# Medium-Voltage Protection with Auto-Reclosure and Control

## 1. Introduction

An important protection criterion in medium-voltage applications is overcurrent-time protection. Hardware redundancy can be dispensed with in favor of lower-cost solutions, thanks to numerical technology and the high reliability of the SIPROTEC 4 protection relays. The SIPROTEC 4 protection relays also allow functions which go beyond the basic scope of protection:

- Unbalanced load (negative-sequence) protection, motor protection functions, circuit-breaker failure protection,...
- Other voltage-dependent protection functions such as voltage protection, directional overcurrent protection
- Auto-reclosure
- Control, including interlocking
- Integration in a control system

This enables all the requirements in the feeder to be met with a single relay. Scalable, flexible hardware allows simple adaptation to any application.

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**Fig. 1** SIPROTEC medium-voltage protection

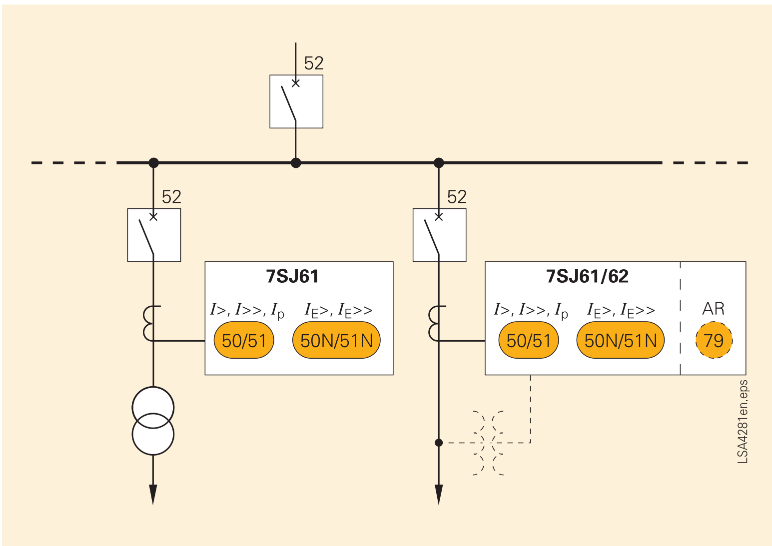



**Fig. 2** Block diagram

## 2. Protection concept

### 2.1 Overcurrent-time protection

The task of overcurrent-time protection is to detect the feeder currents, in order to initiate tripping by the circuit-breaker in the event of overcurrent. Selectivity is achieved here by current grading or time grading. The phase currents $I_{L1}$, $I_{L2}$ and $I_{L3}$ and the earth current $I_E$ serve as measuring variables here. (Non-directional) overcurrent-time protection is used in medium-voltage power systems with single-end infeed or as backup protection in high-voltage applications.

### 2.1.1 Grading and selectivity

The aim of every protective setting is to achieve selectivity, i.e. the protection relay closest to the fault location trips the CB; all the others detect the fault but do not switch off or at least only after a delay. This ensures backup protection if "regular" protection fails.

There are basically two criteria for achieving selectivity:

- Time
  Here a protection relay initiates tripping immediately or with an adjustable delay time. Since the power system fault is usually detected by a number of protection relays in the power system, the protection relay with the shortest delay time initiates tripping. The delay times in the individual protection relays are defined such that the short-circuit is cleared by the protection relay closest to the fault.

This type of grading is normally used for cable and overhead power line systems.

- Current
  Another grading criterion may be the magnitude of the short-circuit current itself. Since the size of the short-circuit current cannot be determined exactly in pure line or cable systems, this method is used for grading of transformers. The transformer limits the short-circuit current resulting in different magnitudes of short-circuit current on the high and low-voltage side.
  This behavior is utilized to achieve selectivity in tripping, as is attained in time grading.

The flexibility of SIPROTEC 4 overcurrent-time protection relays allows a mixture of these two criteria and therefore helps to achieve optimum supply security.

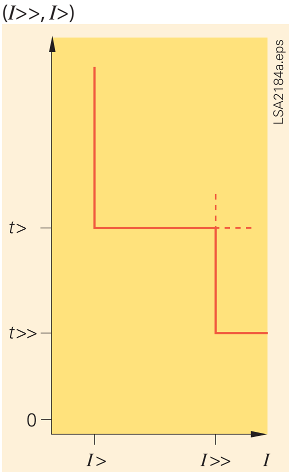
### 2.1.2 Definite-time overcurrent protection

Definite-time overcurrent protection is the main characteristic used in Europe (except in countries with a British influence). Delay times are assigned to several current pickup thresholds.

*I*>> pickup value (high short-circuit current)
*t*>> (short delay time)

*I*> pickup value (low short-circuit current),
*t*> (delay time)

**Fig. 2**
2-stage definite-time overcurrent characteristic (*I*>>, *I*>)




### 2.1.3 Inverse-time overcurrent protection

The inverse-time characteristic is widely used in countries with a British and American influence. Here the delay time is dependent on the current detected.

*Inverse-time overcurrent protection characteristics according to IEC 60255*

IEC 60255-3 defines four characteristics which differ in their slope.

Inverse
Very Inverse
Extremely Inverse
Long Inverse

The calculation formulae and the corresponding characteristics are shown below by way of comparison.

Inverse $$t = \frac{0.14}{\left(I/I_p\right)^{0.02} - 1} \cdot T_p$$

Very inverse $$t = \frac{13.5}{\left(I/I_p\right) - 1} \cdot T_p$$

Extremely inverse $$t = \frac{80}{\left(I/I_p\right)^{2} - 1} \cdot T_p$$

Long inverse $$t = \frac{120}{\left(I/I_p\right) - 1} \cdot T_p$$

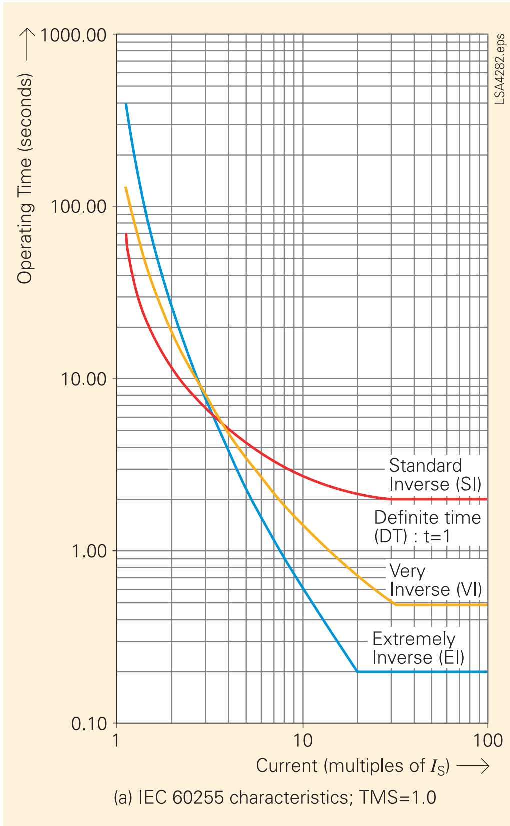



**Fig. 3** Comparison of inverse-time overcurrent protection characteristics

The corresponding characteristic is selected dependent on the overall grading coordination chart. However, the inverse characteristic is sufficient for most applications.

*Inverse-time overcurrent protection characteristics according to ANSI/IEEE*

Characteristics are also defined by ANSI/IEEE similar to those according to IEC 60255. For further details about these, see the application example on “Coordination of Inverse-Time Overcurrent Relays with Fuses”. The ANSI characteristics are also available as standard in all SIPROTEC 4 overcurrent-time protection relays.

### 2.1.4 User-defined characteristics

Numerical protection relays like SIPROTEC 4 also allow the user to freely define characteristics, and therefore enable maximum flexibility. This means ease of adaptation to existing protection concepts, e.g. when renewing the protection, even for special applications.

### 2.1.5 Combined characteristics

SIPROTEC 4 overcurrent-time protection allows the advantages of definite and inverse-time overcurrent protection to be combined. On the one hand, with the high-set current stage *I*>>, the tripping time with high short-circuit currents can be reduced in comparison with inverse-time overcurrent protection characteristics, and on the other hand the grading can be adapted optimally to the characteristic of the HV HRC fuses with inverse-time overcurrent protection characteristic.

### 2.1.6 Sensitivity

The earth current can be measured or calculated in addition to the phase currents. Independent protection stages for phase-to-earth faults are also available in the SIPROTEC 4. As a result, sensitivity below the rated current is achieved for such a fault.

### 2.2 Auto-reclosure

Auto-reclosure is only used on overhead lines, because the chances of success are relatively slight in the event of faults in a cable network. About 85% of reclosures are successful on overhead lines, which contributes greatly to a reduction in power system downtimes.

Important parameters for reclosure are:

Dead time
Lockout (blocking) time
Single or three-pole
Single or multishot

Normally only one single three-pole reclosure is performed for medium-voltage applications. Dead times between 0.3 and 0.6 s usually suffice for adequate de-ionization of the flashover distance and thus a successful reclosure.

The lockout times (time up to next reclosure) are chosen so that protection relays affected by the power system fault have reliably reset. In the past this led to relatively long lockout times (approximately 30 s) due to the dropout time of mechanical protection relays. This is not necessary in numerical protection relays. Shorter lockout times can therefore reduce the number of final disconnections (unsuccessful reclosures), for example during thunderstorms.

In the past separate relays were used for protection and automatic reclosure. The initiation for this was given by parallel wiring with the protection relay. In SIPROTEC 4 relays the auto-reclosure function can be integrated in the protection relay; there is no need for any additional relay and wiring.

### 2.3 Control

There is a noticeable worldwide trend towards automation, even in medium-voltage power systems. SIPROTEC 4 protection relays provide the conditions for controlling the feeder both locally and remotely by telecontrol/station control and protection systems. This is supported by the appropriate control elements on the relay and various serial interfaces. See Chapter 4 for further information.

## 3. Settings

The determining of the most important setting parameters is explained in this chapter by means of a typical application.

### 3.1 Overcurrent-time protection

The setting of the overcurrent stages is defined by the grading coordination chart of the overall network. Current grading is possible for the “transformer” protection object; only time grading can usually be applied for overhead lines/cables.

### 3.1.1 High-set current stage I>>

The high-set current stage *I*>> is set under the address 1202 and the corresponding delay T *I*>> under 1203. It is normally used for current grading at high impedances such as are encountered in transformers, motors or generators. Setting is such that it picks up for short-circuits reaching into this impedance range.

Example:
Transformer in the infeed of a busbar with the following data:

| | |
|---|---|
| Rated apparent power | $S_{NT} = 4$ MVA |
| Short-circuit voltage | $U_k = 10$ % |
| Primary rated voltage | $U_{N1} = 33$ kV |
| Secondary rated voltage | $U_{N2} = 11$ kV |
| Vector group | Dy 5 |
| Neutral | earthed |
| Short-circuit power on 33 kV side | 250 MVA |

The following short-circuit currents can be calculated from these data:

3-pole, high-voltage side short-circuit
$I''_{SC3} = 4389$ A

3-pole, low-voltage side short-circuit
$I''_{SC3,\,11} = 2100$ A

on the high-voltage side flow
$I''_{SC3,33} = 700$ A

rated current of the transformer HV
$I_{NT,\,33} = 70$ A (high-voltage side)

rated current of the transformer LV
$I_{NT,\,11} = 211$ A (low-voltage side)

current transformer (high-voltage side)
$I_{NW,\,33} = 100$ A / 1 A

current transformer (low-voltage side)
$I_{NW,\,11} = 300$ A / 1 A

Due to the setting value of the high-set current stage *I>>*

$$I{>>}/I_N > \frac{1}{U_{k\,\text{Transfo}}} \cdot \frac{I_{N\,\text{Transfo}}}{I_{N\,\text{CT}}}$$

the following setting on the protection relay:

The high-set current stage *I>* must be set higher than the maximum short-circuit current detected on the high-voltage side in the event of a fault on the low-voltage side. In order to attain a sufficient noise ratio even at fluctuating short-circuit power, a setting of

$I{>>}/I_N = 10$, i.e. $I{>>} = 1000$ A

is selected.

Increased inrush current surges are disarmed by the delay times (parameter 1203 T *I>>*) provided their fundamental component exceeds the setting value. The set time is a purely additional time delay which does not include the operating time.

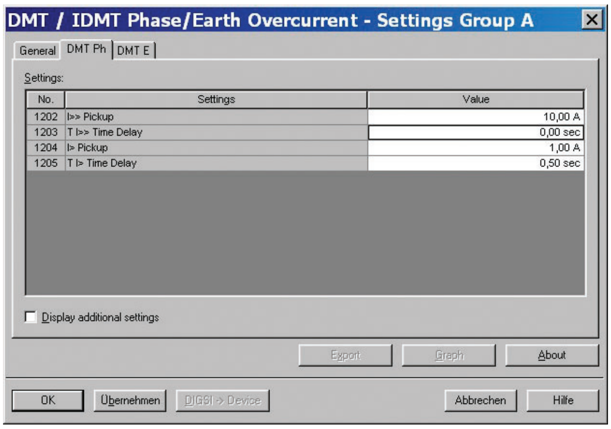



**Fig. 4** DIGSI parameter sheet, definite-time overcurrent protection phase

### *3.1.2 Overcurrent stage I>*

The maximum operating current occurring is significant for the setting of the overcurrent stage *I>*. Pickup by overload must be ruled out because the relay works as a short-circuit protection with correspondingly short operating times in this mode and not as overload protection. It is therefore set for lines at about 20 % and for transformers and motors at about 40 % above the maximum (over) load to be expected. The delay to be set (parameter 1205 T*I>*) is given by the grading coordination chart created for the power system.

The set time is a purely additional time delay which does not include the operating time (measuring time). The delay can be set to ∞. The stage then does not trip after pickup but the pickup is signaled. If the *I>* stage is not needed at all, the pickup threshold *I>* is set to ∞. Then there is neither pickup indication nor tripping.

According to the above example this gives a calculated setting value of

$$I> = 1.4 \cdot I_{NT,\,33} = 1.4 \cdot 70\text{ A} = 100\text{ A} = 1.0 \cdot I_{NW,\,33}$$

### *3.1.3 Inverse-time overcurrent protection stages $I_p$*

It must be taken into account when selecting an inverse-time overcurrent characteristic that a factor of approximately 1.1 is already incorporated between the pickup value and the setting value. This means that pickup only takes place when a current 1.1 times the setting value flows. The current value is set under address 1207 **Ip**. The maximum operating current occurring is significant for the setting.

Pickup by overload must be ruled out because the relay works as a short-circuit protection with appropriately short command times in this mode and not as overload protection. The corresponding time multiplier is accessible under address 1208 T **Ip** (51 TIME DIAL) when selecting an IEC characteristic, and under address 1209 51 TIME DIAL when selecting an ANSI characteristic. This must be coordinated with the grading coordination chart of the power system.

The time multiplier can be set to ∞. Then the stage does not trip after pickup but the pickup is signaled. If the $I_p$ stage is not needed at all, address 1201 DMT/IDMT PHASE = DTM only (FCT 50/51) is selected in the configuration of the protection functions.

### 3.1.4 Earth current stages

$I_E$>> (earth)
The high-set current stage $I_E$>> is set under address 1302 (50 N-2 PICKUP) and the corresponding delay T $I_E$>> under 1030 (50 N-2 DELAY). Similar considerations apply for the setting, as previously described, for the phase currents.

$I_E$> (earth) or $I_{Ep}$
The minimum occuring earth fault current is mainly decisive for the setting of the overcurrent stage $I_E$> or $I_{Ep}$. If great inrush currents are to be expected when using the protection relay on transformers or motors, an inrush restraint can be used in 7SJ62/63/64 for the overcurrent stage $I_E$> or $I_{Ep}$. This is switched on or off for both phase and earth current together under address 2201 INRUSH REST.

The time delay to be set (parameter 1305 T $I_E$>/ 50 N-1 DELAY or 1308 T /$I_{Ep}$/51N TIME DIAL) is given by the grading coordination chart created for the power system, whereby a separate grading coordination chart with shorter delay times is often possible for earth currents in the earthed power system.

### 3.2 Auto-reclosure

The integrated auto-reclosure function can be used for performing reclosures on overhead lines. This can be initiated by every overcurrent stage and other protection functions. External initiation via binary inputs is also possible. In this way the reclosing function can be adapted individually to the respective application without external wiring.

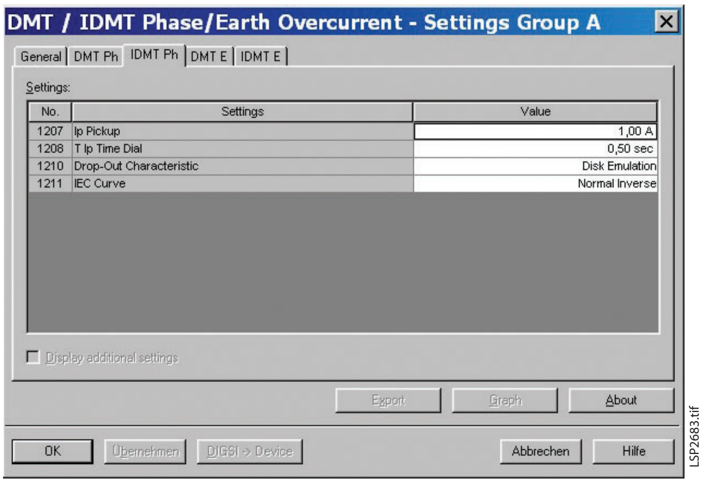



**Fig. 5** DIGSI parameter sheet, inverse time overcurrent protection phase

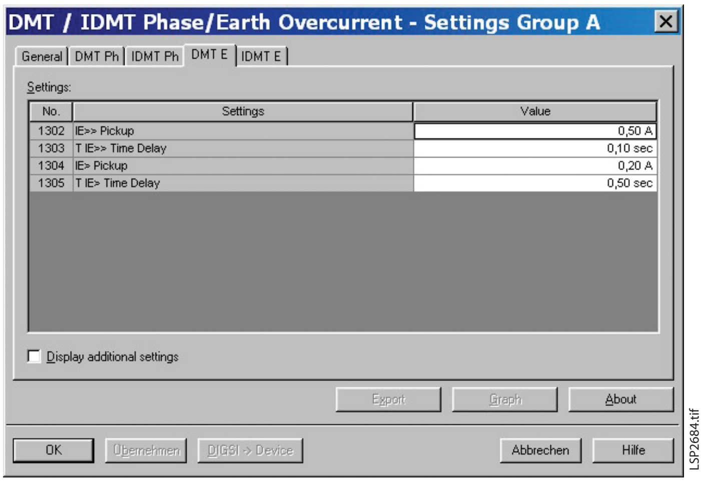



**Fig. 6** DIGSI parameter sheet, definite time overcurrent earth protection

A description for setting the most important reclosure parameters follows:

*7105 Time restraint:*

The blocking time TIME RESTRAINT (address 7105) is the time span following successful reclosure after which the power system fault is considered cleared. Generally, a few seconds are enough. In regions with frequent thunderstorms a short lockout time is recommendable, to reduce the danger of final disconnection due to lightning strikes in rapid succession or cable flashover. The default selection is 3 s.

*7117 Action time*

The action time checks the time between the pickup of a relay and the trip command of a protection function parameterized as a starter, in ready (but not yet running) auto-reclosure.
If a trip command is received from a protection function parameterized as a starter within the action time, auto-reclosure is initiated. If this time is outside the parameterized value of T-ACTION (address 7117), auto-reclosure is blocked dynamically. With inverse-time characteristics the release time is determined essentially by the fault location and the fault resistance. With the help of the action time, no reclosure is performed in the event of very remote or high-resistance faults with a long tripping time.
Presetting of ∞ always initiates a reclosure.

*7135 Number of reclosure attempts, earth*
*7136 Number of reclosure attempts, phase*

The number of reclosures can be set separately for the programs "Phase" (address 7136, NUMBER RC PHASE/# OF RCL. PH) and "Earth" (address 7135 NUMBER RC EARTH/# OF RCL. GND). The presetting for both parameters is 1 (one); one reclosure cycle is therefore executed.

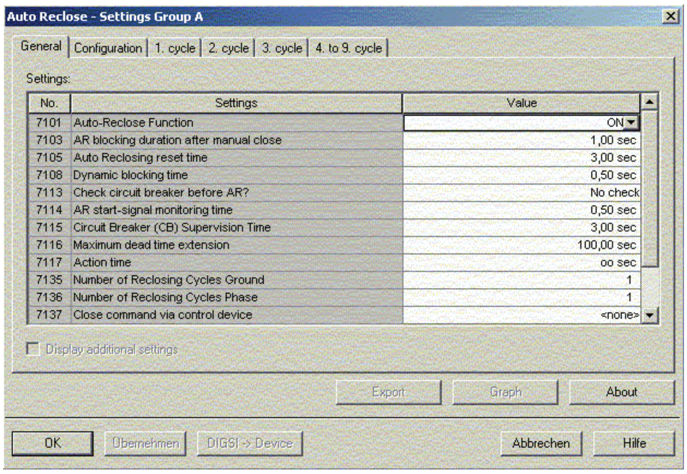



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**Fig. 7** DIGSI parameter sheet, auto-reclosure (general)

The "configuration sheet" defines which of the protection stages starts the reclosure. For each of the stages it can be decided whether this stage starts the reclosure, does not start it or blocks it out.

***7127 Dead time 1: ph***
***7128 Dead time 1: G***

The parameters 7127 and 7128 define the length of the dead times of the 1st cycle. The time defined by the parameter is started upon opening the circuit-breaker (if auxiliary contacts are allocated) or upon reset after the trip command.

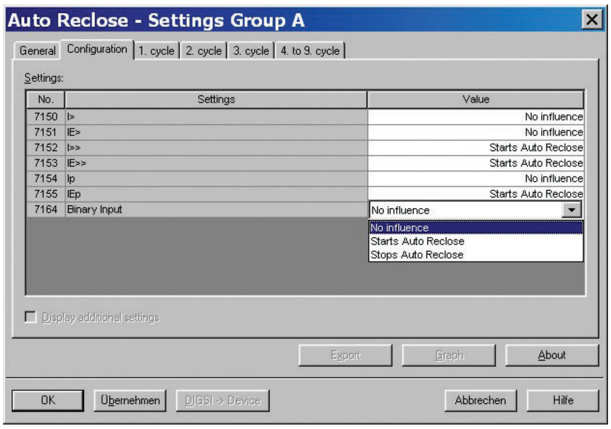


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**Fig. 8** DIGSI parameter sheet, auto-reclosure configuration

The dead time before the 1st reclosure for the reclosure program "Phase" (phase-to-phase fault) is set in address 7127 DEADTIME 1:PH; for the reclosure program "Earth" (single phase-to-earth fault) it is set in address 7128 DEADTIME 1:G.
The duration of the dead time should relate to the type of application. For longer lines the time should be long enough for the short-circuit arc to extinguish and de-ionize the ambient air, to allow successful reclosure (usually 0.9 s to 1.5 s). The stability of the power system has priority in the case of lines fed from several ends. Since the disconnected line cannot develop any synchronizing forces, often only a short dead time is permissible. Normal values are between 0.3 s and 0.6 s. Longer dead periods are usually allowed in radial systems. The default is 0.5 s.

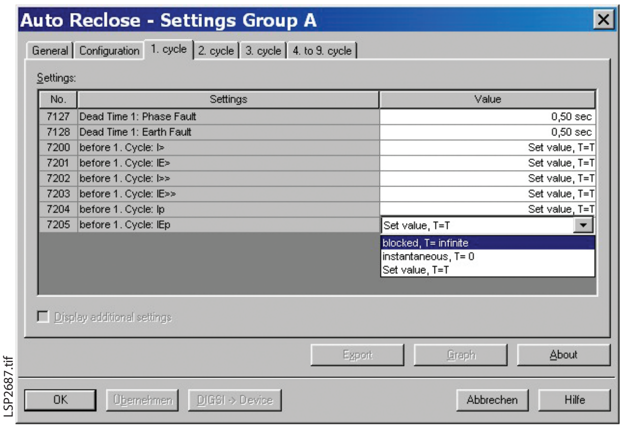


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**Fig. 9** DIGSI parameter sheet, auto-reclosure (1st reclosure cycle)

## ■ *4. Further functions*

As already described in Chapter 2, a number of additional functions can be configured in the SIPROTEC 4 relays. Apart from further protection functions, these also include control tasks for the feeder. All SIPROTEC 4 relays (e.g. 7SJ61 and 7SJ62) have 4 freely assignable function keys F1 to F4 which simplify frequently required operations. These function keys can take the user directly to the display window for measured values, or to fault event logs for example. If the relay is also to be used for feeder control, these keys can be used for controlling the circuit-breaker. The key F1 then selects the ON command for example, key F2 the OFF command and key F3 executes the selected command (two-stage command output).


**Fig. 10** Front view 7SJ61 or 7SJ62

The 7SJ63 also has a graphic display on which the individual feeder mimic diagram can be shown. Separate ON/OFF control buttons ensure safe and reliable local control. An integrated, freely programmable interlock logic prevents switching errors.

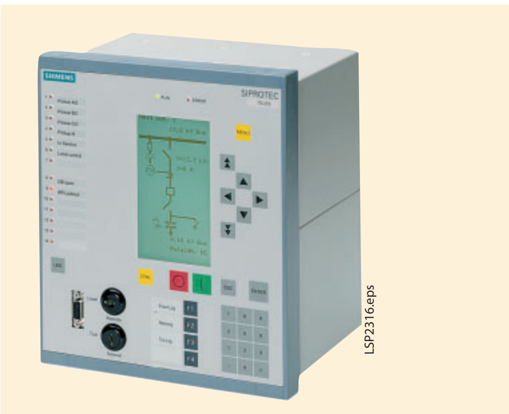



**Fig. 11** Front view 7SJ63

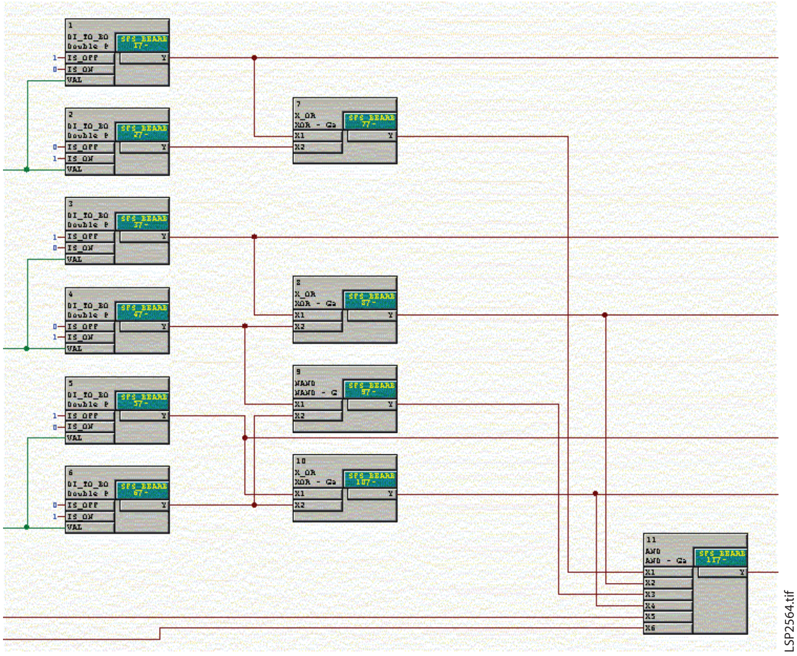



**Fig. 12** Example of interlock logic

The switching authority (local/remote) can be changed and the interlock check overridden by two key-operated switches.

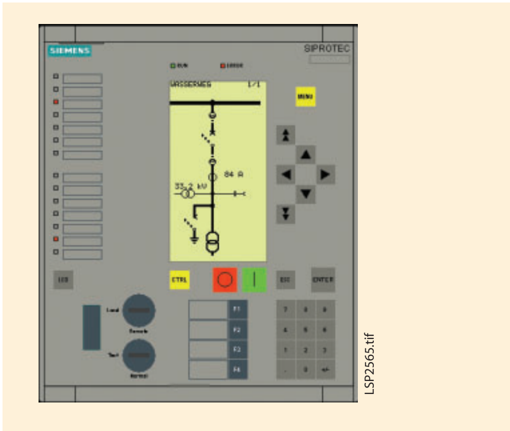



**Fig. 13** Front view, key-operated switch with customer-specific feeder mimic diagram

## 5. Connection examples

### 5.1 Current and voltage transformers

Connection of the protection relays to the switchgear depends on the number of switching objects (circuit-breakers, disconnectors) and current and voltage transformers. Normally at least three current transformers are available per feeder which are connected to the protection relay as follows.

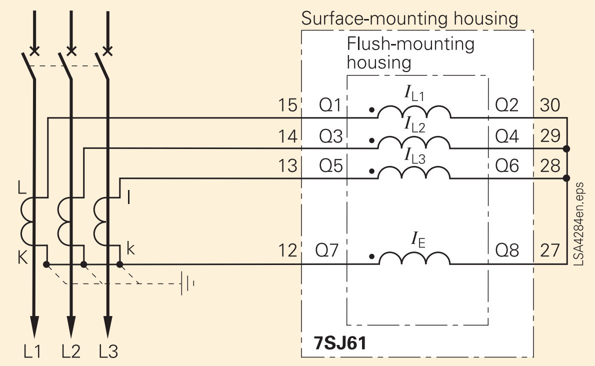
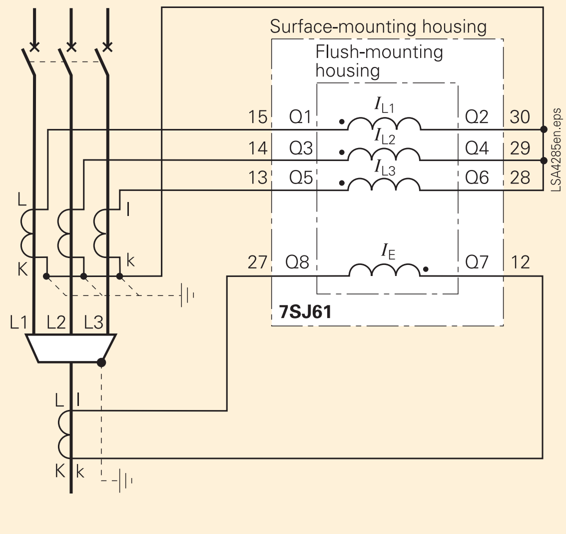



**Fig. 14** Transformer connection to three current transformers

In some systems, also the earth current is measured by a core-balance current transformer. This can be connected to the protection relay separately. A core-balance current transformer achieves greater accuracy (sensitivity) for low earth currents.




Important: The cable shield must be earthed on the cable side!

Note: Reversing the current polarity (address 0201) also reverses the polarity of the current input $I_E$

**Fig. 15** Transformer connection to three current transformers and core-balance CT

If voltages are also available (from the feeder or as a busbar measurement), these can be connected on 7SJ62/63/64 and then also enable voltage-dependent protection functions (directional overcurrent protection, voltage protection, frequency protection, ...).

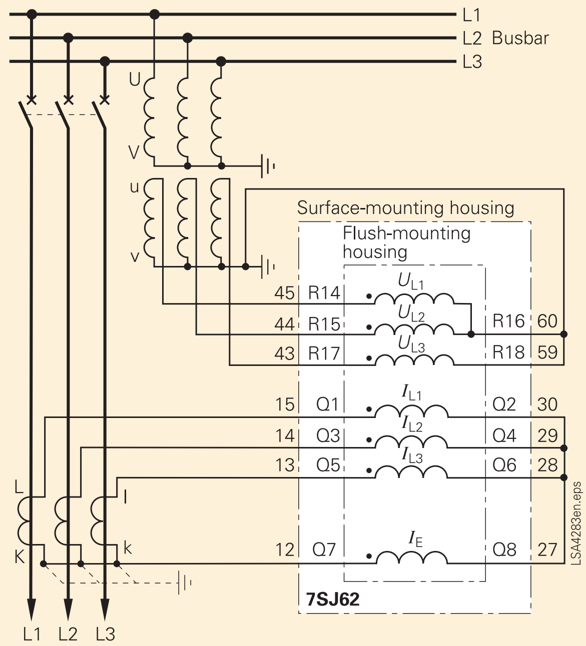



**Fig. 16** Transformer connection to three current and three voltage transformers

### 5.2 Input/output periphery

In addition to the current transformers (and if required to the voltage transformers too), at least the TRIP command has to be wired to the circuit-breaker. The standard allocation supports this by practice-oriented preassignment.

*Preassignment of the inputs and outputs in the 7SJ610:*

Binary inputs

| | |
|---|---|
| BI1 | Block definite/inverse time overcurrent protection |
| BI2 | LED reset |
| BI3 | Display lighting on |

Binary outputs (command relays)

| | |
|---|---|
| BO1 | TRIP command |
| BO2 | Reclosure command |
| BO3 | Reclosure command |
| BO4 | MV monitoring |

LEDs

| | |
|---|---|
| LED1 | TRIP command |
| LED2 | PICKUP L1 |
| LED3 | PICKUP L2 |
| LED4 | PICKUP L3 |
| LED5 | PICKUP E |
| LED6 | MV monitoring |
| LED7 | Not used |

The assignment can be changed and the protection parameters set conveniently with the DIGSI 4 operating program. The parameterizat- ion data can then be saved and copied conveniently as a basis for further feeders.

## ■ 6. Summary

SIPROTEC 4 protection relays are suitable for almost any application due to their modular hardware structure and the flexible scope of functions. A suitable relay with the necessary scope can be selected in line with requirements. Factory parameterization is oriented to typical applications and can often be adopted with only small modifications. In the parameter setting with DIGSI, all unnecessary parameters are hidden so that clarity is much improved.

The retrofitting of serial interfaces for subsequent integration into a substation control and protection system is also possible locally, which reduces downtimes to a minimum. The functional scope can also be changed later by “downloading” a new order number.

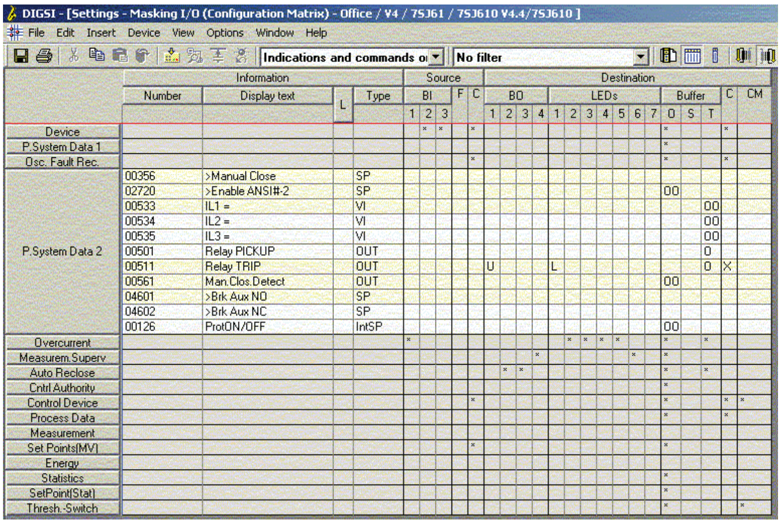



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**Fig. 17** Configuration matrix