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End Fault Protection

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SIPROTEC 5 Application

End Fault Protection

APN-063, Edition 1

Content

1 End Fault Protection

1.1 Introduction

The function end fault protection can be applied with SIPROTEC 5 using standard features included in the scope of functions. This document describes the method in which this can be done. The main part of the application note will not cover the philosophy or method in which the End Fault Protection (EFP) is integrated into the overall protection of a bay, this is provided in the appendix with a more detailed description of End Fault Protection (EFP), covering different configurations and overall fault clearance.

The End Fault Protection (EFP) provides an operate signal when the current flow in the measuring point (CT) is detected while the circuit breaker (CB) is detected in the open position by monitoring of the auxiliary contact status. Referring to Figure 1 below, this would indicate a fault condition in the designated END Fault Zone.

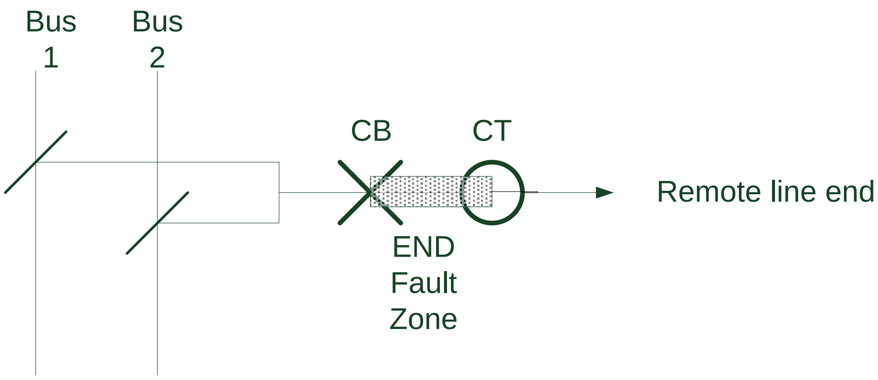

Figure 1: END Fault Zone with Double Bus and CT on the Line Side

The End Fault Protection function in this application note is implemented using two alternative methods:

1.1.1 Method 1

This method follows closely the end fault protection function that was included in SIPROTEC 4 breaker fail functions (e.g. in the 7VK6). For this EFP the fault condition must initially be detected and cause trip by a primary protection function. In Figure 1 above this would typically be the bus zone protection tripping for the fault in the END Fault Zone. This trip will then cause breaker fail operation because the current flow will not be interrupted by the trip to the CB. The breaker fail operation in conjunction with the open condition of the CB (detected via auxiliary contacts) is the prerequisite for operation by this Method1 EFP:

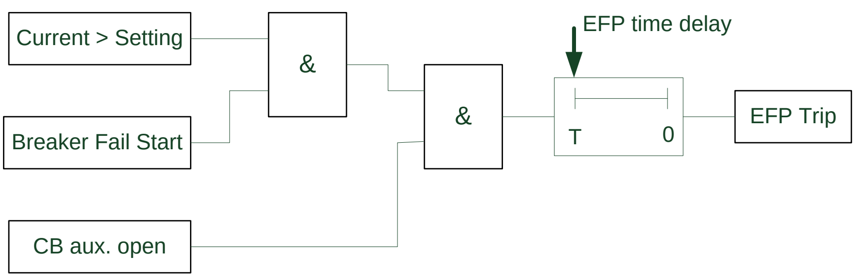

Figure 2: Basic Logic for Method 1 End Fault Protection (EFP)

As the breaker fail pick-up is typically current dependent, the logic in Figure 2 can be further simplified by applying the breaker fail pick-up directly to the 2nd AND gate with the CB open status.

1.1.2 Method 2

A more independent End Fault Protection (EFP), which is not dependent on a "primary" protection function that issues a trip to the open CB and thereby causes breaker fail operation and ultimately EFP, can be implemented. This "Method 2" EFP has a dedicated over-current function that, together with the CB open status, provides the EFP trip. The basic logic for the Method 2 EFP is shown below:

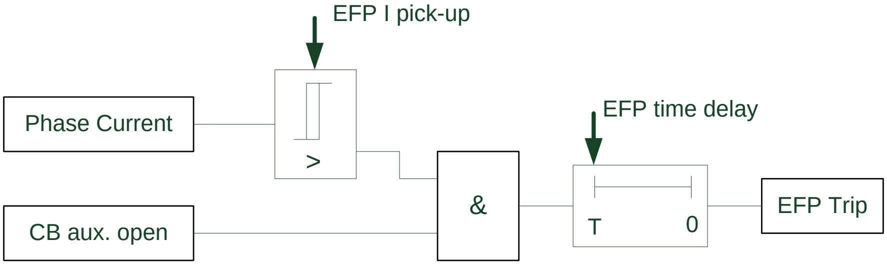

Figure 3: Basic Logic for Method 2 End Fault Protection (EFP)

A comparison of the two methods shows that Method 1 is dependent on breaker fail pick-up while Method 2 has a dedicated current release.

1.2 Implementation Method 1 End Fault Protection

The implementation is done here with a line protection (7SL87), it can however be done in a similar manner in any SIPROTEC 5 relay with configured breaker fail function.

For Method 1 EFP the breaker fail pick-up status is used. In the extract from the SIPROTEC5 manual shown below, in Figure 4, the breaker fail pick-up (_:55) will only reset when the external start and the current criteria reset; this is therefore a suitable input for Method 1.

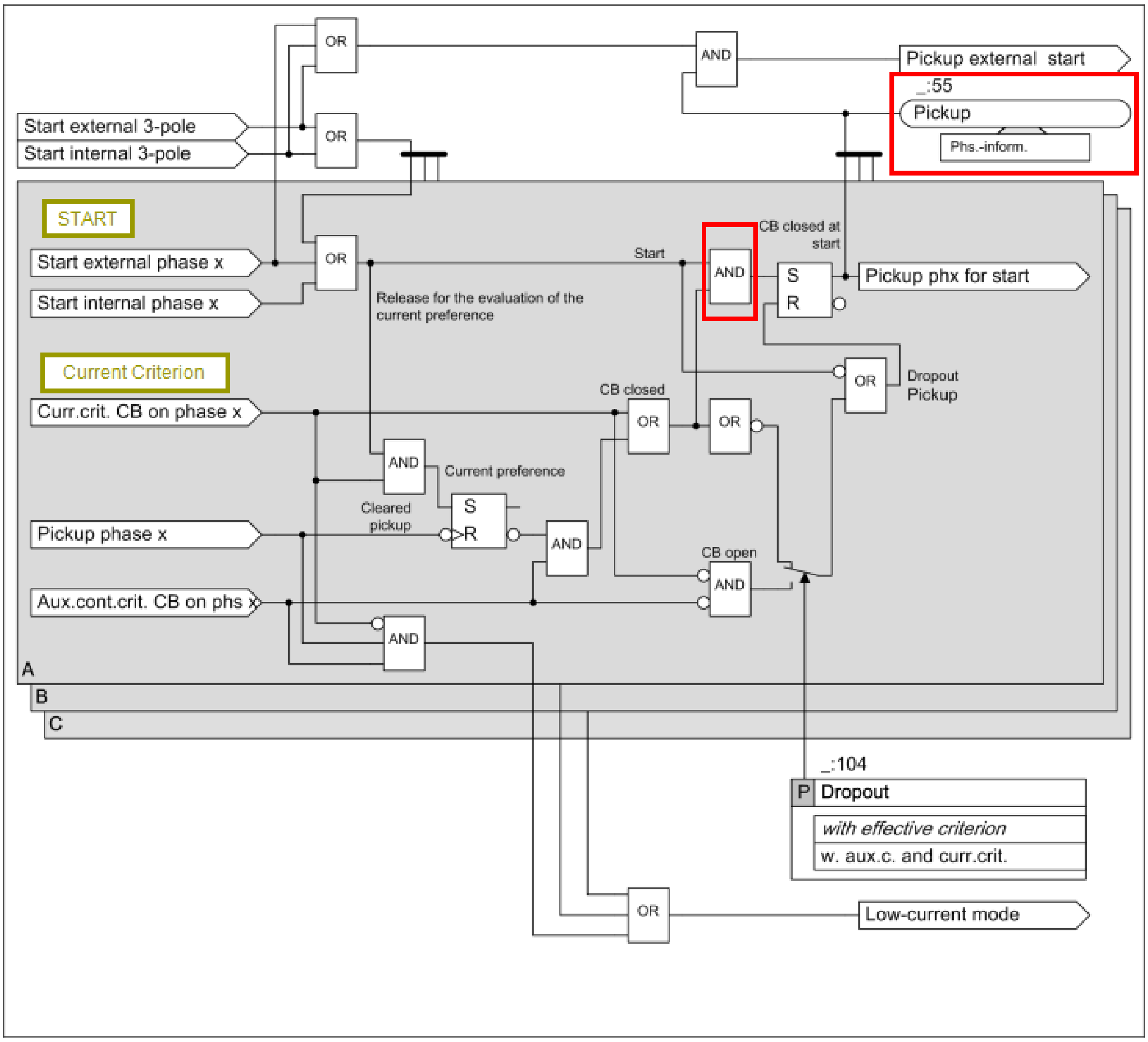

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Figure 6-422 Pickup/Dropout of the Circuit-Breaker Failure Protection Function

Figure 4: Breaker fail logic extract from SIPROTEC5 manual

The auxiliary contact criterion from the CB in the above logic diagram cannot reset the breaker fail pickup (activate "R" input of flip-flop), with an open state, if there is current flow detected. Implementing the Method 1 EFP of Figure 2 with the Breaker Fail Pick-up from Figure 4 can be done as shown with the CFC Logic below in Figure 5:

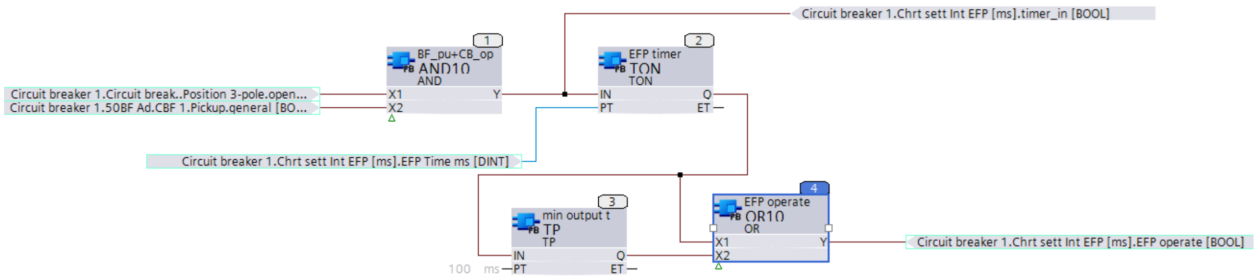

Figure 5: CFC logic to implement Method 1 EFP

The EFP timer is set by means of a chart setting tool that is applied as follows:

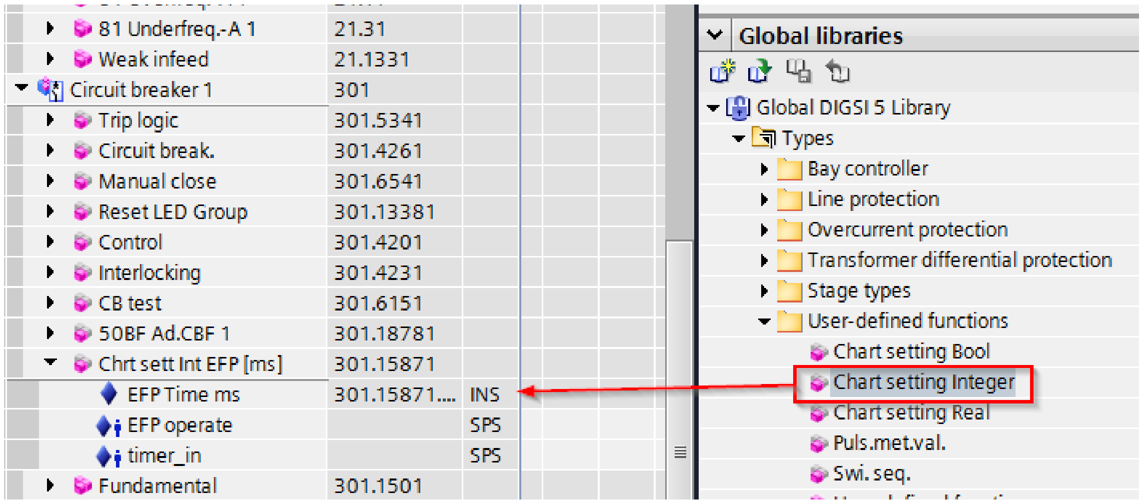

Figure 6: Application of EFP timer and operate to routing matrix

In the Information routing the chart setting integer as well as the EFP operate signal can be applied by dragging the appropriate information from the Library.

1.3 Implementation Method 2 End Fault Protection

For the Method 2 a current protection stage is required. In many cases this could be done within the Function Group used for the principle protection in the device. In order to make the application note generally applicable the function is implemented in a dedicated FG:

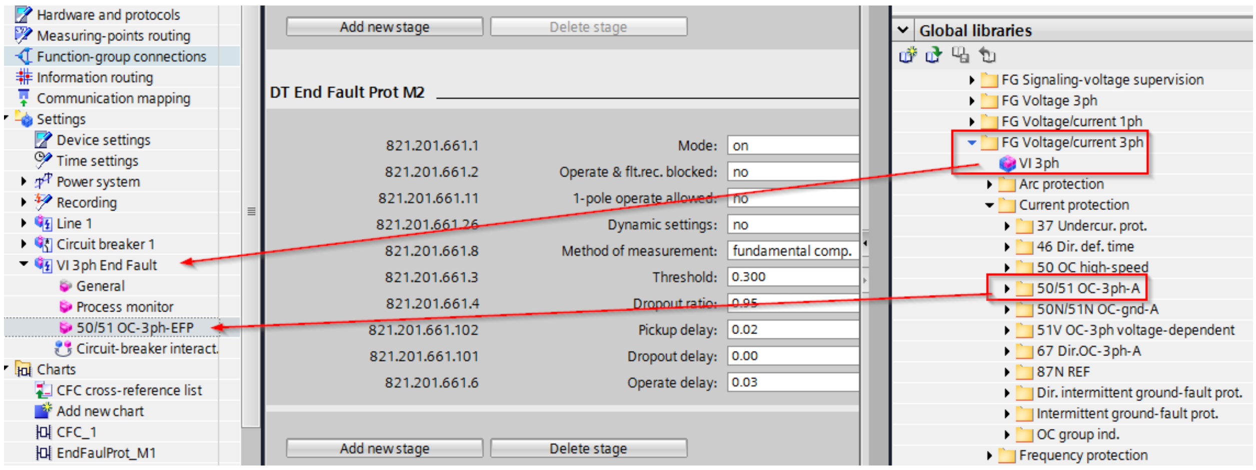

Figure 7: Apply FG VI 3ph and O/C stage for EFP

From the library the FG VI 3ph is inserted and then renamed. Subsequently the over-current stage (50/51 OC-3ph-A) is applied and renamed. The renaming is very helpful to identify the function in the settings and also in event and fault logs.

The following connection to the circuit breaker switching state is done via CFC to ensure the EFP stage only operates when the breaker is open:

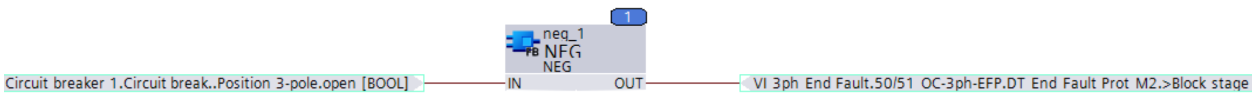

Figure 8: CFC logic for Method 2 EFP

The EFP O/C stage is blocked when the circuit breaker is **not** open. In this manner there is not continuous pick-up signaled by the stage (it can effectively be used to trigger fault recording), and the pick-up delay can effectively be used to prevent spurious pick-up when the CB-aux is faster than the interruption of the current flow. The sum of the two timer settings effectively make up the total EFP time delay:

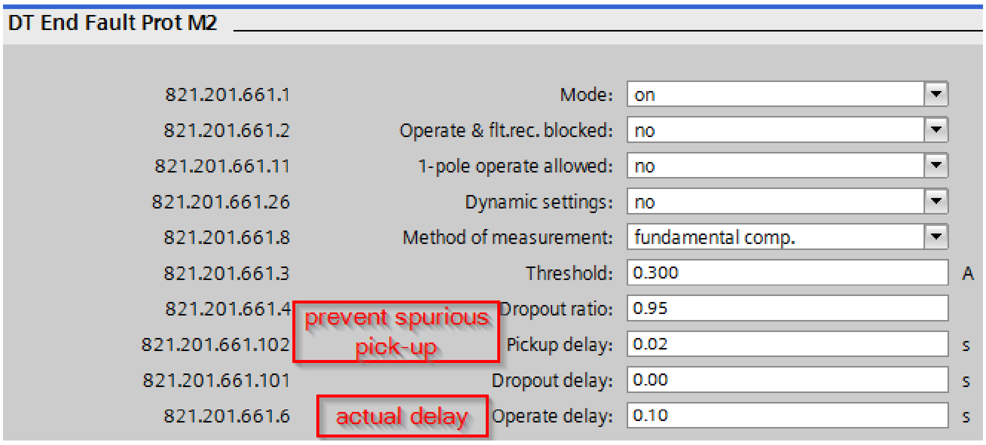

Figure 9: Example setting of EFP O/C stage

1.4 Circuit Breaker Status

The switching state of the circuit breaker must be known for the EFP application. This is done by monitoring the state of CB auxiliary contacts via binary inputs (refer to Information routing in diagram below).

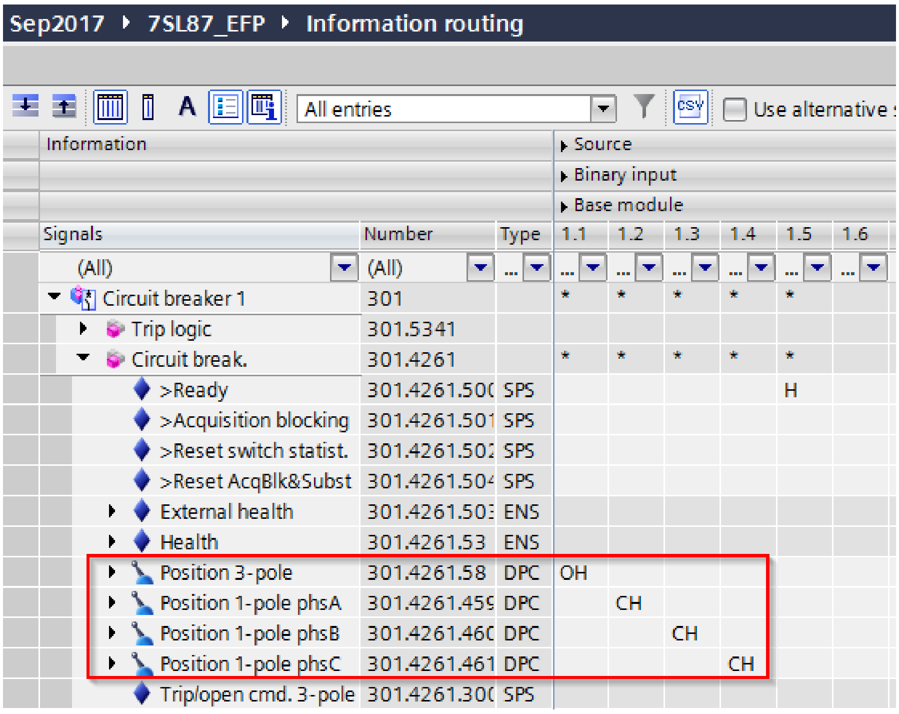

Figure 10: CB Switching state routing in matrix (example CB with 1/3 pole tripping)

For the EFP the 3-pole open state is relevant, so that it would have been sufficient to route only the open high (OH) state in Figure 10 above. The device will determine the switching state of the CB based on the available (routed) information and establish the condition (3pole closed, 3 pole open, 1 pole open, NOT 3 pole closed, NOT 3 pole open, intermediate, disturbed). Optimal information is obtained by using the selection in the template as shown for 1/3 pole tripping CB in Figure 10 above.

1.5 Setting Example End Fault Protection

Under ideal conditions, the EFP is a selective function that does not require time grading with other functions. The setting of the current threshold for Method 2 (in Method 1 the current threshold is defined by the setting in the breaker fail function) will therefore be based on the following consideration:

1. High security: Set the threshold above maximum load (operating current) so that an incorrect circuit breaker open detection (e.g. due to failed auxiliary contact) will not cause a non-desired operation of EFP. In this case it may be useful to apply a 2nd current stage that will pick-up with more sensitive threshold and alarm this condition.
2. High dependability: Set the current threshold below the minimum expected fault current flow during end fault condition.

The time delay setting of the EFP is primarily for preventing non-desired operation due to breaker current interruption (arc quenching) coming after auxiliary contact status showing that breaker is open. The reset time of the current measurement must also be considered. The diagram below in Figure 10 shows the parameters that must be considered.

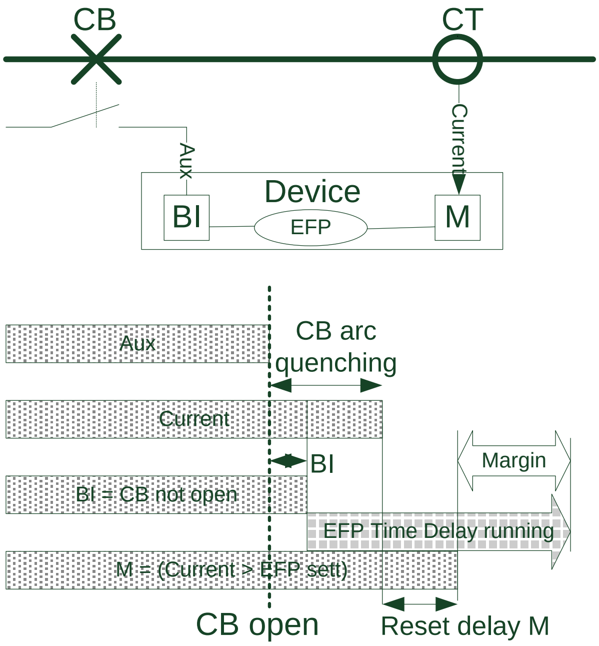

Figure 11: Timing diagram for setting EFP time delay; normal fault clearance

Assume the following for this example:

1. CB Arc quenching time = 2 cycles (40 ms)
2. Max reset delay of measurement (M) = 30 ms
3. Margin (for security) = 50 ms

If the response time of the Binary input (typically 2 ms) is ignored, the setting for the EFP timer is the sum of the 3 times = 120 ms.

1.6 Test

The following test cases will demonstrate:

Test 1: a normal fault clearance with stable End Fault Protection

Test 2: an end fault occurring when the breaker is initially closed

Test 3: an end fault occurring while the breaker is open.

1.6.1 Test 1: Normal Fault clearance (not end fault)

The test device contains both the Method 1 and 2 End Fault Protection:

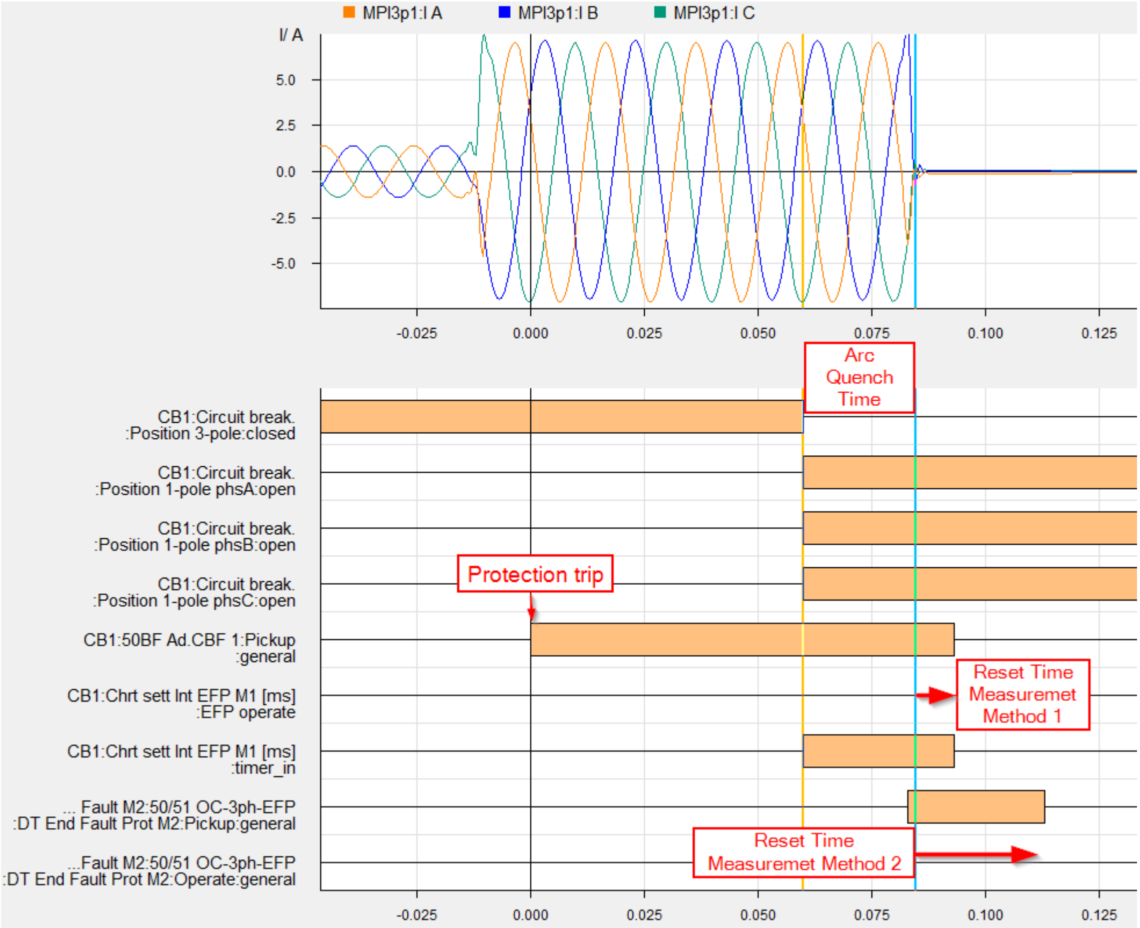

Figure 12: Recording of normal fault clearance (not End Fault)

In Figure 12 the various stages of fault clearance by breaker opening can be seen. Initially the auxiliary contacts show the CB open state. The current still flows due to the arc quenching time in the circuit breaker. The measurement (time delay) of the EFP starts when the CB auxiliary contact show the CB state to be open (timer_in = high). The Method 2 measurement picks up later because of the set Pickup delay (Figure 9). In Figure 12 the reset of the current criteria for the Method 1 and 2 is different. The CBF Pickup that is used for Method 1 (timer_in) resets very fast as this is a significant feature of breaker fail protection. The DT End Fault Prot M2 Pickup is based on a normal over-current protection which is much slower in resetting. This is covered by the set time delay of 120 ms and both Methods do not operate.

1.6.2 Test 2: Fault in End Fault Zone with CB initially closed

In this test sequence the circuit breaker is tripped by the principle protection function. The fault current drops when the circuit breaker opens (could also have increased) but does not go to zero because the fault in the end fault zone keeps current flow on.

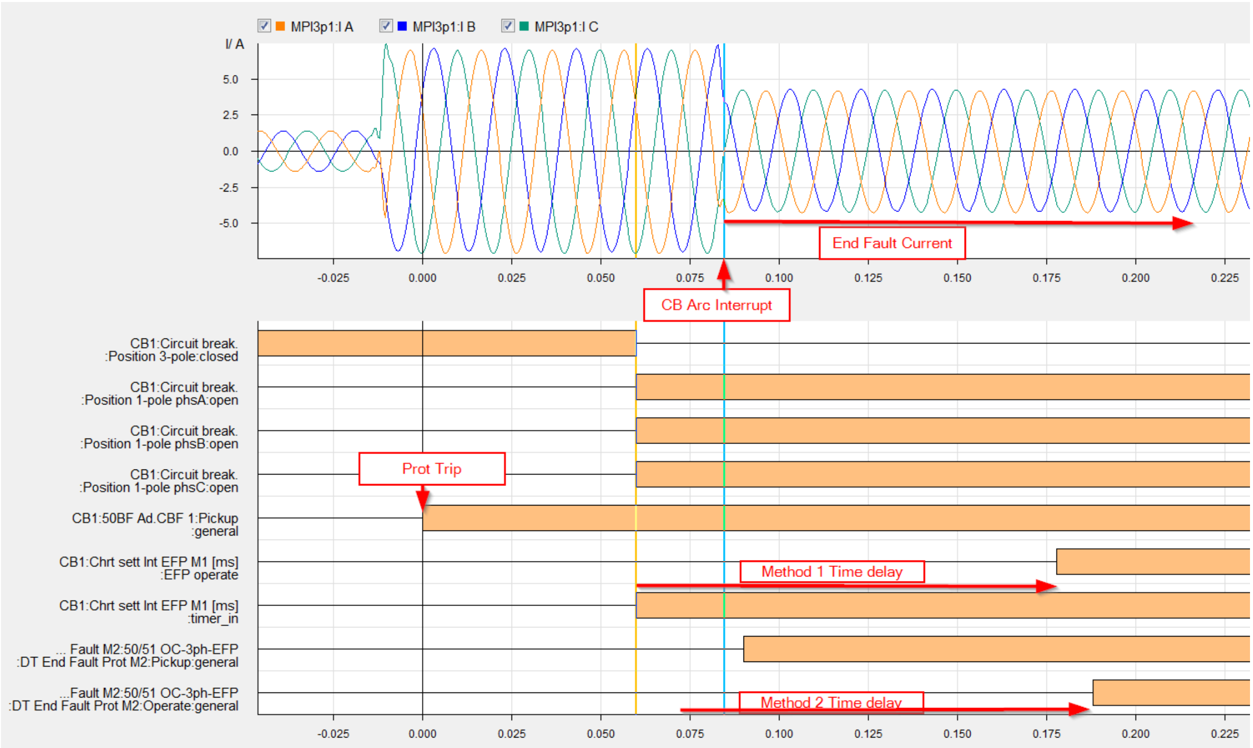

Figure 13: Recording of End Fault with CB initially closed

Both EFP Methods respond with an operate after the set time delay of 120 ms. Note that Method 1 responds faster because the current criteria in this case (breaker fail pick-up) is already present when the CB opens. For Method 2 the dedicated over-current stage is blocked until the CB opens, the initial measuring time (approximately 10 to 20 ms) delays the ultimate operate of Method 2 (in this case it was 10 ms slower).

The EFP of both methods respond with an operate signal as expected.

1.6.3 Test 3: Fault in End Fault Zone with CB initially open

This is a special End Fault protection case as the CB is initially already open when fault current starts to flow:

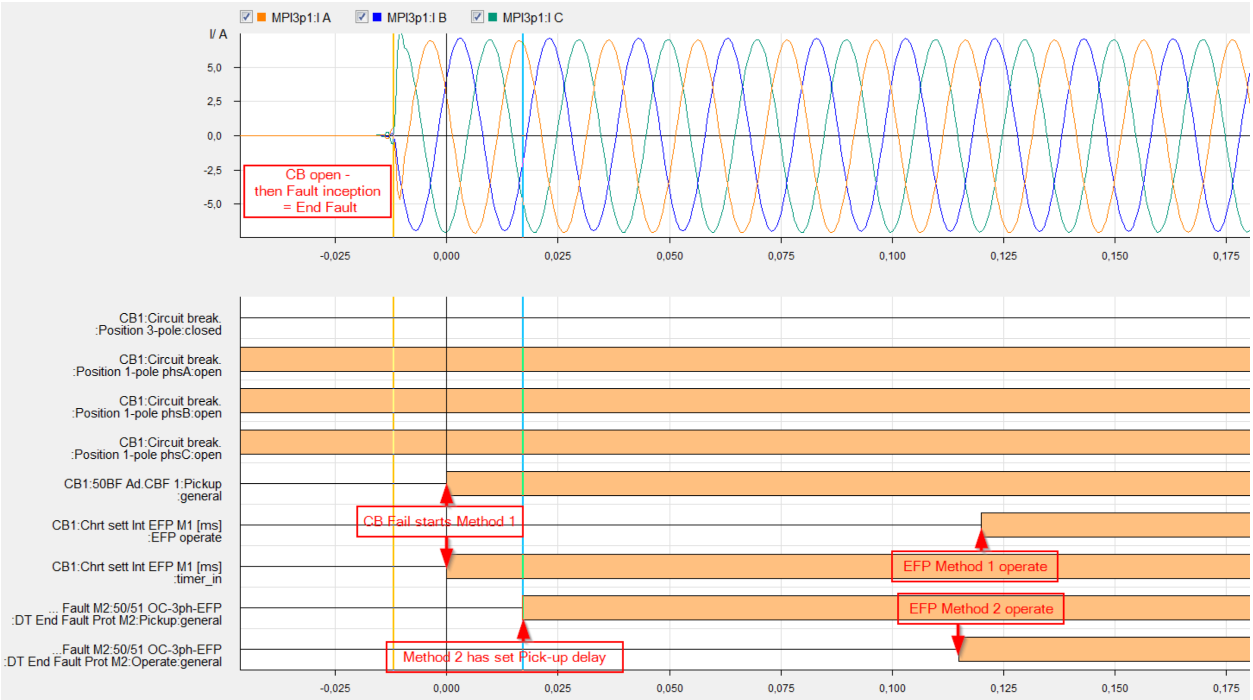

Figure 14: Recording of End Fault with CB initially open

The response of the EFP with Method 1 and Method 2 is as expected after the set time delay. Note that for Method 1 a breaker fail pick-up and therefore a trip signal to the open circuit breaker is required! Method 2 does not require any other protection response. This may have to be considered when choosing the EFP operating method.

1.7 Conclusion

The application shows with practical test cases how the End Fault Protection (EFP) function can be implemented in SIPROTEC 5 protection relays. Two optional methods, a Method 1 alternative that is very similar to the EFP in SIPROTEC 4 (e.g. 7VK6 relays) where it was a supplement within the breaker fail protection, and a Method 2 approach, that is not dependent on any other protection function, are described.

In both Methods the Circuit Breaker that defines the EFP-zone in combination with the CT must be connected to the relay in such a manner that the switching status, in particular the open state, is known. Typically, this is done via auxiliary contacts and a Function Group Circuit Breaker.

In the Appendix further helpful information surrounding the EFP in different configurations is provided.

1.8 Appendix: End Fault Protection

1.8.1 Introduction

A fault in the "END Fault Zone" with the CT on the line side would cause pick-up of the Bus Zone protection; if busbar protection is applied. Tripping by the Bus Zone will however not clear the fault; as a trip of the remote end circuit breaker is also required. After the CB is open, due to the bus zone trip, the breaker fail protection (if this is applied) will operate because the current flow in the CT continues. The breaker fail trip can therefore be used to send an inter-trip to the remote end for final clearance of this fault condition.

In the above consideration no special "End Fault Protection" (EFP) is applied and the fault condition is cleared acceptably. If, however the CB is open – abnormal operating condition – when the fault in the End Fault Zone appears, the above protection operation is questionable:

a. If the Bus Zone Protection does not apply special consideration for this case a Bus Zone Trip will be issued even though this is not necessary.
b. If the Bus Zone Protection does not trip, the fault clearance must be initiated by back-up (reverse) protection in the feeder – slow! Following this the breaker fail protection will respond (trip the bus bar!) and then send the inter trip to remote end.

The EFP can be used to improve this!

Bus Zone protection should have the ability to prevent tripping of the bus for an end zone fault when the CB is already open. In such cases the bus zone protection may already provide the inter-trip signal for final clearance of the fault at remote line end. It may however be desirable to implement the EFP in the feeder protection to achieve fast clearance of faults in the END Fault Zone with an inter trip independent of the bus bar protection. This application note describes alternative methods of EFP in the feeder protection.

1.8.2 Different configurations

Figure 1 in the application note shows a very common, for open air double bus, configuration with the CT on the line side of the circuit breaker. There are however some other configurations that strongly affect the EFP:

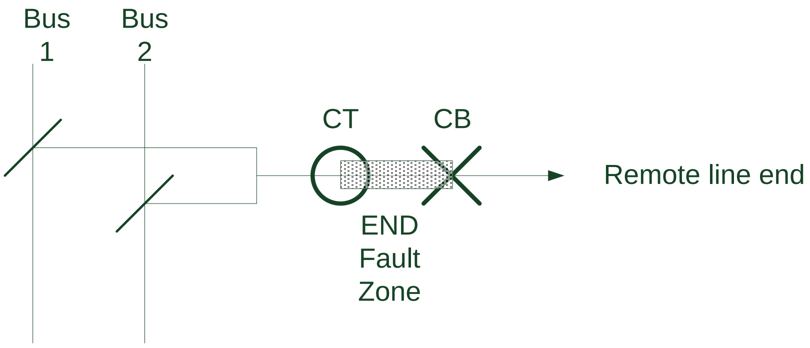

Figure A 1: Double Bus with Bus Side CT

Although the configuration in Figure A1 appears to be very similar to Figure 1 in the application note, the only difference being the position of the CT which is on the bus side in Figure A1, the response to a fault in the END Fault Zone is significantly different. For the condition in Figure A1, the feeder protection will operate as it appears to be the same as a close in fault on the feeder. Opening of the CB will not clear the fault, and this will cause breaker fail protection to operate and initiate clearance of the fault via the bus tripping. A dedicated inter-trip signal to the remote end is not required. In some cases, a signal will be sent to prevent auto re-close at the remote end.

With the CB open operating condition, the response is the same as with closed CB. The need for a dedicated EFP is not so critical here. It must be noted; that some bus zone protection schemes will detect the CB open condition and "extend" the bus zone coverage into the "END Fault Zone" by setting the measured CT current to zero in the bus zone measurement (must be done for main- and check-zone).

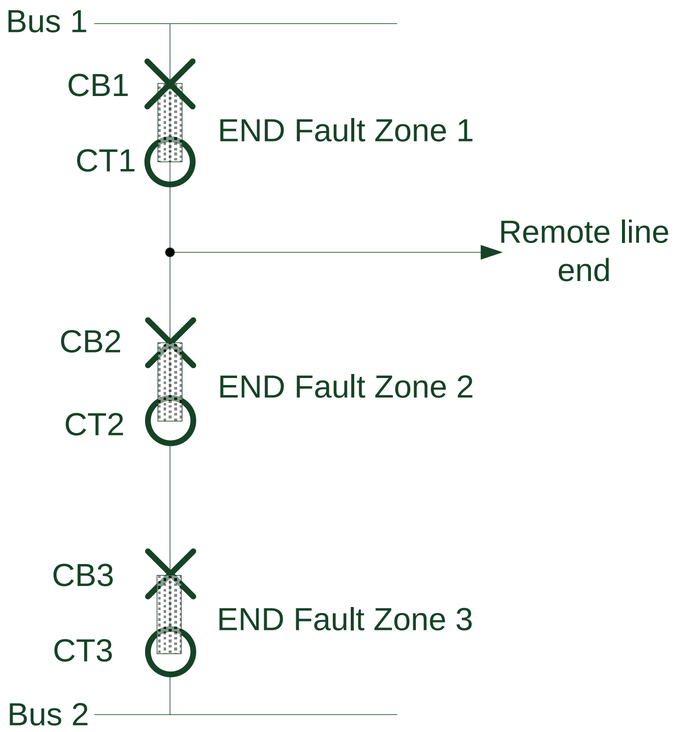

Figure A 2: Breaker-and-a-half Configuration

For the breaker-and-a-half configuration shown in Figure A2, the necessity of special measures for faults in the END Fault Zones is apparent. For the "normal" operating condition with all CB in the closed state corresponding protection functions will operate and then the breaker fail will finally clear the fault:

1.8.2.1 For example, END Fault Zone 1 (CB1 initially closed):

a. The Bus 1 bus zone protection will operate for a fault in END Fault Zone 1.
b. When CB1 is opened by the bus zone trip, the fault current in CT1 will continue to flow resulting in breaker fail operation for CB1.
c. The CB1 breaker fail will trip CB2 and send an inter-trip to remote end for final fault clearance.

1.8.2.2 With END Fault Zone 2 the response is different (CB2 initially closed):

a. The feeder protection will operate for a fault in END Fault Zone 2.
b. When CB2 is opened by the feeder protection trip, the fault current in CT2 will continue to flow resulting in breaker fail operation for CB2.
c. The CB2 breaker fail will trip CB1 and CB3 as well as send an inter-trip to remote end for final fault clearance.

The required response is however different when the CB is initially in the non-typical open operating condition:

1.8.2.3 For example, END Fault Zone 1 (CB1 initially open):

a. The Bus 1 bus zone protection will operate, <u>unnecessarily</u>, for a fault in END Fault Zone 1.
b. The already open CB1 will not interrupt the fault current resulting in breaker fail operation on CB1.
c. The CB1 breaker fail will trip CB2 and send an inter-trip to remote end for final fault clearance.

Overall the result is the same was the case with CB1 initially closed, the serious difference is that the bus protection will operate unnecessarily in this case.

1.8.2.4 With END Fault Zone 2 the response is again different (CB2 initially open):

a. The feeder protection will operate, unnecessarily, for a fault in END Fault Zone 2.
b. When CB2 is opened by the feeder protection trip, the fault current in CT2 will continue to flow resulting in breaker fail operation for CB2.
c. The CB2 breaker fail will trip CB1 and CB3 as well as send an inter-trip to remote end for final fault clearance.

Again, the result is the same, the important difference being, that initially there is an unnecessary and non-selective protection operation.

The following table summarizes the scenarios:

Application	Figure	Response with CB initially Closed	Response with CB initially Open	Improvement with EFP
2 Bus, CT external	Fig 1	Bus Zone Trip Breaker Fail -> Inter Trip	Bus Zone Trip Breaker Fail -> Inter Trip	Faster inter trip when CB is open
2 Bus, CT internal	Fig 2	Feeder Protection Trip Breaker Fail -> Inter Trip	Feeder Protection Trip Breaker Fail -> Bus trip	Faster Bus Trip when CB is open
Breaker-and-a-half, CT line side	Fig 3, CB1	Bus Zone Trip Breaker Fail -> CB2 and Inter Trip	Bus Zone Trip Breaker Fail -> CB2 and Inter Trip	Faster inter trip when CB is open
Breaker-and-a-half, CT bus side	Fig 3, CB2	Feeder Protection Trip Breaker Fail -> CB1 and Inter Trip	Feeder Protection Trip Breaker Fail -> CB1 and Inter Trip	Faster CB1 and Inter trip when CB is open

Table 1: Summary of configurations

From the summary in >Table 1 it is apparent that the application of EFP only provides acceleration ultimate fault clearance when the associated CB is initially in the open operating condition.

End fault protection

An end fault is defined here as a short–circuit which has occurred at the end of a line or protected object, between the circuit breaker and the current transformer set.

Figure 2-148 shows the situation. The fault is located — as seen from the current transformer (= measurement location) — on the busbar side, it will thus not be regarded as a feeder fault by the feeder protection relay. It can only be detected by either a reverse stage of the feeder protection or by the busbar protection. However, a trip command given to the feeder circuit breaker does not clear the fault since the opposite end continues to feed the fault. Thus, the fault current does not stop flowing even though the feeder circuit breaker has properly responded to the trip command.

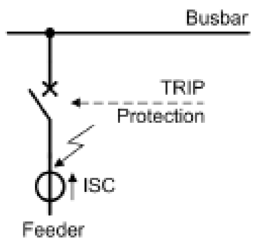

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Figure 2-148 End fault between circuit breaker and current transformers

The end fault protection has the task to recognize this situation and to transmit a trip signal to the remote end(s) of the protected object to clear the fault. For this purpose, the output command ***BF EndFlt TRIP*** is available to trigger a signal transmission device (e.g. power line carrier, radio wave, or optical fibre) — if applicable, together with other commands that need to be transferred or (when using digital signal transmission) as command via the protection data interface.

The end fault is recognized when the current continues flowing although the circuit breaker auxiliary contacts indicate that the circuit breaker is open. An additional criterion is the presence of any circuit breaker failure protection initiate signal. *Figure 2-149* illustrates the functional principle. If the circuit breaker failure protection is initiated and current flow is detected (current criteria "L*> current criterion" according to *Figure 2-137*),

but no circuit breaker pole is closed (auxiliary contact criterion "any pole closed"), then the timer **T-EndFault** is started. At the end of this time an intertrip signal is transmitted to the opposite end(s) of the protected object.

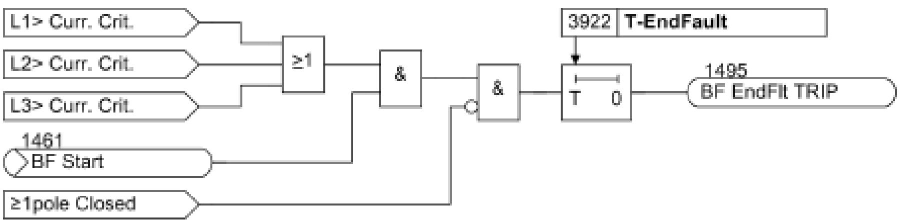

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Figure 2-149 Functional scheme of the end fault protection

1.9 SIPROTEC 5

Implement logic of Figure 2-149 in SIP5:

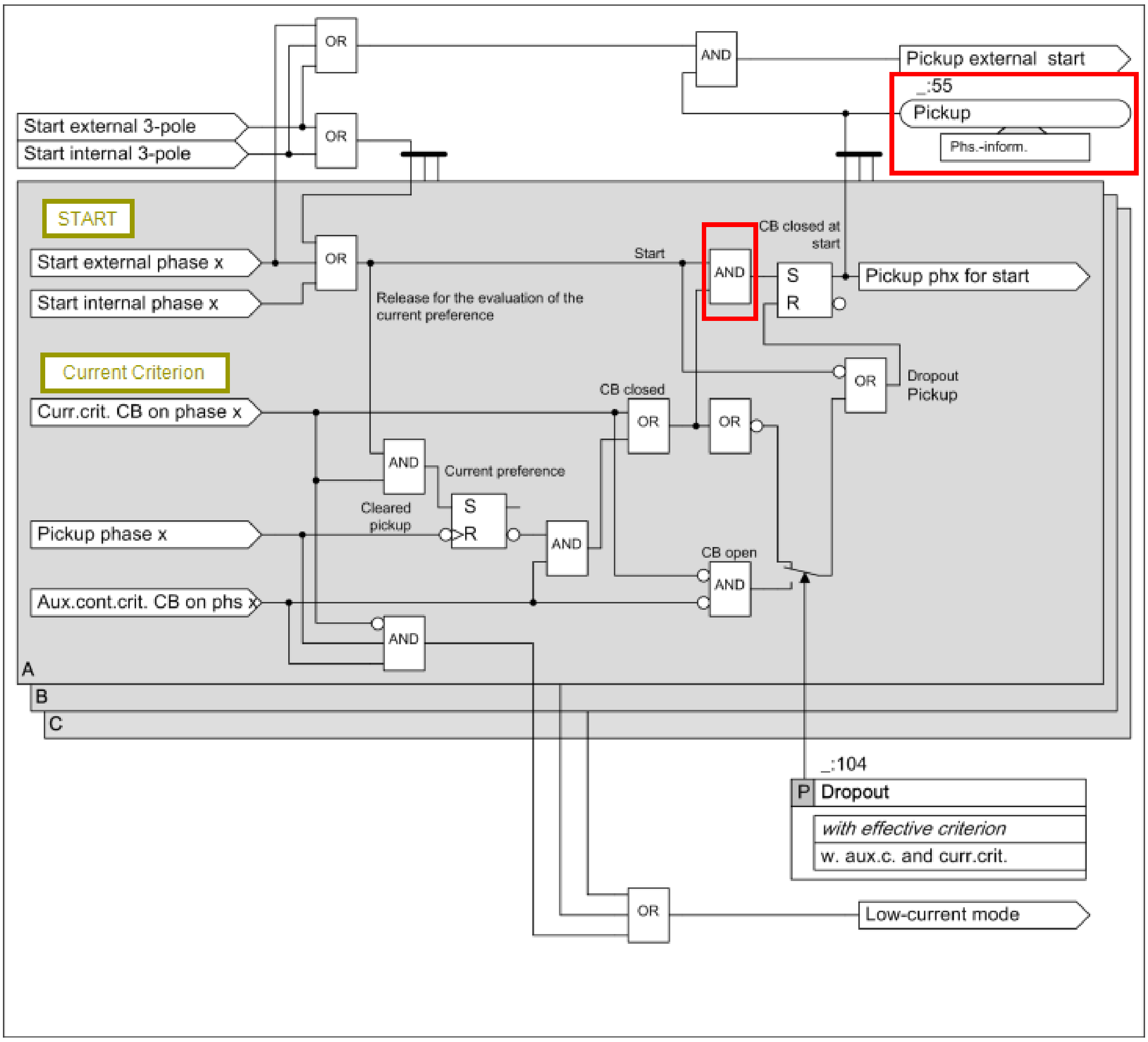

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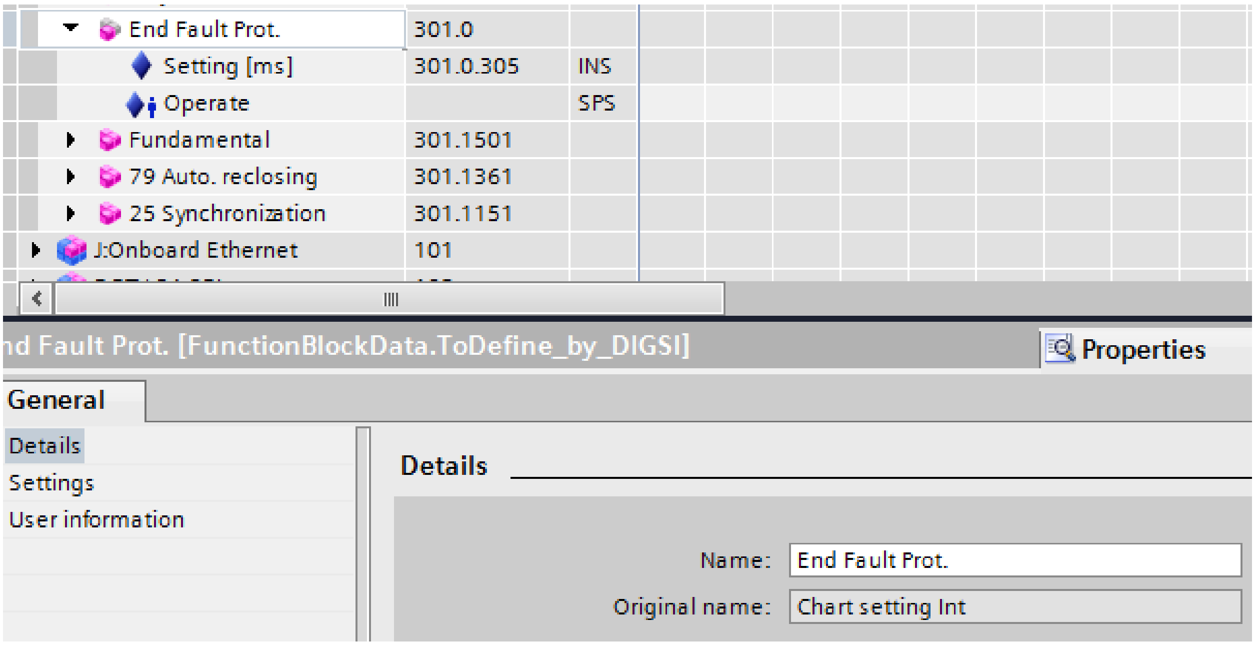
Figure 6-422 Pickup/Dropout of the Circuit-Breaker Failure Protection Function

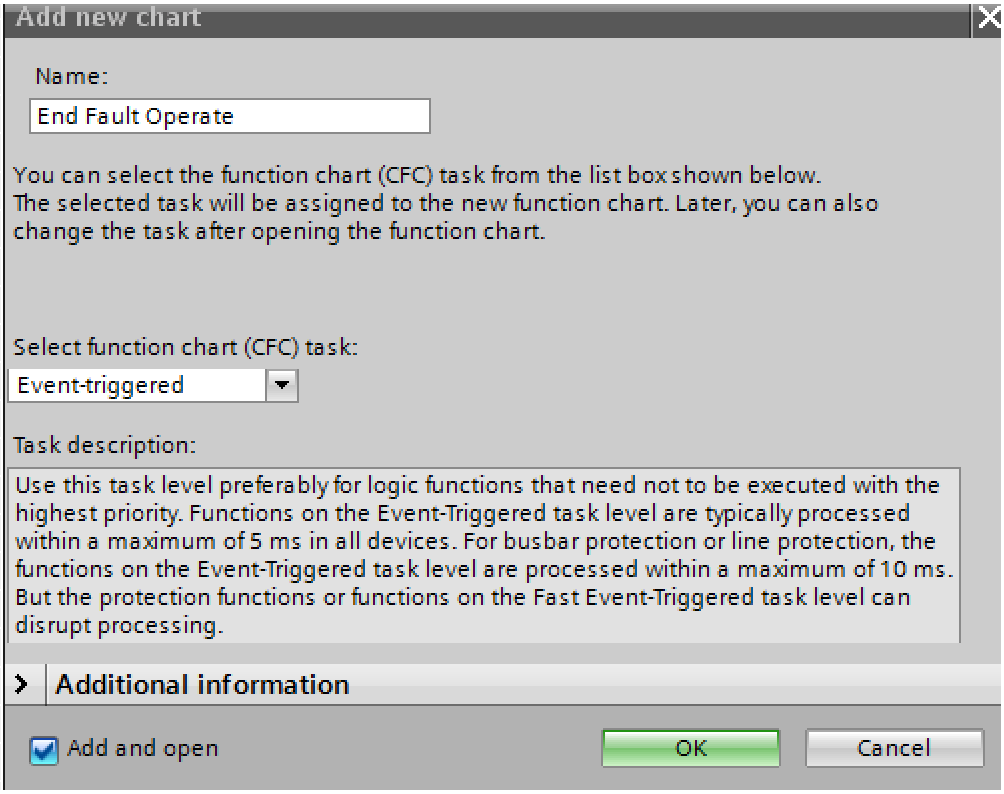
Use the Breaker Fail "..55 Pickup" as this is already the AND combination of Start and current criterion.

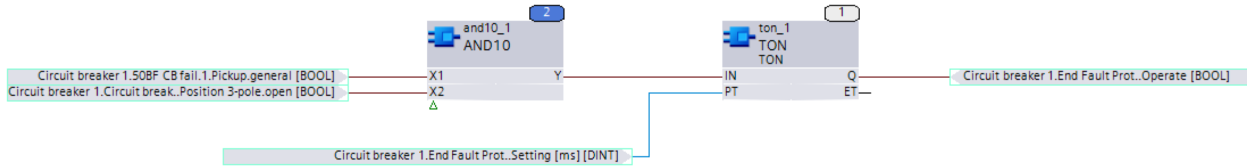
Add "Chart setting Int" and rename it, and then add "user defined single point" and rename this as well:



1.9.1 CFC Logic

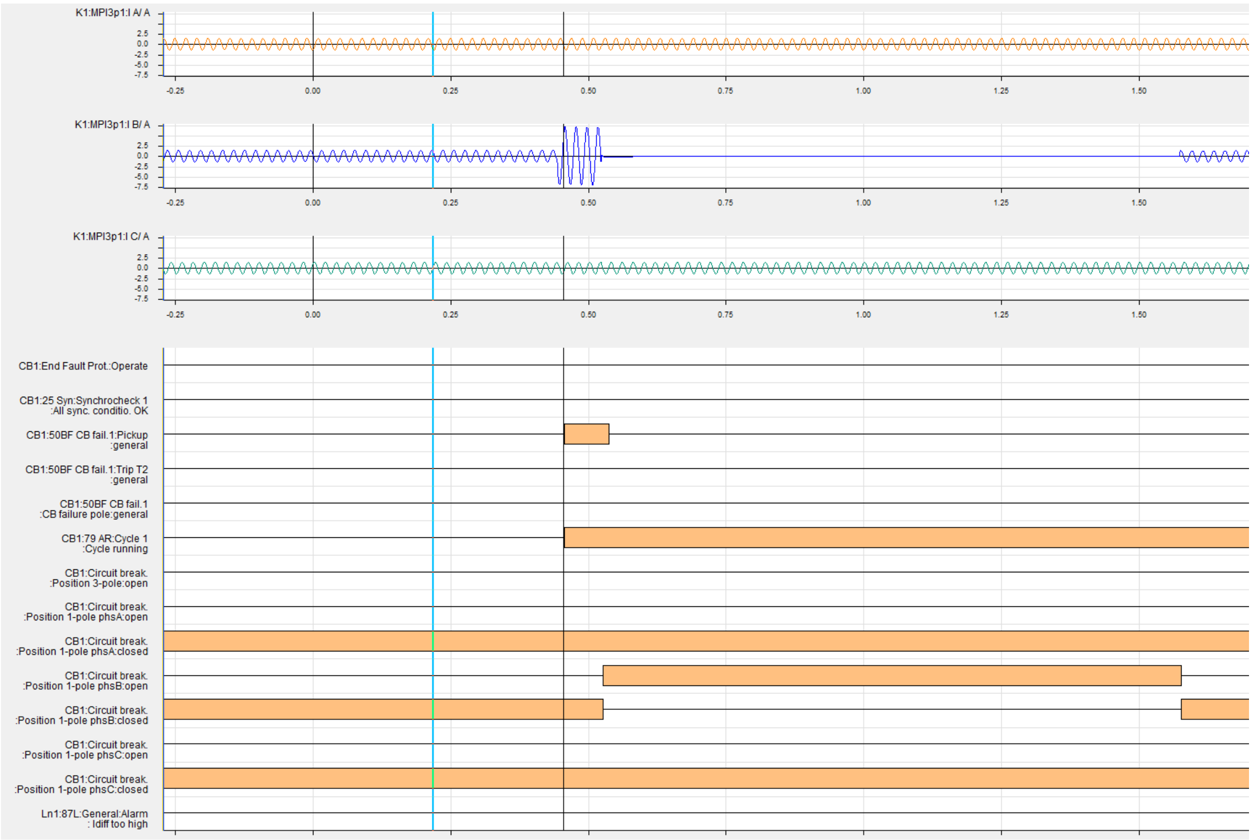
Create the end fault operate signal with the following logic in CFC:





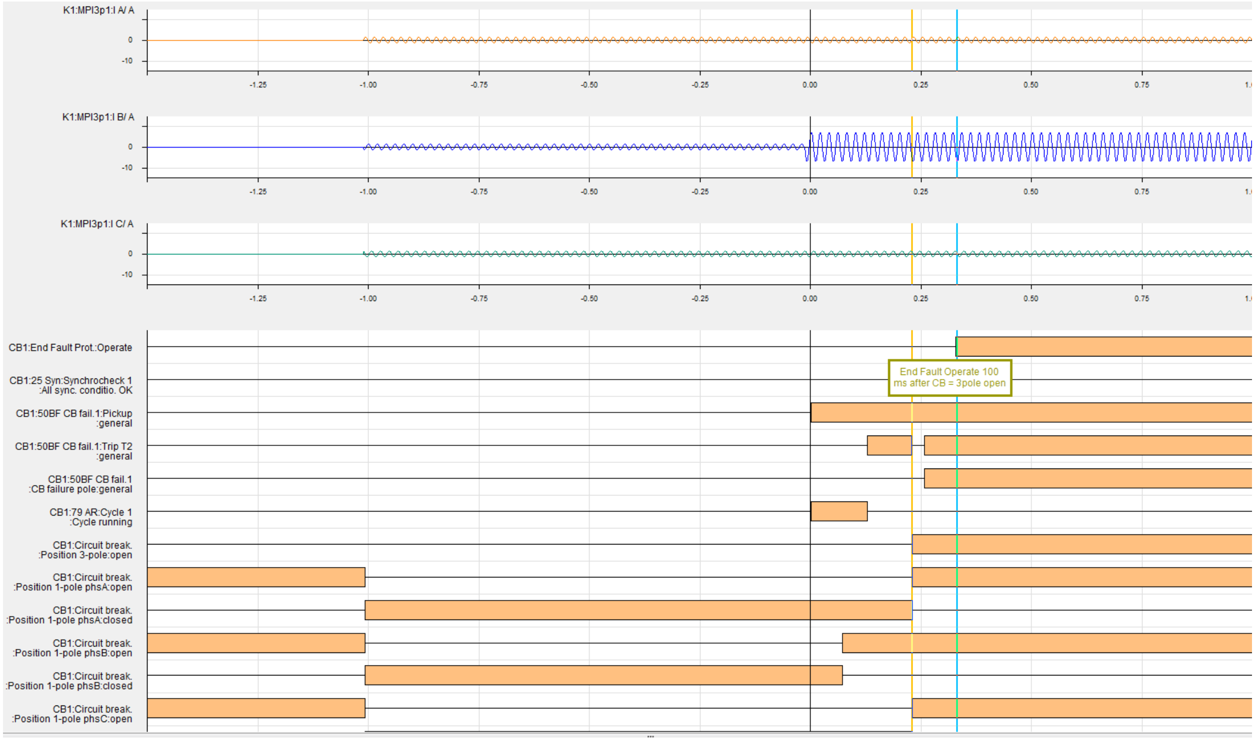
1.10 Tests

1.10.1 Normal 1-pole auto reclosure cycle (B phase)



No End Fault Operate.

1.10.2 Pole fault in End Zone



End Fault operate is 100 ms after CB open 3pole is detected via binary inputs.

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