CHARACTERISTICS OF DISTRIBUTION FAULT AND INRUSH CURRENTS

by

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Characteristics of Distribution Fault and Inrush Currents

In 1978, the Electric Power Research Institute (EPRI) started a project to acquire records of the currents and voltages associated with faults on distribution feeders. An analysis of the records would provide information of particular use to protective relay engineers and distribution engineers charged with the responsibility for system design and distribution equipment application.

Power Technologies Inc., under contract with EPRI to perform this project, arranged with 13 utilities in various parts of the United States to install recorders that would record the voltages and currents during faults. In addition, it was also planned to record the voltages and currents when circuit breakers were reclosed following an outage to characterize inrush and cold load pickup currents.

For various reasons, including cost and the environment in which the recorder was to be used, a new recorder, the ERDAC 1600, was developed as part of this project. The recorder was designed for unattended use indoors or on poletop with a rechargeable battery to keep it operational during power outages. The current and voltage inputs are sampled digitally to provide a maximum frequency response of 10 kHz with a full scale accuracy of ±3% and stored digitally on a cassette tape. The sample rate schedule, shown in Figure 1, was selected to sample at rates appropriate to the frequencies expected at various times during fault or cold load pickup events.

The tape cartridge has storage capacity for eight fault events or four combination fault-cold load pickup events. Because each fault event consists of the initial fault plus three no-hold reclosings, for a total subevent capacity of 32, it was felt that no data would be lost because of storage overflow between the monthly tape replacement intervals.

Fifty recorders were deployed among the 13 utilities at locations shown in Figure 2. The monitored feeders were supplied from substations having transformer capacity from 2 to over 400 MVA and available symmetrical fault currents ranging from 1 to over 17 kA. The feeder line to line voltages were

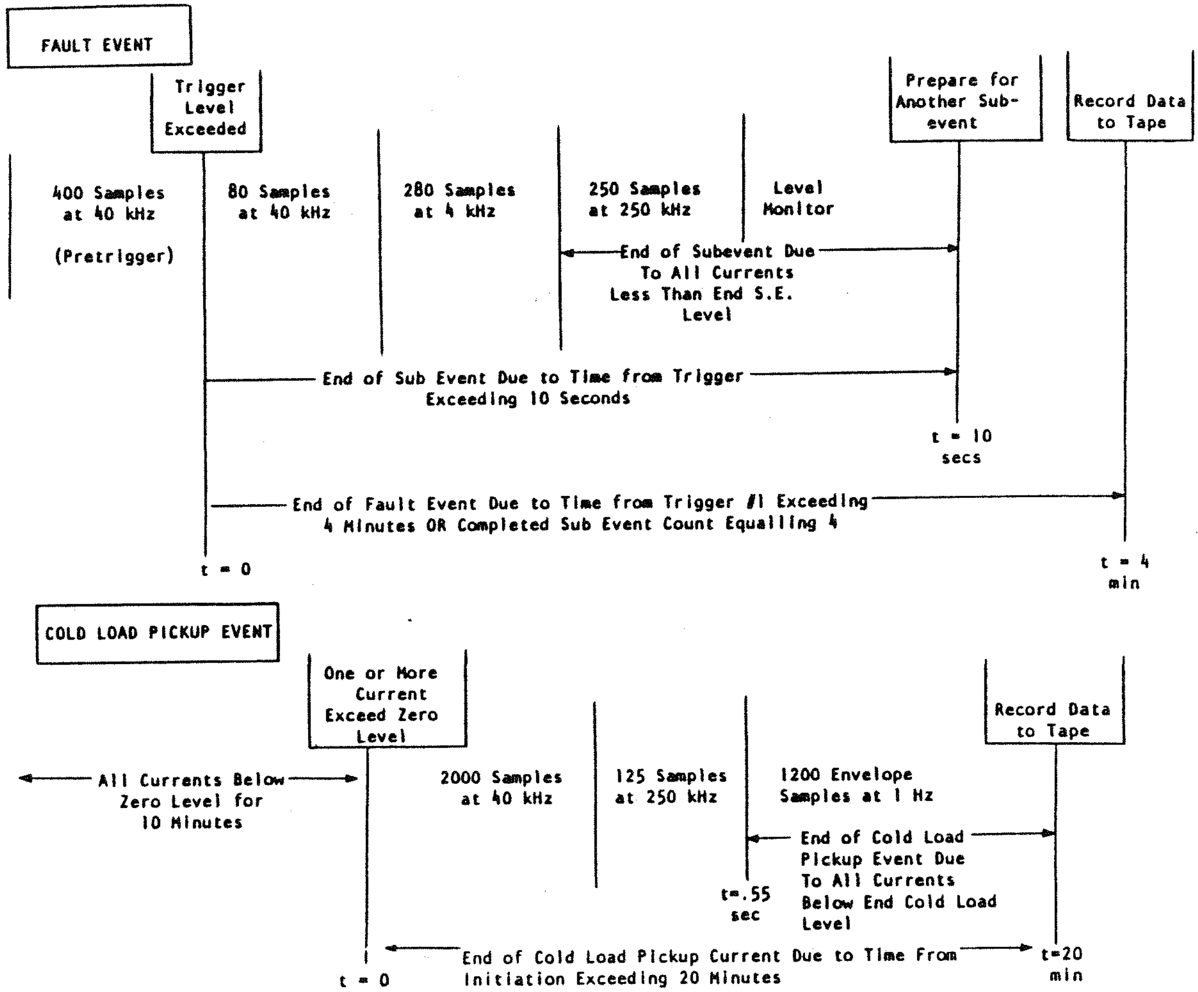

Figure 1. Sequence of Recorder Operation

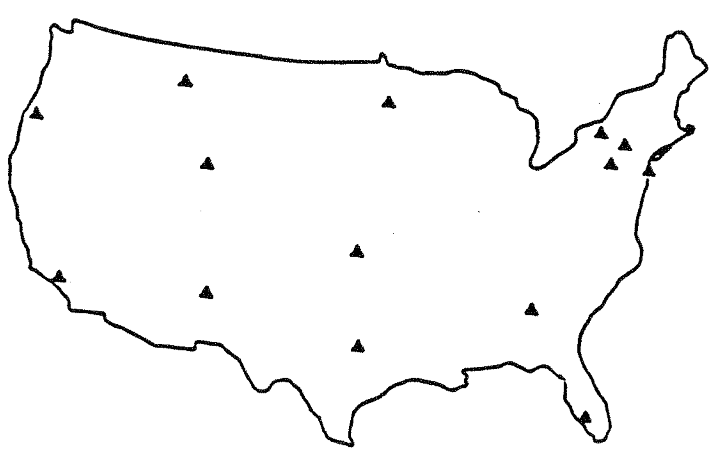

Figure 2. Geographical Location of Feeders

predominantly 12-13 kV, but covered a range from 4 to 35 kV, most of which were grounded wye. The load character of the feeders varied from industrial/urban to rural. Feeder length varied from two to 125 circuit miles, most of which were aerial lines.

The participating utilities not only submitted general feeder information, from which the above data was taken, but they also sent in detailed questionnaires that described the conditions surrounding each fault on the monitored feeders. The record tapes were replaced monthly and sent in for analysis.

Two data bases were established, one containing data taken from the questionnaires, the other containing data taken from the tape recordings. The data from each base was statistically categorized separately, then corresponding data from each base was compared when it was possible to do so. All data is fully described in EPRI EL-3085, from which I have extracted the major electrical aspects of faults for this presentation.

The data taken from over 250 fault report questionnaires provides substantial insight into distribution system operation during and after faults. Table 1 contains performance statistics of the overcurrent protective system.

Table 1
OVERCURRENT PROTECTIVE SYSTEM PERFORMANCE

	NUMBER OF RESPONSES	PERCENT YES	PERCENT NO
Did feeder relay operate?	210	51.4	48.6
Did relay and/or breaker operate properly?	122	96.7	3.3
Did relay operate to lockout on temporary fault?	99	3.0	97.0
Did line recloser clear the fault?	201	5.0	95.0
Did line recloser coordinate properly with load side device?	15	80.0	20.0
Did sectionalizer clear the fault?	199	1.5	98.5
Did sectionalizer operate properly?	8	87.5	12.5
Did a fuse clear the fault?	237	87.8	12.2

Table 1 (continued)
Relay Targets Noted After Faults

Type	Number of Cases	Percent None	Percent Phase Targets	Percent Ground Targets
Instantaneous	101	21.8	15.8	62.4
Time Delay	83	56.6	22.9	20.5

This information shows that the overcurrent protective system performs well. The apparent discrepancy between breaker clearings and fuse clearings is explained by the fact that permanent faults on laterals were frequently cleared by fuses after the circuit breaker reclosed. Figure 3 shows the distribution of faults by type. This confirms the widely held belief that about 80% of all faults are single phase faults. Outage times are shown in Figure 4. Note that these are shown for hourly intervals, meaning that 39% were less than one hour, and so forth. The 39% therefore includes successful reclosings where outages were very short, as well as interruptions that lasted as long as 59 minutes.

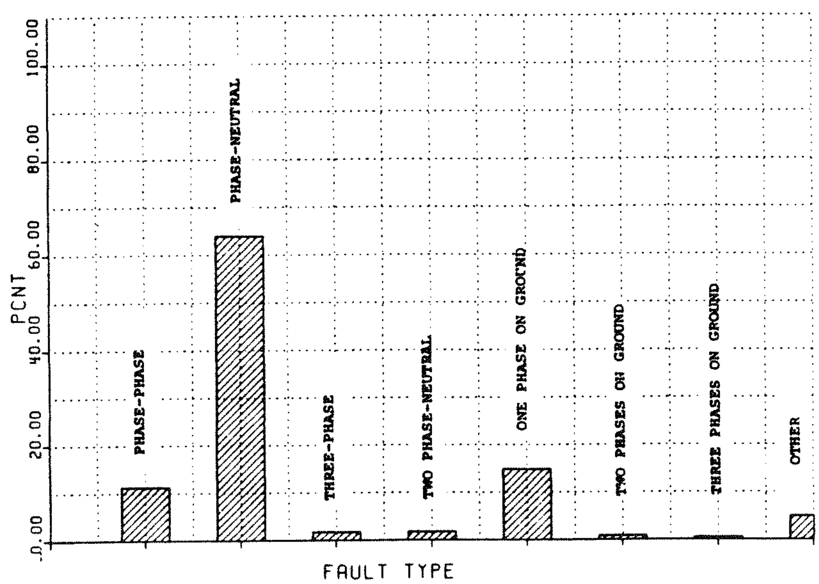

Figure 3. Distribution of Faults by Type

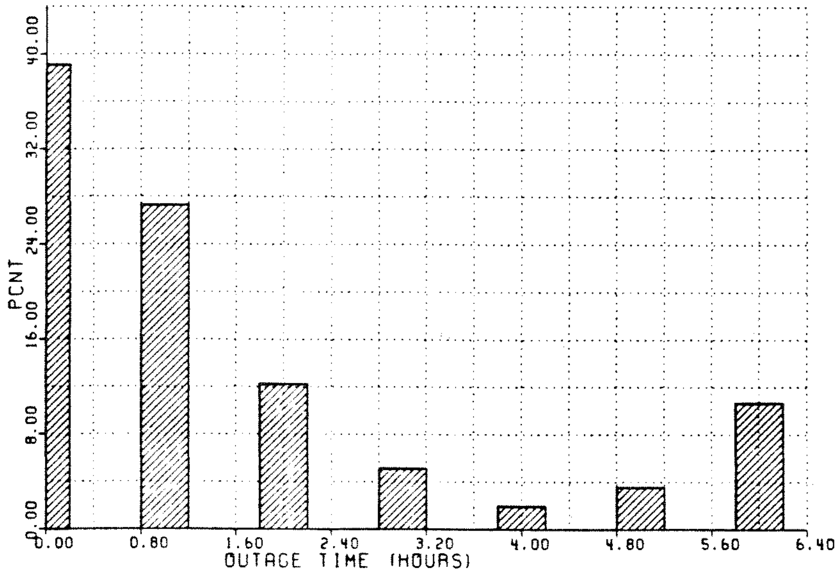

Figure 4. Distribution of Outage Time

The recorder developed for this project recorded the three line voltages and three lines currents simultaneously during each event. In addition, the three currents were processed internally to provide a record of the zero sequence current.

Figure 5 shows an A and B phase to ground fault, caused by lightning, plotted from the tape recording. Time is plotted by data sample rather than actual time to see the detail afforded by the fastest sampling rate. The 400 pretrigger samples and the following 80 samples at the 40 kHz rate show the first 12 ms (approximately 3/4 cycle) in detail. The next 280 samples at 4 kHz span 70 ms, and the four cycles are readily observed. The succeeding sampling rate of 250 Hz does not permit visual resolution on this type of a plot, so only a series of squiggles can be seen. The total time was 7 cycles, and the breaker reclosed automatically and held.

Similar records were obtained for steady state conditions, inrush events, that is when breakers were reclosed after a tripping, and cold load pickup after the breaker had been open for at least ten minutes. Analysis of these records provides a wealth of detailed information. For example, Figure 6 is the plot of the frequency analysis made of the portion of the B phase voltage enclosed by the box in Figure 5. It can be seen that the line voltage contains substantial high frequency components during this 2 ms period.

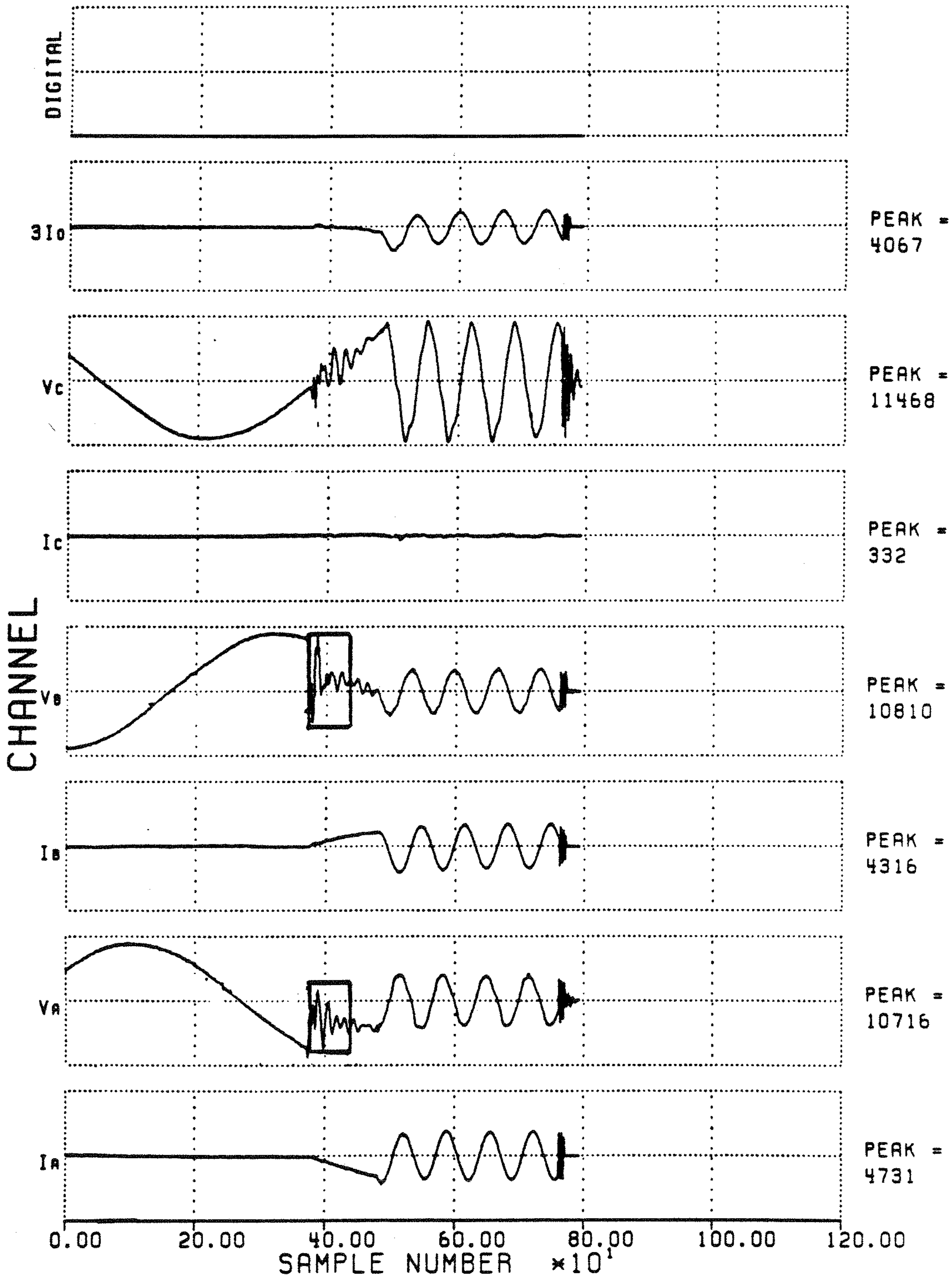

Figure 5. Typical Plot of Recorded Fault

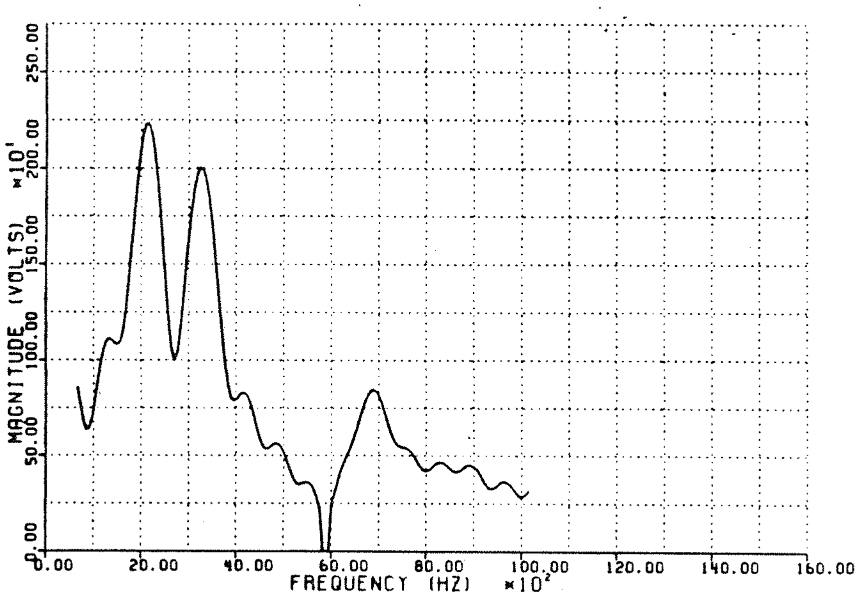

Figure 6. Harmonic Analysis of B Phase Voltage in Figure 5

Of great interest, of course, are the magnitudes of fault currents. As noted earlier, the participating utilities submitted detailed information about each fault, including the calculated magnitude. The distribution of calculated phase to ground magnitudes is shown in Figure 7. Note that almost 30% of the faults fall in the 800 or less ampere range. In Figure 8, the distribution of the measured fault currents shows far fewer faults in the 800 or less range

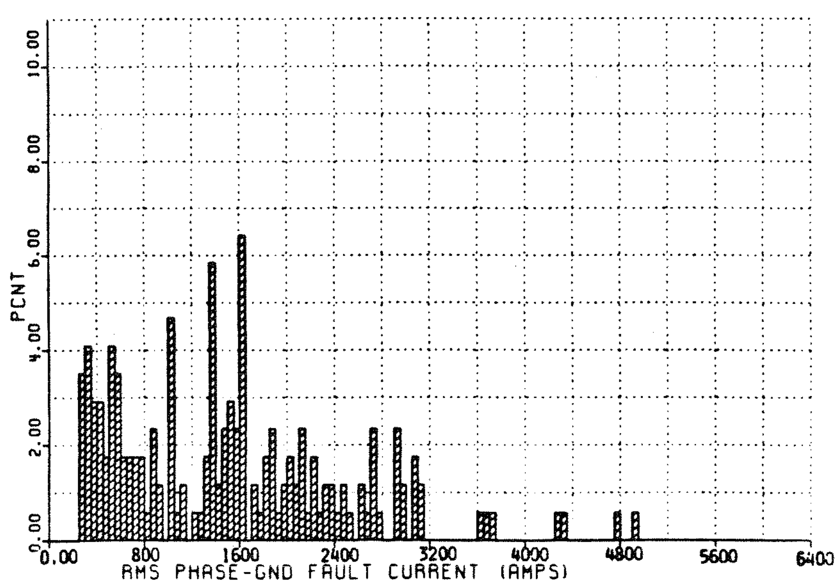

Figure 7. Distribution of Calculated Ground Fault Current

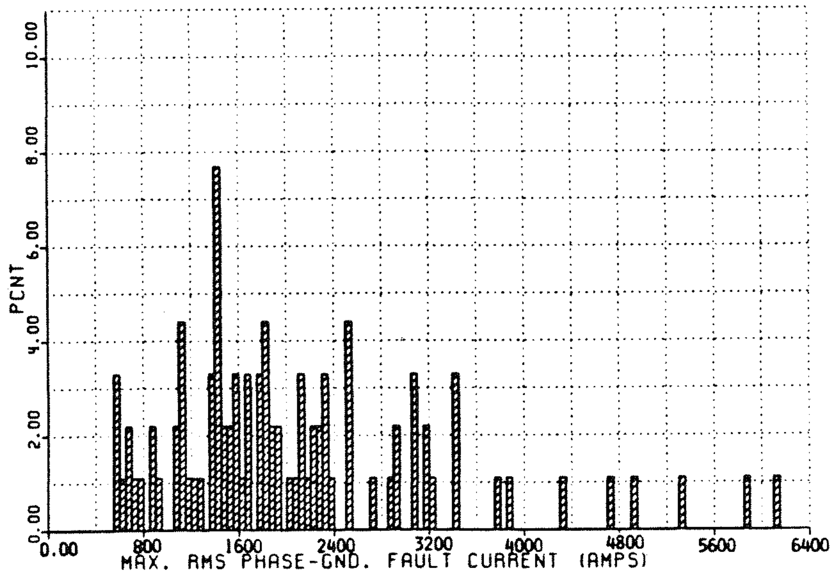

Figure 8. Distribution of Measured Ground Fault Current

primarily because the recorder trigger level frequently had to be set higher than that to avoid nuisance triggers due to transients or high load currents.

It is interesting to note the recorded phase to ground fault current as percent of maximum available, Figure 9. In no case was maximum available fault current experienced, and there is noticeable clustering in the 20 to 40% range. The reference maximum available current is the three phase bolted fault current at the substation.

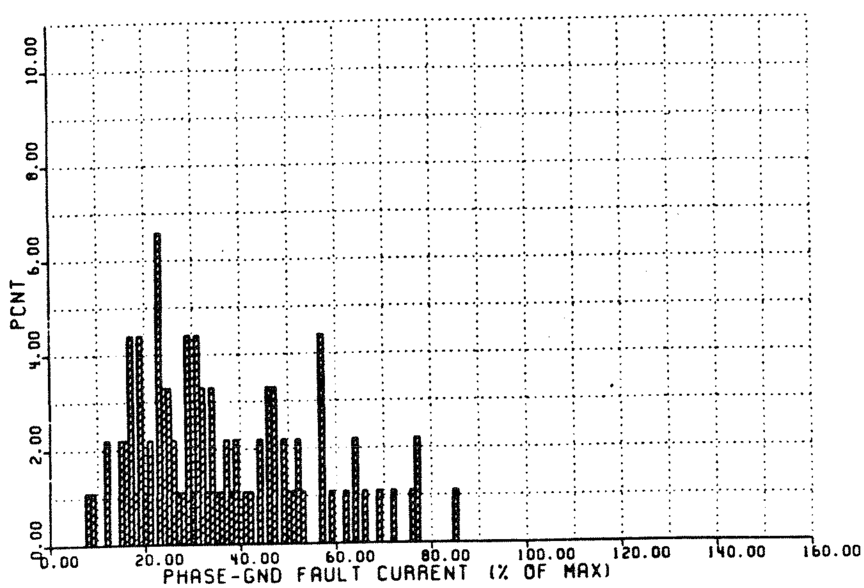

Figure 9. Distribution of Measured Ground Fault Current Related to Available Current

Of the 120 fault events captured on tape, only 27 could be positively correlated with fault data questionnaires. Figure 10 is a plot of the actual and calculated currents for these cases. Some of the cases where the actual

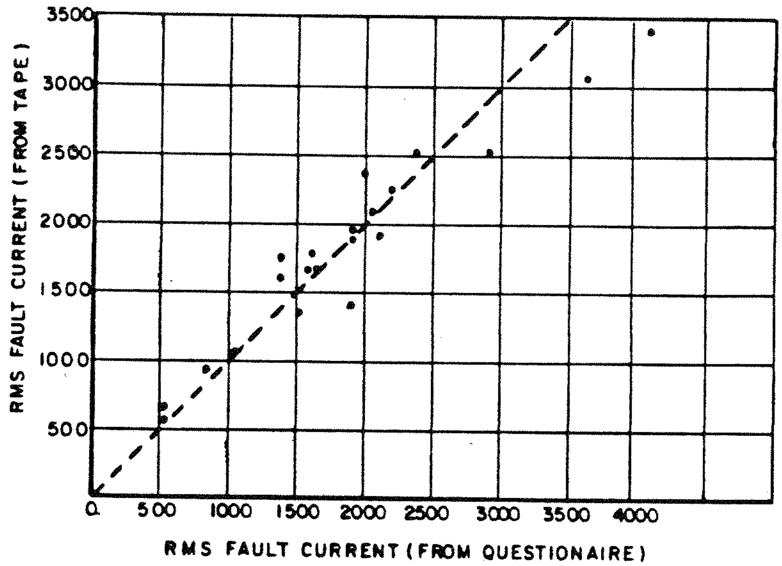

Figure 10. Actual vs Calculated Fault Current

current is greater than the calculated can be attributed to the fact that the actual voltage was greater than the nominal voltage usually used to make the calculation. For the cases where the actual current was lower, there must have been some fault resistance if it is assumed that the parameters used to make the calculation were correct. The apparent fault resistances are mostly in the 3 to 5 ohm range, but in two cases, 9 ohms is required.

The statistics in the following figures are of interest in the application of fault clearing equipment. Figure 11 shows the number of circuit breaker operations per fault. Note that in some cases the fault was cleared downstream, thereby not requiring circuit breaker operation. Figure 12 shows the distribution of phase to ground fault durations.

The very low durations are accounted for by fuse operation. In the case of breaker-cleared faults, the duration is the total of the first trip plus reclosings, thus accounting for the very large durations.

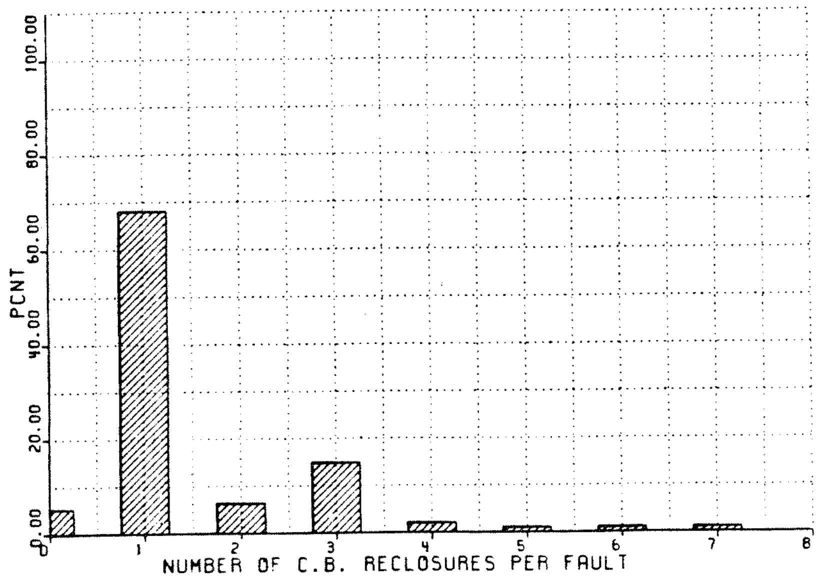

Figure 11. Distribution of Circuit Breaker Operation

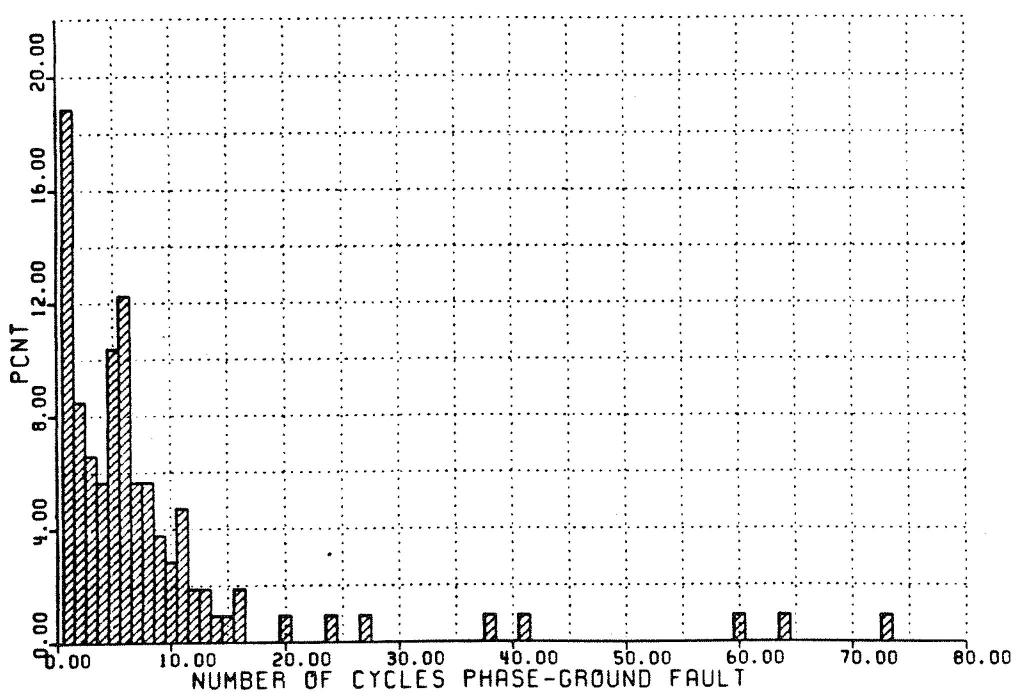

Figure 12. Distribution of Fault Current Duration

The fault current offset ratio distribution (Figure 13) shows that almost 50% of the faults had no offset, and only 5% exceed 1.4 PU of the RMS current. Analysis of the recorded data showed that the offset decay time constant was less than 4 ms in 75% of the faults.

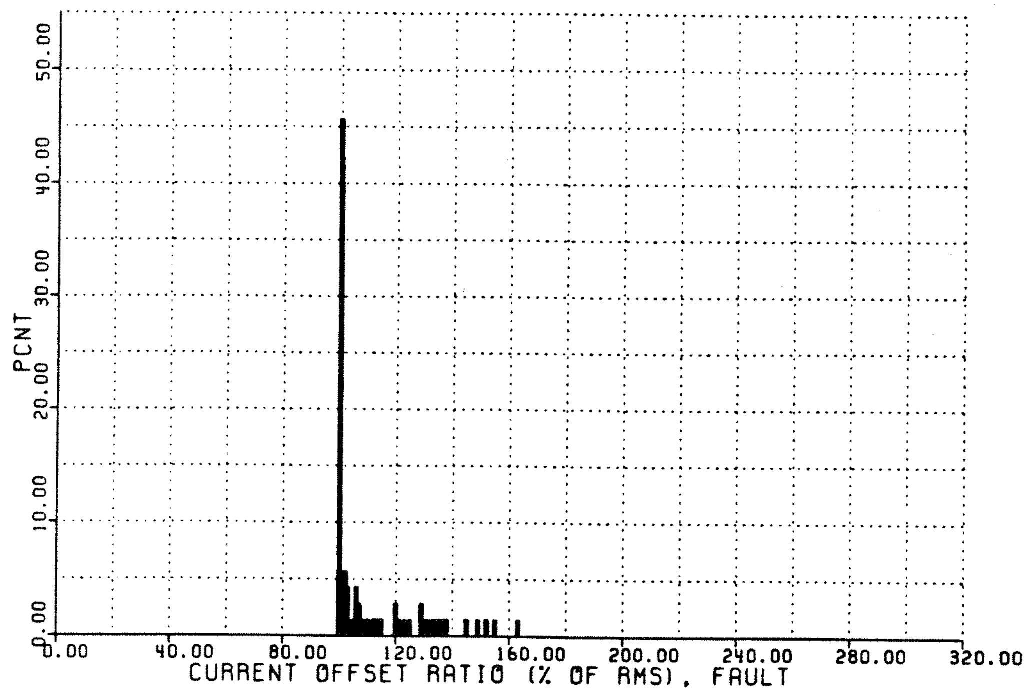

Figure 13. Distribution of Current Offsets

When a feeder is energized, the instantaneous current will be greater than that of the connected load for a period of time largely related to the length of time that the circuit has been off. In the case of a short time, such as when a breaker recloses automatically after a fault tripping, the initial high inrush current is rich in harmonics but usually quickly settles down to load current. Figure 14 shows the distribution of peak inrush currents. Harmonic

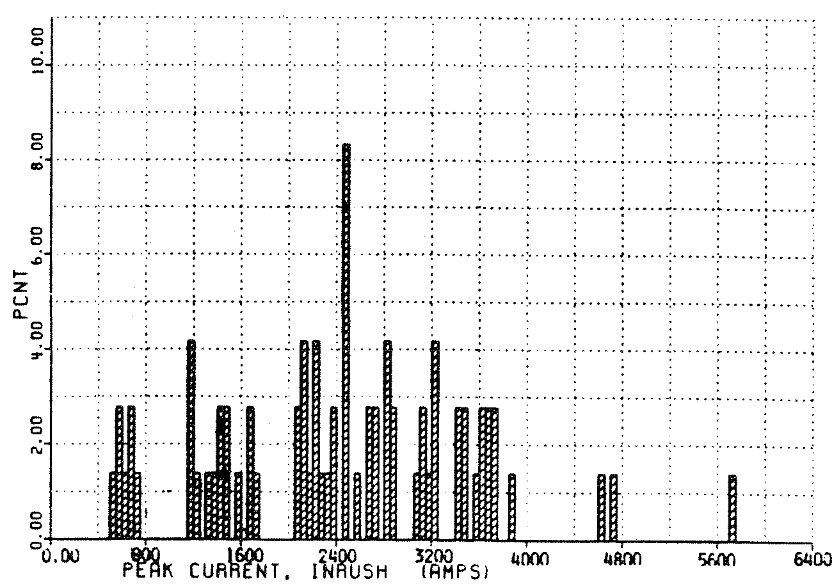

Figure 14. Distribution of Inrush Current

analysis of the voltages associated with inrush currents revealed frequencies and magnitudes similar to those of faults illustrated in Figure 6. The inrush current decay time constant varied widely from 20 to 160 ms, but over 80% of cases were below 80 ms.

When a feeder is de-energized for a long period of time, the initial current that flows upon re-energizetion is commonly known as cold load pickup. In this study, re-energization currents after a ten minute interruption were examined for cold load characteristics. In many cases, the feeder had been extensively sectionalized prior to being re-energized, so little information on cold load pickup for a whole feeder was gained. Figure 15, representing 35 cases, shows the percent of the feeder that was picked up by the breaker as reported by the participating utilities.

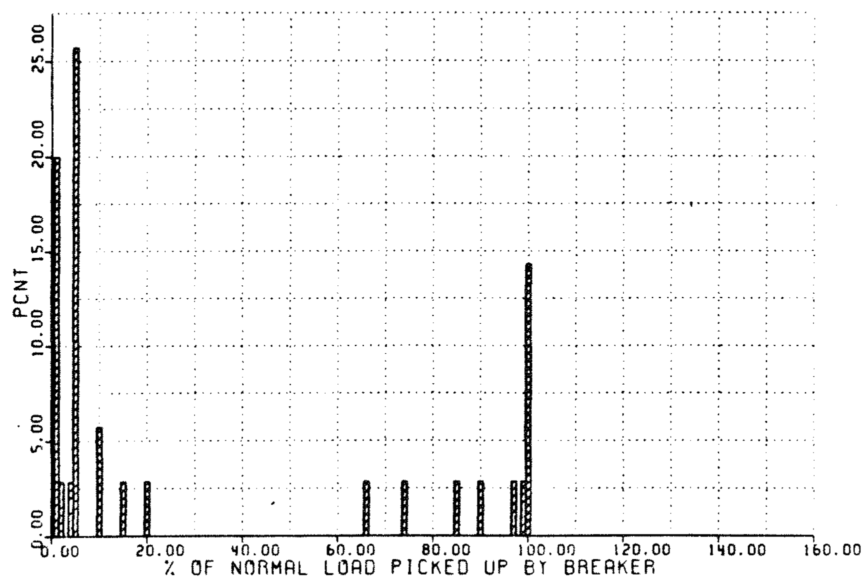

Figure 15. Percent of Cold Load Restored

Only seven recordings were identified as cold load pickup events. There were quite similar to inrush events in magnitude and harmonic content. The average decay time constant was somewhat longer, however, being 70 ms compared to 54 ms.

It is hoped that this brief summary encourages the reader to refer to EL-3085 for more detailed information and to examine the plots and analyses of all the recorded data.