Application Note

Substation Automation and Protection Division

Fault Location and Phase Selection from the Digital Fault Recording

Introduction

One of the primary features of the REL 512 is the digital fault recording function. It collects fault or event data based on relay settings and very sensitive and accurate voltage and current change detectors. It captures a 16-cycle snapshot that includes fault inception, fault clearing (tripping) and any evolving fault event that should occur in between. This is referred to as a single record event if fault clearing occurs within 14 cycles of the fault inception. This normally includes zone-1 and pilot tripping and can be expected for 100% of faults on the protected line for a pilot system and 90% of the faults for a non-pilot system where the zone-1 reach is 90% of the protected line length. Should the time between fault inception and fault clearing be greater than 14 cycles then two records are captured, 16 cycles of fault inception and 16 cycles of fault clearing. Time-delayed tripping such as a zone-2 trip would be an example of a two-record event.

The following discusses the operation of the REL 512 digital fault recording function, how the DFR records are used to compute fault location and phase selection, related settings and expected test results.

Pre- and Post-fault (initiation) Data Requirements

Pre-Initiation Data

Correct fault location and faulted phase selection requires the use of prefault phasor quantities computed from a one cycle [period] of captured sampled data. It is necessary that the prefault samples have correct phase alignment with the fault cycle [period] of sampled data used in the calculation. The fault cycle used could be any cycle during the fault. The REL 512 uses the second fault cycle as a compromise between the fault inception and high-speed clearing transients.

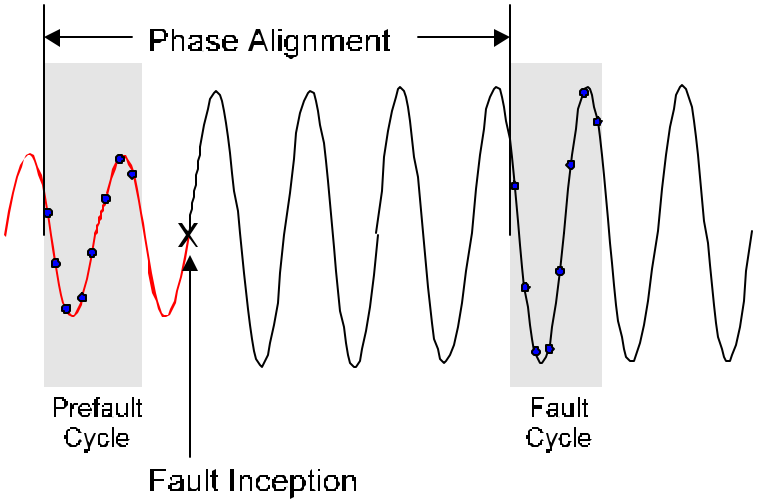

Figure 1 - Prefault and Fault Cycle Phase Alignment

Correct phase alignment requires that the two sample sets, prefault and fault, are taken from the same time points in their respective cycles. This is shown in Figure 1. If you were to start counting from one with the first prefault cycle sample up to and not including the first selected fault cycle sample and divide that number by the sample rate (samples/cycle), in this case 20, the remainder must be zero.

Post Initiation Data

It is desired to capture the fault for its full duration from inception through clearing and reclosing. Forty-five cycles is recommended for conventional DFR applications. For protective relays this is not always practical to do with one continuous record. Correct zone-1 tripping for microprocessor relays would be expected to be in the two to three cycles. This is typically followed by two to four cycles of breaker clearing. Therefore, a 7-cycle post-initiation data record is adequate for most zone-1 or other three cycles or less tripping function. One level greater would be to capture data for sequential tripping on the protected line. Sequential tripping is when a remote terminal clears a line end fault removing the end-feed and the local end responds to the system voltage and current changes (decrease of apparent impedance) and trips. An example would be a loss-of-load trip function where the remote end trips and the local end responds after remote breaker clearing. Considering that the trip logic and breaker trip will be sequential (one after the other) for the line terminal relays, 14 cycles of post-initiation data is collected by the REL 512.

For a zone-2 fault a record with pre- and post-initiation data can be recorded for the fault inception. The change detector drops out during the steady state fault, but will operate again for tripping or the breaker clearing at the end of zone-2 time. These will initiate a second record for this event. There is no real need for the interim steady state fault data between the two records except possibly as a means for maintaining time coordination. The REL 512 will time-tag the two records with less than 1.0 ms resolution providing excellent coordination for the two records.

Recording the Fault Record

The following is a scenario for a typical fault recording in the REL 512. Once the voltage and current change detection logic (FAULT INCEPTION DETECTOR logic signal) indicating a fault inception or system disturbance has asserted the two preceding cycles of prefault [initiation] data is captured and the post fault data for the next 14 cycles is collected. The fault impedance is calculated at each post-fault sample during the 14 cycles, and if determined to be within the reach of the forward or reverse pilot zones, the 16 (2 pre- and 14 post-fault [initiation]) cycle record is time-tagged and saved. Change detection is not required while recording, but after the 14 cycles (the end of the record) the change detector is monitored again. If there are no changes the fault has cleared the event is over. A typical single record event is shown in Figure 2.

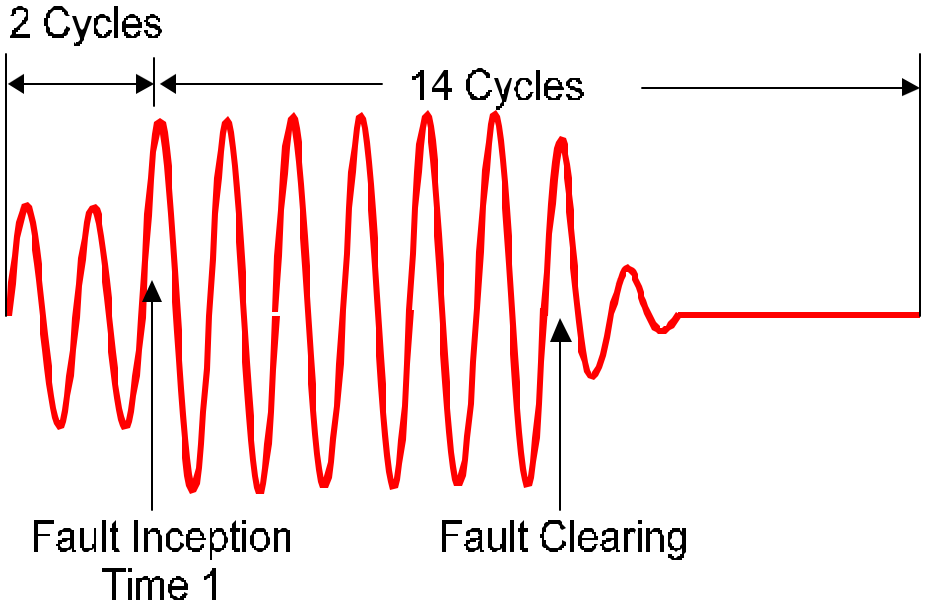

Figure 2 - Typical Single Record Event

If the faults still persist, such as a zone-2 fault, the change detector will not operate until fault clearing [or other interim disturbance]. At that time a second record for the zone-2 event is saved and time-tagged. A typical two-record event is illustrated in Figure 3. Both records are time-tagged and can be coordinated within 1.0 ms.

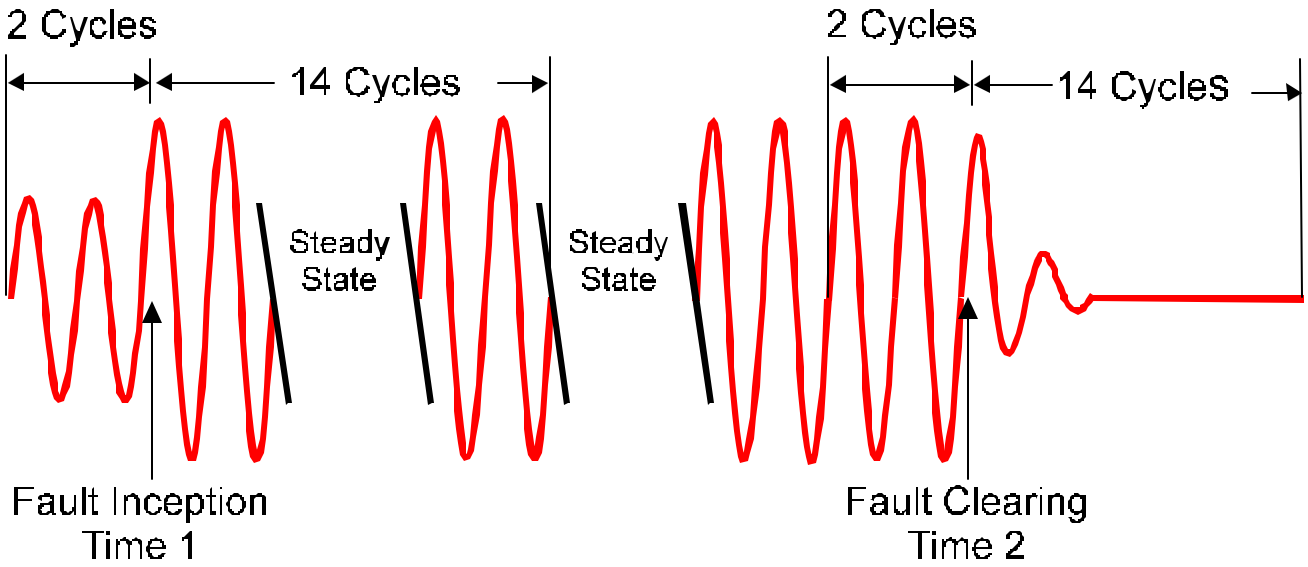

Figure 3 - Typical Two Record Event

Faulted Phase Selection and Fault Location

The saved fault records are used to compute the fault location and faulted phase selection which is displayed on the relay's front panel LCD user interface (UI) and LED's. Only records that include the fault inception can be used to compute accurate results. This requires distinguishing between fault inception and fault clearing records for the time-delayed trips with two record events. Fault inception records contain the true prefault and fault currents that are necessary for accurate computation. Fault clearing or tripping records contain fault and fault clearing currents that will produce erroneous fault location and phase selection results. The REL 512 avoids using the fault clearing records to provide the information displayed on the relay's front panel. In some very remote cases, however, it is unavoidable and erroneous information is displayed. Fortunately this only occurs during testing or possibly tripping for zone-3 or backup overcurrent trips for faults not on the protected line. The following provides information that is useful when applying or testing the DFR function.

Settings

The DATA CAPTURE setting defines what fault records are recorded and how the relay's front panel LED's are illuminated for faulted phase selection. The settings are DVDI, PILOT, and TRIP.

The DVDI setting captures all events triggered by the change detector logic signal FAULT INCEPTION DETECTOR. It operates for fault inceptions, fault clearing and evolving faults that are within the range of the change detector's sensitivity. A 7.0 volt change of any voltage and a 0.5 amp change of any current are required to assert FAULT INCEPTION DETECTOR which triggers and captures a record for this setting. This setting allows the recording of events very remote to the protected line. This can result in recording many undesired events that can rapidly fill the memory pushing out valuable data. It is recommended to

retrieve this data often to avoid data loss. Further, records for faults remote to the protected line will produce unreliable fault location and phase selection results due to other current feeding the fault from sources other than the relay location. This setting is only recommended for troubleshooting.

The PILOT setting requires that one of the forward or reverse pilot impedance units operate to capture a record. This restricts the area of fault data capture and meaningful fault location to the vicinity of the protected line. If a zone-1 or pilot trip occurs within 14 cycles after the fault inception then only one record is necessary to capture the event and display fault location data. If a time delayed trip occurs after the 14-cycle period, such as a non-pilot zone-2, then a second record of fault clearing is recorded. If the zone-2 fault is cleared by the remote protection and tripping does not occur, then one or two records of fault data are still recorded and fault location and phase selection computed and the information is displayed in the UI and LED's.

The TRIP setting allows capturing fault records and displays fault data the same as the PILOT setting except the LED's are not illuminated unless a trip occurs. However, records are saved and the UI is updated.

Operation

The logic signal FAULT INCEPTION DETECTOR is asserted when the voltage and current change as defined above. This signal will assert for fault inceptions, evolving faults and breaker clearing transients. It is not asserted during normal operating and steady state fault conditions. If this signal is immediately followed by the operation of any forward or reverse pilot impedance unit, then the record is saved and is recognized as fault inception data from which accurate fault location and phase selection can be computed and the LED's and UI updated. The fault data is also shown in downloadable fault record header information that is available from the computer terminal emulation interface. If any forward or reverse pilot unit is already operated when the FAULT INCEPTION DETECTOR signal is asserted, then the record is saved and is recognized as fault clearing data and is not used to compute the fault location and phase selection. In this case the fault location and phase selection results from the previous fault inception case are used for the LED, UI and fault record header information.

Application and Testing

As previously stated, faults remote to the protected line will produce unreliable fault location and phase selection results due to other current feeding the fault from sources other than the relay location. Therefore, accurate fault location and faulted phase selection can only be expected for faults on the protected line. The REL 512 limits the region of fault location coverage to the forward and reverse pilot zones with the DATA CAPTURE settings of PILOT or TRIP. This allows accurate fault information for any high-speed or time-delayed trips on the protected line. Generally, tripping of the relay is not expected for faults on adjacent lines unless there is a failure of the adjacent line's primary protection. If time-delayed tripping occurs for a fault outside the pilot region or if there is significant infeed to the fault location, then the fault information displayed on the LED's and UI will be unreliable. This should be considered when testing.

When testing with conventional test sets there are no infeed conditions to consider. However, the set reach of the forward pilot phase and ground impedance units will affect fault location and faulted phase selection results. Any test that does not operate any of the pilot impedance units is subject to error. It is, therefore, recommended to set the forward pilot phase and ground unit reaches to operate for all operating unit (zone-2, zone-3, backup overcurrent, etc.) tests where accurate fault location or faulted phase selection is desired.

Fault Records

Following is an example list of downloadable fault records that are accessed via the computer terminal emulation interface. The records were captured for a number of zone-1, zone-2 and zone-3 operations. They are accessed from the root menu's Retrieve Data menu option.

[1] Receive Fault Records from Relay
[2] Receive Settings from Relay

Fault Records

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[A] Record   0 Fri Sep 10 1999 12:25:18.239 Typ:A-B-C Loc:   3.40 Km
[B] Record  -1 Fri Sep 06 1999 10:24:50.717 Typ:A-B-C Loc:   4.40 Km
[C] Record  -2 Fri Sep 06 1999 10:24:50.130 Typ:A-B-C Loc:   4.40 Km
[D] Record  -3 Fri Sep 01 1999 15:14:10.750 Typ:C-G   Loc:   2.63 Km
[E] Record  -4 Fri Sep 01 1999 12:24:25.434 Typ:C-G   Loc:   2.62 Km
[F] Record  -5 Fri Sep 01 1999 10:44:17.869 Typ:C-G   Loc:   2.61 Km
[G] Record  -6 Fri Sep 01 1999 10:24:12.423 Typ:C-G   Loc:   2.63 Km
[H] Record  -7 Fri Sep 01 1999 09:56:06.423 Typ:C-G   Loc:   2.63 Km
[I] Record  -8 Fri Sep 01 1999 09:23:57.489 Typ:C-G   Loc:   2.63 Km
[J] Record  -9 Fri Aug 30 1999 12:28:26.793 Typ:B-G   Loc:   2.62 Km
[K] Record -10 Fri Aug 10 1999 12:20:07.989 Typ:A-G   Loc:   6.15 Km
[L] Record -11 Fri Aug 10 1999 12:20:05.782 Typ:A-G   Loc:   6.15 Km
[M] Record -12 Fri Aug 02 1999 16:17:51.684 Typ:C-G   Loc:   2.64 Km
[N] Record -13 Fri Jul 20 1999 22:17:19.195 Typ:B-G   Loc:   4.57 Km
[O] Record -14 Fri Jul 20 1999 22:17:18.619 Typ:B-G   Loc:   4.57 Km

Enter selection:
```

The impedance settings are zone-1 = 4.0, zone-2 = 6.0, zone-3 = 9.0 and the forward pilot zone =12.0. The zone-2 timers are set to 0.5 seconds and the zone-3 timers are set to 2.0 seconds. The fault distance parameters are set such that one ohm fault impedance is equal to one kilometer of fault distance. Records A, D, E, F, G, H, I, J and M are all single record events of varying fault types and are within zone-1. Records B and C comprise a two record event capturing a zone-2 time delay trip. Record C is the fault inception and record B is the fault clearing 0.587 second later. Records K and L comprise a two record event capturing a zone-3 time delay trip. Record L is the fault inception and record K is the fault clearing 2.2 seconds later. Records N and O are another two record event for a zone-2 time-delayed trip.

The LED and UI information are also part of the fault record. For a single record event the LED and UI information in the fault record will be as was displayed at the end of the event. For a two record event the LED and UI information in the fault clearing record will be as was displayed on the relay at the end of the event. This is the correct information. The LED and UI information in the fault inception record will be as was displayed on the relay at the start of the event if the DATA CAPTURE setting is set to TRIP. If the LED's and UI have been reset (cleared) then the information will be null as expected. Remember, this record was captured , processed and saved before the end of the event (no tripping has occurred) and the decision to illuminate the LED's has not been made yet. If the LED's and UI have not been reset then the information in the record will be the same as that displayed on the relay at the start of the fault. This may lead to confusion when analyzing the fault record, therefore, resetting the LED's after the fault is reviewed is always a good practice in both application and testing.

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