a range change signal immediately, instead of after Zone 2 time. It is also called an ‘accelerated underreach distance protection scheme’.

The under-reaching Zone 1 unit is arranged to send a signal to the remote end of the feeder in addition to tripping the local circuit breaker. The receive relay contact is arranged to extend the reach of the measuring element from Zone 1 to Zone 2. This accelerates the fault clearance at the remote end for faults that lie in the region between the Zone 1 and Zone 2 reaches. The scheme is shown in Figure 12.7. Modern distance relays do not employ switched measuring elements, so the scheme is likely to fall into disuse.

12.3.4 Permissive Over-Reach Transfer Tripping (POP) Scheme

In this scheme, a distance relay element set to reach beyond the remote end of the protected line is used to send an intertripping signal to the remote end. However, it is essential that the receive relay contact is monitored by a directional relay contact to ensure that tripping does not take place unless the fault is within the protected section; see Figure 12.8. The instantaneous contacts of the Zone 2 unit are arranged to send the signal, and the received signal, supervised by Zone 2 operation, is used to energise the trip circuit. The scheme is then known as a ‘permissive over-reach transfer tripping scheme’ (sometimes abbreviated to ‘POP’), ‘directional comparison scheme’, or ‘permissive overreach distance protection scheme’.
Since the signalling channel is keyed by over-reaching Zone 2 elements, the scheme requires duplex communication channels - one frequency for each direction of signalling.

If distance relays with mho characteristics are used, the scheme may be more advantageous than the permissive under-reaching scheme for protecting short lines, because the resistive coverage of the Zone 2 unit may be greater than that of Zone 1.

To prevent operation under current reversal conditions in a parallel feeder circuit, it is necessary to use a current reversal guard timer to inhibit the tripping of the forward Zone 2 elements. Otherwise maloperation of the scheme may occur under current reversal conditions, see Section 11.9.9 for more details. It is necessary only when the Zone 2 reach is set greater than 150% of the protected line impedance.

The timer is used to block the permissive trip and signal send circuits as shown in Figure 12.9. The timer is energised if a signal is received and there is no operation of Zone 2 elements. An adjustable time delay on pick-up \( t_p \) is usually set to allow instantaneous tripping to take place for any internal faults, taking into account a possible slower operation of Zone 2. The timer will have operated and blocked the ‘permissive trip’ and ‘signal send’ circuits by the time the current reversal takes place.

The timer is de-energised if the Zone 2 elements operate or the ‘signal received’ element resets. The reset time delay \( t_d \) of the timer is set to cover any overlap in time caused by Zone 2 elements operating and the signal resetting at the remote end, when the current in the healthy feeder reverses. Using a timer in this manner means that no extra time delay is added in the permissive trip circuit for an internal fault.

The above scheme using Zone 2 relay elements is often referred to as a POP Z2 scheme. An alternative exists that uses Zone 1 elements instead of Zone 2, and this is referred to as the POP Z1 scheme.

12.3.5 Weak Infeed Conditions

In the standard permissive over-reach scheme, as with the permissive under-reach scheme, instantaneous clearance cannot be achieved for end-zone faults under weak infeed or breaker open conditions. To overcome this disadvantage, two possibilities exist.

The Weak Infeed Echo feature available in some protection relays allows the remote relay to echo the trip signal back to the sending relay even if the appropriate remote relay element has not operated. This caters for conditions of the remote end having a weak infeed or circuit breaker open condition, so that the relevant remote relay element does not operate. Fast clearance for these faults is now obtained at both ends of the line. The logic is shown in Figure 12.10. A time delay \( T_1 \) is required in the echo circuit to prevent tripping of the remote end breaker when the local breaker is tripped by the busbar protection or breaker fail protection associated with other feeders connected to the busbar. The time delay ensures that the remote end Zone 2 element will reset by the time the echoed signal is received at that end.

The logic is shown in Figure 12.10. A time delay \( T_1 \) is required in the echo circuit to prevent tripping of the remote end breaker when the local breaker is tripped by the busbar protection or breaker fail protection associated with other feeders connected to the busbar. The time delay ensures that the remote end Zone 2 element will reset by the time the echoed signal is received at that end.
Signal transmission can take place even after the remote end breaker has tripped. This gives rise to the possibility of continuous signal transmission due to lock-up of both signals. Timer \( T_2 \) is used to prevent this. After this time delay, ‘signal send’ is blocked.

A variation on the Weak Infeed Echo feature is to allow tripping of the remote relay under the circumstances described above, providing that an undervoltage condition exists, due to the fault. This is known as the Weak Infeed Trip feature and ensures that both ends are tripped if the conditions are satisfied.

### 12.4 BLOCKING OVER-REACHING SCHEMES

The arrangements described so far have used the signalling channel(s) to transmit a tripping instruction. If the signalling channel fails or there is no Weak Infeed feature provided, end-zone faults may take longer to be cleared.

Blocking over-reaching schemes use an over-reaching distance scheme and inverse logic. Signalling is initiated only for external faults and signalling transmission takes place over healthy line sections. Fast fault clearance occurs when no signal is received and the over-reaching Zone 2 distance measuring elements looking into the line operate. The signalling channel is keyed by reverse-looking distance elements (\( Z_3 \) in the diagram, though which zone is used depends on the particular relay used). An ideal blocking scheme is shown in Figure 12.11.

The single frequency signalling channel operates both local and remote receive relays when a block signal is initiated at any end of the protected section.

#### 12.4.1 Practical Blocking Schemes

A blocking instruction has to be sent by the reverse-looking relay elements to prevent instantaneous tripping of the remote relay for Zone 2 faults external to the protected section. To achieve this, the reverse-looking elements and the signalling channel must operate faster than the forward-looking elements. In practice, this is seldom the case and to ensure discrimination, a short time delay is generally introduced into the blocking mode trip circuit. Either the Zone 2 or Zone 1 element can be used as the forward-looking element, giving rise to two variants of the scheme.

##### 12.4.1.1 Blocking over-reaching protection scheme using Zone 2 element

This scheme (sometimes abbreviated to BOP Z2) is based on the ideal blocking scheme of Figure 12.11, but has the signal logic illustrated in Figure 12.12. It is also known as a ‘directional comparison blocking scheme’ or a ‘blocking over-reach distance protection scheme’.

The single frequency signalling channel operates both local and remote receive relays when a block signal is initiated at any end of the protected section.
end B. No signal transmission takes place, since the fault is internal and the fault is cleared in Zone 1 time at end B and after the short time lag (STL) at end A.

A fault at F3 is seen by the reverse-looking Zone 3 elements at end B and the forward looking Zone 2 elements at end A. The Zone 1 relay elements at end B associated with line section B-C would normally clear the fault at F3. To prevent the Zone 2 elements at end A from tripping, the reverse-looking Zone 3 elements at end B send a blocking signal to end A. If the fault is not cleared instantaneously by the protection on line section B-C, the trip signal will be given at end B for section A-B after the Z3 time delay.

The setting of the reverse-looking Zone 3 elements must be greater than that of the Zone 2 elements at the remote end of the feeder, otherwise there is the possibility of Zone 2 elements initiating tripping and the reverse looking Zone 3 elements failing to see an external fault. This would result in instantaneous tripping for an external fault. When the signalling channel is used for a stabilising signal, as in the above case, transmission takes place over a healthy line section if power line carrier is used. The signalling channel should then be more reliable when used in the blocking mode than in tripping mode.

It is essential that the operating times of the various relays be skilfully co-ordinated for all system conditions, so that sufficient time is always allowed for the receipt of a blocking signal from the remote end of the feeder. If this is not done accurately, the scheme may trip for an external fault or alternatively, the end zone tripping times may be delayed longer than is necessary.

If the signalling channel fails, the scheme must be arranged to revert to conventional basic distance protection. Normally, the blocking mode trip circuit is supervised by a 'channel-in-service' contact so that the blocking mode trip circuit is isolated when the channel is out of service, as shown in Figure 12.12.

In a practical application, the reverse-looking relay elements may be set with a forward offset characteristic to provide back-up protection for busbar faults after the zone time delay. It is then necessary to stop the blocking signal being sent for internal faults. This is achieved by making the 'signal send' circuit conditional upon non-operation of the forward-looking Zone 2 elements, as shown in Figure 12.13.

Blocking schemes, like the permissive over-reach scheme, are also affected by the current reversal in the healthy feeder due to a fault in a double circuit line. If current reversal conditions occur, as described in section 11.9.9, it may be possible for the maloperation of a breaker on the healthy line to occur. To avoid this, the resetting of the 'signal received' element provided in the blocking scheme is time delayed.

The timer with delayed resetting ($t_d$) is set to cover the time difference between the maximum resetting time of reverse-looking Zone 3 elements and the signalling channel. So, if there is a momentary loss of the blocking signal during the current reversal, the timer does not have time to reset in the blocking mode trip circuit and no false tripping takes place.

12.4.1.2 Blocking over-reaching protection scheme using Zone 1 element

This is similar to the BOP Z2 scheme described above, except that an over-reaching Zone 1 element is used in the logic, instead of the Zone 2 element. It may also be known as the BOP Z1 scheme.

12.4.2 Weak Infeed Conditions

The protection at the strong infeed terminal will operate for all internal faults, since a blocking signal is not received from the weak infeed terminal end. In the case of external faults behind the weak infeed terminal, the reverse-looking elements at that end will see the fault current fed from the strong infeed terminal and operate, initiating a block signal to the remote end. The relay at the strong infeed end operates correctly without the need for any additional circuits. The relay at the weak infeed end cannot operate for internal faults, and so tripping of that breaker is possible only by means of direct intertripping from the strong source end.

12.5 DIRECTIONAL COMPARISON

The permissive over-reach scheme described in Section 12.3.4 can be arranged to operate on a directional comparison unblocking principle by providing additional circuitry in the signalling equipment. In this scheme (also called a 'deblocking overreach distance protection
scheme), a continuous block (or guard) signal is transmitted. When the over-reaching distance elements operate, the frequency of the signal transmitted is shifted to an 'unblock' (trip) frequency. The receipt of the unblock frequency signal and the operation of over-reaching distance elements allow fast tripping to occur for faults within the protected zone. In principle, the scheme is similar to the permissive over-reach scheme.

The scheme is made more dependable than the standard permissive over-reach scheme by providing additional circuits in the receiver equipment. These allow tripping to take place for internal faults even if the transmitted unblock signal is short-circuited by the fault. This is achieved by allowing aided tripping for a short time interval, typically 100 to 150 milliseconds, after the loss of both the block and the unblock frequency signals. After this time interval, aided tripping is permitted only if the unblock frequency signal is received.

This arrangement gives the scheme improved security over a blocking scheme, since tripping for external faults is possible only if the fault occurs within the above time interval of channel failure. Weak Infeed terminal conditions can be catered for by the techniques detailed in Section 12.3.5.

In this way, the scheme has the dependability of a blocking scheme and the security of a permissive over-reach scheme. This scheme is generally preferred when power line carrier is used, except when continuous transmission of signal is not acceptable.

### 12.6 COMPARISON OF TRANSFER TRIP AND BLOCKING RELAYING SCHEMES

On normal two-terminal lines the main deciding factors in the choice of the type of scheme, apart from the reliability of the signalling channel previously discussed, are operating speed and the method of operation of the system. Table 12.1 compares the important characteristics of the various types of scheme.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Transfer tripping scheme</th>
<th>Blocking scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of operation</td>
<td>Fast</td>
<td>Not as fast</td>
</tr>
<tr>
<td>Speed with in-service testing</td>
<td>Slower</td>
<td>As fast</td>
</tr>
<tr>
<td>Suitable for auto-reclose</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Security against maloperation due to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current reversal</td>
<td>Special features required</td>
<td>Special features required</td>
</tr>
<tr>
<td>Loss of communications</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Weak Infeed/Open CB</td>
<td>Special features required</td>
<td>Special features required</td>
</tr>
</tbody>
</table>

Table 12.1: Comparison of different distance protection schemes

Modern digital or numerical distance relays are provided with a choice of several schemes in the same relay. Thus scheme selection is now largely independent of relay selection, and the user is assured that a relay is available with all the required features to cope with changing system conditions.