HOW CAN CURRENT DROPOUT AFFECT BREAKER FAILURE TIMING MARGINS?

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I. Introduction

City Public Service (CPS) is a gas and electric utility serving the City of San Antonio, Texas, and the surrounding Bexar County. In the spring of 1995, CPS had two unexplained disturbances involving the Spruce Power Plant. A one-line diagram of this facility is shown in Figure 1. The first disturbance involved a fault located a few miles from the power plant on the CP&L transmission line. Because the two lines share the same circuit breaker, this disturbance resulted in the loss of the Cagnon B transmission line. The second disturbance involved a fault on the Cagnon B transmission line, which similarly resulted in tripping the CP&L tie line. One of these faults, captured on a fault recorder, was a 40A peak (secondary) fault with near full dc offset. Although the breaker cleared the fault, the breaker failure relay operated and false tripped a tie line. These disturbances led to an investigation of the breaker failure relays involved.

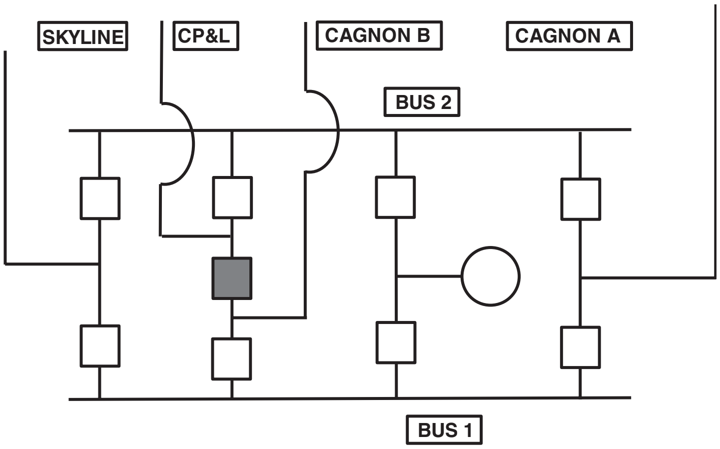


Figure 1. J. K. Spruce Power Plant One-Line

For many years CPS had been using electromechanical breaker failure relays in each of its transmission schemes. However, in recent years, CPS discovered two significant problems with applying these relays. First, normal load current in the transmission line kept the contacts in the breaker failure relay picked up and, consequently, would result in the contacts being stuck together. Second, the published dropout time of 34 ms was not desirable when required critical clearing time was short. For an understanding of this subject consider Figure 2.

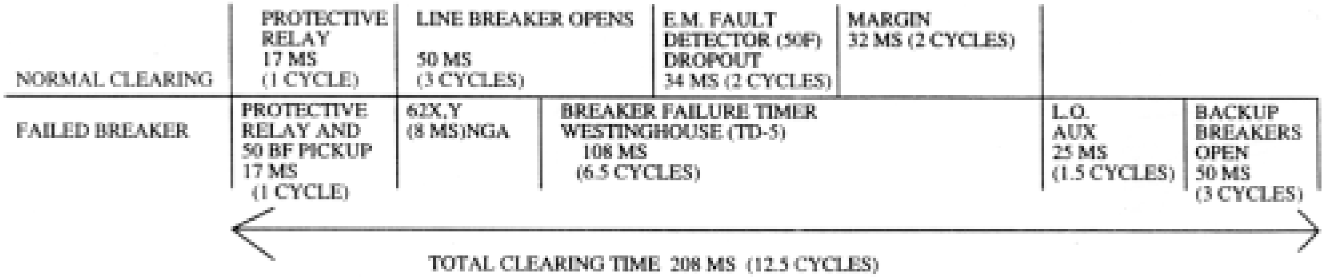


Figure 2. Typical 12 cycle Timing Chart (138kV)

The timing chart in Figure 2 reflects the timing sequence of 138 kV breakers at most substations in the CPS system. At the 345 kV CPS Spruce Power Plant, the required critical clearing time was calcultated to be 10 cycles. The recommended total clearing time was 9 cycles as shown in Figure 3. In order to achieve this total clearing time, it was necessary to purchase a breaker failure relay that had a short fault detector dropout time. The Basler BE1-50BF relay was selected because its instruction manual reflected a dropout time of less than 1 ms.

During relay commissioning, CPS adjusted the T1 timer by measuring the relay operate time from initiate contact input to output contact closure. Figure 3 indicates a total operating time of 67 ms, providing a perceived margin of 39 ms.

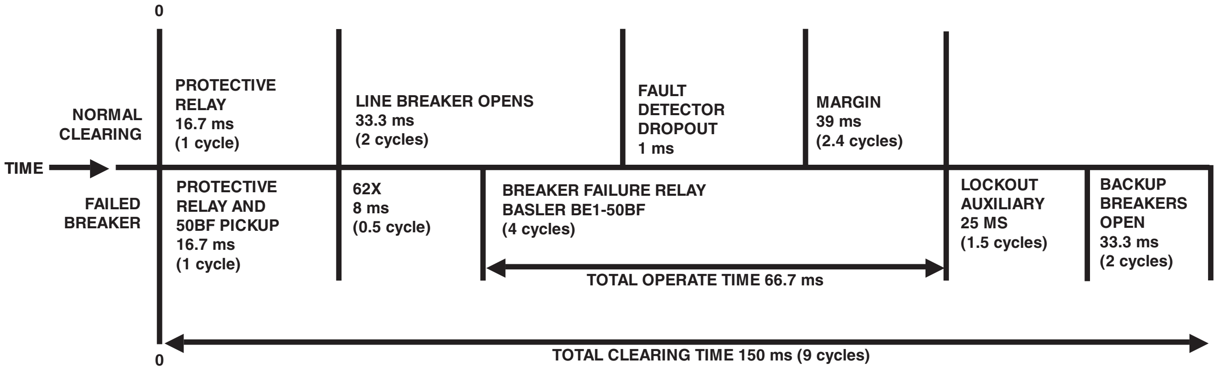


Figure 3. Typical 9 cycle Timing Chart (345kV at Power Plant)

However, the 67 ms total operate time includes contact recognition time, current detector pickup time, output relay time and T1 timer setting. From Figure 4, based on the required 9 cycle clearing time, the actual margin is reduced to 22.7 ms. Therefore, during the two disturbances described above, the current was maintained above the pickup setting for a time in excess of 22.7 ms after current interruption. This resulted in additional equipment being cleared from the bus.

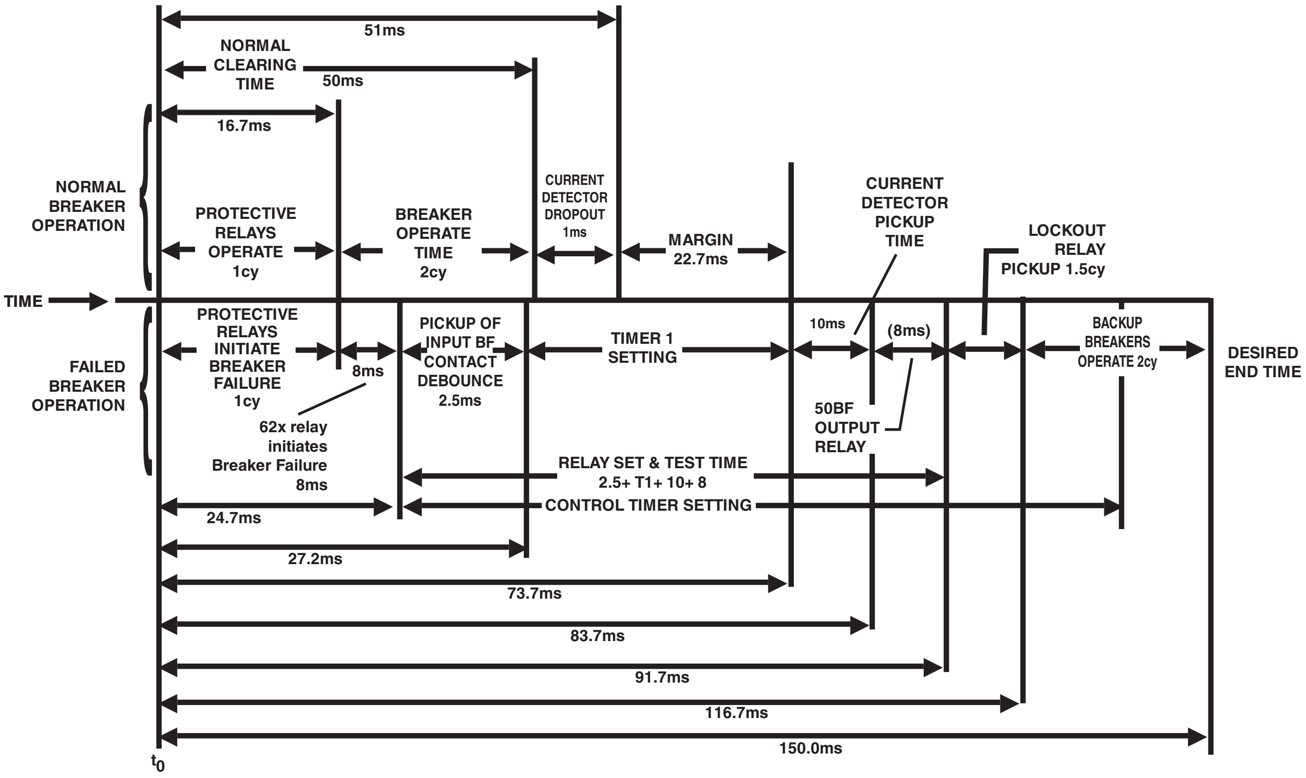


Figure 4. Actual 9 cycle Timing Chart

CPS was very fortunate at the time of one of these disturbances to have a fault recorder monitoring the breaker current. The data from this fault was captured and converted to a COMTRADE format which, in turn, allowed CPS to replay this data into the relay affected. In doing so, CPS discovered that the breaker failure relay was initiating a trip. This same data was used to inject a signal into several different Basler BE1-50BF relays with similar results. It appeared that even though the current to the relay had been interrupted, the relay was still operating. This data was then sent to Basler Electric for further analysis.

II. The Analysis

The COMTRADE file and several relays were sent from CPS to Basler Electric for analysis. Tests were conducted on these relays as well as a new unit from the production line. Tests included pickup and dropout verification with the COMTRADE signal and a 60 Hz signal from the test equipment. The COMTRADE signal, shown in Figure 5, was a fault of approximately 40 amperes peak current with almost full dc offset. This signal was scaled to fault magnitudes of 5A, 10A, 25A, 50A, and 60A. The pickup of the relays were set to nominal values of 0.5A, 1.0A, and 2.0A.

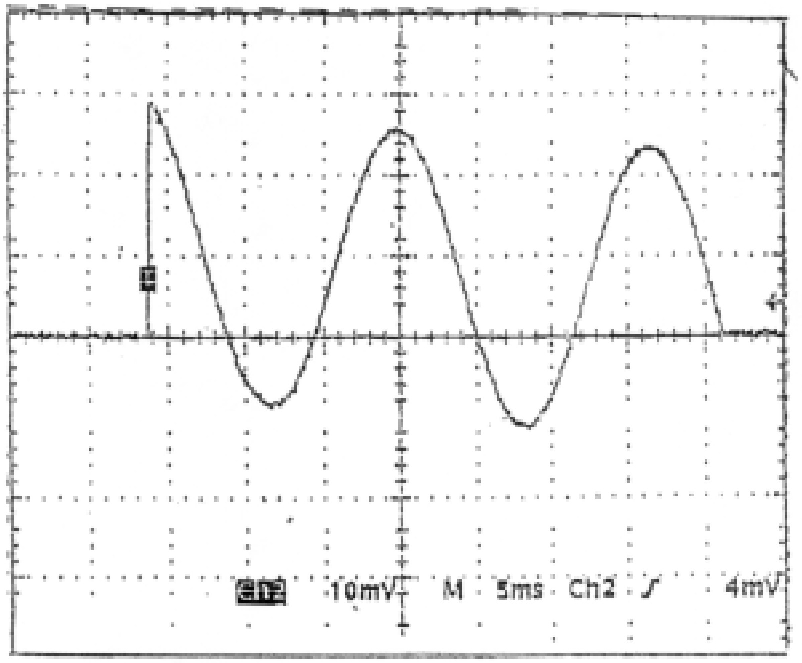


Figure 5. The COMTRADE Fault Signal Used for Testing

The Basler BE1-50BF relay was designed such that when initiated by an external contact closure, the continuous input current sensing and the timing sequence will function in parallel as shown in Figure 6.

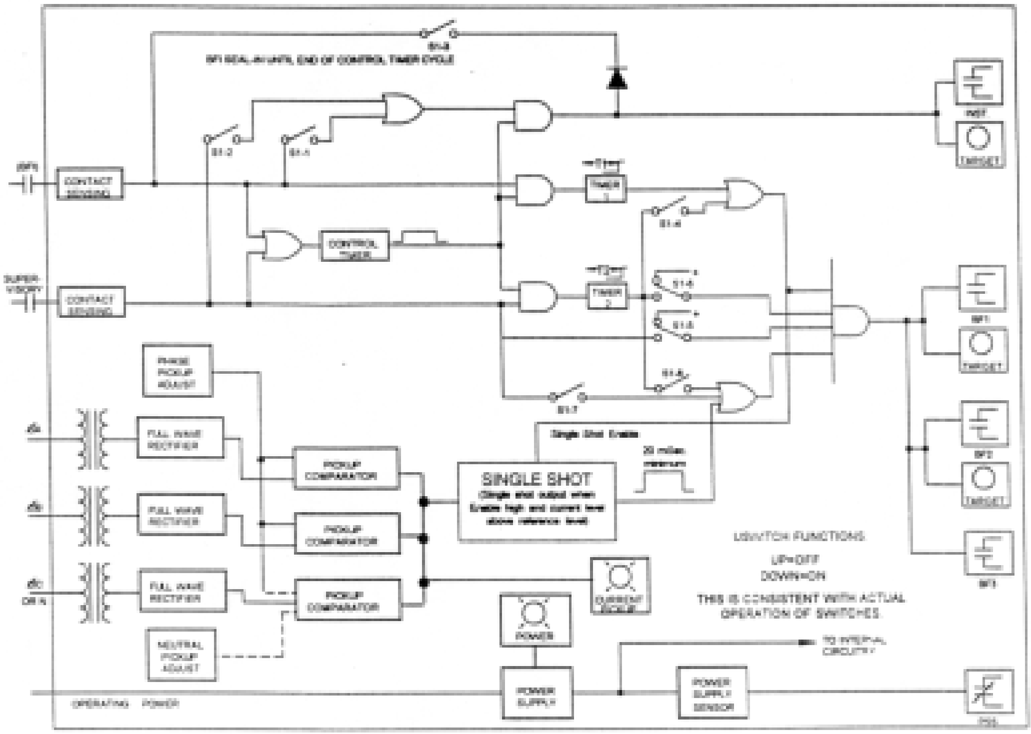


Figure 6. Block Diagram

The pickup comparator produces an output anytime the current signal is above the overcurrent reference setting. If an output occurs after T1 has expired and enabled the single shot, yet before the control timer has expired, the breaker failure output relay will be energized and will close its contact within 8 milliseconds after the single shot has operated. An output from the single shot depends on the relationship between its being enabled by T1 timer and the detection of the next current reference level crossing. This could add up to an additional 10 milliseconds to energizing the output relay. Figure 7 shows this time relationship for three different enable scenarios.

The response of the BE1-50BF to a 25A fault at 0.5A tap setting for the 60 Hz signal without dc offset and the COMTRADE signal with near full dc offset are shown in Figures 8 and 9, respectively. It is clear from these figures that without dc offset, the relay performs as expected with a dropout of less than 1 ms. However, when the signal with dc offset is applied, the dropout time increased to 30 ms as indicated in Figure 9.

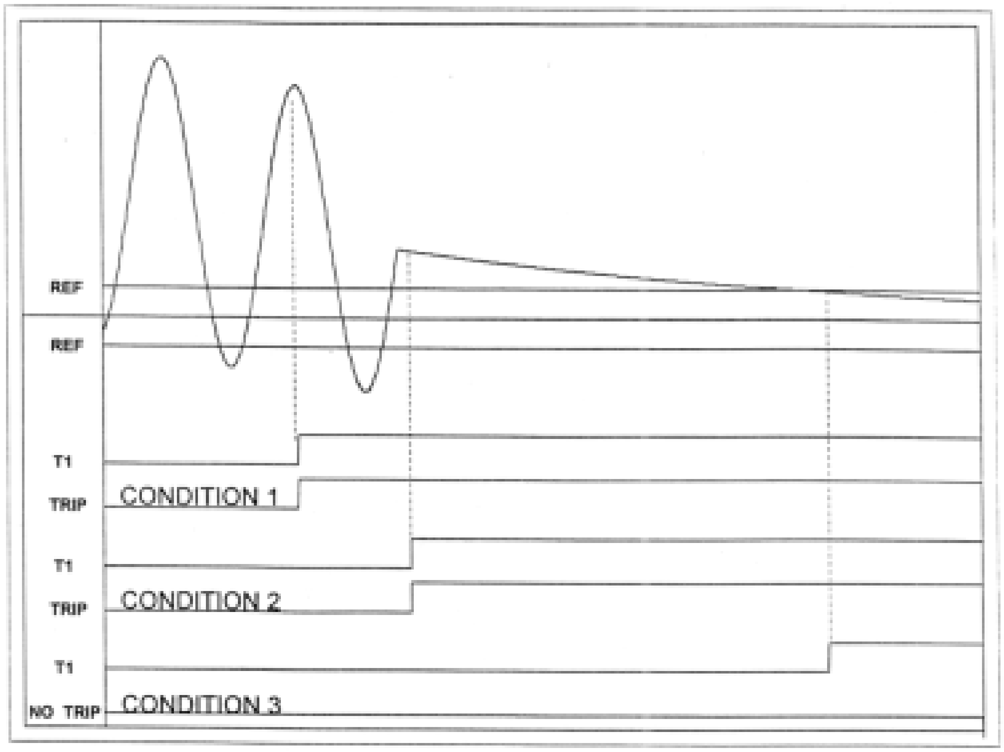


Figure 7. Timing Relationship Comparison

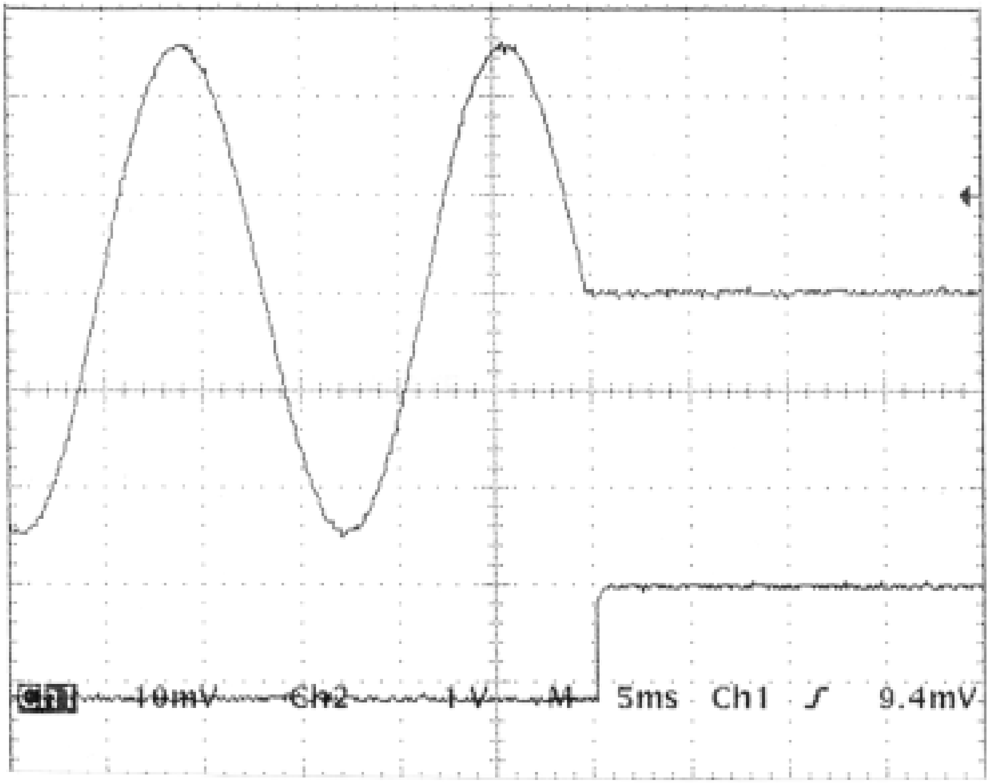


Figure 8. Relay Response with 60 Hz Signal without dc Offset

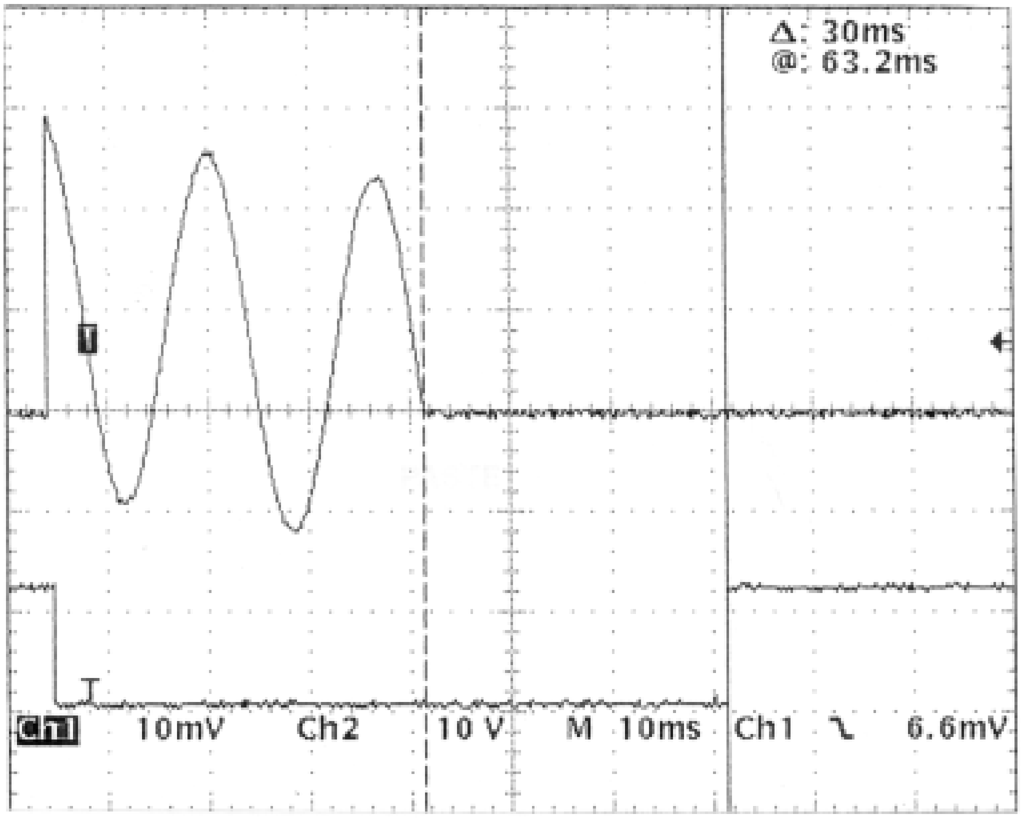


Figure 9. Relay Response with COMTRADE Signal with dc Offset

It is clear from an analysis of these two tests that the dc offset component of the fundamental fault current signal produced a magnitude at the secondary of the relay's input current transformers above the reference pickup setting. Under these conditions, if the timer delay, T1, expires after the fault current is cleared but before the signal in the ct secondary has decayed below the reference pickup setting, the relay would initiate a trip. This was the case at CPS where the margin did not allow significant time for reset under these conditions. This was the same problem that CPS was trying to avoid at locations where short critical clearing times were necessary.

Further tests using the COMTRADE signal revealed that the effect of the dc offset on the current reset time varied with the fault current magnitude and relay tap setting, as shown in Figure 10.

This data led us in two directions: 1) to determine a corrective design modification to reduce the dropout time of the BE1-50BF to as minimal as possible, and 2) to perform comparison testing against breaker failure relays from other manufacturers. The purpose of this comparison testing was to determine their response to dc offset.

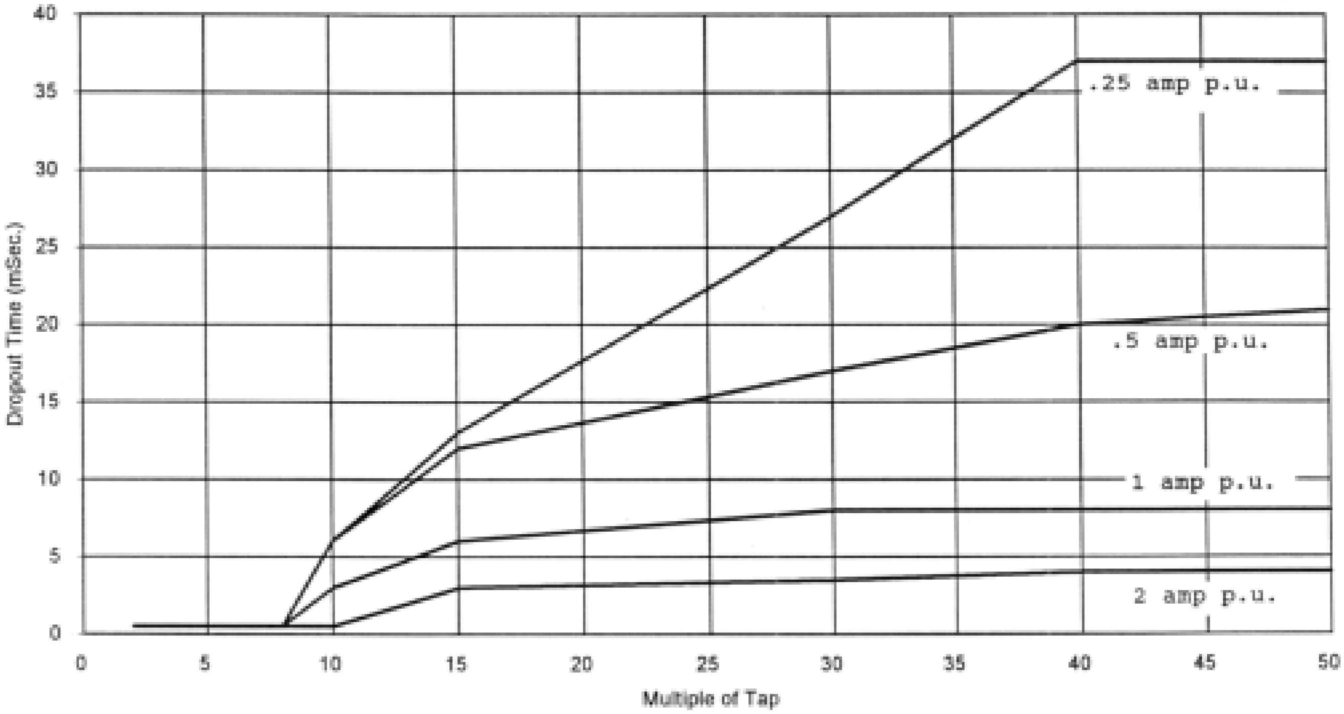


Figure 10. Reset Characteristics

III. Relay Design Modification

It is clear from the above analysis that current waveforms which include prominent dc offset can affect the timing margin in breaker failure protection schemes. To reduce the affect of the dc component in the BE1-50BF, it was necessary to modify the method of curent measurement to limit the time required for the dc component to decay.

As previously described, the single shot in the BE1-50BF relay produces an output when the current is above the pickup setting. This single shot device produces an output for currents going in either the positive or negative direction. To achieve the desired effect, modifications were made such that once the single shot is enabled by the T1 timer, a negative going edge is required from the current detector to provide an output. The negative edge will occur each time the input current level goes above the reference level in a positive going direction. If a dc tail is present, it will not be detected by the single shot because it will not cross the reference in a positive direction, as indicated in Figure 11. Therefore, current detector dropout is not affected by dc offset. This was verified by successfully playing the COMTRADE file into the modified relay design.

Figure 12 shows the addition of current comparators. The purpose of these is to detect both positive and negative going current waves to obtain faster operate time.

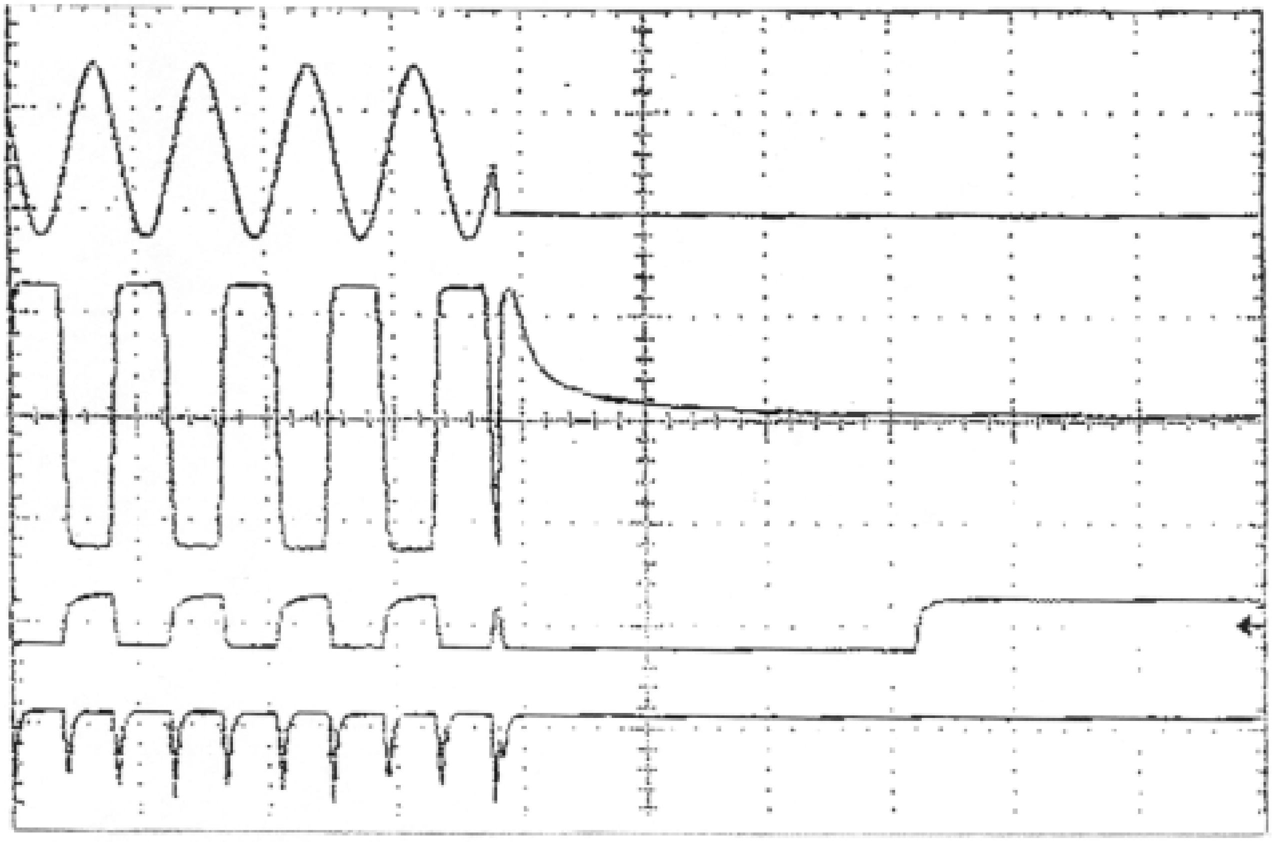


Figure 11. Modified Relay Reset Characteristics

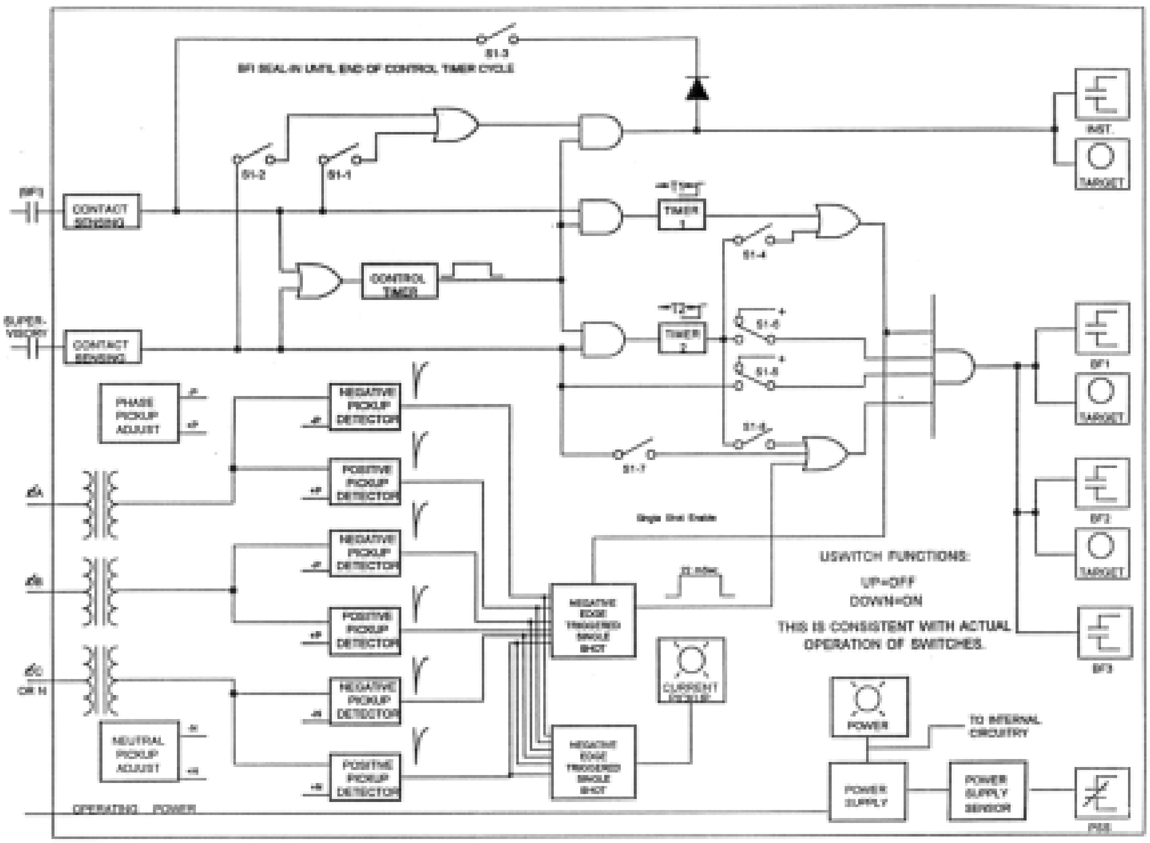


Figure 12. Modified Block Diagram

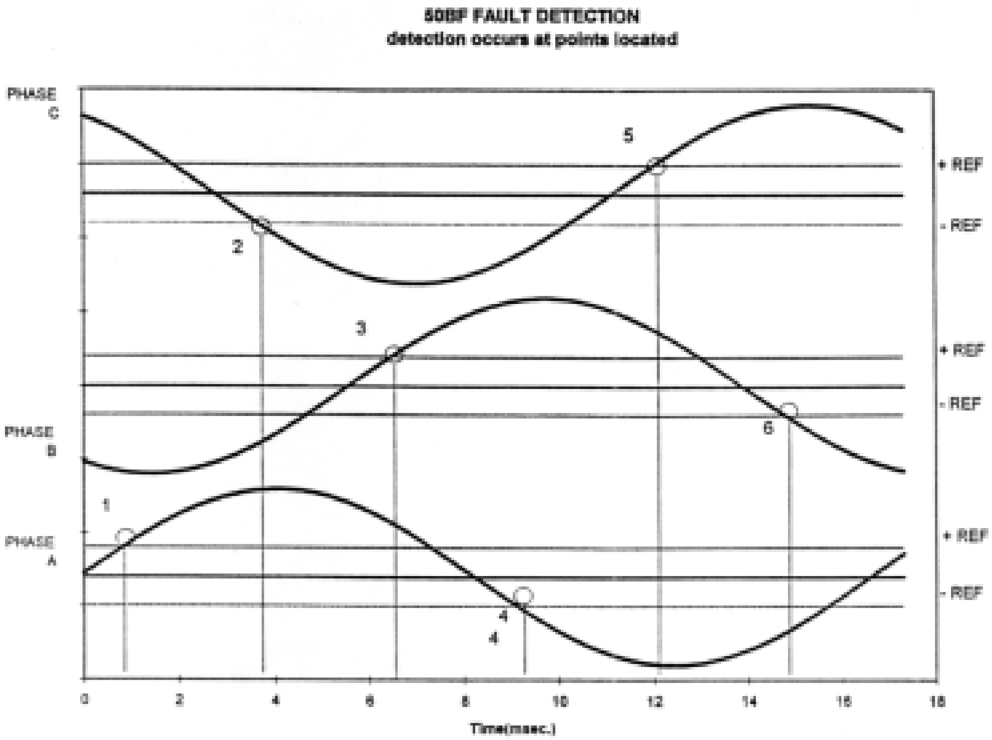


Figure 13. Three Phase Fault Detection Time

These comparators provide essentially full wave rectification of the current signals. For three phase faults where the vectors are 120 degrees apart, with both positive and negative pickup current detectors, the one shot will have the opportunity to detect current within 2.8 milliseconds or six times per cycle as shown in Figure 13. This results in a timing chart as shown in Figure 14. For a single line-to-ground fault, the detection will be within 8.3 milliseconds.

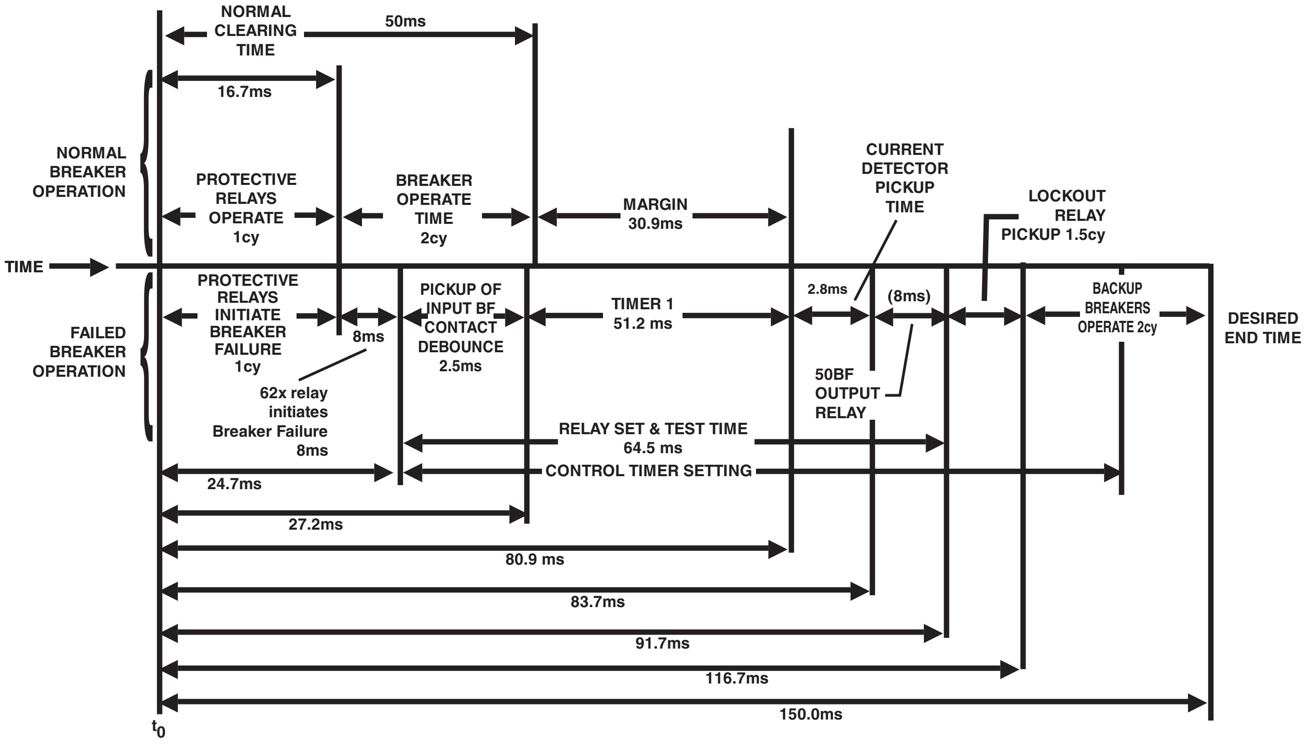


Figure 14. Time Chart for Three Phase Fault on Modified Relay

IV. Relay Comparison Testing

Dropout tests were performed on one electromechanical and two solid state breaker failure relays from three manufacturers. The purpose of these tests was to determine the relay's response to current waves containing significant dc offset. The tests were performed using scaled versions of the fault current waveform captured in COMTRADE format by CPS and a 60 Hz signal from the test equipment as described above. Similarly, the magnitude of both signals were scaled to fault levels of 5A, 10A, 25A, 40A, 50A, and 60A and the pickup of the relays was set to nominal values of 0.5A, 1.0A, and 2.0A.

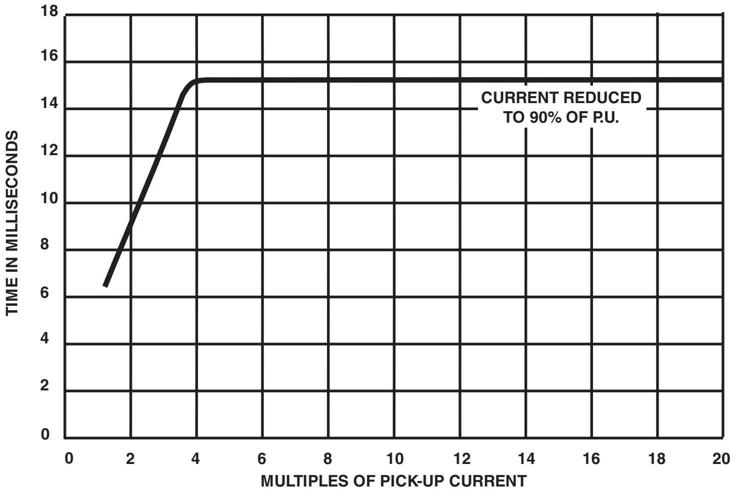


Figure 15. Typical Plotted Dropout Characteristic for Relay A and Relay C

A review of the instruction manuals for each of these relays gave varied dropout characteristic information. The dropout for Relay A and C are plotted curves with the decay time increasing for higher multiples of fault current similar to that shown in Figure 15. The dropout for Relay B was stated as “less than 1 ms”. In all three cases, there was no indication of the affect an input signal containing dc offset would have. A summary of the specified dropout times is shown in Table 1.

RELAY	RESET TIME (ms)
A	< 15 ms
B	< 1 ms
C	< 22 ms

Table 1. Published Reset Time (approximate)

The measured pickup of Relay A was .495, .986 and 1.86 amperes for the three tap settings of 0.5A, 1.0A and 2.0A, respectively. Channel 2 was connected to go high when pickup is detected. Relay B measured pickup values were .496, 1.00, and 2.00 amperes with Channel 2 low when the unit detects current pickup. And Relay C measured pickup values were .492, .990 and 1.96 amperes with Channel 2 high when the unit has the current detection output closed.

The timing measurement was made from the point at which the input current to the relay was removed until the decay of the current was recognized by the relay. The measurement point varied on the three relays because of design differences. The current signal was monitored at the point on the relay where the final trip decision is made before the output is triggered. This was the point where if the time delay had expired and the current was still above the reference point, the relay would initiate a trip signal.

For a comparison of all three relays with an input current void of any dc offset signal consider Figure 16. This figure shows that Signal 1 to the oscilloscope was the input current and Signal 2 monitored the point where the trip decision was made. In each case shown, a current magnitude of 25.0A was applied with a 0.5A pickup setting.

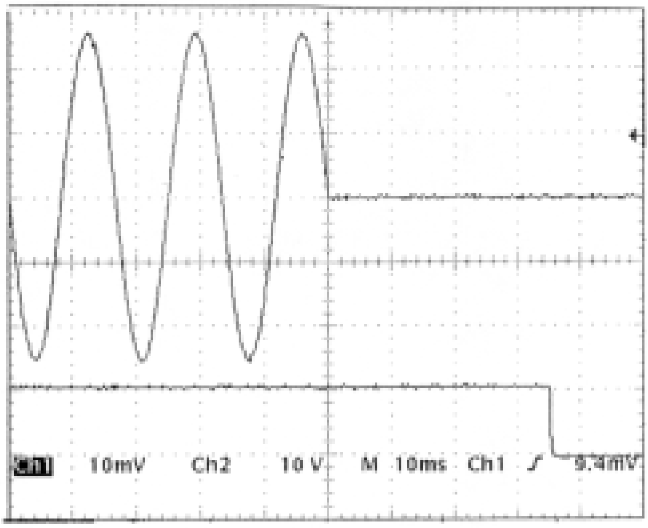


Figure 16. Relay A

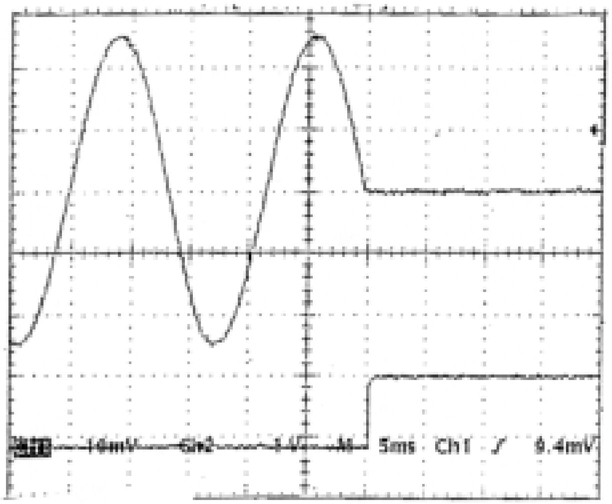
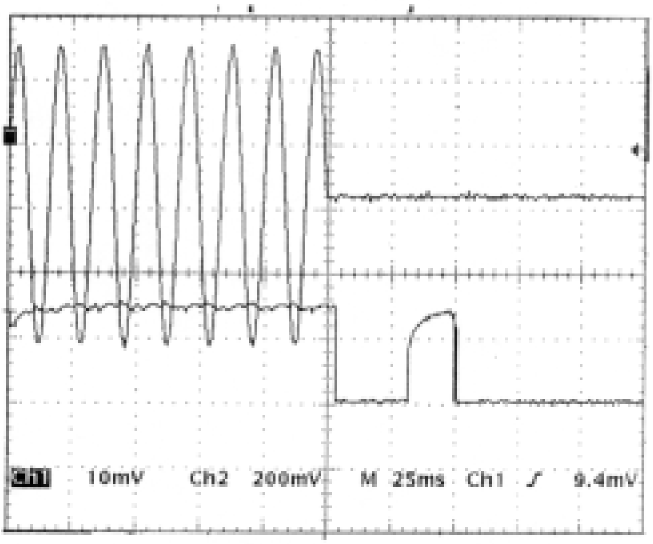


Figure 16. Relay B



Relay C

Figure 16. Decay Time Measurement Without dc Offset

From this test you would expect that all three relays would perform within the specifications stated in their respective instruction manuals. Relay B did, in fact, dropout within its stated characteristic of less than 1 ms. Relay A, however, did not dropout until approximately 35 ms, more than twice its stated dropout time. Relay C initially dropped out within 5 ms, then picked up again at 30 ms. It produced final dropout at 50 ms. This phenomena was attributed to contact bounce and was consistant with all fault levels and tap ranges for this relay. However, at the higher tap and fault levels its affect was less pronounced. The results for all three relays remained consistent at all tap settings and fault current magnitudes tested.

Figure 17 shows a comparison of the three relays' response to the COMTRADE signal with dc offset. These curves consider a 25 ampere fault with a tap setting of 0.5 ampere. It is clear to see that the decay time of all three relays increased substantially. Relay A remained consistent at about 35 ms. Relay B increased to 30.6 ms. Relay C again exhibited a similar response as noted above. The unit reset initially within just a few milliseconds. However, approximately 25 ms later the output reenergized and remained active until 51.6 ms after removal of input current.

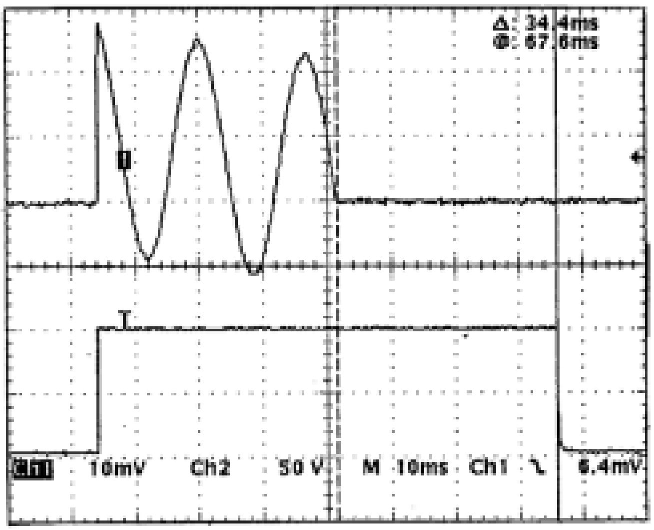


Figure 17. Relay A

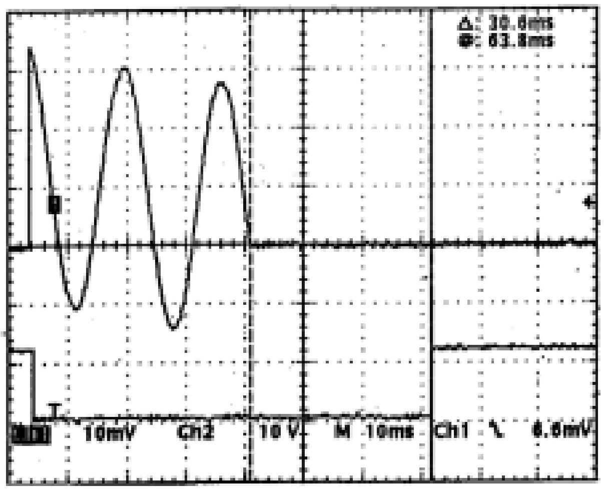
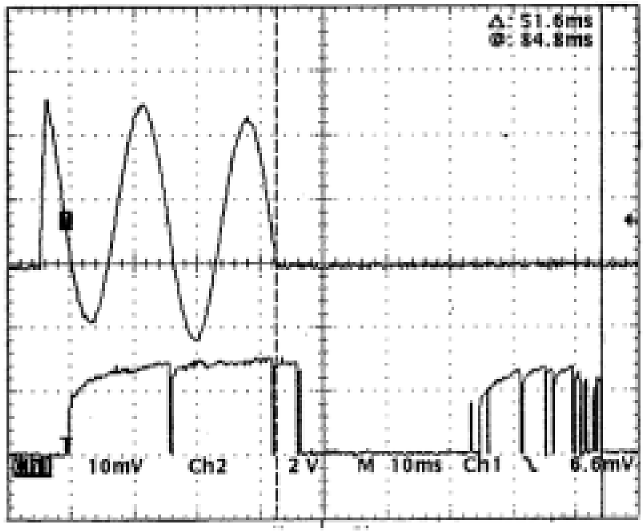


Figure 17. Relay B



Relay C

Figure 17. Decay Time Measurement With dc Offset

Table 2 is a compilation of the test results which shows that dc offset in a current wave will cause a relay to respond in a different manner than a pure 60 hertz sine wave. The measured response was generally different than the published response times. Also included in Table 2 is the measured values for the modified BE1-50BF relay (Relay D).

RELAY	PUBLISHED RESET TIME	ACTUAL RESET TIME WITH NO dc OFFSET	ACTUAL RESET TIME WITH dc OFFSET
A	< 15 ms	35 ms	34.4 ms
B	< 1 ms	< 1 ms	30.6 ms
C	< 22 ms	5 ms + 19 ms	5 ms + 21.6 ms
D	0 ms	0 ms	0 ms

Table 2. Comparison of Reset Times

VI. Conclusion

Current decay time can be extremely important in applying breaker failure protection. The affect of dc offset on relay dropout time should be considered for the specific relay and location in which it is to be installed. This is especially true where maximum margin time may be in the two to three cycle range. As illustrated in this paper, dropout characteristics most likely will vary between relay designs. It is important to understand how these differences will impact the timing coordination of your application.

Waveforms which include dc offset function to maintain the current above the pickup level of the relay's fault detector. When the system X/R is high, such as in the vicinity of generating plants, the affect of dc offset can be more pronounced, thus possibly extending the dropout time of the fault detector. These isues should be considered in applications where the timing margin is set to a low value. If the breaker failure relay is located where the critical clearing time is longer, or is located away from plant generation, where the X/R is lower, dc offset will most likely not be an issue.

Figure 14, which shows the final timing chart, emphasizes an important fact. When a breaker failure relay is being set and tested, the quantities being tested should be examined carefully. Figure 14 shows the different elements to consider during testing which involves injecting an input current and measuring the time from the point of the initiating contact closure until the output contact closes. In this case, the setting value of the T1 timer is different from the total operate time being tested. Even if the T1 test point on the relay front is used, the input contact recognition time of 2.5 ms must be subtracted from the T1 tested value to derive the actual T1 setting. If these factors are taken into consideration, there should be no problems in properly setting and coordinating the breaker failure relay.

The captured fault disturbance on the CPS system allowed the analysis of the various relays described in this paper. By converting the waveforms into the COMTRADE format and injecting them into the relays, we were able to analyze relay operation under actual system conditions. Through this analysis, an improved design which eliminates the affect of dc offset was developed for the Basler BE1-50BF relay. This new design reduces the dropout time to zero, thereby allowing closer timing margins.

Author Biosketches

John A. Brogan received his BSEE with Honors from the University of Texas at Austin in 1972. He received his MS in the power field of Electrical Engineering from Ohio State University in Columbus, Ohio in 1973. John has worked for City Public Service in San Antonio for 22 years. He has worked in Underground Network Design, System Operations, Construction, Substation Design and System Protection. John is currently a Senior Engineer in charge of the System Protection Section at CPS. He is a senior member of IEEE and a past chairman of the IEEE Central Texas Power Socity and a past chairman of the IEEE Central Texas Section. John is also a member of TSPE, E.t.a. Kappa Nu and Tau Beta Pi. He is also a registered engineer in the State of Texas.

Gerald R. Dalke received the Associate Degree in Electrical Technology from Oklahoma State University, Stillwater, Oklahoma, in 1960. Upon graduation he was briefly employed in Odessa, Texas, as a Relay Technician with Texas Electric Service Company. Gerald worked for Oklahoma Gas & Electric Company in various positions associated with system protection from January 1961 until retirement July 31, 1994, as Supervisor of Relay and Control Engineering. he became a Registered Professional Engineer in the State of Oklahoma in 1982. Present employment is with Basler Electric Company as a Regional Application Engineer. He is presently a member of the IEEE Power System Relaying Committee and Texas A&M Protective Relay Conference Planning Committee. Gerald has previously presented papers at the Texas A&M Protective Relay Conference and the Missouri Valley Electric Association Engineering Conference.

Norman T. Stringer received his B.S. degree in Electrical Engineering from the University of Texas at Arlington in 1982 and his MBA in Engineering Management from the University of Dallas in 1985. His professional career began with TUElectric, where he was an Engineer in Power System Protection. After nine years with TUElectric he served as a Regional Technical Manager at ASEA Electric, where he was responsible for applications support of all transmission and distribution products. in 1989, he moved to Brown & Root USA, Inc. in Houston as a Senior Engineer in the Engineering Technical Services Group. In 1991 he joined Basler Electric as an Applications and Sales Manager for the Utility Products Division. In 1995 he became the manager of the Sales and Technical Support Divison. Mr. Stringer is a member of the Power Engineering and the Industry Applications Societies of the IEEE. He is actively involved in the I&CPS Department of the IAS. He serves on several committees including: Chairman, I&CPS Awards & Recognition Committee, Power System Protection Committee; Chairman, Medium-Voltage Protection Subcommittee, Protection and Coordination Subcommittee; Chairman, Chapter 14 and Co-Chairman, Chapter 4, IEEE Standard 242 (Buff Book); and a member of the Refining Subcommittee of the Petroleum and Chemical Industry. Mr. Stringer is a Registered Professional Engineer in the State of Texas.

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