PC-51Q01 • April, 2024
Published for the Basler Electric Power Systems Group

Application Note

Applying Negative-Sequence Overcurrent Relays in Distribution Circuits

General Considerations

Unbalanced faults (L-G, L-L, L-L-G) can be detected by relays using symmetrical components sequence filters. These filters allow the user to apply settings that are significantly lower than phase relays which must be set above the maximum load. Due to the simplicity of zero sequence current filtering, it has always been easy and common to apply sensitive settings to ground fault relays. The advent of microprocessor relays has made negative current detection easy as well and, thus, offered Relay Engineers the option to apply more sensitive phase-to-phase fault settings.

A Brief Symmetrical Components Review

L-G Faults

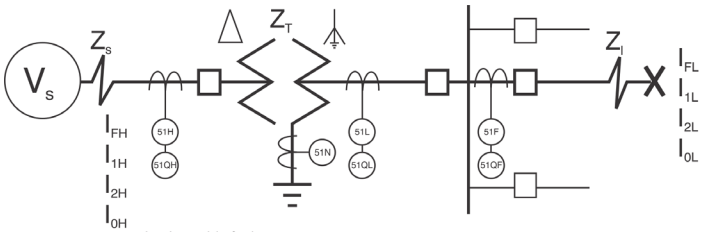
L-G faults generate all three components: $I_1=I_2=I_0=I_F/3$ (in a radial circuit, see Figure 1).

L-L Faults

L-L faults generate only positive and negative sequence components: $I_1=I_2=I_F/3=0.57 \bullet I_F$.

Consequence

There is adequate negative sequence current ("handle") to detect L-L faults. Since balanced loads contain only positive sequence currents, we expect that very sensitive settings can be achieved. The challenge, as usual, is to keep the settings above all tolerable unbalance conditions and maintain coordination with other devices.



I_{FL}=Low side fault current
I_{FH}=High side fault current for low side fault
51N=Neutral overcurrent element
51H=Overcurrent element of relays on the high side
51QH=Negative sequence overcurrent element of relays on the high side
51L=Overcurrent element of relays on the low side
51QL=Negative sequence overcurrent element of relays on the low side
51F=Overcurrent element of relays on the feeder side
51QF=Negative sequence overcurrent element of relays on the feeder side

Figure 1 - Typical Configuration

Figure 1 represents a typical distribution substation with a delta-wye transformer feeding a bus with multiple feeders.

Feeder Protection

We first consider the relays on a feeder in the typical configuration shown in Figure 1. Fault calculations show that the phase-to-phase current on a long distribution line can be below the maximum load and, therefore, below the setting of the phase relays, especially for arcing faults. Such faults can be detected, however, with a 51Q (51 mode set to I2 - Negative Sequence) element in the BE1-FLEX Protection, Automation and Control System. The Minimum Pickup (MPU) of this element is set below the minimum I_2L current for the most remote fault with arc resistance (obtained from a fault calculation program). In order to avoid undesirable tripping, the setting must be *above* the worst case continuous load unbalance (open fuse in a single phase lateral) and the time delay must be set to coordinate with downstream fuses and reclosers. It is useful to remember that, for a magnitude only unbalance, the negative and zero sequence currents in a radial circuit are nearly equal. The BE1-FLEX calculates I_2 (negative sequence) and $3I_0$ (zero sequence) from the fundamental components of each of the three phase current inputs. If coordination with a ground relay is to be checked, remember to shift the negative sequence current scale (to the right) by a factor of 3.

Low Side Backup

The relay located on the transformer low side in the typical configuration (51QL) can also be set to detect remote L-L faults. Because this relay detects the unbalance from all the feeders, the I_2 MPU is necessarily higher than for the individual feeders.

A most useful application of the negative sequence overcurrent element in the relay at this location is to detect open fuses on the transformer high side, when fuses are used for transformer protection. The user should check that the MPU is low enough to detect

an open fuse under light loading. A compromise is necessary to be able to tolerate continuous unbalance and to detect open fuses at light loads.

The negative sequence overcurrent is particularly effective in industrial systems where motor loads can hide the open fuse from 47N relays.

High Side Backup

A negative sequence overcurrent relay located on the high side (delta) of the delta-wye transformer (51QH) will detect L-L and L-G faults on the low side feeders, because the transformer blocks only the zero sequence component. This relay can serve as an additional backup for phase and ground faults on the low side. For coordination studies note that the per unit magnitudes of I_1 and I_2 are identical on both sides of the transformer for all faults.

L-G Faults on the Low Side

For L-G faults on the low side, the per unit phase current on the high side is reduced by a factor of 1.73 ($I_{FH}=(I_F/3)\bullet I_{FL}=0.577\bullet I_{FL}$) because the zero sequence components are trapped in the delta and not seen by the delta-side phase relay (51H).

The negative sequence component on the high side (delta), I_{2H}, is equal to one third (1/3) of the per unit L-G fault on the low side (I_{FL}) because $I_1=I_2=I_0=I_{FL}/3$ for the L-G fault and the per unit values are the same on both sides of the transformer.

The per unit MPU of the 51QH on the high side must, therefore, be lower than 1/3 of the minimum low side ground fault if the relay is to provide backup for low side ground faults. The time dial and curve must coordinate with the low side relays.

L-L Faults on the Low Side

For L-L faults on the low side, the per unit current of one of the phases on the high side is 1.15 times larger than the low side fault current. The per unit I_2 component on both sides of the transformer is 0.577 of the fault current.

Summary

The following table provides a summary of negative sequence to fault current ratios. These ratios are required to scale the I_2 current axis for time coordination studies. The MPU setting suggestion is slightly less than 1.732 and is based on the assumption that it is desired to obtain full coverage of L-L faults in a protected zone (defined by the minimum fault current). This minimum current may be too low to allow the maximum expected unbalance in some applications. The user must make certain that the setting is secured.

Example

For an illustration of the coordination of a negative sequence time overcurrent, visit the Technical Resources tab on the BE1-FLEX page of the Basler web site.

Per Unit Current Ratios and Settings Suggestions for BE1-FLEX					
Fault	Low Side	High Side			Suggested 51Q Settings for L-L Faults (worst case)
	I_{LF}/I_{2L}	I_{FHmax}/I_{FL}	I_{FHmax}/I_{2H}	I_{FL}/I_{2H}	
L-G	3	0.577	1.732	3	High and Low Side: MPU=$I_{FLmin}/2$ Check that MPU<max continuous unbalance. Use the multipliers in this table to shift the 51Q current to the right for time coordination with 51P studies.
L-L	1.732	1.15	2	1.732	

Basler Electric®
Highland, Illinois USA
Tel +1 618.654.2341
Fax +1 618.654.2351
email: info@basler.com

Suzhou, P.R. China
Tel +86 512.8227.2888
Fax +86 512.8227.2887
email: chinainfo@basler.com