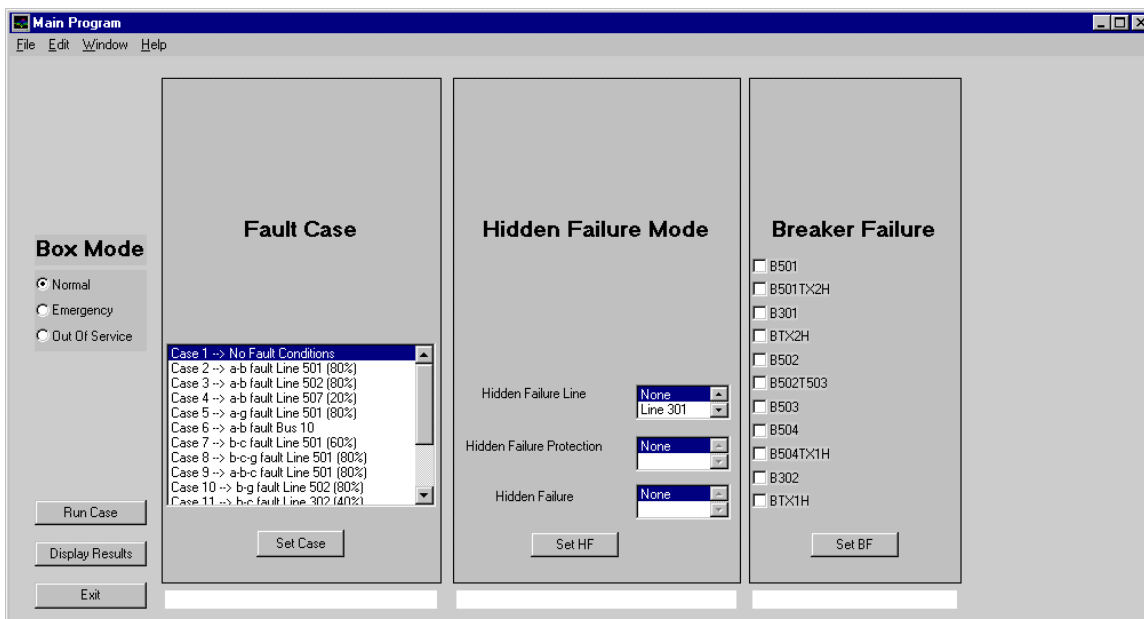# 6 Case Results

A graphical user interface (GUI) main screen, as shown in Figure 19, provides for the selection of case data and system operating modes. The user selects the test case from a list,

**Figure 19: Case Selection GUI**

which in turn picks the appropriate data files. All EMTP studies have been run in advance of starting this screen. The user determines the RSS operating mode, selects a hidden failure mode, if any, and sets breakers to fail. Picking the RSS operating mode is a simple model of external signals from the system operator, or of RSS removal from service due to component failure. Run Case starts program execution.

The output of a test case includes a text listing of RSS actions, shown in Figure 20. This output shows time of case (in cycles), time since fault inception (in cycles), existing relay trips, every RSS calculation and result, and breaker operations. Also illustrated is the final status of all breakers. Examples of this are listed in Appendix VII.

Another output of the model is strip plots showing the contact status of affected devices for the case. These plots show the status of device contacts over time. Time is measured in cycles after fault inception. Contact status is "Open" of "Closed", with Open the normal condition. These plots illustrate very effectively how the RSS supervises the protection system.

6.1 Cases

The example fault cases adequately test the operating principles of the model. All fault types (3-ϕ, ϕ-ϕ, ϕ-ϕ-G, ϕ-G) are tested. All hidden failure modes are tested for all three RSS operating modes: Normal, Emergency, and Out of Service. This means faults are set that fall within the region of vulnerability for a specific zone of protection. 15 cases were studied to test operation of the model.
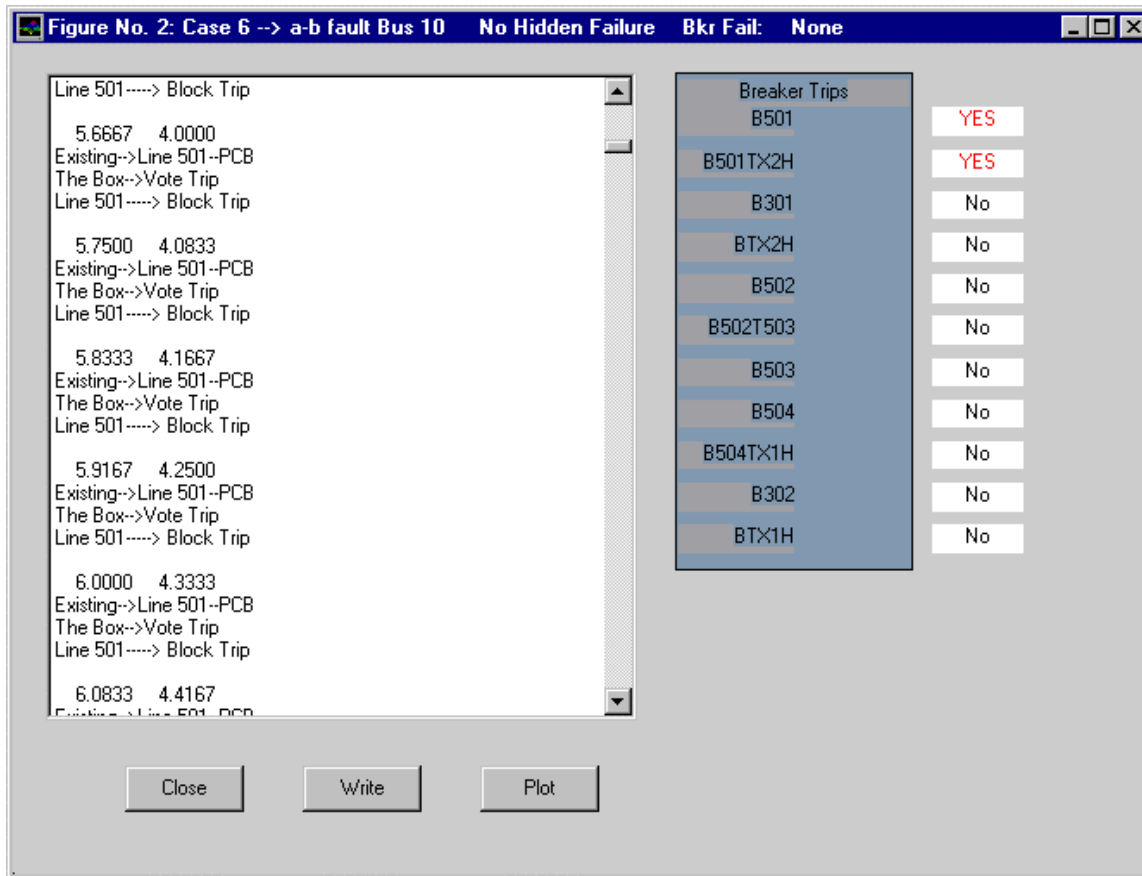
Figure 20: Case Output Listing

The model of the system has some weaknesses. The opening of breakers at the remote end of the line is not accounted for. Normally, other lines open to clear faults in Zone 2 or Zone 3. However, since the model doesn't include these breakers, if the fault case is long enough, the timers for the zone 2 and 3 relays eventually expire, allowing a trip. The model also doesn't allow for the local breaker opening, which means relay operations occur in the model for a case after the breaker has already opened and cleared the fault. This is not significant in terms of the model. An actual device based on this model will not have these problems. Faults and fault currents will be cleared, eliminating trip signals from existing relays.
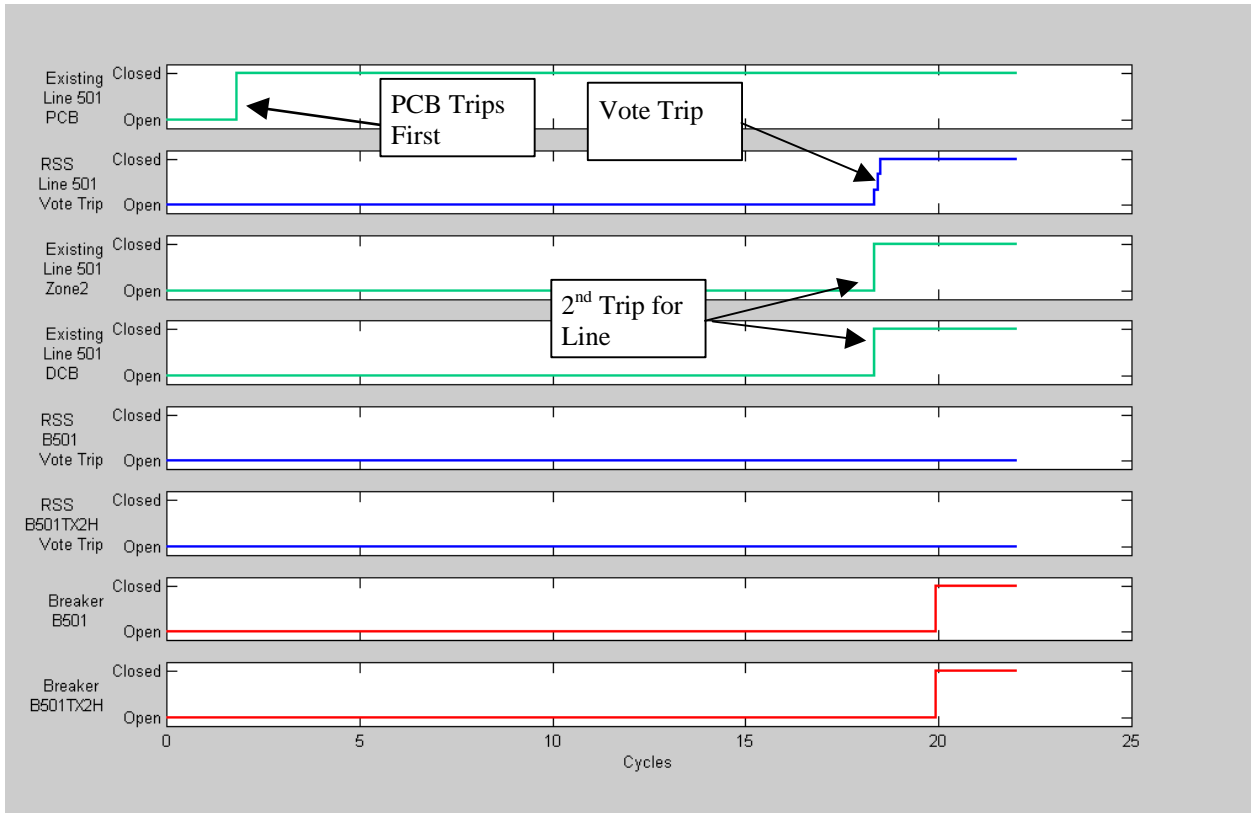
6.2   Sample Case 1

Emergency mode
A-B φ-φ fault at Bus 10
No hidden failures
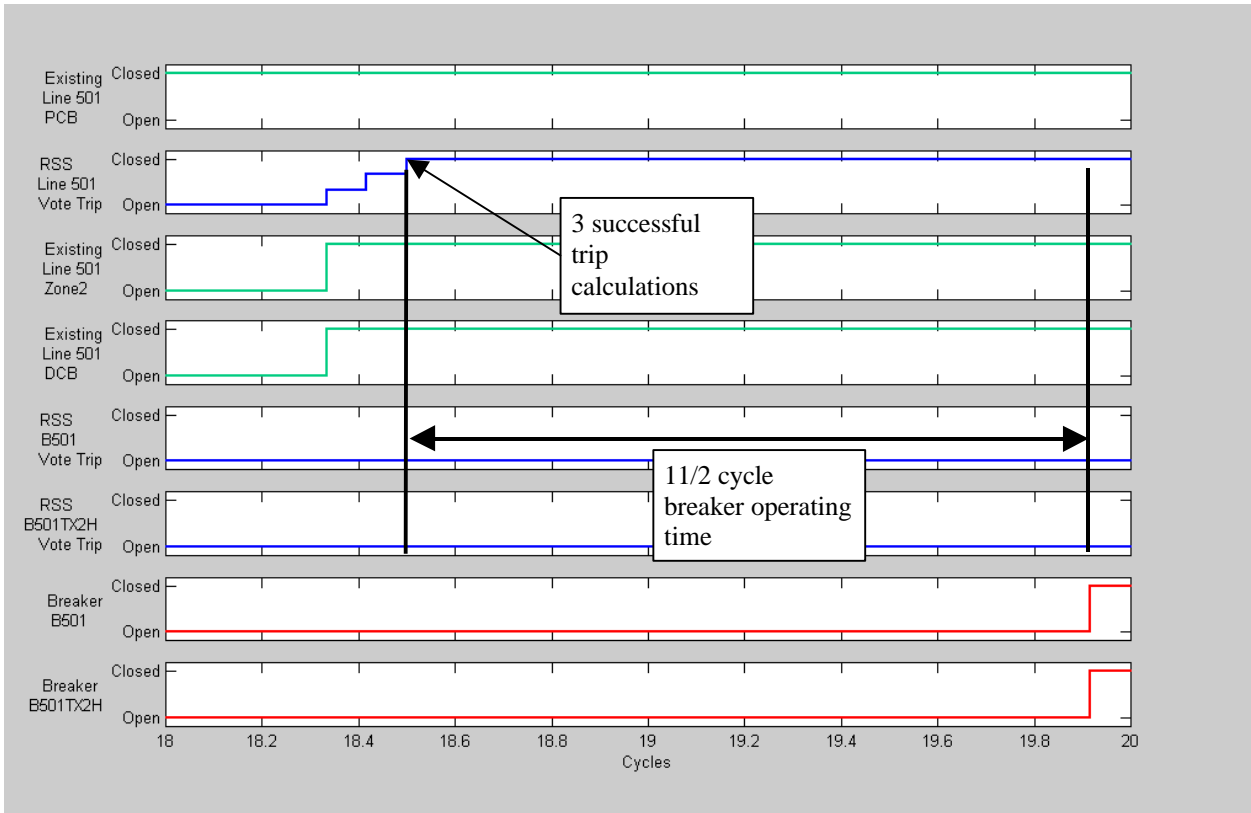
This case illustrates the RSS in Emergency, or "vote" mode, with no hidden failures. The φ-φ fault at Bus 10 represents a case where the fault is on Line 501, but beyond the reach of zone 1. With no hidden failures, the RSS should not effect the dependability of the protection scheme,

Figure 21: Sample Case 1

and allow appropriate breaker trips. The existing Phase Comparison Blocking (PCB) scheme operates first for the fault in approximately 1½ cycles after the fault. The vote logic blocks the trip of any breaker, since the PCB is the only relay scheme to operate. 18 cycles after the fault, both zone 2 and the Directional Comparison Blocking (DCB) scheme operate for the fault. Either one is sufficient to permit breaker operation. The protection scheme is still dependable, but very secure.

Figure 22 is a detail view of the same case. This figure illustrates the 3 consecutive trip calculations necessary to permit a trip, as well as the 1½ cycle breaker operating time. The breaker itself operates in 1 cycle. The contact in the breaker trip circuit controlled by the RSS takes a ½ cycle to close.

Figure 22: Sample Case 1 Detail

6.3   Sample Case 2

Emergency Mode

Aφ, φ-G fault on Line 501

Hidden Failure: Line 302 Directional Overcurrent relay directional element failed closed.

This case illustrates the vote scheme preventing an inadvertent line operation. With the directional element failed for Line 302, the overcurrent relay will see a fault in any direction with fault current sufficient to be in the region of vulnerability for the relay.   This relay operates for
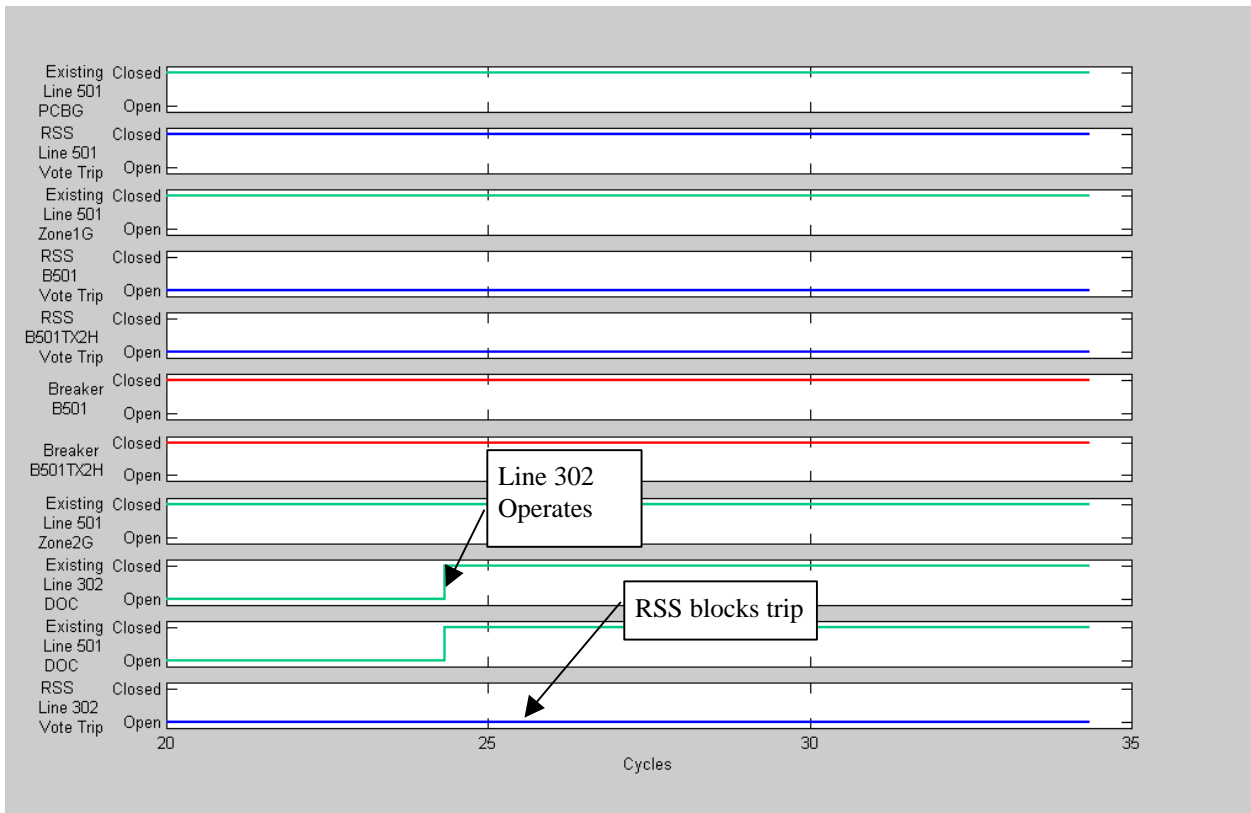
Figure 23: Sample Case 2

the fault on Line 501. The vote logic prevents any breaker operation for line 302, however. This illustrates how the vote scheme increases the security of the existing protection system.

This case also illustrates how the model is incorrect. In reality, the Line 501 relays operate and clear the fault before the Line 302 relay operates incorrectly for the fault.
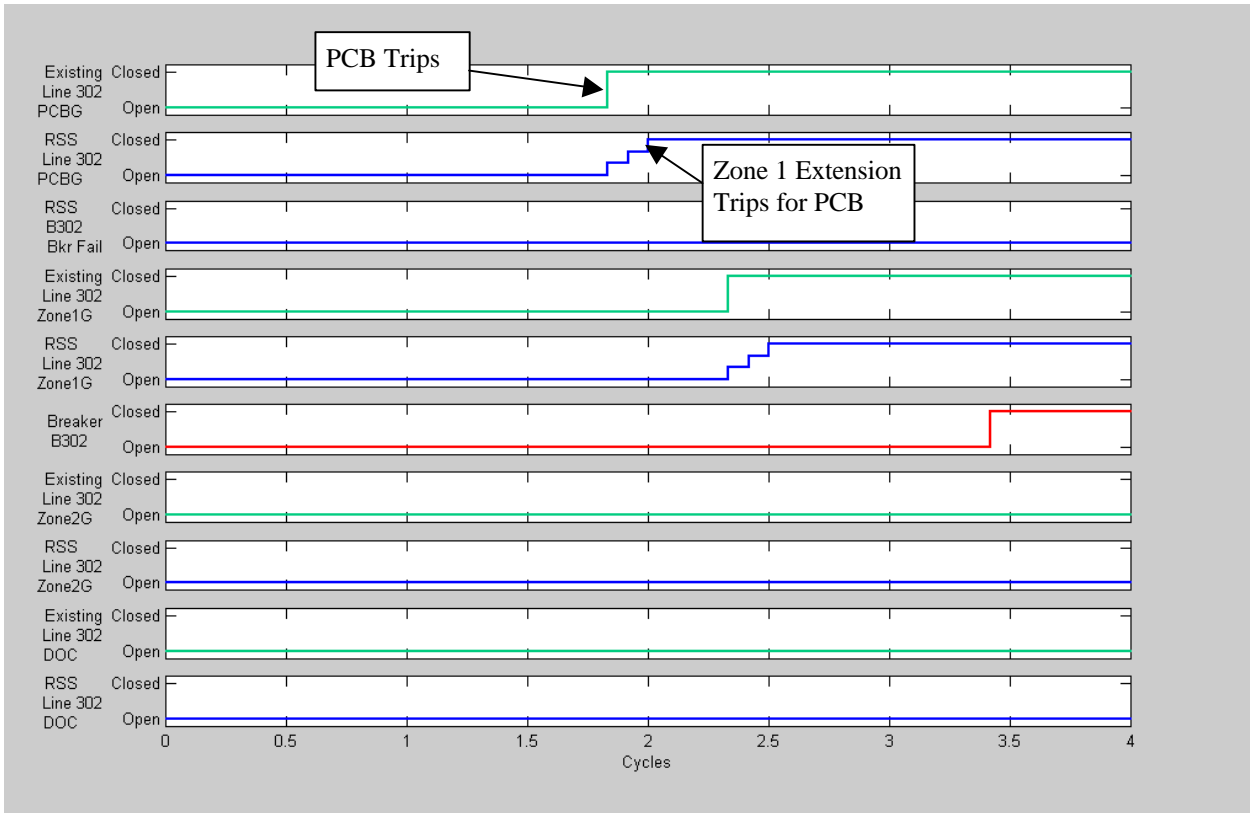
6.4 Sample Case 3

Normal Mode

C φ φ-G fault on Line 302

No Hidden failure

This is the Normal operating mode for the RSS, with no hidden failure. The RSS supervises any relay operation. The fault is a φ-G fault on Line 302. The first relay to operate is the Phase Comparison Blocking (PCB) scheme, in approximately 1½ cycles. The PCB scheme

Figure 24: Sample Case 3

is supervised by Zone 1 Extension. Since the fault is in zone 1, the supervision method permits an immediate trip, after 3 consecutive successful trip calculations. The normal mode keeps the dependability of the protection system intact, and only slows the system down by ¼ cycle.
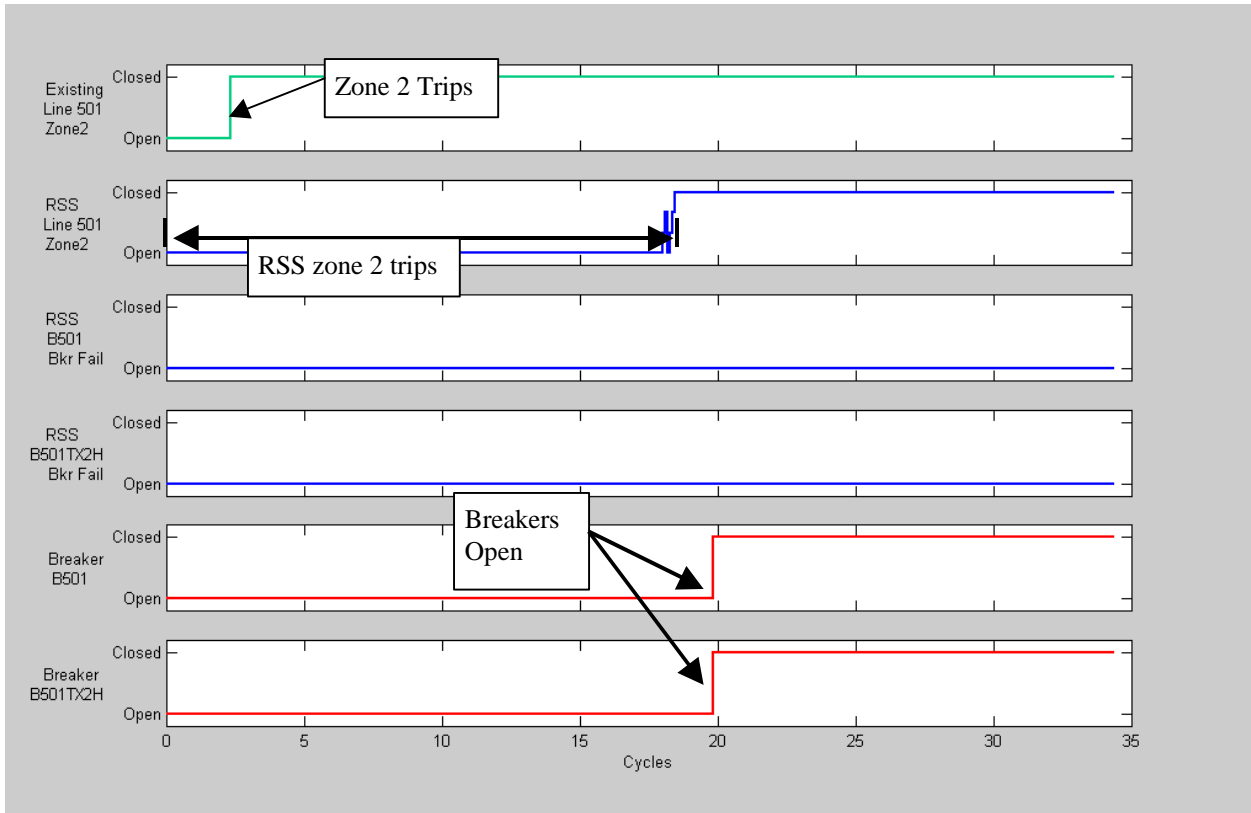
6.5 Sample Case 4

Normal mode
A-B φ-φ fault on Line 507
Hidden failure: Line 501 Zone 2 timer failed picked up
This case shows successful hidden failure supervision increasing the security of the protection scheme. The fault is a φ-φ fault in zone 2 of the Line 501 protection scheme. This fault is in the region of vulnerability for the zone 2 timer failure. With the zone 2 timer failed
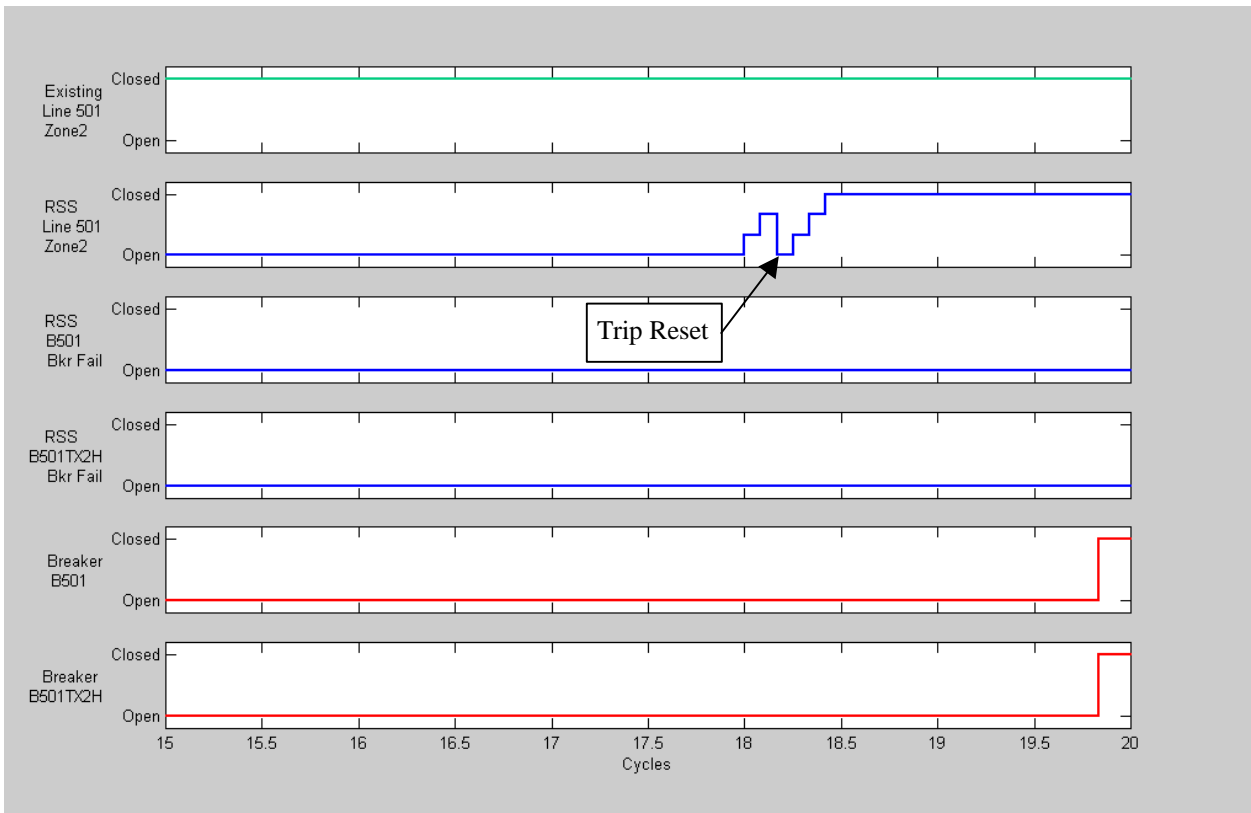

Figure 25: Sample Case 4

closed, the zone 2 relay operates approximately 2 cycles after the fault. However, the RSS zone 2 blocks the line trip from this relay. The zone 2 supervision must wait for its timer to expire before permitting any trip. In this case, zone 2 supervision operates 18 cycles after the fault begins. In practice, the Line 507 relays should operate and clear the fault before this timer expires.

The zone 2 timer is not actually a timer, but a distance to retreat through the DataBuffer to retrieve samples. If these samples indicate a trip condition, a trip result occurs, even if the time since the fault is not precisely equal to the timer.

This case also shows the effects of an unsuccessful trip calculation. the expanded view of the trip result is in Figure 26. For an unsuccessful calculation, the RSS output is reset to 0, requiring 3 additional consecutive trips calculations to return the output state to trip.



Figure 26: Sample Case 4 Detail

6.6 Sample Case 5

Normal mode

C-A-G φ-φ-G fault on Line 505

Hidden failure: Line 502 Zone 3 Timer failed picked up

     This case shows the increased security of the protection scheme. The fault is a φ-φ-G fault in Line 502's Zone 3 protection scheme. The hidden failure is the Line 503 zone 3 timer picked up, with a region of vulnerability of zone 3 reaching beyond Bus 9. Since the zone 3
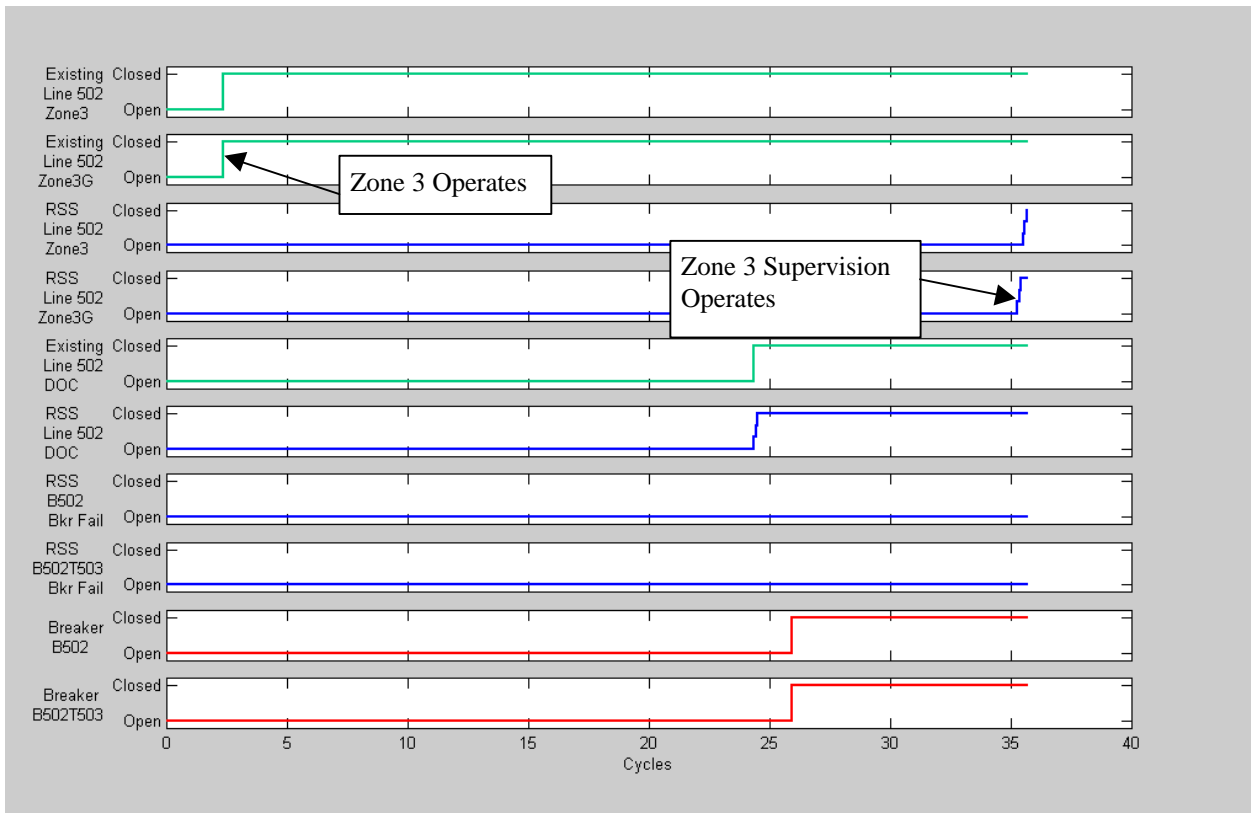
Figure 27: Sample Case 5

timer failed, the relay operates in approximately 2 cycles. The RSS Step-Distance supervision scheme doesn't operate until the timer expires, 36 cycles after the fault. Before this amount of time elapses, Line 505 protection should operate and clear the fault. This case also illustrates how dependability is unaffected by the RSS. If Line 505 doesn't clear the fault, some Line 502 protection scheme will eventually operate, (if permitted to do so by the RSS), and clear the fault.
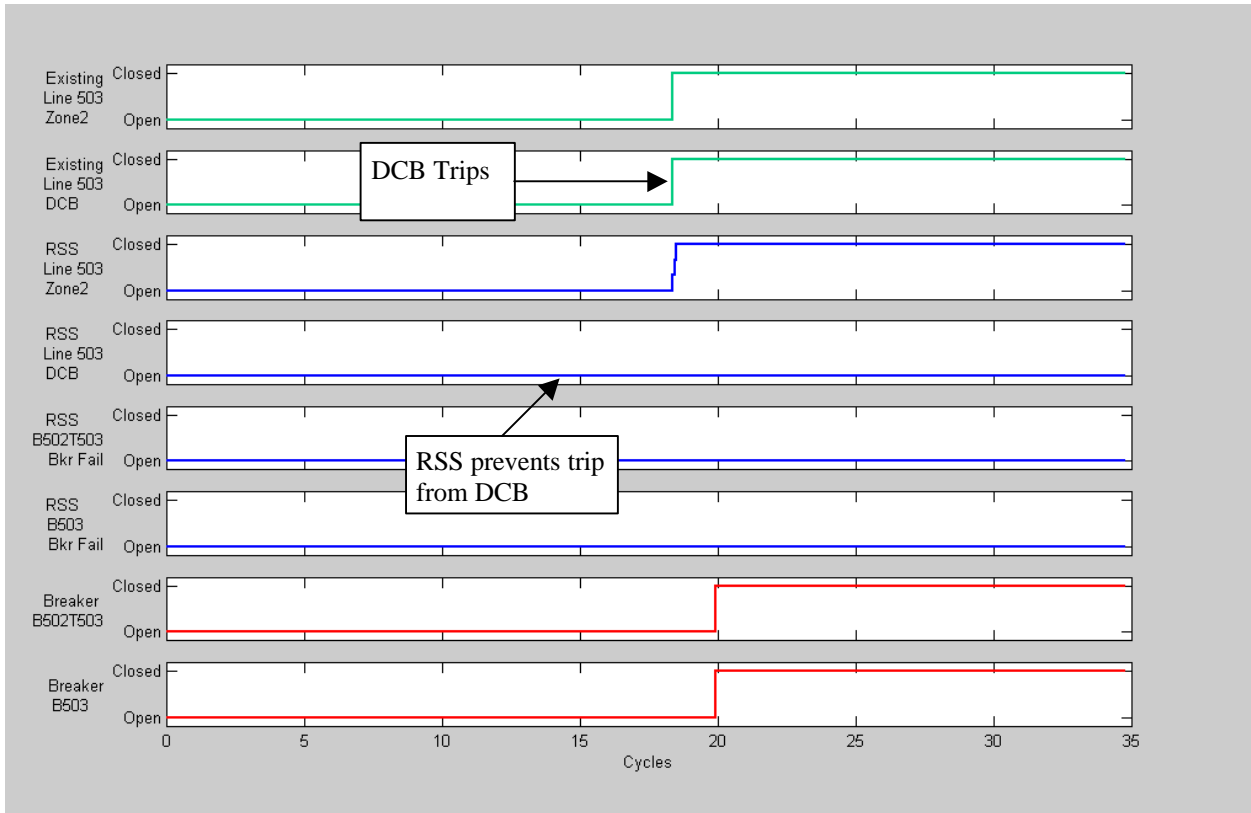
6.7   Sample Case 6

Normal mode
3φ fault on Line 509
Hidden failure: Line 503 DCB Receiver fails.

     Again, this case illustrates the increased security of the system. The hidden failure of the Line 503 DCB receiver has an region of vulnerability equal to the reach of the DCB scheme onto Line 509. The receiver failure prevents the DCB scheme from receiving a blocking signal.

Figure 28: Sample Case 6

Since the fault is in an over-reaching zone, the DCB waits for a coordination timer to expire before tripping. The RSS uses the zone 1 extension method to supervise the DCB scheme. Since the fault is not in zone 1, no trip is permitted. Eventually, the timer of the extension method will expire, and the method performs a zone 2 calculation. The data of this case doesn't last long enough to illustrate this principle. Unlike the zone timer, the zone 1 extension timer starts when the RSS receives a trip signal from a relay supervised by the zone 1 extension method.
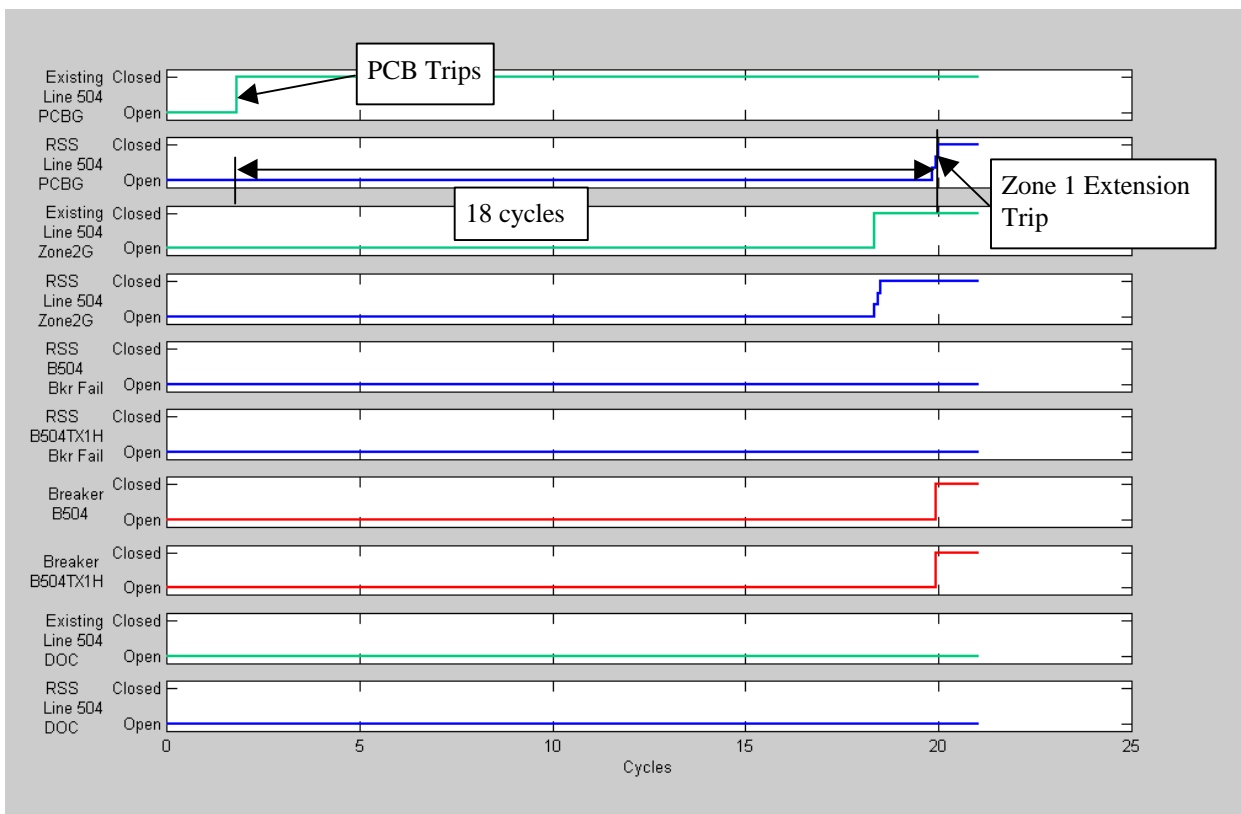
40

6.8 Sample Case 7

Normal mode

B ϕ ϕ-G fault on Line 511

Hidden failure: Line 504 PCB scheme loss of signal.

Increased security of the protection system. The fault is a ground fault in the region of vulnerability for the Line 504 PCB scheme. The PCB scheme hidden failure is a loss of comparison signal, turning the PCB into an overcurrent relay with no time delay. The relay

Figure 29: Sample Case 7

operates incorrectly after 1½ cycles. The Zone 1 Extension method supervises PCB schemes. The fault is not in zone 1, so the method waits until the coordination timer completely expires to check for a fault. There is no effect on system dependability, since a trip is eventually permitted.