Tutorial: Complex Busbar Protection Application

Laura Steenkamp
Eskom Transmission

Casper Labuschagne and Edmund Stokes-Waller
Schweitzer Engineering Laboratories, Inc.

Presented at the
34th Annual Western Protective Relay Conference
Spokane, Washington
October 16–18, 2007

Tutorial: Complex Busbar Protection Application

Laura Steenkamp, *Eskom Transmission*
Casper Labuschagne and Edmund Stokes-Waller, *Schweitzer Engineering Laboratories, Inc.*

Abstract—**Complex busbar layouts provide more system security than simpler busbar layouts, but also require more complex busbar protection, particularly at stations that select zones according to the status of the disconnect auxiliary contacts. For numerical busbar protection relays, complexity is no longer the issue; instead, the number of zones and the number of bays are the limiting factors. This paper discusses application aspects of disconnect auxiliary contact selection and connections and shows existing applications that overcame, within limits, the limitations of too few zones and/or too few current channels.**

I. INTRODUCTION

Kirchhoff's current law, the operating principle of percentage differential busbar protection, states that the sum of current flowing into a point is zero. Applying this law to busbar protection, the current flowing towards the busbars must again flow away from the busbars, so that the sum is zero. If the sum is not zero, the busbar protection relay declares a system fault and trips all circuit breakers connected to the faulted busbar.

II. ZONE SELECTION

In large substations, the busbars are usually divided into smaller pieces called bus zones. Bus zones provide a method to reduce the impact of busbar faults on the system. For example, if a station is divided into four zones, only twenty-five percent of the station is lost when a busbar fault occurs in any one of the four zones. Because current transformers (CTs) can be assigned to more than one zone in large substations, some selection process is necessary to assign the correct CT to the correct differential element. This selection process of assigning the input currents to a differential element is called zone selection.

III. DISCONNECT STATUS AND DYNAMIC ZONE SELECTION

To allow operational flexibility, some busbar protection relays dynamically reassign input currents to appropriate differential elements when the station configuration changes.

Disconnect (and in certain cases circuit breaker) auxiliary contacts provide station configuration information in the form of contact inputs, wired to the busbar protection relay. By evaluating the status of the auxiliary contacts, the relay dynamically assigns (dynamic zone selection) the currents to the appropriate differential elements.

IV. OPERATING CONDITIONS

Although dynamic zone selection provides operational flexibility, there are instances that may cause misoperations. Of particular concern are instances when more than one disconnect for any terminal are closed at the same time. When this happens, parallel paths form, possibly resulting in the unbalance of multiple zones, as shown in Fig. 1(a) and Fig. 1(b).

Fig. 1(a) shows a double busbar layout in which two disconnects can be closed simultaneously (8901 and 8902, for example). With the tie breaker (BC) connected in overlap, CT1 and CT3 form Differential Element 1 and CT2 and CT4 form Differential Element 2. There are no parallel paths in Fig. 1(a) and the differential current in both differential elements is practically zero. Fig. 1(b) shows the operating condition where both disconnects of Feeder 1 (8901 and 8902) are closed. Closing Disconnect 8902 when Disconnect 8901 is closed forms a parallel path between the two busbars and both differential elements are unbalanced. Fig. 1(b) shows the resulting differential currents during this unbalance (assuming an arbitrary 60/40 percent current distribution).

To prevent misoperation when parallel paths form, combine the parallel paths into a single zone and route the CTs to a single differential element. Referring to Fig. 1(b), after merging the two bus zones to form a single zone that includes CT1 and CT4 (but not CT2 and CT3), current in this single zone sums to zero and no misoperation occurs.

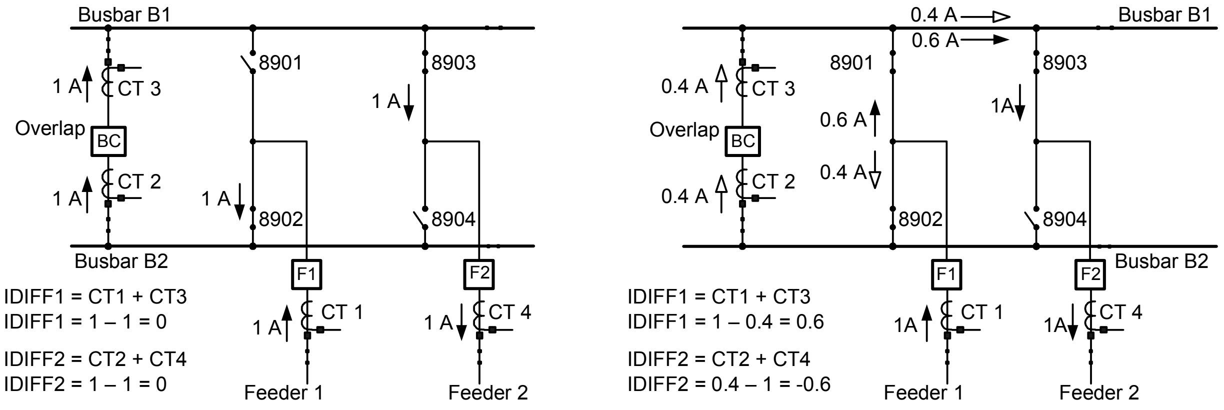


Fig. 1(a). Both Elements Balanced

(b) Both Elements Unbalanced

V. DISCONNECT AND CIRCUIT BREAKER AUXILIARY CONTACT REQUIREMENTS

A. *Disconnect Auxiliary Contact Requirements*

Successful merging of zones depends solely on proper timing coordination between disconnect main and auxiliary contacts. The following discussion applies to stations where both 89A (normally open) and 89B (normally closed) auxiliary contacts are present. Having both 89A and 89B auxiliary contacts available makes the monitoring of the disconnect travel time possible. To ensure correct differential element operation, the auxiliary contacts must comply with the requirements listed in Table I.

TABLE I
DISCONNECT AUXILIARY CONTACT REQUIREMENTS
TO ENSURE CORRECT DIFFERENTIAL ELEMENT OPERATION

Operation	Requirement
From disconnect open to disconnect close operation.	Assign currents to applicable differential elements before the disconnect main contact reaches the "arcing" point, the point where primary current starts to flow.
From disconnect close to disconnect open operation.	Remove the current from the applicable differential element only once the disconnect main contact has passed the "arcing" point, the point where primary current has stopped flowing.

Fig. 2 shows the disconnect auxiliary contact requirements with respect to the arcing point. The position of 0% travel indicates the position when the main contacts are fully open, and the 100% position indicates when the main contacts are fully closed.

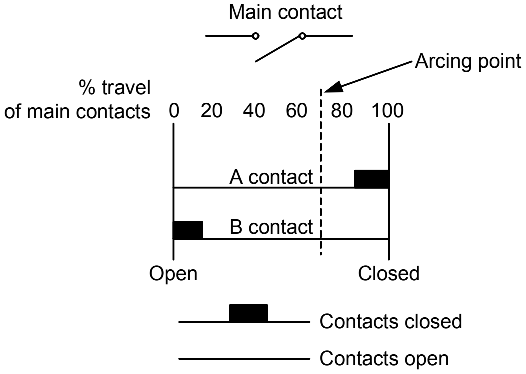


Fig. 2. Disconnect Auxiliary Contact Requirements With Respect to the Arcing Point for an Open-to-Close Disconnect Operation

Applying the principle of

$$\text{(disconnect) NOT OPEN} = \text{(disconnect) CLOSED}$$

the relay properly coordinates the primary current flow and the CT current assignment to the appropriate differential element. Table II shows the four possible disconnect auxiliary contact combinations and the way the relay interprets these combinations.

TABLE II
DISCONNECT A AND B AUXILIARY CONTACT STATUS INTERPRETATION

Case	89A	89B	Status
1	0	0	Closed
2	0	1	Open
3	1	0	Closed
4	1	1	Closed

Table II (Status column) shows that the relay interprets the disconnect as always closed, except for Case 2. With this interpretation, the relay assigns the input currents to the applicable differential elements for Case 1, Case 3, and Case 4. The following discussion considers the four cases in more detail.

B. *Disconnect Open Position*

Fig. 3 shows the disconnect main contact starting to travel in an open-to-close operation. Auxiliary Contact B is still closed and Auxiliary Contact A is open. Table II shows this as Case 2; the disconnect is considered open, and the current is removed from all differential elements. This is the only combination of auxiliary contacts for which the relay considers the disconnect main contacts to be open.

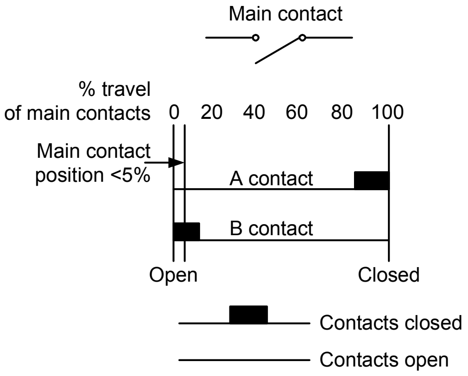


Fig. 3. Disconnect Main Contacts and Auxiliary Contact A Open, Auxiliary Contact B Closed; Disconnect Is Considered Open

C. *Intermediate Position*

Fig. 4 shows the intermediate position (Case 1 in Table II) in a disconnect open-to-close operation, with both A and B auxiliary contacts open for a period of time. When Auxiliary Contact B opens, the disconnect is considered closed and the CTs are assigned to applicable differential elements. The instant that 89B opens (both auxiliary contacts are open), the relay starts a timer to monitor the disconnect travel. At the end of the travel (the 89A contact closes) the timer stops and the relay considers the operation completed. To accurately measure the intermediate position, choose auxiliary contacts that will change status as soon as disconnect travel starts and close only near the end of travel.

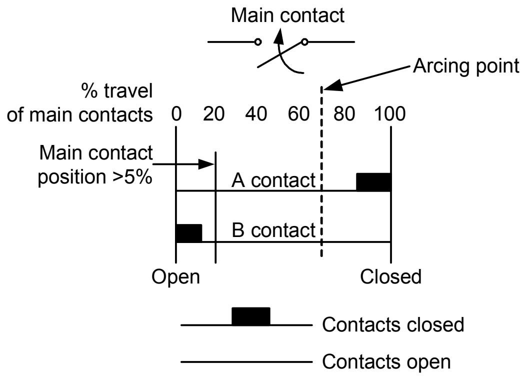


Fig. 4. Intermediate Position With Both Auxiliary Contacts Open; the Disconnect Is Considered Closed

Because disconnect Auxiliary Contact 89B opens well in advance of the arcing point, the CT currents are assigned to applicable differential elements before primary current flows.

D. Auxiliary Contact A Closes

Fig. 5 shows contact status after Auxiliary Contact 89A closes with the main contact past the arcing point and approaching the end of the close operation. When the A contact closes, the relay considers the disconnect main contact to be closed.

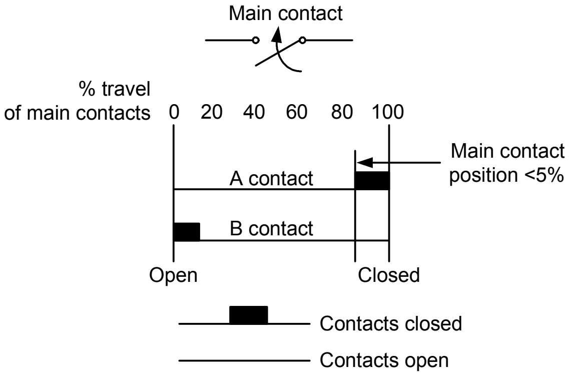


Fig. 5. Main Contact Completed 95% Travel; Contact A Is Closed, Contact B Is Open, and the Disconnect Is Considered Closed

E. Disconnect Open and Closed Simultaneously

Case 4 shows the disconnect main contact to be open and closed simultaneously, resulting from, for example, short circuited cable cores. The relay considers the disconnect main contact closed during this period and the CTs are considered in the differential calculations.

F. Close-to-Open Operation

For the close-to-open operation, CT currents must remain assigned to the differential elements for as long as primary current flows. When the Auxiliary Contact 89A opens (Case 1), we again enter the intermediate position, as depicted in Fig. 3. In the intermediate position, the CT currents are still assigned to the differential elements. Only when Auxiliary Contact 89B closes (Fig. 2) are the CT currents removed from the differential elements, which is safely past the arcing point.

G. Series/Parallel Combinations of Disconnect Auxiliary Contacts

Sequentially operated disconnects (such as pantographs) or disconnects with auxiliary contacts for each phase pose an additional problem: which of the following series/parallel auxiliary contact combination is the best solution?

- 89A contact in parallel, 89B contact in parallel
- 89B contacts in series, 89A contacts in parallel
- 89B contact in parallel, 89A in series
- 89B contacts in series, 89A contacts in series

Table III summarizes the open-to-close operation, and Table IV summarizes the close-to-open operation (see Appendix I for an example analysis). Table III shows all 89B contacts closed in Row 1, and the relay interpretation for each of the four auxiliary contact combinations. Row 2 shows the 89B contact of the A-phase disconnect opened, but the 89A contact not yet closed. This is the intermediate position when the monitor timer must time. Row 3 shows the completion of the A-phase operation when the 89A contact closes. Row 4 shows the opening of the B-phase, and so on.

TABLE III
DISCONNECT PRIMARY CONTACT OPEN-TO-CLOSE OPERATION

	89B Contacts			**89A Contacts**			**BP/AP**		**BP/AS**		**BS/AP**		**BS/AS**	
	A	**B**	**C**	**A**	**B**	**C**	**Dis**	**Mon**	**Dis**	**Mon**	**Dis**	**Mon**	**Dis**	**Mon**
All 89B closed, all 89A open	1	1	1	0	0	0	O	N	O	N	O	N	O	N
A-phase 89B opens	0	1	1	0	0	0	O	N	O	N	C	Y	C	Y
A-phase 89A closes	0	1	1	1	0	0	O	Y	O	N	C	N	C	Y
B-phase 89B opens	0	0	1	1	0	0	O	Y	O	N	C	N	C	Y
B-phase 89A closes	0	0	1	1	1	0	O	Y	O	N	C	N	C	Y
C-phase 89B opens	0	0	0	1	1	0	C	N	C	Y	C	N	C	Y
C-phase 89A closes	0	0	0	1	1	1	C	N	C	N	C	N	C	N

Note: BP = 89B auxiliary contacts in parallel, BS = 89B auxiliary contacts in series, AP = 89A auxiliary contacts in parallel, AS = 89A auxiliary contacts in series, Dis = Disconnect status as processed by the relay (O = open, C = closed), Mon = Monitoring timer (Y = timer is running, N = timer is not running).

TABLE IV
DISCONNECT PRIMARY CONTACT CLOSE-TO-OPEN OPERATION

	89B Contacts			89A Contacts			BP/AP		BP/AS		BS/AP		BS/AS	
	A	**B**	**C**	**A**	**B**	**C**	**Dis**	**Mon**	**Dis**	**Mon**	**Dis**	**Mon**	**Dis**	**Mon**
All 89B open, all 89A closed	0	0	0	1	1	1	C	N	C	N	C	N	C	N
A-phase 89B closes	0	0	0	0	1	1	C	N	C	Y	C	N	C	Y
A-phase 89A opens	1	0	0	0	1	1	O	Y	O	N	C	N	C	Y
B-phase 89B closes	1	0	0	0	0	1	O	Y	O	N	C	N	C	Y
B-phase 89A opens	1	1	0	0	0	1	O	Y	O	N	C	N	C	Y
C-phase 89B closes	1	1	0	0	0	0	O	N	O	N	C	Y	C	Y
C-phase 89A opens	1	1	1	0	0	0	O	N	O	N	O	N	O	N

Note: BP = 89B auxiliary contacts in parallel, BS = 89B auxiliary contacts in series, AP = 89A auxiliary contacts in parallel, AS = 89A auxiliary contacts in series, Dis = Disconnect status as processed by the relay (O = open, C = closed), Mon = Monitoring timer (Y = timer is running, N = timer is not running).

Table III and Table IV show that both BS/AS and BS/AP combinations provide the desired protection result, but the BS/AS combination provides better monitoring. This analysis excludes contingencies such as auxiliary contacts failing, which may influence the final choice between the BS/AS and BS/AP selection. Fig. 6 shows the wiring to connect the disconnect auxiliary contacts in series.

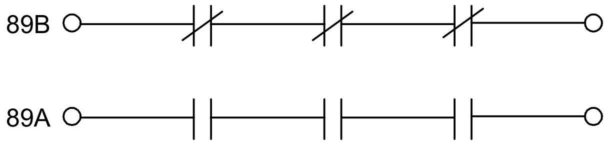


Fig. 6. 89B and 89A Auxiliary Contacts in Series

VI. TOO FEW CURRENT CHANNELS

Fig. 7 shows the single line diagram of a large station with all tie-breakers and sectionalizing breaker installed with a single CT. Unlike high-impedance busbar protection where CTs are connected in parallel with practically no limit to the number of parallel CTs, low-impedance busbar protection uses the input from each CT to form a restraint quantity to ensure proper security. Therefore, if the number of terminals exceeds the available current inputs of the busbar protection relay (assumed to be 18 in this paper), then the relay cannot protect the busbars.

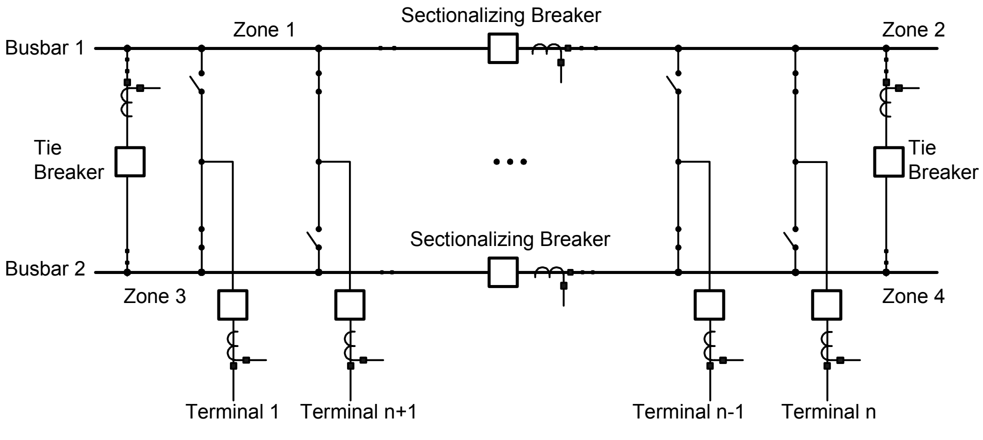


Fig. 7. Large Station Single-Line Diagram

Adding more relays increases the number of current channels, however, adding more relays is feasible only if the station layout permits the separation of the busbars into independent systems. Fig. 8 shows an example of such a separation, where a sectionalizing breaker in each busbar divides the busbars into two separate systems. With this arrangement, disconnects can assign currents to either of the two relays, but not both. For example, Terminal 1 can only be assigned to Relay 1 (i.e., to Zone 1 or Zone 3, but not to Zone 2 or Zone 4).

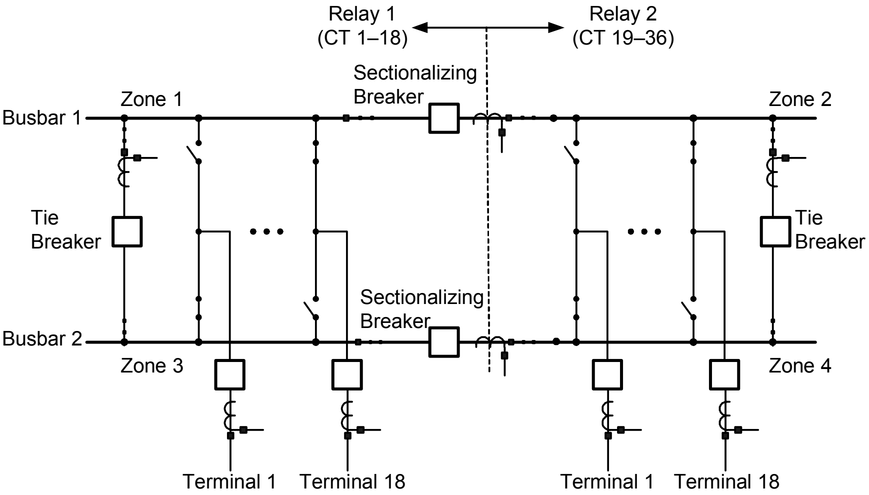


Fig. 8. Electrical Separation Large Station Single-Line Diagram

Note that when the zones separate, the sectionalizing breaker becomes an ordinary terminal and the sectionalizing breaker CTs must be included in the check zone of both relays. Provided that CT ratio and polarity are software settings, use a single CT core wired with the relays in series instead of using dedicated CT cores for each relay.

There is no limit to the number of relays that can be added in this way provided that the busbars can be broken into independent systems and that CTs are available at these break points. Large installations are always multirelay installations, (each relay protects only one phase), so that Relay 1 in Fig. 8 consists of an A-phase, a B-phase, and a C-phase relay. Although separating the busbars into two systems requires more relays, the reliability of the overall busbar protection scheme actually increases, despite the increase in the number of relays. For example, if the A-phase relay of Relay 1 in Fig. 8 fails (one of six relays), then the only fault that the remaining five relays cannot protect against is an A-phase-to-ground fault in Zone 1 or Zone 3. This means that, of the twenty possible shunt faults on the two systems (one 3-phase fault, three phase-to-phase faults, three phase-to-ground faults, and three phase-to-phase-to-ground faults on each system), the remaining five relays can still protect 19/20 (95%) of faults on the two systems. Compare this to 9/10 faults covered (90%) if one relay fails when only three relays are installed.

VII. TOO FEW ZONES

Depending on the function of the additional zone, a programmed zone can provide compatible results to a hard-coded zone. In particular, if the additional zone requires zone selection, a programmed zone should be avoided. However, for an application such as a check zone, the programmed zone provides satisfactory results. Many utilities require that one of the criteria of the two-out-of-two tripping principle be a check zone.

A. *Check Zone Requirements*

Following are the general requirements of a check zone:

- Check zone element operation is independent of the status of any auxiliary contact (i.e., no zone selection).
- Provides station wide supervision of all differential element trippings (e.g., check zone element operation allows all differential elements in the station to operate).
- May not prevent or slow down differential element operation for a valid internal fault condition.

Fig. 9 shows the logic to create a programmed check zone. Fig. 10 shows an example programmed check zone consisting of a substation with one buscoupler (I09 and I10), one sectionalizing breaker (I07 and I08), four feeders, and two transformers.

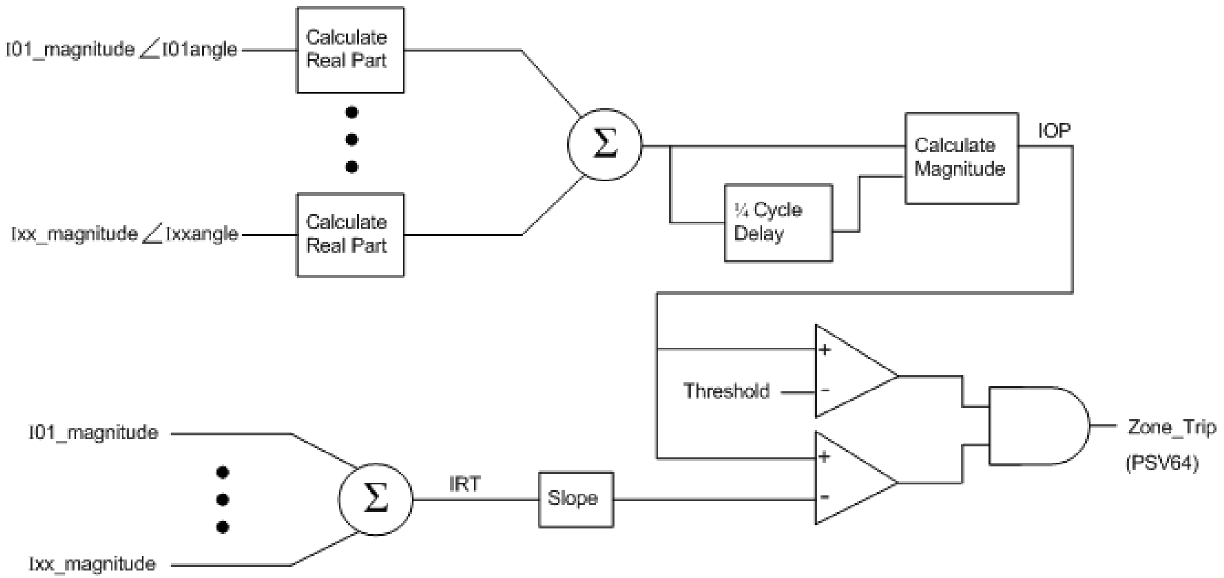


Fig. 9. Check Zone Logic Diagram

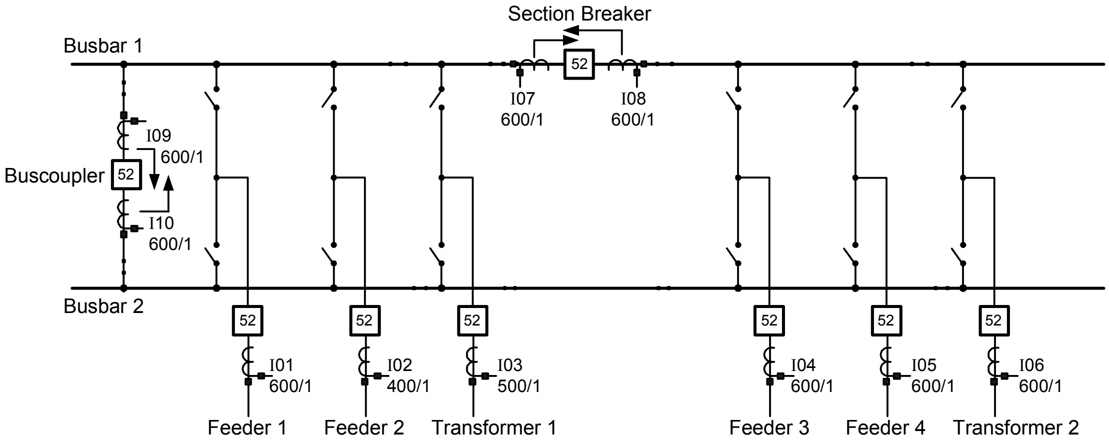


Fig. 10. Substation Bus Arrangement Including One Buscoupler, One Section Breaker, Four Feeders, and Two Transformers

Perform the following steps to program the check zone:

Step 1. Obtain the current normalization factors (CNF), since the relay processes currents from differing CT ratios. With the 600/5 CT ratio as reference the CNF (TAPxx) values are as shown in Table V.

TABLE V
CNF VALUES

TAP01	TAP02	TAP03	TAP04–TAP09
1.00	1.50	1.20	1.00

Step 2. Identify and record all buscouplers and sectionalizing breakers to ensure that the check zone does not include these terminals. In Fig. 10, I07, I08 (sectionalizing breaker), I09, and I10 (buscoupler) are excluded from the check zone.

Step 3. Identify and record all terminals that are to be included in the check zone. In Fig. 10, I01, I02, I03, I04, I05, and I06 are included in the check zone.

Step 4. Check the relay programming capacity.

Step 5. Program the check zone using the filtered, instantaneous analog quantities of the terminals included in the check zone, as shown in Table VI.

TABLE VI
ANALOG QUANTITIES IN POLAR FORM
FOR TERMINAL I01 THROUGH TERMINAL I06

Terminal	Current Magnitude	Current Angle
I01	I01FIM	I01FIA
I02	I02FIM	I02FIA
I03	I03FIM	I03FIA
I04	I04FIM	I04FIA
I05	I05FIM	I05FIA
I06	I06FIM	I06FIA

Use (1) to convert the analog quantities in Table VI from polar form to rectangular form.

$$\begin{aligned}\mathrm{IxxFIM}\angle\mathrm{IxxFIA} &= \mathrm{IxxFIM}\bullet\cos(\mathrm{IxxFIA})\\ &+ j\mathrm{IxxFIM}\bullet\sin(\mathrm{IxxFIA})\end{aligned} \tag{1}$$

Where IxxFIM = I01FIM through I06FIM (see Table VI) and where IxxFIA = I01FIA through I06FIA (see Table VI).

To reduce the number of trigonometric functions necessary for the program, the relay uses (2) to calculate only the real part (cosine term) of the phasor and then delays the calculated value by 90 degrees to produce the imaginary part (sine term) of the phasor.

$$\mathrm{Ixx}(\mathrm{phasor\_real\_part}) = \mathrm{IxxFIM} \bullet \cos(\mathrm{IxxFIA}) \qquad (2)$$

The relay calculates the real parts of the input currents and adds these values. After this addition, the relay delays the summed value by three processing intervals to form an orthogonal value and uses the present value (real part) and the delayed value (imaginary part) to calculate the phasor magnitude. The relay delays each current value for three processing intervals, as Fig. 11 illustrates, because the relay calculates current values every 1/12 of a power system cycle (or 360/12 = 30 degrees).

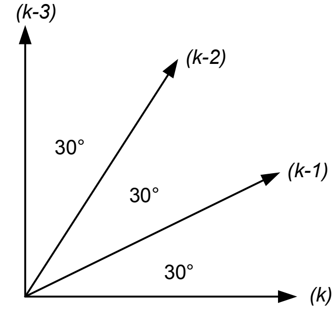


Fig. 11. Delay Necessary for Ninety-Degree Phase Shift

Fig. 12 shows the complete check zone programming (see Appendix II for program commentary) using Protection Math Variables (PMV) and Protection Variables (PSV).

```
15: PMV48 := I02FIM / 1.500000 #SCALE I02FIM TO THE BASE
16: PMV49 := I03FIM / 1.200000 #SCALE I03FIM TO THE BASE
17: PMV50 := (I01FIM * COS(I01FIA)) + (PMV48 * COS(I02FIA)) + (PMV49 * \
COS(I03FIA)) + (I04FIM * COS(I04FIA)) + (I05FIM * \
COS(I05FIA)) #REAL PART OF CURRENTS AND SUMMATION THEREOF
18: PMV51 := (I06FIM * COS(I06FIA)) #REAL PART OF CURRENT
19: PMV54 := PMV50 + PMV51 #PHASOR SUM OF REAL PARTS OF ALL CURRENTS
20: PMV55 := SQRT((PMV54) * (PMV54) + (PMV56) * (PMV56)) #OPERATE CURRENT
21: PMV56 := PMV57 #THIRD DELAY INTERVAL
22: PMV57 := PMV58 #SECOND DELAY INTERVAL
23: PMV58 := PMV54 #FIRST DELAY INTERVAL
24: PMV59 := I01FIM + PMV48 + PMV49 + I04FIM + I05FIM + I06FIM #RESTRAINT \
CURRENT
25: PMV60 := PMV59 * 0.500000 #RESTRAINT CURRENT AT 50 % SLOPE
26: PSV64 := (PMV55 > PMV60) AND (PMV55 > 1.000000) #DIFFERENTIAL ELEMENT
```

Fig. 12. Check Zone Programming

VIII. Too Few Current Channels and Too Few Zones

Installations with too few current channels and too few zones require more programming if the sectionalizing breakers at the separation point have only one CT. This additional programming consists of trip signals between the two check zones to ensure correct operation for a fault between the circuit breaker and CT of the sectionalizing breakers. If the sectionalizing breakers at the separation point have two overlapping CTs, then communication between relays is not necessary. Fig. 13 shows the final stage of the differential element trip logic. Zone x Differential Trip is the output from the differential element and Check Zone is a programmable input that supervises the differential trip output.

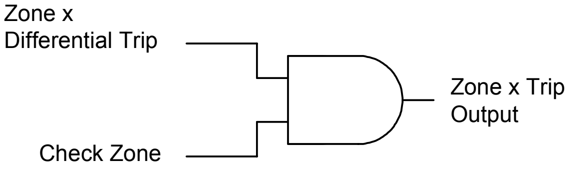


Fig. 13. Final Stage of the Differential Element Trip Logic

Fig. 14 shows both a single check zone (dotted line) that covers the entire station and the individual check zones of two separate relays (Check Zone 1 and Check Zone 2). Both sectionalizing breakers have only one CT and F1 is a fault between Sectionalizing Breaker 1 and its CT. Because Fault F1 is external to Zone 2, Zone 2 does not operate for F1 and the fault is not cleared. A common approach to this case is to use the breaker auxiliary contacts to remove the sectionalizing breaker CT from the Zone 2 differential calculations, causing Zone 2 to operate.

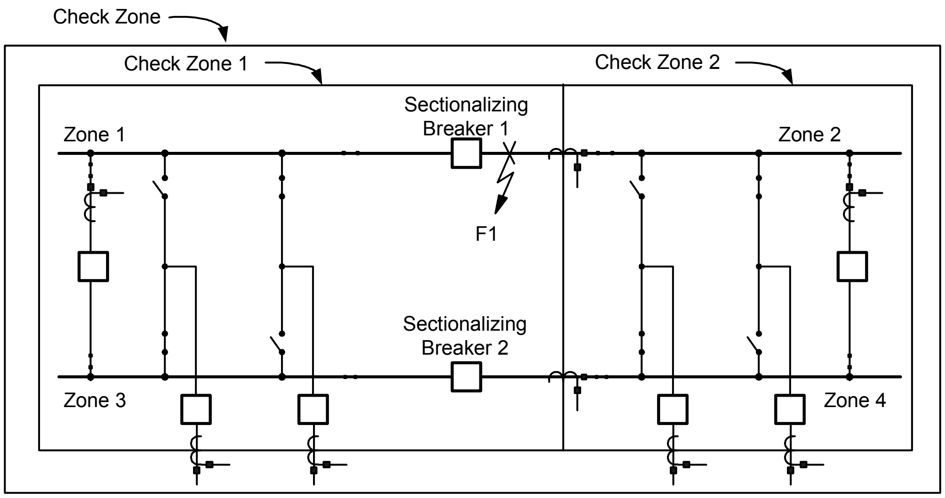


Fig. 14. Check Zones

When Fault F1 occurs, Zone 1 and Check Zone 1 operate, but because F1 is external to Zone 2 and Check Zone 2, neither operates. When Sectionalizing Breaker 1 opens, Zone 2 operates (breaker auxiliary contact removes the sectionalizing breaker CT from the Zone 2 differential calculations), but not Check Zone 2 (recall that the check zone is independent of the status of any auxiliary contact). Because Check Zone 2 does not operate, the relay does not give a trip output. Fig. 15 shows the logic that causes Zone 2 to trip.

Route the output from Relay 1 Check Zone to Relay 2 and initiate a drop-off timer in Relay 2. This timer ensures that the tripping signal from Relay 1 is present long enough to trip all terminals connected to Relay 2. Route the output from the drop-off timer, together with the output from the Check Zone Trip of Relay 2, to supervise all zones in Relay 2. Table VII summarizes the events.

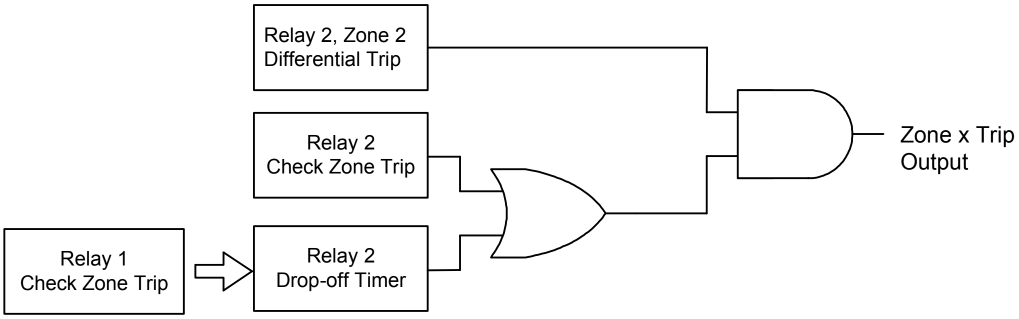


Fig. 15. Logic-to-Trip Zone 2

IX. CONCLUSION

This paper discussed the importance of proper disconnect auxiliary contact choice to achieve proper zone selection.

For sequentially operated devices, wire the disconnect "B" contacts from the three phases in series for proper protection operation.

If the station layout permits the separation of the busbars into independent systems, add more relays to increase the number of current channels. Increasing the number of relays in this way increases the overall protection reliability.

Add an additional check zone with simple programming, thereby increasing the number of zones available in the relay.

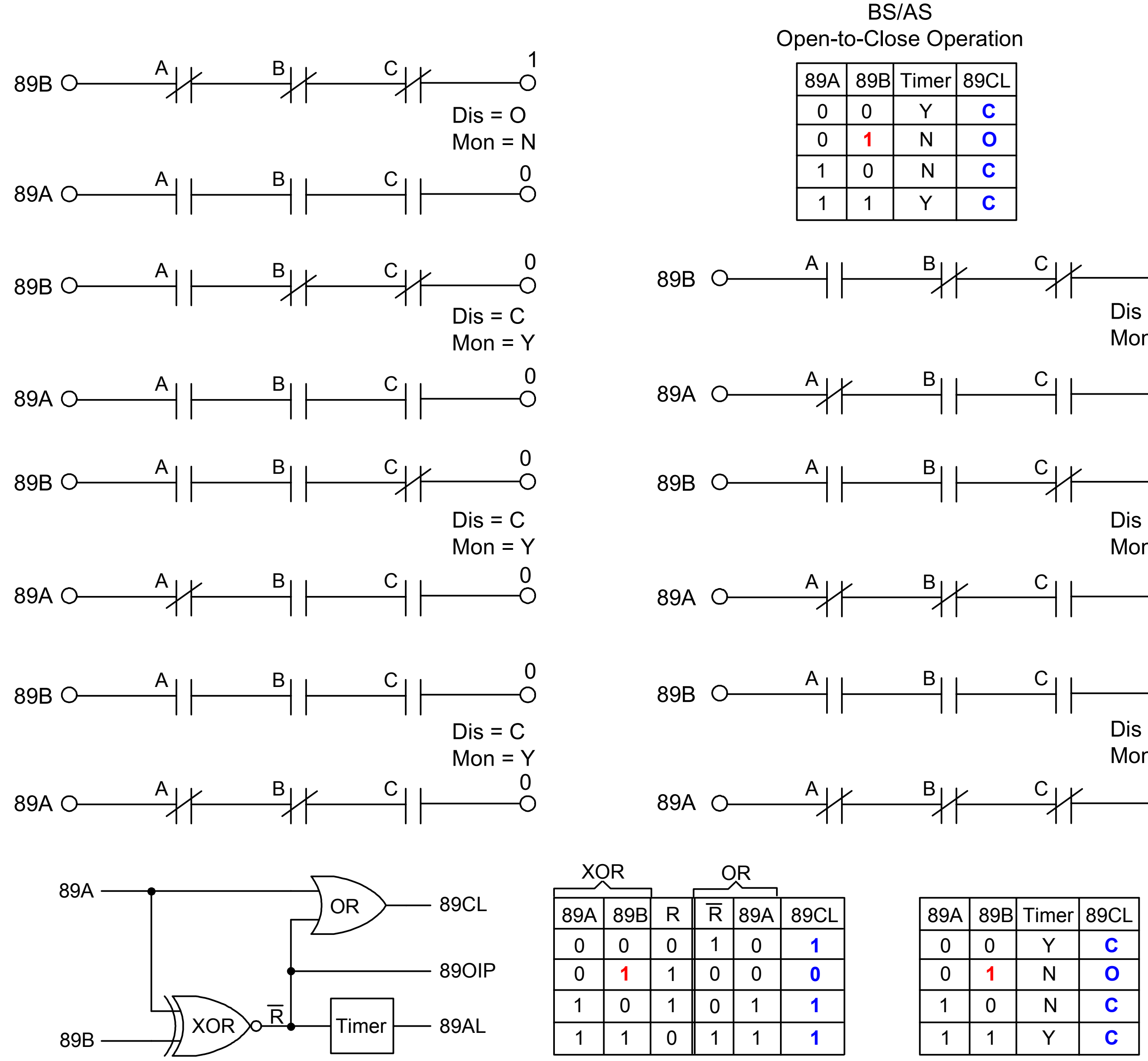
TABLE VII
SUMMARY OF EVENTS

Relay 1	Relay 2
Zone 1 and Check Zone 1 differential elements operate.	Zone 2 and Check Zone 2 restrain (external fault).
Trip issued to the sectionalizing breaker and to Relay 2.	Drop-off timer starts, and asserts supervision condition.
Sectionalizing breaker and all other terminals in Zone 1 trips.	Sectionalizing breaker CT removed from Zone 2 differential calculations.
	Zone 2 trips and clears the fault, but Check Zone 2 never operates.

Signaling between the relays is possible either with hardwiring or with communications protocols, such as IEC 61850.

X. Appendix I: Detailed Analysis

Fig. 16 and Fig. 17 show a per-contact change analysis of both open-to-close and close-to-open operations for the BS/AS combination. At the bottom of each figure is the disconnect logic and the truth tables. Figures on the left display a contact change (89B for example, opens) and the figures on the right display the subsequent contact change on completion of the operation (89A now closes).



BS/AS
Open-to-Close Operation

89A	89B	Timer	89CL
0	0	Y	**C**
0	1	N	**O**
1	0	N	**C**
1	1	Y	**C**

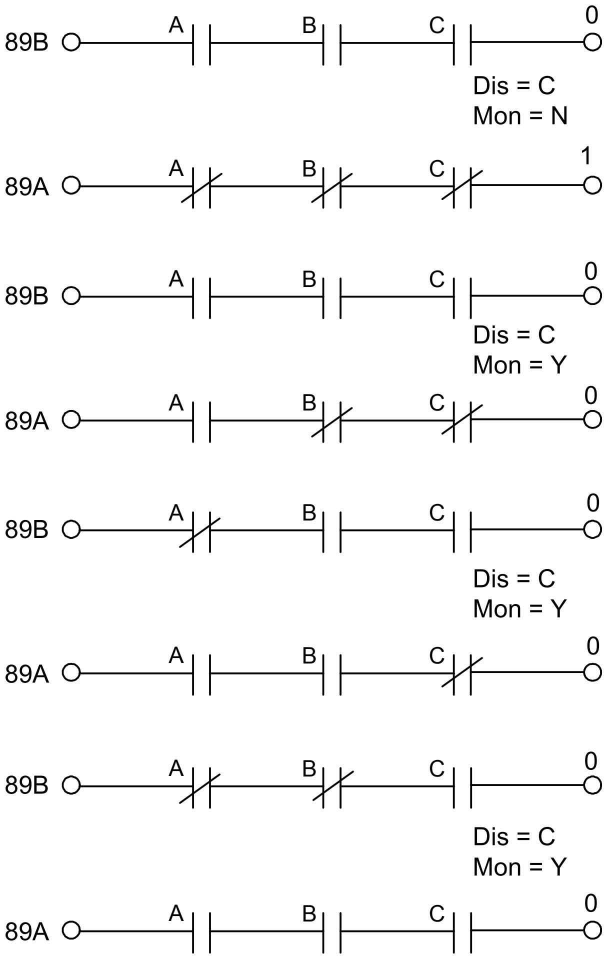
XOR			OR		
89A	89B	R	$\overline{R}$	89A	89CL
0	0	0	1	0	**1**
0	1	1	0	0	**0**
1	0	1	0	1	**1**
1	1	0	1	1	**1**

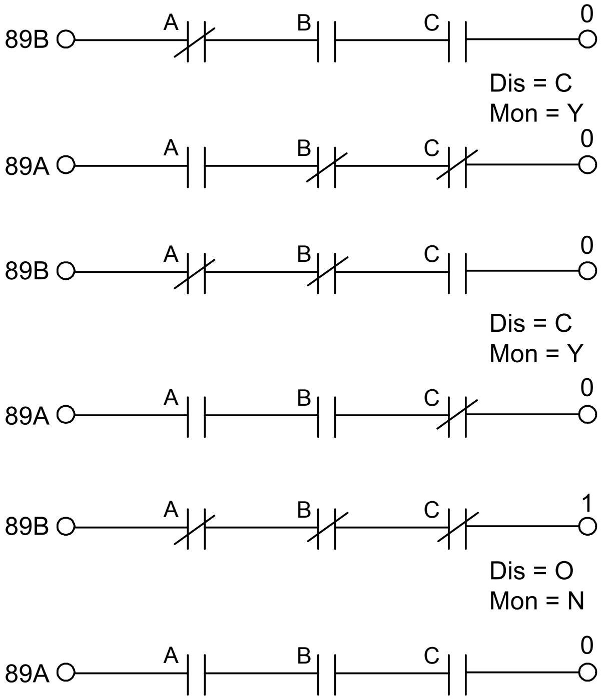
89A	89B	Timer	89CL
0	0	Y	**C**
0	1	N	**O**
1	0	N	**C**
1	1	Y	**C**

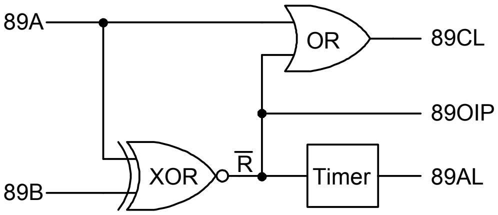
Fig. 16. BS/AS Open-to-Close Analysis

BS/AS
Close-to-Open Operation

89A	89B	Timer	89CL
0	0	Y	C
0	1	N	O
1	0	N	C
1	1	Y	C







XOR			OR		
89A	89B	R	R̄	89A	89CL
0	0	0	1	0	1
0	1	1	0	0	0
1	0	1	0	1	1
1	1	0	1	1	1

89A	89B	Timer	89CL
0	0	Y	C
0	1	N	O
1	0	N	C
1	1	Y	C

Fig. 17. BS/AS Close-to-Open Analysis

XI. APPENDIX II: PROGRAMMING COMMENTARY

In Fig. 12, Lines 15 through 26 describe the programming of the differential check zone. The following text describes the programming. Lines 15 and 16 scale those values that have CNFs other than 1. In this example, I02 (1.5) and I03 (1.2) both have CNFs other than 1. To convert I02 and I03 to the same base as the reference current, divide I02 and I03 by their respective CNFs. Scaling the currents here saves programming steps in Line 24. Lines 17 and 18 include the following two steps.

Step 1. Calculation of the real part of the listed currents. Using the cosine function produces the real part of a phasor.

Step 2. Summation of the real part of the listed currents.

Line 19 calculates the sum of the real parts of all the currents listed in Lines 17 and 18.

Line 20 uses (3) to calculate the magnitude of the operating current.

$$\mathrm{IOP\_CZ_k} = \sqrt{(\mathrm{IOP_k})^2 + (\mathrm{IOP_{k-3}})^2} \tag{3}$$

IOP_CZ is the alias name for PMV55, the check zone operating current.

Lines 21 and 23 are the delays necessary for calculating the imaginary parts of the currents.

Line 24 is the sum of the current magnitudes (this sum is the restraint current).

Line 25 is the restraint current scaled by the slope setting (50 percent in this example).

Line 26 is the actual differential element and shows comparison of the differential current against both scaled restraint current and the threshold setting (1 per unit in this example). The line has two components:

- Comparison of the differential current with the solution of the restraint current at a specific slope (PMV55 > PMV60)
- Comparison of the differential current with a specific per unit threshold (PMV55 > 1.000000). Slope and threshold values can both be set differently from the zone-specific slope and threshold settings.

XII. REFERENCES

[1] A. Guzman, C. Labuschagne, and E. Stokes-Waller, "Using SELOGIC to implement an SEL-487B Bus Differential Check Zone," AG2007-01. [Online] Available http://www.selinc.com/ag07xx.htm.

[2] SEL-487B Relay Instruction Manual. (2003–2007) Schweitzer Engineering Laboratories, Inc. PM487B-01 [Online] Available http://www.selinc.com/sel-487b.htm.

[3] Eskom Protection Philosophy Implementation.

XIII. BIOGRAPHIES

Laura Steenkamp received her Baccalaureus and Masters Degrees in Electronic Engineering (B.Eng. and M.Eng.) in 2001 and 2003 respectively at the University of Pretoria. She is currently employed by Eskom Transmission and works in the field of protection, focusing her attention on busbar protection. She strives for the continuous improvement of protection functions within the Transmission Grid

Casper Labuschagne earned his Diploma (1981) and Masters Diploma (1991) in Electrical Engineering from Vaal Triangle Technicon, South Africa. After gaining 20 years of experience with the South African utility Eskom where he served as Senior Advisor in the protection design department, he began work at SEL in 1999 as a Product Engineer in the Substation Equipment Engineering group. In 2003 he transferred to his present position as Lead Engineer in the Research and Development group where his responsibilities include the specification, design and testing of protection and control devices. Casper is registered as a Professional Technologist with ECSA, the Engineering Counsel of South Africa, and has authored and co-authored several technical papers.

Edmund Stokes-Waller received his Baccalaureus and Masters Degrees in Heavy Current Electrical Engineering (B.Eng. and M.Eng.) in 1994 and 2003 respectively at the University of Pretoria. He is registered as a Professional Engineer at the Engineering Council of South Africa and has published different papers in the areas of power system behavior, protection, automation, communications and performance. A passion for practical power system performance is evident from the ability to identify performance root causes and to develop, implement and manage enhancements. He is presently employed with SEL situated in Centurion, South Africa.

20070912 • TP6287-01