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# SIPROTEC Protection Technology

The Basis for Highest Availability of Supply

# Objectives of this Brochure

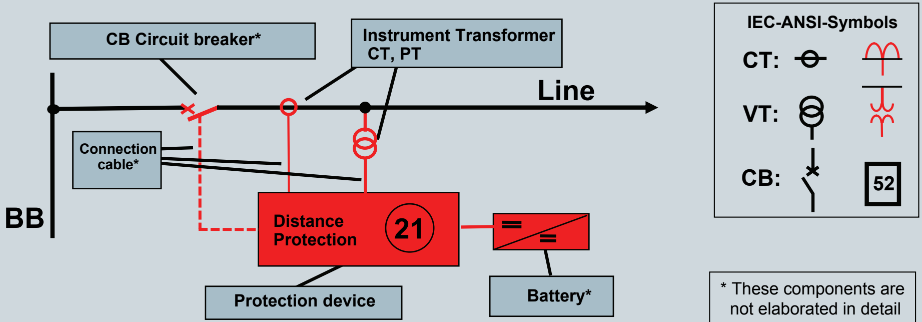
- Objective
  - The following examples give an overview of the requirements for protection devices in medium-voltage systems with solution references.

- Notes on the use of this brochure
  - First select a subject in the footer.
  - The starting situation is shown in the upper part.
  - The bottom part points out various possible solutions.
  - In due case, reference is made to further pages.

With this document, we are providing solution references from the field of protection technology for your successful application.

# The Protection System

When designing the protection for the respective protected object, not only the protection device shall be considered, but the entire protection system.
In particular, the current transformers must be designed such that even for the maximum short-circuit current, the protection device is supplied with adequately precise secondary currents over a sufficiently long period of time to clear the fault.




* These components are not elaborated in detail in this brochure.

**The system is as strong as its weakest link!**

# Redundancy principle

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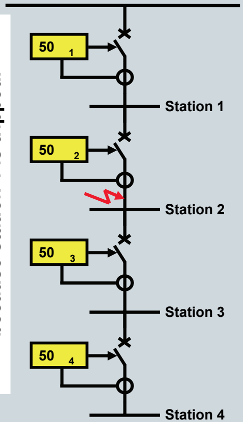
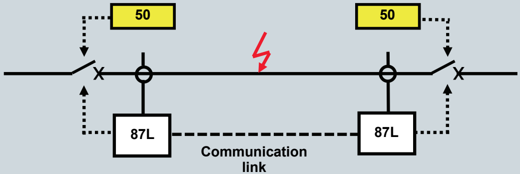
**Protection systems are normally designed such that the failure of one component can be "overcome" ("n-1 principle").**
**Depending on the degree of redundancy, concessions with regard to tripping time and/or selectivity are acceptable.**

## Example 1: Protection grading

If the protection device ($50_2$) fails, device $50_1$ trips with time delay.
Result: Lower selectivity because station 1 is tripped.




## Example 2: Backup protection




If the differential prot. (87L) fails, the time overcurrent protection (50) will trip with time delay.

# Current Transformers

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The current transformers must be designed such that they can transfer the maximum short-circuit current in nearly non-saturated condition for a certain period of time while the protection correctly evaluates the fault. A precise calculation of this time is only feasible by a dynamic simulation (e.g. with CTDim). Alternatively, however, the actual accuracy limiting factor of the transformer can also be determined.

***Current transformer designation:***

**5 P 10; 15VA**

- 15VA: Transformer rated power
- 10: Nominal accuracy limit factor
- P: Core type: P = Protection, M = Measurement
- 5: Maximum fault in % at $K_{SSC} \times I_N$

***Current transformer rating:***

$$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R_{Ltg} + R_{relais}}$$

$K'_{SSC}$ = Effective sym. short-cct current factor

$K_{SSC}$ = Rated sym. short-circuit current factor

$R_{ct}$ = Current transformer burden

$R_b$ = Rated resistive burden

$R_{Ltg}$ = connection cable burden

$R_{relais}$ = Relay burden

# Neutral Point Treatment

In central Europe, medium-voltage systems are predominently operated in compensated condition, i.e. the starpoints of the three-phase system are grounded via an arc compensating coil (Petersen coil).

This way, the single-pole fault current (ground fault current) is largely compensated by the inductive current in phase opposition so that most ground faults quickly disappear on their own (overhead line system). Even in continuous ground faults (cable system), in case of single-pole faults the operation can continue for the time being. At the same time, however, the ground fault must be located, as the increased voltage of the sound phases entails the risk of double ground faults which then must be switched off as soon as possible.

The size of a compensated system is limited by the permissible uncompensated ground fault $I_{CE}$ :
at 6kV to 30kV to $I_{CE} < 600A$, at 110kV to $I_{CE} < 1500A$.

Systems of smaller size (i.e. systems of industrial plants) may even be operated in an isolated manner, provided the capacitive ground current (cable data per unit length) of the system does not exceed 50A.

Also in this case – just like in the compensated system – the operation will continue in the event of ground faults for the time being.

Low-ohmic (grounded) systems limit the short circuit current. Single-pole faults (ground fault in solidly grounded system) have to be tripped as soon as possible.
This is easy on the equipment, but it may mean that consumer loads are disconnected abruptly.

# Neutral Point Treatment
# "low-ohmic grounded system"

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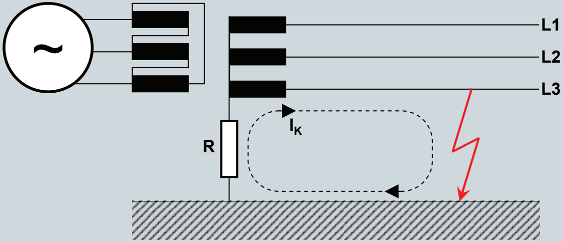
**System with resistive grounding:**




In the low-ohmic grounded system, ground faults cause short-circuit-type fault currents to flow which are limited by the neutral point resistance and are switched off in accordance with the grading coordination chart of the system.

The fast tripping off of ground faults may cause consumers to be disconnected. However, the quick elimination of faults helps preserve the equipment.

# Neutral Point Treatment
# "isolated system"

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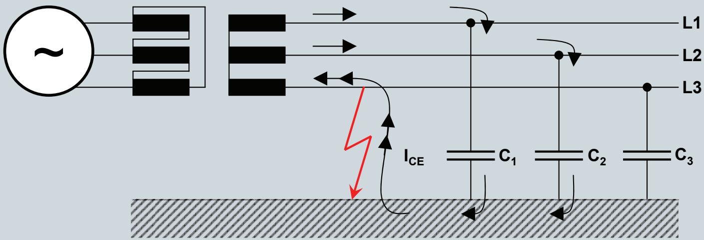
**Isolated system:**




The ground current $I_{CE}$ flows back to the neutral point via the fault location.
Based on the phase angle of this current to the simultaneously occurring displacement voltage, the direction can be determined in which the ground fault – with regard to the transformer installation site – is located.

Depending on the total cable capacity, the ground current $I_{CE}$ can be detected via Holmgreen connection or by means of core-balance current transformers.

If the size of the system is too great ($I_{CE}$ > 50A), the neutral point must no longer be used in an isolated manner because otherwise the arc will no longer be self extinguishing.

# Ground Fault Detection
# "isolated system"

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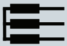
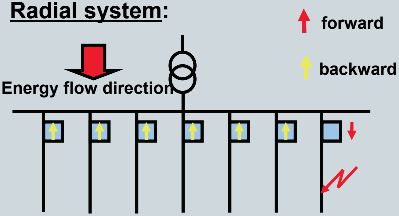
## Neutral point treatment:



non-grounded -> isolated system

- Ground fault = ground fault in isolated and compensated systems, no short circuit
- Operation continues for the time being
- Ground fault must be reported and eliminated as soon as possible

## Radial system:




directional earth-fault relay, sin φ method

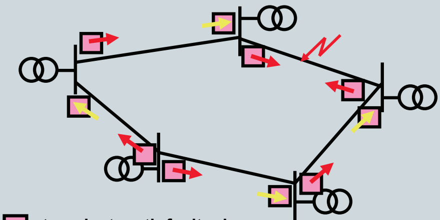
**Determination of direction:**

**Phase angle between capacitive current (cable data per unit length) and displacement voltage**

**Holmgreen connection or cable-type current transformer, depending on the level of capacitative current!**

**Sensitive ground current input at protection device required!**

## Meshed system:



transient earth-fault relay

**Ground fault is present on that line at the end of which both transient earth-fault relays indicates "forward".**

**Determination of direction:**

**Evaluation of phase angle of ground current and displacement voltage (1st half-wave) at the time of ground fault occurrence**

**CT connection: Holmgreen connection**

# Neutral Point Treatment
# "resonant-grounded system"

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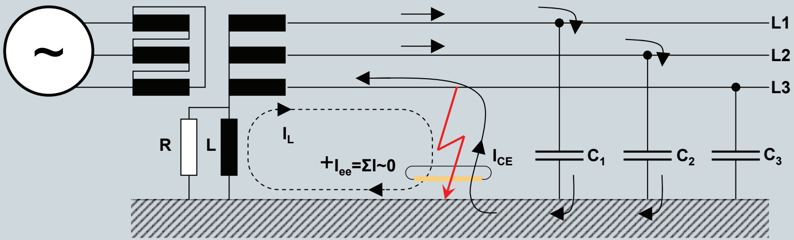
**Resonant-grounded system:**




The ground current $I_{CE}$ flows back to the neutral point via the fault location and is (nearly) compensated by the inductive compensating current $I_L$ of the Petersen coil. Thus,
at the location of the ground fault, merely the remaining ground current $I_{ee}$ flows which can be reliably measured only by a core-balance current transformer. The direction of the ground fault can be determined from the phase angle of the active component of this ground current $I_{ee}$ to the displacement voltage present at the same time.

The phase-to-ground voltages of the fault-free phases increased by $\sqrt{3}$ burden the cable insulation and can cause a double ground fault (short-circuit current!). If such double ground fault occurs before the single fault has been located, this is an indication of rotten cables. In this case it should be considered to ground the neutral point of the system via a resistance.

# Ground Fault Detection
# "resonant-grounded system"

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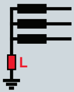
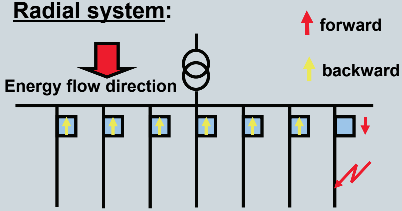
## Neutral point treatment:




Grounded via Petersen coil
-> compensated or
resonant-grounded system

- Ground fault = ground fault in isolated and compensated systems, no short circuit
- Operation continues for the time being
- Ground fault must be reported and eliminated as soon as possible

## Radial system:




directional earth-fault relay, cos φ method (wattmetric)

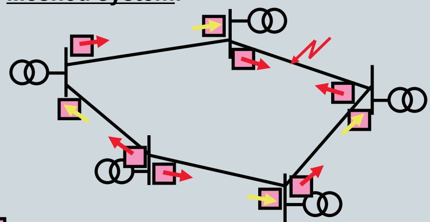
**Determination of direction:**

Phase angle between residual wattmetric current and displacement voltage

**Core-balance current transformer required!**

**Sensitive ground current input at protection device required!**

## Meshed system:



transient earth-fault relay

**The ground fault is located on that line at which ends both interval time relays indicate "forward".**

**Determination of direction:**

Evaluation of phase angle of ground current and displacement voltage (1st half-wave) at the time of ground fault occurrence

**CT connection: Holmgreen connection**

## Radial System

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**Radial systems distribute the energy from the feeding point to the consumers. However, in case of a protection trip, all downstream consumers will be disconnected. Switching over to another line these consumers can be supplied again.**
**Because of the one-end infeed and unmeshed topology, a radial system is easy to protect.**
**Nevertheless there is a variety of possible solutions:**

- Usually a grading of non-directional overcurrent protection relays(50) is sufficient. A disadvantage of this solution is the increase of tripping times in the direction of the infeed, the location with the highest short circuit power. Due to the increased tripping time, also the number of downstream stations is limited. The upstream relays also represent a backup protection for the downstream devices. Moreover, this system structure can be used for the busbar protection by reverse interlocking.
- An alternative protection concept with minimum tripping times is provided by differential protection (87L).
  Line differential protection relays (87L) protect the connection between the stations at high speed.
  The protection of busbar itself requires additional consideration (compare *busbar protection*). Also the backup protection concept must be considered separately. For the reason of hardware redundancy the integrated definite-time overcurrent protection (50) function of the differential protection devices(87L) should not be used for the same section of the system.
- Of course, the radial system can also be protected by means of distance protection devices(21) provided that the distances between the stations allow correct grading of distance zones. Faults can be tripped at high speed in most cases.
  For busbar protection the principle of reverse interlocking can be used. By overreaching the zones and distances, the backup protection can be implemented easily. However, distance protection devices do require voltage transformers (at least on the busbars).

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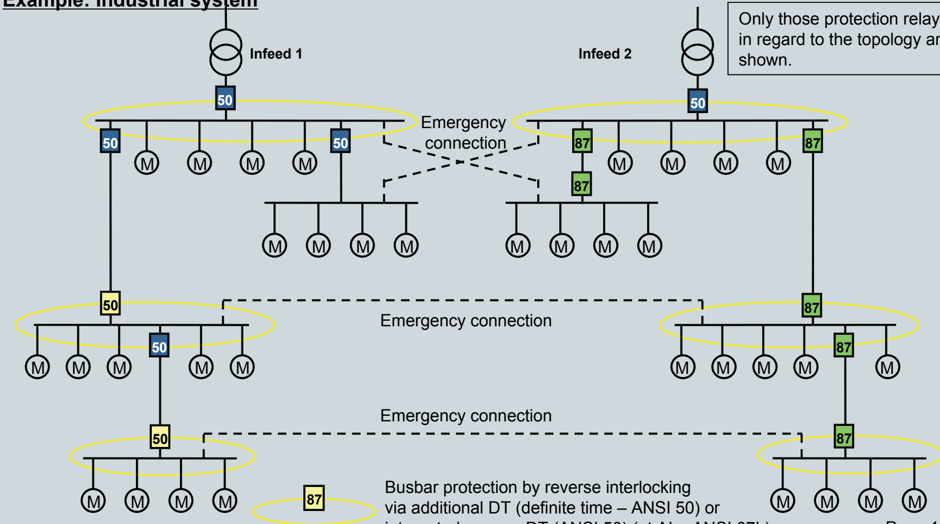
# Radial System

**Example: Industrial system**




Only those protection relays in regard to the topology are shown.

Busbar protection by reverse interlocking via additional DT (definite time – ANSI 50) or integrated reserve DT (ANSI 50) (at ΔI = ANSI 87L)

## Ring Network

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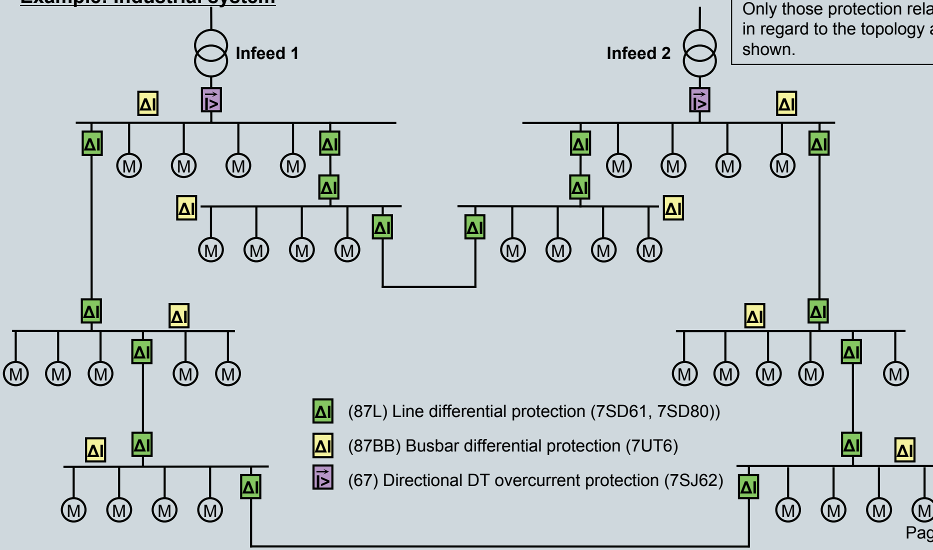
**Ring networks are used primarily in industrial plants because they permanently supply all stations with electrical energy from two sides. This allows faults on connection cables to be selectively switched off without disconnecting the consumers.**
**The bilateral or multilateral infeed requires higher efforts on the protection scheme as the fault current can flow in both directions, i.e. non-directional overcurrent protection relays are unsuitable as main protection.**

- Ring networks are usually protected by means of differential protection relays. This way, faults on connection lines between the stations are disconnected at high speed. The non-directional definite-time overcurrent protection function contained in this relay can be applied for a backup protection concept, however, it is not an option for a busbar protection with reverse interlocking.
  So the use of 7UT6 or 7SS60 presents itself as useful for busbar protection, but here, too, some thought must be given to the question of backup protection.
- As an alternative, ring networks can also be protected by directional comparison protection. For this purpose, directional definite-time overcurrent protection relays are used which, however, require voltage transformers as well as a communication link to the respective partner device at the opposite end of the line. The busbar protection can be realized with this relay by means of reverse interlocking. By the overreach grading of neighboring sections of the system, a backup protection concept can be set up at the same time in which restrictions with regard to the selectivity may occur.
- Of course, ring networks can also be protected by means of distance protection devices provided that the distance between neighboring stations allows a correct grading of distance zones. With this device, faults would in most cases be switched off at high speed. An option for the protection of the busbars again is the principle of reverse interlocking. Due to grading of the (50) relays in neighboring sections of the system, the backup protection is included. However, distance protection devices also require voltage transformers.

# Ring Network

**Example: Industrial system**

Only those protection relays in regard to the topology are shown.



## Time-Overcurrent Protection

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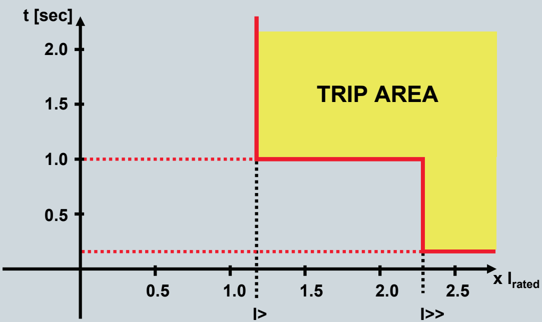
**The time-overcurrent protection (50/51) detects faults based on the current magnitude and trips after the delay time has expired. Time-overcurrent protection devices work either with sharply defined current thresholds (50) or an inverse trip characteristic (51). Modern digital devices work phase-selectively and have designated setting values for ground faults.**

### Definite time:




Trip characteristic of a two-stage (50) protection (definite time-overcurrent)

- The 50 requires a minimum of 3 current inputs, and optional an earth current input
- No voltage acquisition ⇒ no direction determination
- Easily settable through time and current thresholds

# Time-Overcurrent Protection (51)

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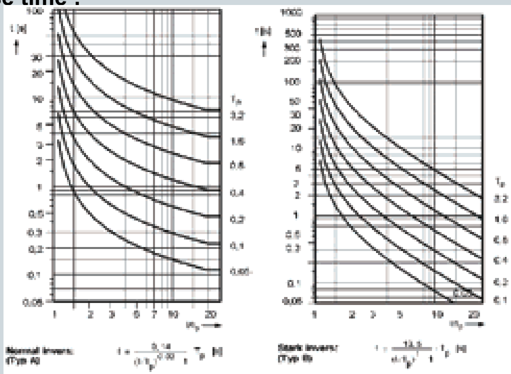
**The inverse time-overcurrent protection 51 is used preferably outside of Germany as its tripping time is variable, depending on the current magnitude.**
**Relay operating characteristics and their settings must be carefully coordinated to achieve selective tripping**

**Inverse time :**



51 characteristic diagrams (exemplary)
(inverse time-overcurrent protection)

- The 51 requires a minimum of 3 current inputs, and optional an earth current input
- No voltage acquisition ⇒ no direction determination
- Variable, inverse-current-dependent tripping time
- Characteristics according to IEC, ANSI or BS (British Standard)

# Time-Overcurrent Protection (50)

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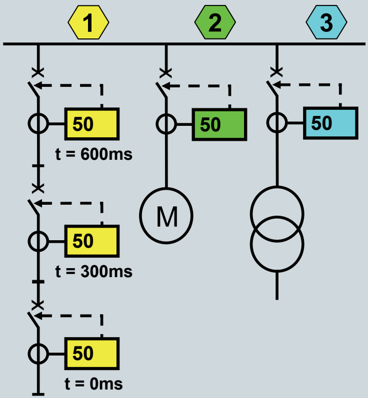
**Main applications:**

**The 50 can be used as main protection as soon as the values of operating current and fault current are clearly differentiable.**

**Selectivity is reached by grading the delay times.**

**Application Examples:**




1 Line Protection

- Use of 50 as line protection possible in case of one-side power supply and radial system structure.
- Disadvantage: highest tripping time at infeed point

2 Motor protection

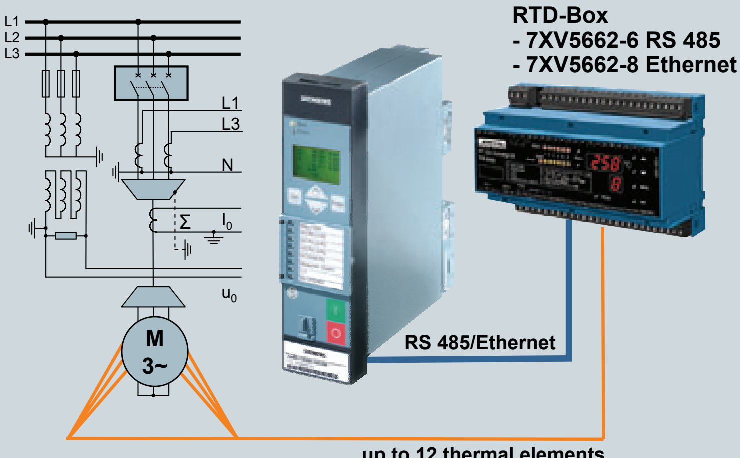
- Use of 50 on motors as short-circuit protection.
- Modern digital 50 devices usually comprise further protection functions for motors, such as e.g. overload protection (49).

3 Transformer protection

- Use of 50 as main protection of transformers (up to ~ 5 - 10MVA).
- High-current stage I>> acts as instantaneous short-circuit protection on the high-voltage side, overcurrent stage I> as backup protection for the low-voltage side
- Additional function "thermal overload protection" (49) protects against overload of the transformer.

# Time-Overcurrent Protection as Motor Protection

**Modern digital time-overcurrent devices also possess additional protection functions to protect medium-voltage motors. By means of so-called "RTD boxes", the temperatures of critical points of the motor (e.g. bearings) can be detected and monitored. This way, especially the sensitivity of the thermal overload protection can be increased.**



## Time-Overcurrent Protection

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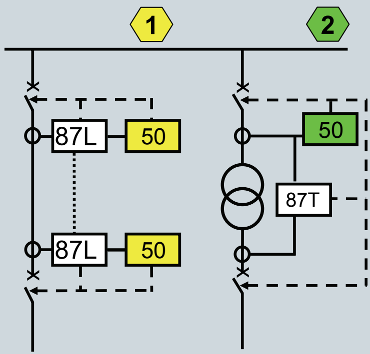
**Backup protection applications:**

**Being a low-price, simple protection, the 50 protection is predestined as backup protection. Upon failure of the main protection, the 50 has the ability, in a higher grading time, to trip faults, at least those of high current intensity, and thus prevent damage of the primary equipment. Even a lack of selectivity may be acceptable then.**

**Examples:**




**1 Backup protection for line diff. protection (87L)**

- Blocking of the 50 elements as long as the line differential protection is active.
- Hardware redundancy compared to integrated backup protection function of line differential protection
- in case of grading of the 50 device, lower selectivity may be possible

**2 Backup protection for transformer diff. protection**

- Hardware redundancy compared to integrated backup protection function of transformer differential protection
- Permanent activation as backup protection possible as differential protection quicker than 50
- Settings same as for 50 as main transformer protection, high-current element I>> slightly delayed (approx. 50ms)

# Directional Time-Overcurrent Protection (67)

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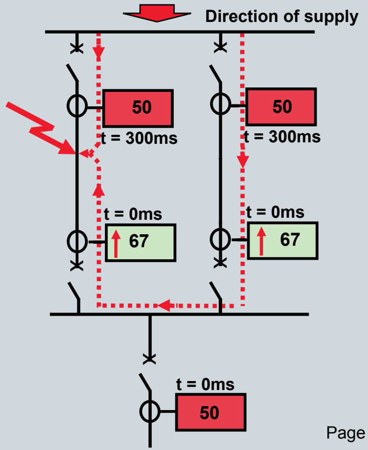
**The directional time-overcurrent (67) protection determines the direction of current flow based on the phase angle of current and voltage and, in addition to the non-directional (50) overcurrent elements, offers directional ones. This allows the current thresholds and delay times to be different for the two directions.**

**Main applications are parallel lines and lines supplied from both sides.**

**Example for Parallel line:**

In case of one-side supply via a parallel line, a fault in a line is also fed via the parallel line and thus by feedback from the opposite end.

A directional overcurrent protection(67) can trip a fault current flowing against the supply direction at high speed since this cannot be the operating current.



# Directional Time Overcurrent Protection

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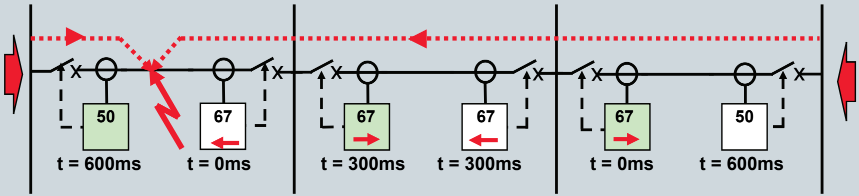
Lines supplied from both sides (see *Ring networks*) can be protected with directional relays (67). For this purpose, the grading ensues from both infeeds in opposite directions. At the two outer ends, a non-directional (50) each is sufficient.

Example: Line supplied from both sides




As with the grading of non-directional devices (50), the grading cannot be applied to an unlimited number of relays, because otherwise the delay time would exceed the permissible grid stability limit.

# Directional Comparison Protection (67)

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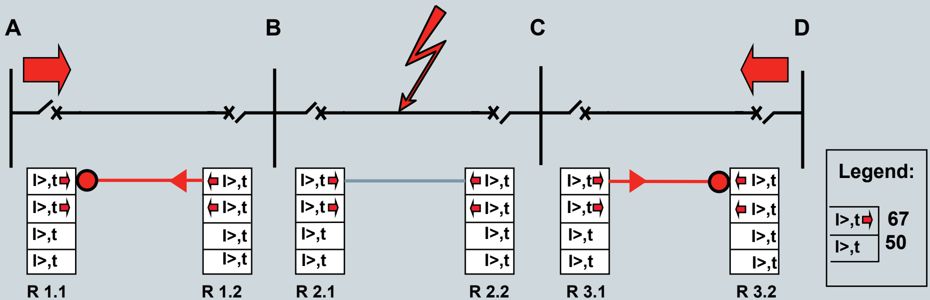
**Directional relays (67) placed at the beginning and end of a line section can trip any system faults in between without delay provided they receive information from the opposite side in which direction the relay sees the fault. If both devices see the fault in forward direction, they will trip without delay. This protection principle requires a communication link between the two relays of each section!**




The information that the fault is located in "backward" direction is transferred to the partner device by the communication link. This device will then block the directional, instantaneous tripping element, the protection operates with "normal" grading time.

In the faulty line section, both devices will see the fault in "forward" direction. The directional high-speed element will not be blocked, the fault will be switched off instantaneously.

# Line Differential Protection (87L)

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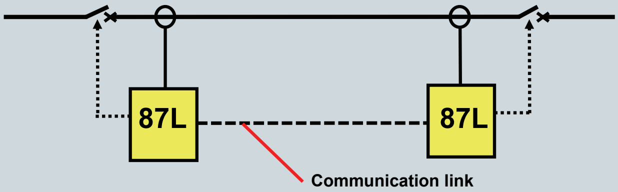
**The line differential protection (87L)is used to protect strictly selective areas at high speed. The simple measuring principle of current comparison requires a communication link between the partner devices.**
**While in former times, analog measured values used to be transmitted via pilot wires, modern devices use the advantages of digital communication.**




<u>Advantages:</u>
- Simple measuring principle
- Requires current transformers only
- No grading time (fast tripping)
- Strictly selective

<u>Drawback:</u>
- Requires reliable communication link to the remote end

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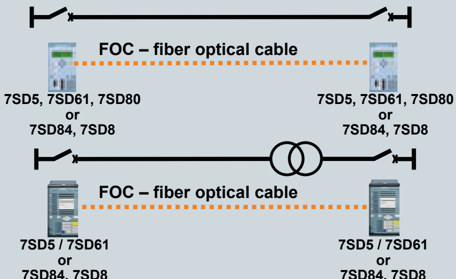
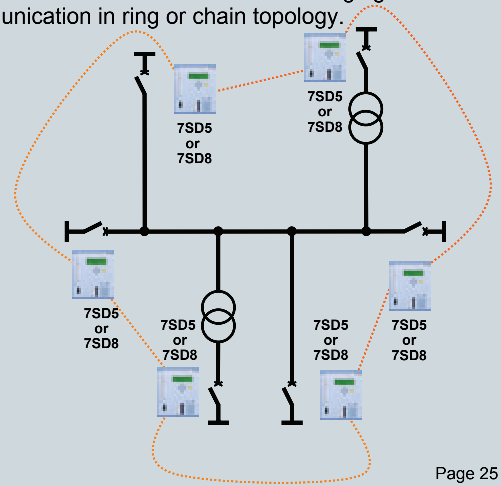
# Line Differential Protection (87L)

SIPROTEC 4 line differential protection devices (87L) can protect system configurations with up to six ends. While the 7SD61 or 7SD84 are designed as a two-end protection, the 7SD5 (7SD52/53) or 7SD8 (7SD86/87) relays provide two active interfaces for exchanging data with the partner devices by means of digital communication in ring or chain topology.

Intelligent algorithms with Inrush detection and vector group treatment allow even transformers in the protection zone.

**Example: <u>Different system topologies</u>**



## Line Differential Protection (87L)

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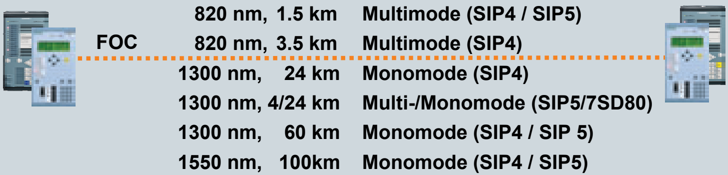
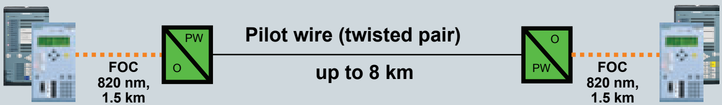
**The use of digital communication for exchanging protection-relevant data (e.g. measured values, intertrip command, etc.) allow a flexible adaptation to existing data transfer paths. In particular fiber optic direct links enable a secure communication. But there are other communication options as well.**

Use of fiber optical cables




Use of pilot wire cables (PW) or telefone wires (2 wires used) by conversion from FO cables (FOC) to copper cables with the communication converter 7XV5662-0AC00



## Line Differential Protection (87L)

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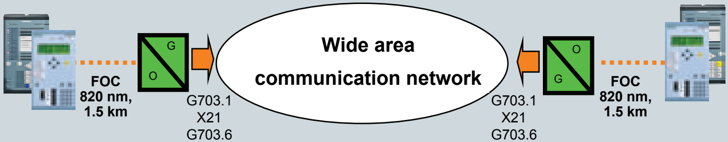
**The use of digital communication for exchanging protection-relevant data (e.g. measured values, intertrip command, etc.) allow a flexible adaptation to existing data transfer paths. In particular fiber optic direct links enable a secure communication. But there are other communication options as well.**

Use of digital communication systems by means of conversion from FOC to X.21 or G703.1 with communication converter 7XV5662-0AA00 or G703.6 (E1,T1) with 7XV5662-0AD00.




Use of digital communication systems by means of conversion from FOC to IEEE C37.94

# Line Differential Protection (87L) - 7SD80

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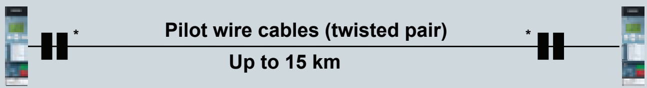
**The use of digital communication for exchanging protection-relevant data (e.g. measured values, intertrip command, etc.) allow a flexible adaptation to existing data transfer paths. In particular fiber optic direct links enable a secure communication. But there are other communication options as well.**

Use of fiber optical cables


Use of existing pilot wire cables or telefone wires (2 wires used)




* Isolation transformer 5kV or 20 kV

# Transformer differential protection (87T)

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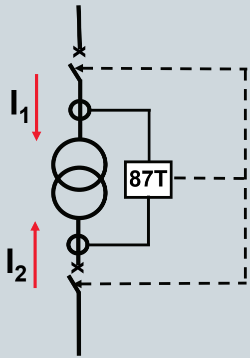
**The transformer differential protection (87T) is used for the selective, instantaneous protection of transformers. Compared to the line differential protection the transformer differential current can be calculated in one device because the distances and burdens from devices to the CTs are limited.**
**In modern transformer differential protection relays, no matching transformers are required. The digital protection device does this by way of calculation.**




| | |
|---|---|
| Normal operation: | $I_1 + I_2 = 0$ |
| Transformer fault: | $I_1 + I_2 \neq 0$ |

The digital transformer differential protection(87T) takes the following into account by calculation:

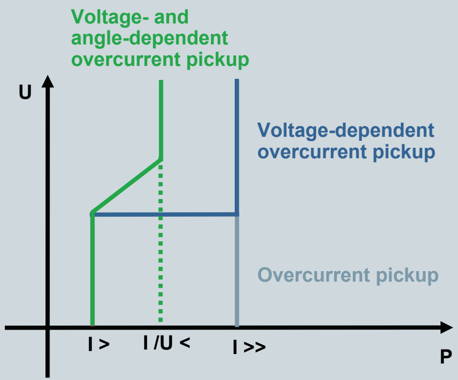
- Correction of CT misadaption to the rated transformer current
- Correction of phase shift of vector group
- Correction of zero sequence current, e.g. elimination

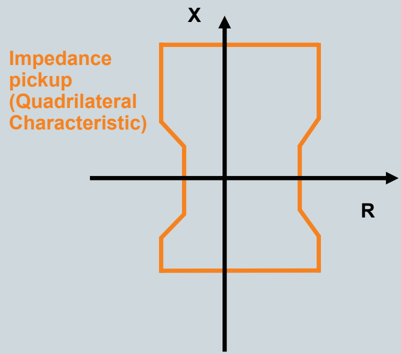
## Distance protection (21)

SIEMENS

**The distance protection(21) monitors the acquired currents and voltages with regard to the configured pickup type. Depending on the respective system conditions, various distance characteristics have been established. As long as load and fault current can be clearly distinguished by the current magnitude, an overcurrent pickup is sufficient. If the current and voltage conditions between operating and fault status are more complicated, more elaborate pickup types will be required.**

**Types of pickup:**



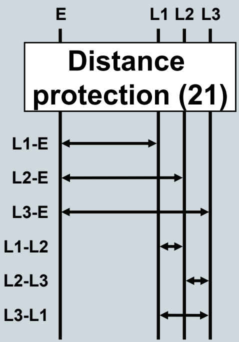



## Distance protection (21)

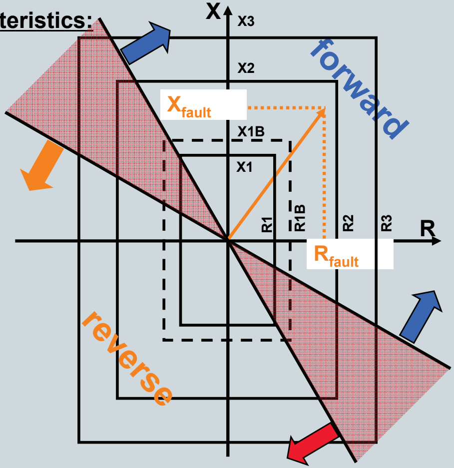
SIEMENS

**If the distance protection (21) picks up, the impedances of all six possible fault loops are determined from the acquired currents and voltages and compared to the configured zone settings (~ fault distances).**
**After the delay time stored for the respective zone has elapsed, the distance protection trips and clears the fault.**

**Fault loops**




**Trip characteristics:**



# Distance protection (21) Time grading

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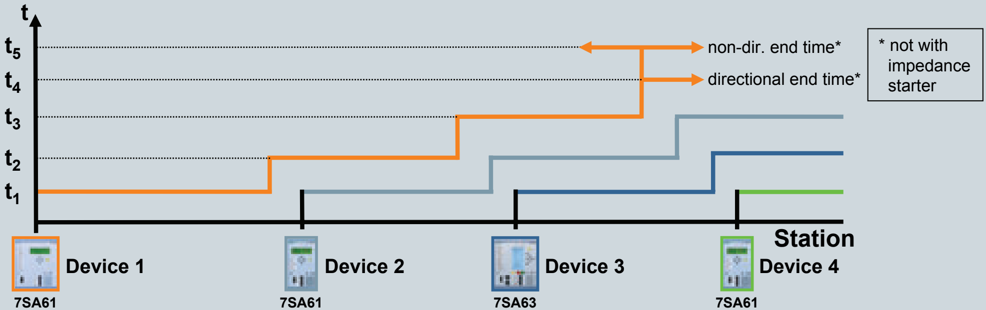
**The fault impedance acquired enables the distance protection (21) to be graded such that it will trip faults up to the nearest station at high speed. For more remote faults, it simultaneously poses a backup protection for the protection device in the nearest station. Due to measuring inaccuracies, however, zone 1 is set smaller than the distance to the closesed station in order to avoid overreach (unselective tripping).**

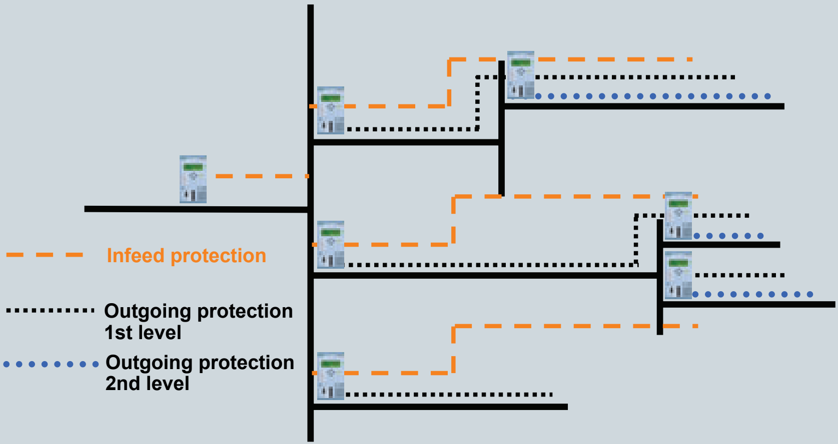



The SIPROTEC 4 distance protection devices 7SA6 have 5 independent time zones as well as the overlap zone Z1B for reliable rapid tripping in case of "Switching onto Fault" and "Automatic Reclosing".

## Distance Protection (21)

SIEMENS

The distance protection (21) in the incomer feeder serves as backup protection for the relays of the outgoing feeder and as busbar protection at the same time. Since no selective grading for the busbar is possible (insufficient impedance), this relay is set as backup protection for the outgoing protection with the shortest zone 1. For this reason, busbar faults are not switched off until the first grading time has elapsed.



# Busbar Protection (87BB)

Busbars (BB) are the locations in switchgears with the highest energy concentration. BB faults that persist for too long can easily lead to damage to primary equipment. The resulting interruptions in supply – particularly in industrial systems – can have a considerable negative impact (loss of production, etc.). For this reason, important busbars must be protected with its own (87BB) system to ensure at high speed tripping.

In view of the fact, however, that busbar faults are very rare, BB-faults are normally switched off in a higher grading time. Depending on the complexity of the BB system (from single to quintuple BB), a dedicated BB protection(87BB) is more or less elaborate.

The simplest BB protection scheme works by the principle of "reverse interlocking", if a comparison of the protection pickups clearly reveals whether incomer bays (BB fault) are involved, or also outgoing bays (external faults).

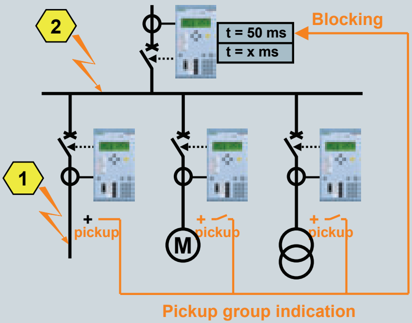
In a single busbar, a dedicated BB protection can be realized by means of a simple node protection (eg. 7UT6) as this does not require an isolator replica.

In a complex BB topology, the BB protection is more elaborate because only the faulty BB section is to be switched off. For this purpose, the BB protection (7SS52) has to capture also the isolator replica of each feeder in addition to the current and on that basis calculate the selective areas.

# Busbar Protection
## Principle of reverse interlocking

SIEMENS

**A protection pickup in an outgoing feeder means that the fault at issue is not located in the area of the busbar even though the protection devices of the incomer bays have also picked up. This pickup of an outgoing feeder protection can be used to block the (nearly) instantaneous tripping of the incomer protection.**
**If only the protection devices of the incoming feeder pick up, this blocking is missing and the BB fault is switched off at high speed.**




**Principle of reverse interlocking**

1. Outgoing feeder protection (50) trips and blocks 50 ms stage in feeder protection over ring line
2. Protection (50) in incoming feeder trips in 50 ms, because no protection in outgoing feeder has picked up and thus blocked

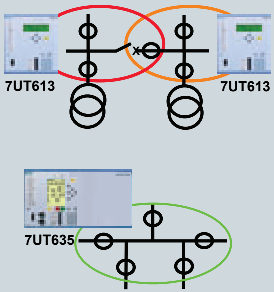
In case of infeed from two sides, directional pickup messages are required in order to detect feedback to external faults.

If in double busbars selective areas are to be considered, it is required to create BB-related blocking messages (via disconnector auxiliary contacts).

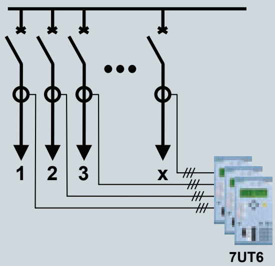
# Busbar Protection (87BB)

**BB protection (87BB) for single busbars does not require an isolator replica; it is sufficient to sum up the currents of all feeders of the selective area. The current in the sectionalizer must be considered in the neighboring selective zones.**
**The feeder currents can be detected either selectively for each phase or as matching transformer current in order to further reduce the effort for the BB protection.**

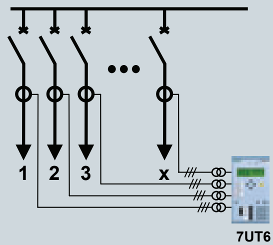
**3-phase:**
(3 phases / relays)
BB protection for up to 5 ends




**3 times 1-phase:**
(1 phase / relay)
BB protection for up to 12 ends




**1-phase:**
(via mixing transformer)
BB protection for up to 12 ends



# Busbar Protection (87BB) Hardware

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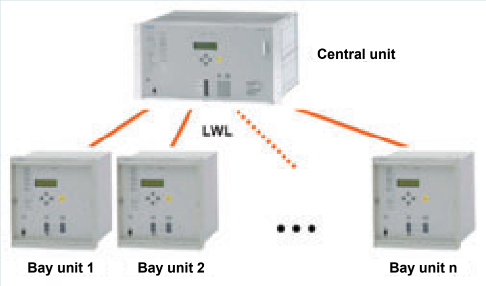
**The decentralized BB protection (87BB) 7SS52 aquires feeder current and disconnector positions in each switchgear bay by a dedicated bay unit. These bay units are connected to the central BB protection device star-shaped via fiber optic cable. Based on the isolator replica, the BB protection determines the selective area and calculates the respective current sum.**




To the central unit of the 7SS52, up to 48 bay units may be connected which can be assigned to up to 12 selective areas (BB sections). To safely distinguish between interior and exterior faults, 3 ms of saturation-free transmission time of the maximum through-flowing current are sufficient.
The tripping time (at the contact of the bay units) is less than 15 ms, independent of the number of bay units.

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If you desire further information,
please contact our
Customer Support Center.
Phone: +49 180/524 8437
Fax: +49 180/524 24 71
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