Disconnecting Facility with Flexible Protection Function

1. Introduction

The flexible protection functions allow single-stage or multi-stage directional protection to be implemented. Each directional stage may be operated on one phase or on three phases. The stages may use optionally forward active power, reverse active power, forward reactive power or reverse reactive power as a measuring variable. Pickup of the protection stages can take place when the threshold value is exceeded or undershot. Possible applications for directional power protection are listed in Table 1.

A practical application example for reverse-power protection using the flexible protection function is described below.

2. System example

2.1 Functions for the disconnecting facility

Fig. 2 shows the example of an industrial switchgear with autonomous supply from the illustrated generator. All the lines and the busbar shown are in three-phase layout (except the earth connections and the connection for voltage measurement on the generator). The two feeders 1 and 2 supply the customer loads. In the standard case, the industrial customer receives power from the utility. The generator runs only in synchronous operation without feeding in power. If the utility can no longer maintain the required supply quality, the switchgear should be disconnected from the utility power system and the generator should assume autonomous supply. In the example shown, the switchgear is disconnected from the utility power system when the frequency leaves the rated range (e.g. 1-2 % of the rated frequency), the voltage drops below or exceeds a given value or the generator feeds active power back into the utility power system. Some of these criteria are combined depending on the user's philosophy. This would be implemented using CFC.

Here, reverse-power protection with the flexible protection functions is explained. Recommendations are given for frequency and voltage protection in the Chapter 4 on setting instructions.

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Fig. 1 Protection for industrial plants

	Direction	Evaluation	
		Overshoot	Undershoot
P	Forward	Monitoring of forward power limits of equipment (transformers, lines)	Detection of motors running at no load
P	Reverse	– Protection of a local industrial power system against feeding energy back into the utility power system – Detection of reverse energy supply from motors	

Table 1 Application overview, reverse-power protection

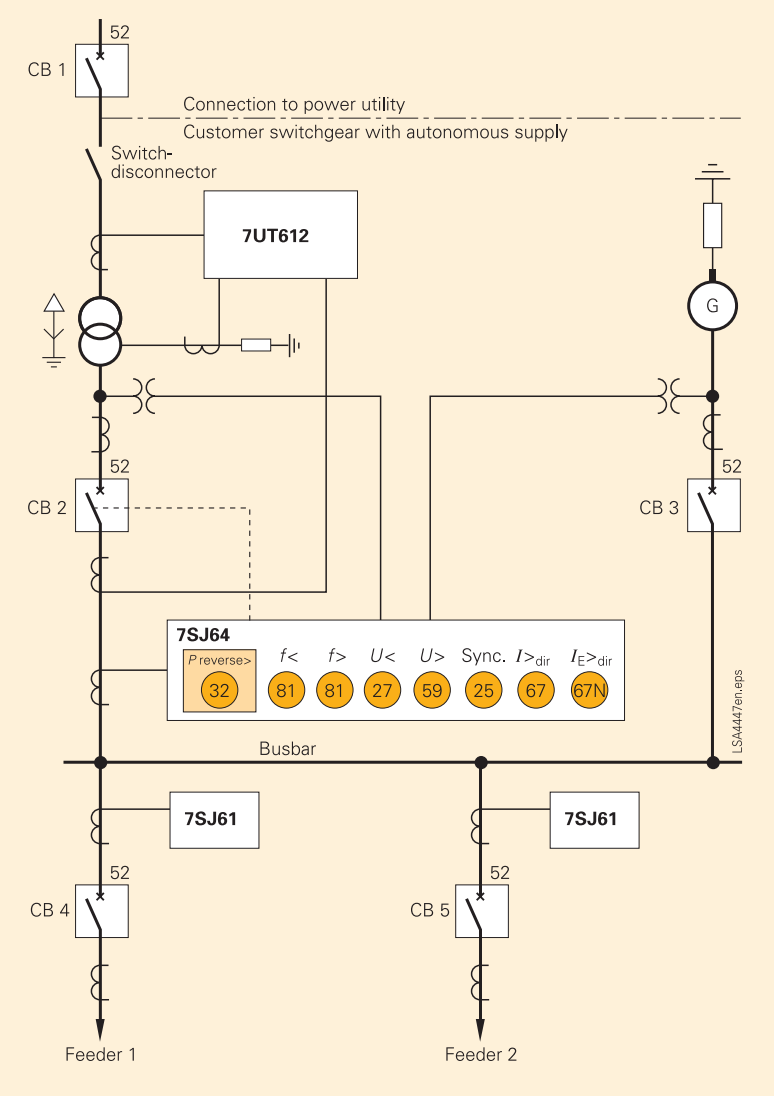

Fig. 2 Example of a switchgear with autonomous generator supply

2.2 System data

A 110 kV line connects the switchgear to the utility power system on the high-voltage side. The circuit-breaker CB1 belongs to the utility power system. The switch disconnector decouples the switchgear from the utility power system if necessary. The transformer with a ratio of 10:1 transforms the voltage level to 11 kV. On the low-voltage side the transformer, the generator and the two feeders are connected by a busbar. The circuit-breakers CB2 to CB5 disconnect loads and equipment from the busbar.

Switchgear data	
Rated power of generator	$S_{N,\,Gen}$ = 38.1 MVA
Rated power of transformer	$S_{N,\,Transfo.}$ = 40 MVA
Rated voltage of high-voltage side	U_N = 110 kV
Rated voltage of busbar side	U_N = 11 kV
Primary rated current of the current transformers on the busbar side	$I_{N,\,prim}$ = 2000 A
Secondary rated current of the current transformers on the busbar side	$I_{N,\,sec}$ = 1 A
Primary rated voltage of the voltage transformers on the busbar side	$U_{N,\,prim}$ = 11 kV
Secondary rated voltage of the voltage transformers on the busbar side	$U_{N,\,sec}$ = 100 kV

Table 2 Switchgear data for the application example

3. Protection functionality

The SIPROTEC protection relay 7SJ64 disconnects the switchgear from the utility power system if the generator feeds energy back into the power system (protection function P reverse >). This functionality is achieved by using flexible protection. Disconnection also takes place in the event of frequency or voltage fluctuations in the utility power system (protection functions $f<$, $f>$, $U<$, $U>$, $I_{dir}>$., $I_{Edir}>$/ 81, 27, 59, 67, 67N).

The protection receive the measured values via a three-phase current and voltage transformer set and a single-phase connection to the generator voltage transformer (for synchronization). The circuit-breaker CB2 is activated in the case of a disconnection.

The transformer is protected by differential protection and inverse or definite-time overcurrent-time protection functions for the phase currents. In the event of a fault, the circuit-breaker CB1 on the utility side is tripped by a remote link. Circuit-breaker CB2 is tripped additionally.

Overcurrent-time protection functions protect feeders 1 and 2 against short-circuits and overload caused by the connected loads. Both the phase currents and the zero currents of the feeders can be protected by inverse and definite-time overcurrent-time stages. The circuit-breakers CB4 and CB5 are tripped in the event of a fault.

The busbar could be equipped additionally with the differential protection 7UT635. The current transformers required for this are already shown in Fig. 2.

3.1 Synchronization when connecting the generator

In most cases the electricity customer is responsible for restoring the switchgear or substation to normal operation after shutdown. The SIPROTEC 7SJ64 tests whether synchronous conditions are satisfied. After successful synchronization, the generator is connected to the busbar. The voltages required for synchronization are measured at the transformer and at the generator. The voltage at the transformer is measured in all three-phase because this is also necessary for determining the direction. The generator feeds the phase-to-phase voltage U31 to the device input U_4 via a voltage transformer in a star-delta connection (see Fig. 3).

3.2 Connection diagram

Fig. 3 shows the connection of the relay for reverse-power protection and synchronization. The power flow in positive or forward direction takes place from the high-voltage side busbar (not shown) via the transformer to the low-voltage side busbar.

3.3 Reverse-power protection with flexible protection functions

The reverse-power protection evaluates the active power from the symmetrical fundamental components of the voltages and currents. Evaluation of the positive-sequence systems makes the reverse-power determination independent of the asymmetries in the currents and voltages and reflects the real load on the drive side. The calculated active power value corresponds to the total active power. In the connection shown in the example the power in the direction of the busbar from the relay is measured as positive.

3.4 Function logic

The logic diagram in Fig. 4 shows the function logic of the reverse-power protection.

The reverse-power protection picks up when the configured pickup threshold is exceeded. If the pickup condition persists during the equally parameterizable pickup delay, the pickup message "P reverse pickup." is emitted.

This starts the trip command delay. If pickup does not drop out while the trip command delay is running, the trip message "P reverse TRIP" and the time-out indication "P reverse timeout" are generated (latter not illustrated). The picked-up element drops out when the value falls below the dropout threshold. The blocking input ">P reverse block" blocks the entire function; i.e. pickup, trip command and running times are reset.

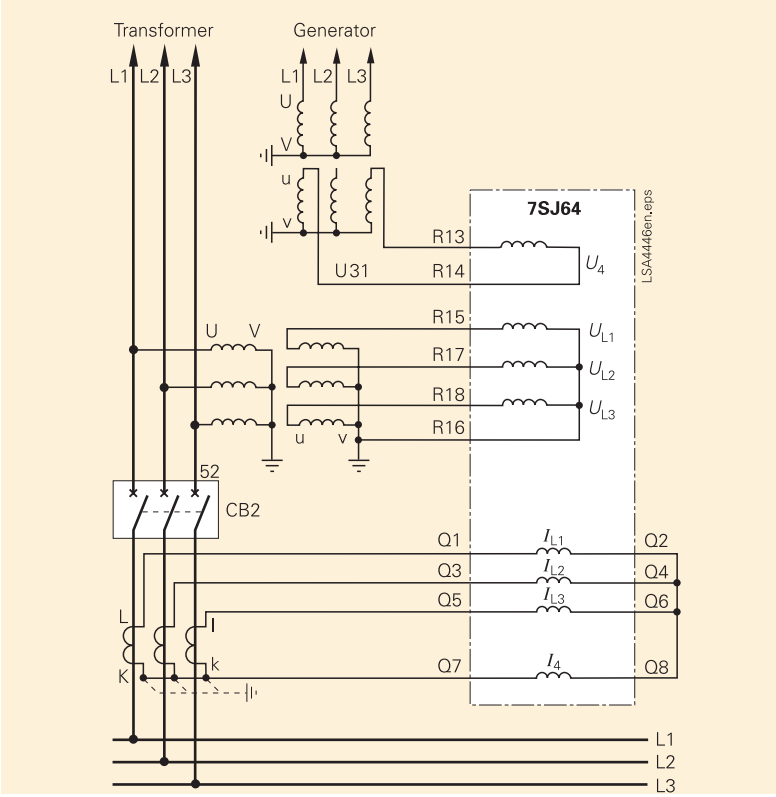

Fig. 3 Connection diagram for a 7SJ642 as reverse-power protection (flush-mounted housing)

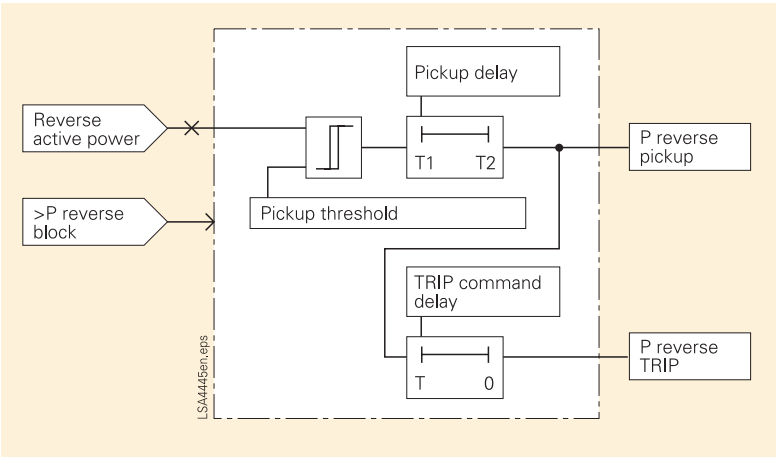

Fig. 4 Logic diagram of the reverse-power determination with flexible protection function

After the blocking has been released, the reverse power must exceed the pickup threshold and both times must run out before the protection trips.

4. Setting instructions

4.1 Reverse-power protection

The pickup value of the reverse-power protection is set at 10 % of the generator rated output. In this example the setting value is parameterized as secondary power in Watts. The primary and secondary power have the relation:

$$P_{sec} = P_{prim} \cdot \frac{U_{N,\,sec}}{U_{N,\,prim}} \cdot \frac{I_{N,\,sec}}{I_{N,\,prim}}$$

With the indicated data, the pickup values can be calculated – taking account of $P_{prim} = 3.81$ MW (10 % of 38.1 MW) on the primary level – as

$$P_{sec} = 3.81\,\text{MW} \cdot \frac{100\,\text{V}}{11000\,\text{V}} \cdot \frac{1\,\text{A}}{2000\,\text{A}} = 17.3\,\text{W}$$

on the secondary level. The dropout ratio is parameterized to 0.9. This gives a secondary dropout threshold of $P_{sec,\,dropout} = 15.6$ W. If the pickup threshold is reduced to a value close to the lower setting limit of 0.5 W, the dropout ratio should likewise be reduced to approximately 0.7.

The reverse-power protection requires no short trip times as protection against undesirable feedback. In this example it is useful to delay pickup and dropout by about 0.5 s and tripping by about 1 s. Delaying the pickup minimizes the number of opened fault logs when the reverse power fluctuates around the threshold value. If the reverse-power protection is used to make it possible to disconnect the switchgear from the utility power supply system quickly in the event of faults in the latter, it is advisable to select a higher pickup value (e.g. 50 % of the rated power) and shorter delay times.

4.2 Frequency protection f<, f>

The relay 7SJ64 contains 4 frequency stages. One stage is parameterized as $f>$ and set to 50.5 Hz; it operates without time delay. This stage detects the frequency increase caused by a short-circuit in the utility. The other 3 frequency stages should be parameterized as $f<$ stages to serve as load shedding criteria for isolated operation of the industrial power supply system.

Suggested settings:

$f_1< = 49.5$ Hz $\quad t_1 = 0.2$ s
$f_2< = 49$ Hz $\quad t_2 = 0.1$ s
$f_3< = 48$ Hz $\quad t_3 = 0.2$ s

On reaching stage $f_3<$, the generator should be operated in isolated mode to safeguard autonomous auxiliary supply coverage.

4.3 Undervoltage protection U< (ANSI 27)

The voltage dip in the event of a short-circuit in the system is detected with the $U<$ criterion. The $U<$ criterion should always be linked with the fault current direction, to open the coupler circuit-breaker only in the event of a fault in the utility system. The voltage level should be set to 0.5 x U_N.

4.4 Parameterization of reverse-power protection with DIGSI

A relay 7SJ64x (e.g. 7SJ642) is created and opened first in the DIGSI Manager. A flexible protection function 01 is configured for the given example in the scope of functions (Fig. 5).

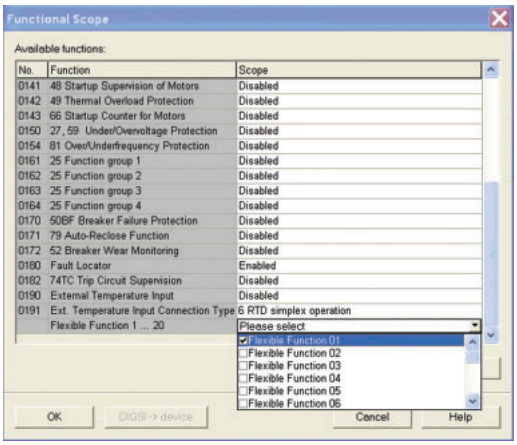

Fig. 5 Configuration of a flexible protection function

Select "Additional functions" in the "Parameters" menu to view the flexible functions (Fig. 6)

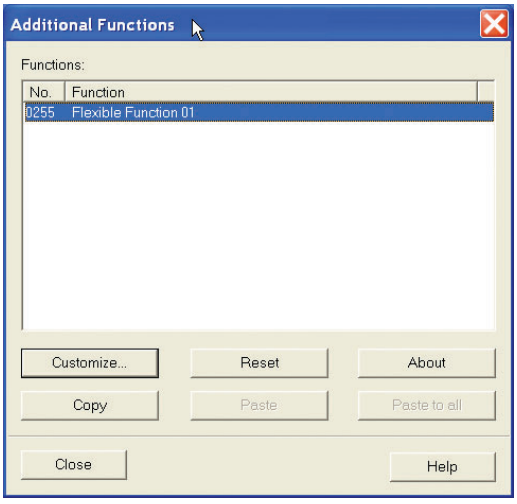

Fig. 6 The flexible function is visible in the function selection

First the function must be activated under "Settings → General", and "3-phase" operating mode must be selected (Fig. 7).

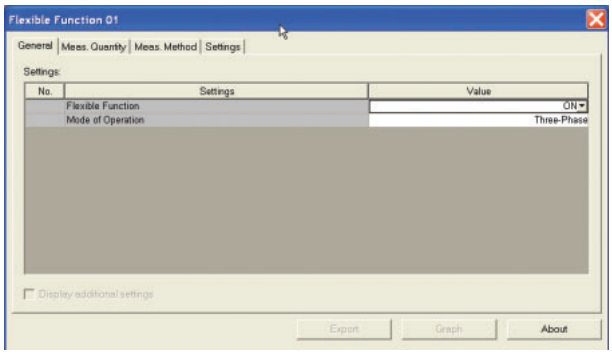

Fig. 7 Selection of three-phase operation

Select "Active power reverse" or "Overshoot" in the menu items "Measured quantity" and "Measurement method". If the "Display additional settings" box is activated in the "Settings" menu item, the threshold value, pickup delay and TRIP command delay can be configured (Fig. 8). Since the power direction cannot be determined in the event of a measuring voltage failure, protection blocking is useful in this case.

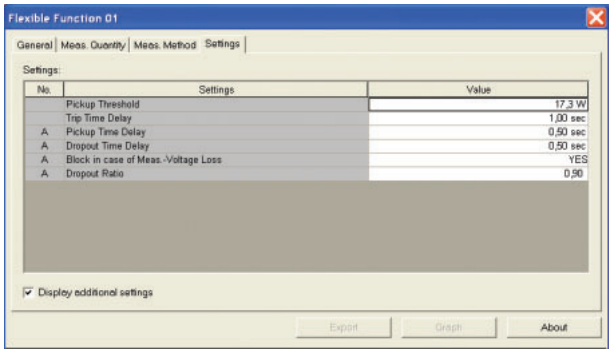

Fig. 8 Setting options of the flexible function

4.5 Configuration for reverse-power protection in DIGSI

The names of the messages can be edited in DIGSI and adapted accordingly for this example. The names of the parameters are fixed.
The DIGSI configuration matrix initially shows the following indications (after selecting "Indications and commands only" and "No filter": Fig. 9).

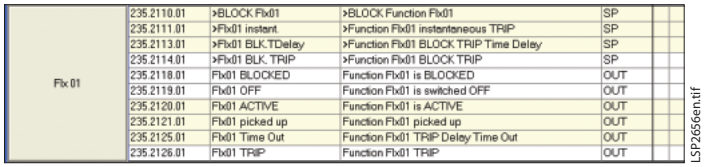

Fig. 9 Indications prior to editing

It is possible to edit short text and long texts to suit the application by clicking the texts (Fig. 10).

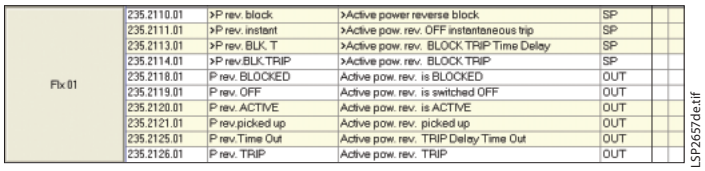

Fig. 10 Indications after editing

Configuring of the indications is performed in the same way as for the configuring of the indications of other protection functions.

5. Summary

With the flexible protection functions, it is easy to implement measuring criteria not available as standard, such as power direction. This measuring criterion is a fully fledged protection function and can therefore be integrated as an equivalent criterion in a disconnecting facility. The synchronization function of the SIPROTEC 7SJ64 can be used to advantage here, to synchronize the industrial power supply system to the utility power supply system.