Differential Protection of Cables via Fiber Optics (Relay Type: 7SD610)

- 20 kV single-core cross-linked polyethylene cable N2XS(F)2Y 1x120RM/16
- Resonant-earthed system
- Fiber-optic link
- ANSI 87L differential protection
- ANSI 50/51 definite-time overcurrent-time protection as backup protection
- ANSI 50HS instantaneous high-current switch-onto-fault protection
- ANSI 49 thermal overload protection

1. Introduction

The ever higher load imposed on primary equipment requires it to be protected in a selective manner and fast fault clearing in case of a short-circuit, in order to minimize possible consequential damage resulting from faults. For overhead lines and cables this requirement is met by line differential protection relays.

A full example of how to set SIPROTEC 4 7SD610 protection relays for a power cable in the distribution network is described, in addition to notes on design.

2. Protection concept

The 7SD610 numerical differential protection relay is a modern short-circuit protection relay for cables and overhead lines in power supply system. Due to rigorous local selectivity – the protected zone is limited at both ends of the line section – power system topology and voltage levels play no role. Furthermore, the star-point conditioning of the current network is of no significance as current comparison takes place per phase and thus variable weightings for different faults – as they occurred in the conventional summation current transformer differential protection process – are nowadays unimportant. Due to its selectivity, the differential protection is generally set as an undelayed, instantaneous main protection since no other protection can disconnect the line more quickly and selectively.

2.1 Differential protection (ANSI 87L)

The differential protection function of the 7SD610 detects short-circuits using phase-selective comparison of the current values measured by separate relays at both ends of the line in the zone to be protected, including weak current or high-resistance short-circuits.

Fig. 1 SIPROTEC 7SD610 line differential protection relay

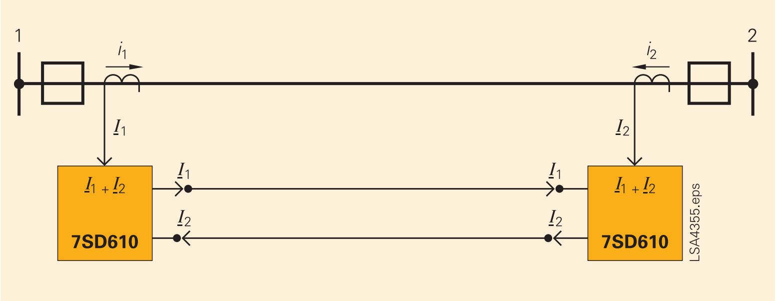


Fig. 2 Differential protection for a line

Each 7SD610 compares locally measured current values with those from the remote end and decides independently whether there is a system disturbance or not. A communication link between both relays is required to exchange the measured values. The relays are designed for a fiber-optic link, which is the preferred method. System-tested communication converters for other transmission media (copper conductors, ISDN line, digital communication networks with X21 or G703.1) are nevertheless also available.

The differential protection function implemented in the 7SD610 uses two algorithms in order to meet the demands of speed and sensitivity. The charge comparison process integrates the measured currents and compares the charge values at both ends over a short time interval. This simple process makes it possible to detect high-current faults as quickly as possible.

This crude algorithm is complemented by a substantially more sensitive vector comparison process. In this process, the current vectors per phase of both relays are compared with each other at each sampling time point. In particular, the errors for each measured value during the process are considered. This includes the current measured value error based on the stored transformer data. The error consideration also takes into account both the signal transmission time of the measured-value telegram from the partner relay and the cable charge current. Finally, each protection relay can decide whether its own (directly measured) current value corresponds to the measured value received by telegram from the remote end via the functional interface, including all magnitude and phase errors. If this is not the case, a further (fault) current must be responsible for the difference and the 7SD610 decides on tripping.

Converted to the conventional characteristic, this means that the restraint current is not simply formed as the sum of the magnitudes of the currents measured at both ends, but as the sum of the errors described above plus the minimum tripping threshold $I_{DIFF}>$, which are converted into a single current component. Protective tripping occurs at the moment when the differential current is greater than the adaptively formed restraint current.

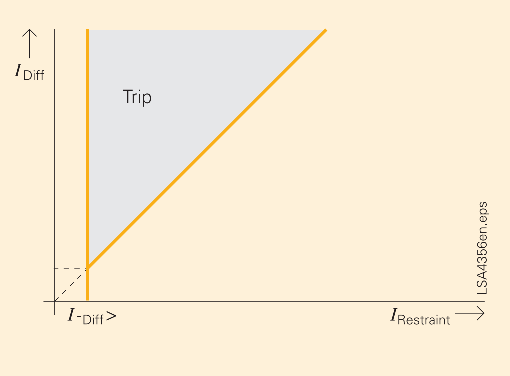


Fig. 3 Differential protection tripping characteristic

In order to ensure reliable operation of the differential protection system, the current transformers deployed must comply with the following requirements:

- 1st condition:
  When the maximum short-circuit current is flowing through, current transformers may not be saturated in steady state.

  $$n' \geq \frac{I_{Kd\,max}}{I_{N\,prim}}$$

- 2nd condition:
  The operating overcurrent factor n' must be at least 30 or a saturation-free time t'_{AL} of min ¼ period is ensured
  $n' \geq 30$ or $t'_{AL} \geq$ ¼ period
- 3rd condition:
  Maximum mutual ratio of the current transformer primary rated currents at the ends of the object to be protected

  $$\frac{I_{prim\,max}}{I_{prim\,min}} \leq 8$$

2.2 Backup protection functions

As usual with modern, numerical protection relays, the 7SD610 also offers a range of further protection and additional functions, which make it flexibly customizable for almost all uses. The user must nevertheless be aware of the lack of hardware redundancy when deploying these functions. For this reason at least one additional, separate short-circuit protection relay should be installed. Depending on voltage level and/or importance of the line, this can be a separate distance protection (7SA6) or a definite-time overcurrent-time protection relay (7SJ6).

The overcurrent-time protection included in the 7SD610 should therefore only be used as backup protection against external faults in the power system outside the differential protection zone.

2.2.1 Overcurrent-time protection (ANSI 50/51)

Parameterization makes it possible to specify whether the three-stage overcurrent-time protection included in the 7SD610 should be working permanently as an independent protection function (backup), or whether it should only be activated as an emergency function in case of malfunction in the communication link.

As mentioned above, if the backup function is used, the concept of hardware redundancy must not be neglected. Consequently, the backup definite-time overcurrent-time protection function is recommended primarily for protection outside the differential protection area, such as e.g. protection of an incoming feeder panel in a substation.

Two of the three stages (*I*> and *I*>> stage) are configured as incoming feeder protection in this case. It has only been possible to authorize and set the *I*>>> stage in such a way, that it trips high-current faults quickly in this exceptional situation, losing the selectivity. If the overcurrent-time protection is used as an emergency function, all stages can be set in terms of tripping threshold and delay time for this exceptional case, in line with selectivity and speed.

2.2.2 Instantaneous high-current switch-onto-fault protection (ANSI 50HS)

This function is meant to disconnect immediately in the event of single-end switching onto a high-current short-circuit.
The measured values of each phase, filtered to the fundamental component, are compared with the set threshold.
If the measured value exceeds twice the threshold, protective tripping occurs immediately. For this function, the circuit-breaker position of the remote end must be known.

A further stage of this protection function works without data on the status of the circuit-breaker at the remote end, but can only be used if current grading above the object to be protected is possible.

2.2.3 Thermal overload protection (ANSI 49)

The thermal overload protection prevents overloading of the object. In the case of the 7SD610, this function is used specifically for a transformer situated within the protected zone, but is also appropriate for power cables that are working to full capacity.

The 7SD610 uses a thermal model to calculate (from the measured phase currents and from the set parameters that characterize the object to be protected) the temperature of the equipment. If this temperature exceeds an adjustable threshold, the 7SD610 issues a warning message, and if a second, higher threshold is exceeded, the protection trips.

2.3 Additional functions

The additional functions listed in the following are not used in the example given and are therefore only mentioned for the sake of completeness.

- Automatic reclosure makes it possible to quench arc short-circuits on overhead lines by a brief interruption of the current flow, i.e. not necessarily immediately and fully disconnecting the line.
- The breaker failure protection in the 7SD610 has two stages. If a TRIP command issued by a protection relay does not lead to the fault current being shut off, the 7SD610 can initially repeat the TRIP command before, at the second stage, the higher-level protection is informed of this malfunction by parallel wiring and trips the circuit-breaker allocated to it.
- The 7SD610 supports three-pole and single-pole circuit-breaker activation, required particularly frequently on the high-voltage level, thanks to its phase-selective operation.
- Transformers and shunt reactors in the differential protected zone are also governed by integrated functions.
- By means of a connected binary input, a TRIP command can be generated by the 7SD610 via an external coupling.
- The digital communication link of the R2R interface makes it possible to transfer 4 remote commands and 24 remote messages from one relay to the other and process them individually in that relay.
- Because the 7SD610 also has voltage inputs, the line-to-earth voltages of the three phases and, where applicable, the shift voltage can be connected to the relay. This does not affect the protection function, but makes it possible to detect the measured voltages and to calculate with the current measured values the derived electrical magnitudes such as active power, reactive power, apparent power, cos φ (power factor) and frequency.

■ 3. Setting example:

As an example, the settings of the 7SD610 relays are described, such as are intended to protect a 20 kV single-core XLPE cable of type N2XS(F)2Y 1x120RM/16 with a length of 9.5 km. The cable rated current is 317 A, on side 1 a new 400 A/1 A, 10P10, 5 VA current transformer is used, and an existing 300 A/5 A, 10P20, 30 VA current transformer is located at the remote end. The maximum short-circuit current flowing through is 12.7 kA.

3.1 Checking the transformers

Initial checks must be made to ascertain whether or not the transformer requirements are met. The quotient of the primary side transformer rated currents evidently amounts to 400 : 300; a value smaller than 8 is thus achieved.

The operational overcurrent factor is calculated from the formula

$$n' = n \cdot \frac{P_N + P_i}{P' + P_i}$$

Equation 1

n' = Operational accuracy limiting factor
n = Rated overcurrent factor
P_N = Rated burden of the current transformers [VA]
P_i = Inherent burden of the current transformers [VA]
P' = Actual connected burden [VA]

The current transformer's own inherent load is calculated from

$$P_i = R_i \cdot I_{N,CT}^2$$

Equation 2

If R_i (the transformer's secondary winding inner resistance) is unknown, the estimation of $P_i = 20\,\% \cdot P_N$ is a good approximation. To arrive at the actually connected burdens, all burdens connected to the transformer core must be added. In this example, it is assumed that only the burdens of the protection relay (0.05 VA for relay rated current of 1 A, 0.3 VA for relay rated current of 5 A) and the incoming feeder cable load are concerned.

The latter is calculated from the formula

$$P_{Line} = \frac{2 \cdot \rho_{Cu} \cdot l_{Line}}{a_{Line}}$$

Equation 3

P_{Line} = Incoming feeder cable load [VA]
ρCu = Specific resistance of Cu [0.0175 Ω mm²/m]
l_{Line} = Secondary-side, single line length [m]
a_{Line} = Line cross-section [mm²]

It is clear from equation 2, that with a secondary-side transformer rated current of 5 A, an incoming feeder cable load 25 times higher appears than for 1 A.

For our example, a 5 m incoming feeder cable (single distance, therefore factor 2) with a cross-section of 4 mm² is assumed. From this we calculate an incoming feeder cable load for both transformers of 0.045 VA (transformer 1) and 1.116 VA (transformer 2).

The overcurrent factors for both transformers are now calculated from these values. According to equation 1 for transformer 1 we have

n' = 44.6

and for transformer 2

n' = 97.1.

These values must now be greater than or equal to the required overcurrent factors in order to be able to transmit the maximum through-flowing short-circuit current at a level of 12.7 kA in a saturation-free manner.

The following are required for transformer 1

n' > 12700 A/400 A = 31.75

and for transformer 2

n' > 12700 A/300 A = 42.33.

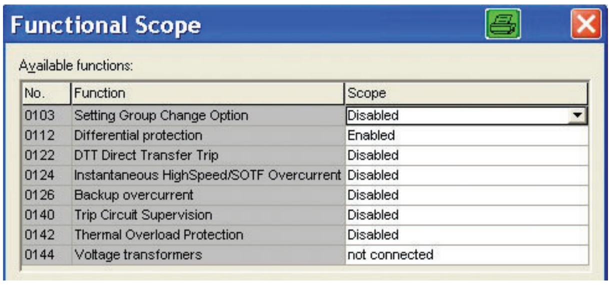
In both cases this is clearly achieved, as is the third condition n' > 30. Consequently, the transformers available are suitable for use in this differential protection system.

3.2 Local relay settings

The parameter settings of both the differential protection relays usually differ only in a few points. This is why only the settings mentioned at the beginning of this application example of a 7SD610 are explained initially. The settings to be changed of the second relay are explicitly listed towards the end of this chapter. Initially, using the DIGSI 4 software for configuration, the 7SD6 relay with Order No. 7SD6101-4BA39-0BA0+M2C is applied and opened in the current project.

3.2.1 Functional scope

In the next step the parameters, beginning with the "functional scope", are set. At this point, we determine which of the functions provided by the protection relay should be used. The other functions are set at "not available" and are consequently concealed for the remainder of the relay parameterization. For our example, we have selected differential protection as the main protection function together with overcurrent-time protection, instantaneous high-current switch-onto-fault protection and overload protection.



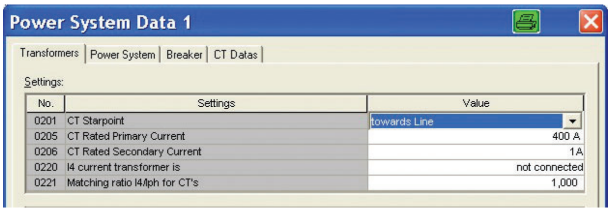
Available functions:

No.	Function	Scope
0103	Setting Group Change Option	Disabled
0112	Differential protection	Enabled
0122	DTT Direct Transfer Trip	Disabled
0124	Instantaneous HighSpeed/SOTF Overcurrent	Disabled
0126	Backup overcurrent	Disabled
0140	Trip Circuit Supervision	Disabled
0142	Thermal Overload Protection	Disabled
0144	Voltage transformers	not connected

Fig. 4 "Functional scope" menu item settings

3.2.2 Power system data

In the section called "power system data 1", the parameters defined by the primary equipment are set. These are in particular the current transformer transformation ratio (400 A/1 A), the position of its star (neutral) point (assumed to be "on the line side") as well as the rated frequency (50 Hz) of the power supply system.



No.	Settings	Value
0201	CT Starpoint	towards Line
0205	CT Rated Primary Current	400 A
0206	CT Rated Secondary Current	1A
0220	I4 current transformer is	not connected
0221	Matching ratio I4/Iph for CT's	1,000

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Fig. 5 "Power system data/Transformer data" menu item settings

On the next card the minimum and maximum circuit-breaker trigger times are input in order to ensure the execution of switching commands.

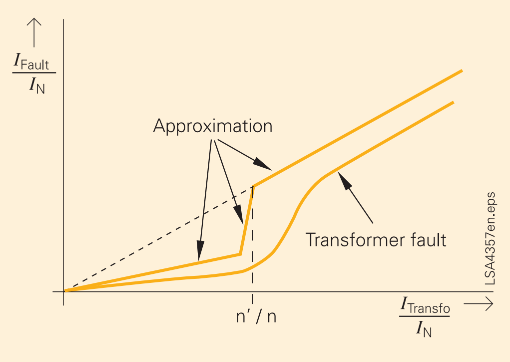

Fig. 6 Current transformer fault approximation

Next, three parameters must be set. These characterize the current transformer in terms of its characteristic progression and also define differential protection sensitivity.

Broadly, due to transformer faults, the influence of current-proportional measuring accuracy can be divided into two areas, which are separated on the current scale by the quotients n'/n. These percentage error values are dependent on the transformer class and can be taken from the Table 1 below. The footnote demonstrates that the quotient n'/n should be set at a maximum of 1.50, which corresponds to a "defensive" setting that prematurely migrates to the higher error influence and thereby increases the self-restraint.

The preset values were defined under the same aspect. They refer to a transformer in the "10P" class and also lie "on the safe side" for the quotients. These preset values can be left for all current transformer types. Under certain circumstances, some of the potentially very high differential protection sensitivity may be lost.

For our example this means, that the presetting for both error values are suitable; the quotient can be increased to the set value of 1.50, since in this case n'/n = 4.46 is clearly over the recommended maximum value of 1.50.

Transformer class	Standard	Error at rated current		Error at rated overcurrent factor	Setting recommendations		
		Transformation	Angle		Address 251	Address 253	Address 254
5P	IEC 60044-1	1.0 %	± 60 min	≤ 5 %	≤ 1.50[1]	3.0 %	10.0 %
10P		3.0 %	–	≤ 10 %	≤ 1.50[1]	5.0 %	15.0 %
TPX	IEC 60044-1	0.5 %	± 30 min	ε ≤ 10 %	≤ 1.50[1]	1.0 %	15.0 %
TPY		1.0 %	± 30 min	ε ≤ 10 %	≤ 1.50[1]	3.0 %	15.0 %
TPZ		1.0 %	± 180 min ± 18 min	ε ≤ 10 % (only I ~)	≤ 1.50[1]	6.0 %	20.0 %
TPS	IEC 60044-1 BS: Class X				≤ 1.50[1]	3.0 %	10.0 %
C100 to C800	ANSI				≤ 1.50[1]	5.0 %	15.0 %

Table 1 Current transformer data setting recommendations

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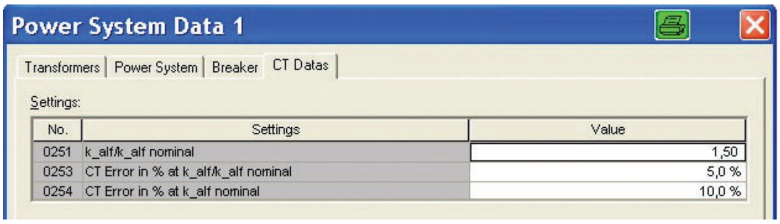
1) If n'/n ≤ 1.50, then setting = calculated value;
if n'/n > 1.50, then setting = 1.50.



Settings:

No.	Settings	Value
0251	k_alf/k_alf nominal	1,50
0253	CT Error in % at k_alf/k_alf nominal	5,0 %
0254	CT Error in % at k_alf nominal	10,0 %

Fig. 7 Settings in the menu item “Power system data 1-*I*- CT characteristic”

When parameter set switchover is deactivated, only the “parameter set A” is available for the further settings. Under “power system data 2”, only the rated operating current of the line (317 A), as well as correct line state recognition and connection recognition details, are set. At this point the rated operating current of the object to be protected (i.e. the power cable) in particular can deviate from the transformer rated current. The rated operating current must be set identically for both 7SD610 relays, since this value is the basis for the current comparison at both ends.

3.2.3 Differential protection settings

The differential protection is parameterized and set in a few steps as the main 7SD610 protection function. As in the case of all protection functions included in the scope, the differential protection can once again be switched either on or off at this point in order to simplify function-selective checking. The differential protection function must be switched on as a matter of course for normal operating status.

Concerning the differential protection function, only five parameters need be set in the example given. In particular, two discrete pickup thresholds ($I_{DIFF}>$ and $I_{DIFF}>>$) of the differential protection function are set. Both these values determine the pickup thresholds of both protection algorithms (described above) of the differential protection function.

1233 $I_{DIFF}>>$: Pickup value

The $I_{DIFF}>>$ value defines the charge comparison tripping threshold, which decides on tripping very quickly in the event of high-current faults. This value is usually set at rated operating current. In the case of a resonant-earthed power system, the setting must not be below the non-compensated earth-fault current. Otherwise the starting oscillation on occurrence of an earth fault could lead to (unwanted) tripping. Consequently, the Petersen coil rated current provides a good guide for setting the $I_{DIFF}>>$ threshold if this lies above the rated line current.

1210 $I_{DIFF}>$: Pickup value

The $I_{DIFF}>$ stage corresponds to the tripping threshold of the actual current comparison protection and is set at approximately 2.5 times the charge current. This charge current is calculated according to the equation:

$$I_C = 3.63 \cdot 10^{-6} \cdot U_N \cdot f_N \cdot C_B' \cdot s$$

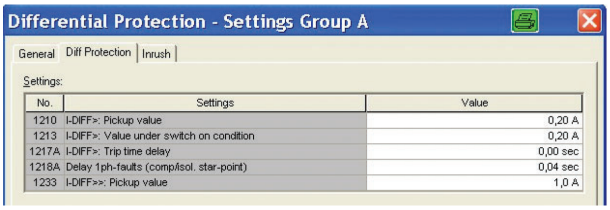
I_C	Primary charge current to be calculated [A]
U_N	Power system rated current [kV]
f_N	Power system rated frequency [Hz]
C_B'	Line operating capacity [nF/km]
s	Line length [km]

The data for the single-core oil-filled cable to be protected are: C_B' = 235 nF/km, s = 9.5 km

At a rated voltage of 20 kV and a power system frequency of 50 Hz, a charge current of 8.1 A is calculated from the above equation. Consequently, a set value of 20.3 A (primary) arises for $I_{DIFF}>$ or, in the case of a current transformer ratio of 400 A/1 A, a secondary value of 0.05 A. This figure is below the minimum threshold setting of 0.10 A (secondary). The “safe side” was once again sought with the preset value of 0.30 A. This figure results from the assumption of three times the charge current at a level of 10 %, referred to rated current. In the case of transformers with comparable response qualities and which – in the event of external faults – transmit the maximum through-flowing current while remaining unsaturated, this threshold can also be lowered to as little as 0.10 A. With various transformer types (e.g. iron-core and linear), the preset value remains unchanged, in order to ensure protection stability against transients in the event of external faults.

In this case, on comparable transformers with good response (n’ high), a setting of 0.10 A or – with a safety margin – of 0.20 A is possible. If 2.5 times the charge current is greater than 0.30 A, the higher value must clearly be set.

When comparing the apparently very sensitive preset value of 0.30 A with customary differential protection settings (I_N), the different failure type weighting prevailing in the latter must be taken into account. Single-pole faults are often detected by the summation current transformer circuit with a sensitivity higher by a factor close to 3, which would also correspond to a $I_{DIFF}>$ threshold close to 0.30 A.



No.	Settings	Value
1210	I-DIFF>: Pickup value	0,20 A
1213	I-DIFF>: Value under switch on condition	0,20 A
1217A	I-DIFF>: Trip time delay	0,00 sec
1218A	Delay 1ph-faults (comp/isol. star-point)	0,04 sec
1233	I-DIFF>>: Pickup value	1,0 A

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Fig. 8 Settings in the menu item “Settings group A – Differential protection – Diff protection”

Further differential protection function parameters (settings)

Three further parameters also exist for finer adjustment of the differential protection function.

First, there is the possibility to raise the $I_{\text{DIFF}}>$ pickup threshold when the line is switched in. This is recommended when long off-load cables or overhead lines are energized. In order to avoid causing pickup of the differential protection in this case, this parameter $I_{\text{DIFF}}>$ *SWITCH ON* should be set at approximately 3.5 times the charge current, provided that this value is greater than $I_{\text{DIFF}}>$. Tripping of the current comparison protection should only be delayed in exceptional cases and it is therefore advisable to leave the presetting for $T\text{-}I_{\text{DIFF}}>$ unchanged at 0.00 s. In a resonant-earthed system however, in the event of single-pole pickup, a delay is recommended in order to avoid tripping due to the earth-fault ignition process. A delay of 0.04 seconds has proved suitable.

Because it is not necessary to take a transformer into account in the range of the differential protection system, the transient rush restraint may remain deactivated. All further parameter settings of this small card are consequently irrelevant.

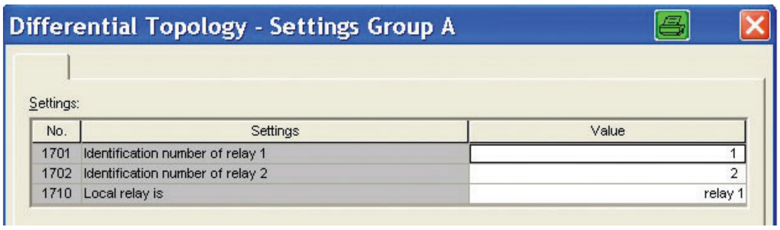
3.2.4 Setting the communication

Both 7SD610 relays communicate via a fiber-optic link laid parallel to the power cable. With a section length of 9.5 km, a fiber-optic cable with 9/125 µm mono-mode fibers is used. This communication link also requires a few parameter settings, which means that the presettings in the “R2R interface” section can generally be left unchanged.

As already mentioned, data (i.e. predominantly the current measured values) is transmitted between the two relays by telegram. Individual erroneous or missing telegrams pose no problem since they are counted for statistics purposes, but are otherwise ignored. However, if such an error status remains over long time periods and an initial time threshold is exceeded, a link malfunction is reported. At a second, higher threshold, this is recognized as a link failure (outage). It is also possible to set the length of time for which transmitted remote signals should retain their “old” status when a link malfunction is recognized.

In the "CT 1” card file, the R2R interface is activated and the type of communication connection, in this case “fiber-optic cable direct”, is selected. Further parameters can be left at the presettings.

Under the concept of "differential protection topology" the relays must now be assigned the identification number "n". This differential protection system consists of two 7SD610 relays. One of the two relays must be set as "relay 1", the other as "relay 2". The difference lies in that the absolute chronology management of the system conforms to relay 1. Relay 2 adjusts itself accordingly and consequently the time data of both relays is always comparable. Since both the relays could also be linked to each other via a digital communication network in which more than one differential protection system is communicating, each relay can in addition have a relay identification number assigned to it. This may only be used once in the communication network. Both these addresses must be set identically in both relays. In our example of a direct fiber-optic link, no adaptation of the identification numbers is necessary.


Differential Topology - Settings Group A

Settings:

No.	Settings	Value
1701	Identification number of relay 1	1
1702	Identification number of relay 2	2
1710	Local relay is	relay 1

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Fig. 9 Settings in the menu item "Settings group A – differential topology"

3.2.5 Backup protection functions

3.2.5.1 Instantaneous high-current switch-onto-fault protection

This function is only operative if the circuit-breaker at the remote end is open and the local 7SD610 is informed of this via the communication link. Assuming that the function is activated in both relays, the data relating to the circuit-breaker position must also be detected by the local 7SD610. For this purpose the data items 00379 ">CB 3p Closed" and 00380 ">CB 3p Open" in the allocation matrix in the "power system data 2" data group must be combined with the associated binary inputs. The pickup threshold for the I>>> stage should be set at the approximate charge current of the line. This value offers a sufficient safety margin since the protection algorithm compares the instantaneous values with double the set root-mean-square (r.m.s.)value. The stage I>>>>, which is independent of the circuit- breaker, is left deactivated (set value "∞") as no current grading is possible via the object to be protected.

3.2.5.2 Overcurrent-time protection

Since further short-circuit protection is generally provided in addition to the differential protection – for reasons of hardware redundancy in an independent relay – the integrated definite-time overcurrent-time protection is only activated if there is a communication link failure (outage). The current thresholds are set – as far as possible – between maximum operating current and minimum short-circuit current. The associated delay time is adjusted to the power system grading plan in the best possible way, in order to maximize selectivity. In the example here – without knowing the minimum short-circuit current – the recommended setting is 20 % above the maximum permitted continuous current for the cable (407 A), i.e. 488 A or 1.22 A secondary.

If current-dependent grading via the object to be protected is possible, a high-current stage with immediate disconnection can also be set. In this case it must be ensured that the threshold does not pickup in the event of fault current flowing through.

If the definite-time overcurrent-time protection integrated into the 7SD610 is set as a permanently active backup protection function, overcurrent and high current stages can be used for regular definite-time overcurrent-time protection duties outside the differential protection area. In the event of a communication link outage, the I>>> stage can be used in the sense described above as an emergency definite-time overcurrent stage.

3.2.5.3 Thermal overload protection

Thermal overload protection prevents overload of the object to be protected, in this case the 20 kV cable. Because the cause of the overload normally lies outside the object to be protected, the overload current is a through-flowing current. The relay calculates the temperature rise in accordance with a thermal single-body model according to the differential equation:

$$\frac{\mathrm{d}\Theta}{\mathrm{d}t} + \frac{1}{\tau_{\mathrm{th}}} \cdot \Theta = \frac{1}{\tau_{\mathrm{th}}} \cdot \left(\frac{I}{k \cdot I_{\mathrm{N}}} \right)^2$$

For each phase, the protection function calculates a thermal replica of the object to be protected from the square of the phase current. The unfiltered measured value is used so that harmonics are also taken into account in the thermal consideration. Whether the overload function should in fact disconnect when the tripping limit is reached, or whether reaching this threshold should only be reported, must initially be set.

The basic current for overload detection is the thermally continuous permitted current of the object to be protected (compare cable data). This can be referred to the protection relay rated current via the setting factor k:

$$k = \frac{I_{\max}}{I_N}$$

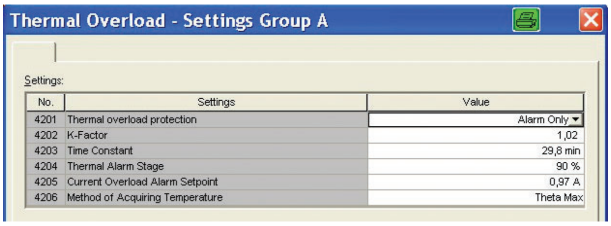
Consequently, at a maximum permitted continuous current of 407 A and a primary transformer rated current of 400 A, a value for k of 1.02 results.

The temperature rise time constant τ_{th} must also be taken from the manufacturer's data. It must be borne in mind that this must be set in minutes, whereas often a maximum permitted 1 second current is specified, and the same applies to our cable. In this case the 1 second current is 17.2 kA. The conversion formula is

$$\frac{\tau_{\mathrm{th}}}{\mathrm{min}} = \frac{1}{60} \cdot \left(\frac{\text{permissible 1 second current}}{\text{permissible continuous current}} \right)^2$$

τ_{th} is 29.8 minutes in this case.

Before reaching the tripping threshold, a thermal and/or current alarm stage can be set. These should typically be set somewhere below the tripping threshold in order to give the operating staff sufficient time to reduce the equipment load. For the thermal alarm stage it is recommended that the preset value of 90 % be left unchanged. The current alarm stage is set somewhere below the maximum continuous permitted operating current. 95 % of this figure is selected here, i.e. 387 A primary. Referred to the transformer rated current, this gives approximately 0.97 A secondary. Finally, it is also possible to set the method used to calculate the temperature rise. This is calculated separately for each phase. There is a choice as to whether the maximum of the three excess temperatures (preset), the arithmetic mean of these three, or the temperature rise calculated from the maximum phase current should be significant for comparison with the tripping thresholds. In this case, the preset value remains unchanged, provided no other algorithm must be preferred.



Settings:

No.	Settings	Value
4201	Thermal overload protection	Alarm Only
4202	K-Factor	1,02
4203	Time Constant	29,8 min
4204	Thermal Alarm Stage	90 %
4205	Current Overload Alarm Setpoint	0,97 A
4206	Method of Acquiring Temperature	Theta Max

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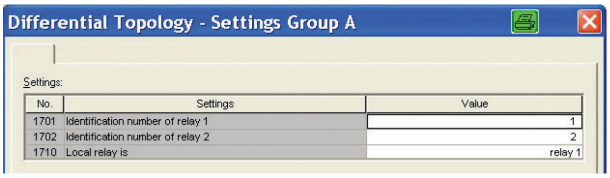
Fig. 10 Settings in the menu item "Settings group A – thermal overload protection"

3.3 Settings of the relay at the remote end

The settings of the local relay just parameterized can mostly be used as a basis for parameter assignment on the relay at the remote end. The record is simply duplicated by copying and pasting. This creates a new relay file, the only difference in which is the VD address. This ensures that the record copied belongs to another relay, even though that relay was until now identical.

In the "Settings group A – differential protection topology" section, the parameter 1710 must be set to "relay 2". In the absence of this setting, there cannot be any communication between the two relays.



Settings:

No.	Settings	Value
1701	Identification number of relay 1	1
1702	Identification number of relay 2	2
1710	Local relay is	relay 1

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Fig. 11 Settings for the relay at the remote end in the "Settings group A – differential topology" section

The transformer data and the transformer characteristic in the "Power system data 1" section must be adapted. Whether intertripping should be operable from both ends should also be checked. Otherwise, this must also be changed.

The settings in the "Power system data 2" (differential protection function, R2R interfaces, instantaneous switch-onto-fault and overload) are identical for both relays and need not be changed. The definite-time overcurrent-time function settings are dependent on power system topology and must therefore be checked. If the relays are connected to a substation control system or RTU, the respective relay addresses must be checked.

4. Connection example

Generally, connection of three phase current transformers to the 7SD610 in Holmgreen circuit is recommended in accordance with Fig. 12. This allows the differential protection to work with the three directly measured phase currents. For other protection functions (e.g. definite-time overcurrent-time protection), an earth current summated from the three phase currents is available. If there are higher demands for the accuracy of the earth current, a core-balance current transformer can also be connected to the 7SD610 IE input (Fig. 13). In this case the modified transformation ratio for this input must be entered via parameter 221 in “Power system data 1 – transformer data”.

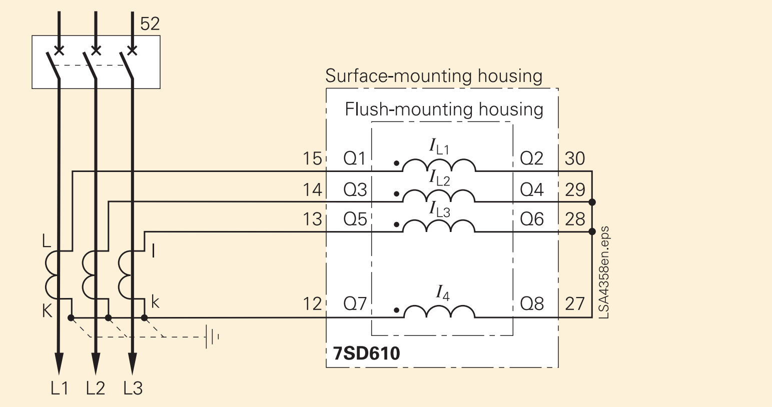
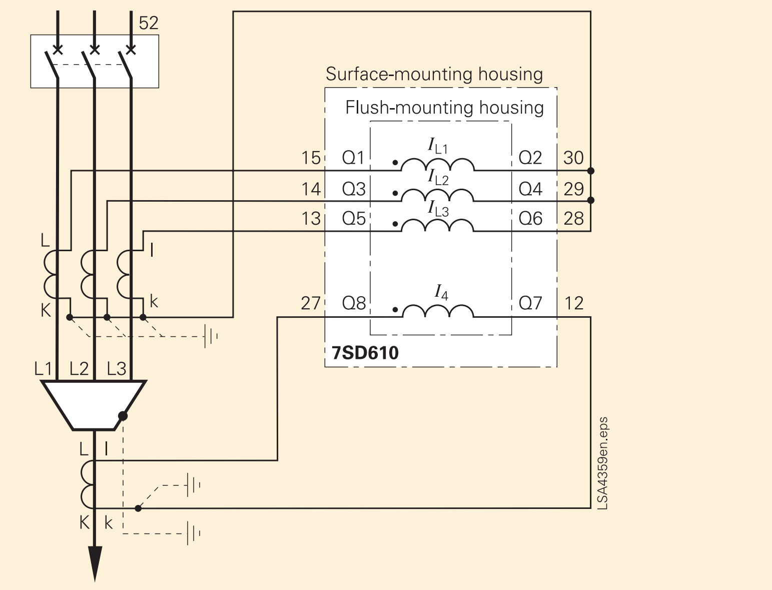


Fig. 12 Current transformer connection to three primary current transformers and neutral point current (normal connection)



Important: The cable shielding must be earthed on the cable side.

Note: Changing over the current polarity (address 0201) also causes a polarity reversal of the current input I_4.

Fig. 13 Current transformer connection to three primary current transformers and separate earthing transformer (core-balance current transformer)

5. Summary

The instantaneous and at the same time selective protection of cables and lines reduces the consequences of unavoidable power system disturbances. For one this means protection of equipment, secondly it contributes to maximizing supply security.

A differential protection system consisting of two SIPROTEC 7SD610 relays provides comprehensive safeguarding of cables and overhead lines. Built-in emergency and backup protection functions – as well as extensive additional facilities – allow problem-free connection of the relay and integration in complex power system protection grading schemes, without the need for any additional equipment.

The preset values on the relay are selected in such a way that the user only has to set the known cable and primary transformer data. Many of the preset values can be taken over without difficulty, thereby reducing the effort involved in parameterization and setting.