Identification of Symptom Parameters for Failure Anticipation by Timed-Event Trend Analysis

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Abstract: This letter investigates a timed-event trend analysis method to evaluate and identify symptom parameters for incipient fault detection. To quantify the trend, the Laplace test statistic is adopted and applied to an actual distribution event log. A case study shows that the Laplace test statistic could be of great help in identification of the parameters for incipient fault detection and predictive diagnostics.

Keywords: Incipient fault, symptom parameters, Laplace trend test.

Introduction: Electric power distribution systems experience faults for a variety of reasons. The majority of the distribution faults are caused by natural degradation of distribution equipment. When equipment begins to deteriorate, intermittent incipient faults persist in the system from as little as several days to several months. Hence, characterizing equipment failure behavior is essential to allow scheduling distribution maintenance and execute remedial action aimed at replacing failing equipment prior to the occurrence of faults and service interruptions [1]. Since an exact failure process of a piece of equipment or system is not completely known, we usually monitor a large number of parameters to relate the behavior of the parameters to the faults. Therefore, it is critical to identify which parameters are the indicators of the symptoms of the failure process.

Several studies have been made for monitoring the conditions of various pieces of equipment such as circuit breaker, transformer, and underground power cables [2]-[4]. In addition, an approach for distribution fault anticipator/locator was proposed. [5]. There is no systematic method for isolating symptom parameters for fault anticipation, however, and these studies exemplify the importance of the evaluation and identification of the parameters.

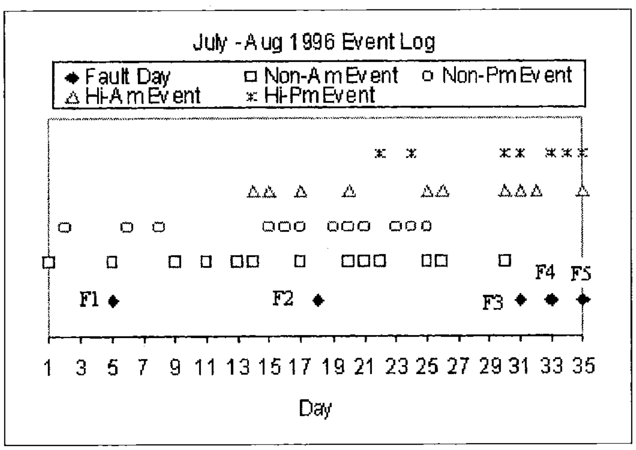

Figure 1. Event log for July through August 1996

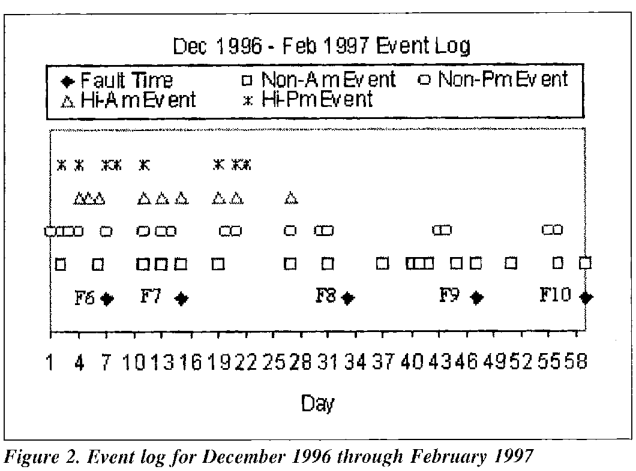

Figure 2. Event log for December 1996 through February 1997

This letter introduces a timed-event trend analysis method to evaluate and identify symptom parameters. In timed-event statistics, over a given observation length an event of a symptom parameter that reoccurs more and more frequently will show a distribution with mean at or near the end of the length. To quantify the distribution shapes, the Laplace test statistic is applied.

Event Trend Analysis: The Laplace trend test is a simple and powerful test for distinguishing between a constant rate at which events occur and an increasing rate of occurrence of such an event [6]. Consider a fault at time t_f and m events that have been recorded while monitoring a parameter over an observation length of $[0, t_f]$. The arrival times of the m events of the parameter are designated as $T_1, T_2, \ldots, T_m$. Then, the Laplace test statistic is defined as [7]

$$U_L = \frac{\frac{1}{m}\sum_{i=1}^{m} T_i - \frac{t_f}{2}}{t_f \cdot \sqrt{\frac{1}{12 \cdot m}}}.$$

The Laplace test statistic has the following interpretation. Under a constant rate of event occurrence, the arrival times to fault will occur randomly around the midpoint of the length, $t_f / 2$. Therefore, the sample mean of the T_i's will be approximately equal to $t_f / 2$; hence, the test statistic U_L will be small. If events occur more frequently towards the end of the interval, however, the sample mean will be large. If U_L is larger than the z-value of the standard normal distribution, $z_{\alpha/2}$, there is evidence at a significant level α that the event occurrence indicates the trend of increasing possibility of imminent fault. The z-value for 95% confidence level ($\alpha = 0.05$) is 1.96. In other words, if the Laplace test statistic exceeds 1.96, then we are confident that the parameter is a precursor of the fault. Using the z-value as a reference, we can evaluate parameters and select the ones whose timed-event test statistics exceed 1.96 as the symptom parameters for incipient fault detection and predictive diagnostics.

The Laplace test is very useful when no single parameter is found for a specific fault and there are too many candidate parameters to be considered. For a case study, we applied the Laplace test statistic to an actual distribution event log. The event log used in this letter is adopted from [8].

Distribution Event Log Description: The distribution feeder data were collected at a substation twice per day, at 5:00 a.m. and 5:00 p.m., for one minute at each time. The candidate parameters for incipient fault detection were as follows:

- nonharmonic component (such as 30 Hz, 90 Hz, 150 Hz, and so on) of 5:00 a.m. data ("Non-Am" parameter);
- nonharmonic component of 5:00 p.m. data ("Non-Pm" parameter);
- high-frequency component (above 1 kHz) of 5:00 a.m. data ("Hi-Am" parameter);
- high-frequency component of 5:00 p.m. data ("Hi-Pm" parameter).

The "event" of a parameter was defined as follows. Since the incipient faults caused random variation in the magnitude of the parameter, the magnitude variation was quantified and counted. If the count was above a certain threshold, it was considered as an "event." In Figures 1 and 2 the occurrences of the events of the four parameters and the faults are chronologically arranged for the records of July through August 1996 and December 1996 through February 1997, respectively. As can be seen in the figures, "Hi-Am" and "Hi-Pm" parameters were not recorded for the first several days of the first record and for the last 30 days of the second record. All five faults in the first record (F1 through F5) were incipient faults. In the second record, the first three faults (F6, F7, and F8) were unpredictable faults and the other two, F9 and F10, incipient faults.

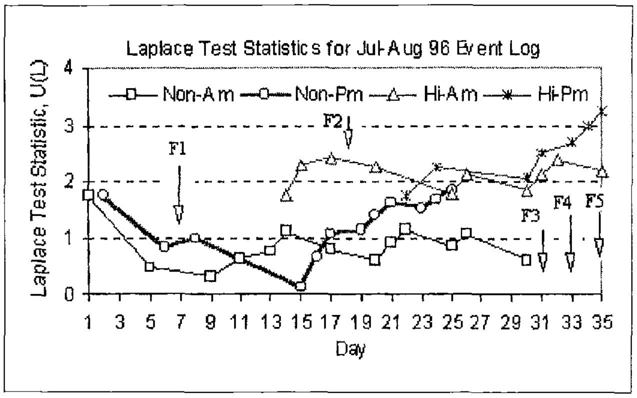

Figure 3. Laplace test statistics for July through August 1996 event log

Application of Laplace Test Statistic: A typical distribution feeder has equipment that has been in service for varying periods of time and in various states of health. At any time, some of it is at some stage of incipient failure and generates "events," and it is likely that only one or a few pieces will reach the point of fault. Therefore, even after the source of a particular fault is located and repaired, most of the partially failed equipment is still present on the system. In other words, an event observed before a fault may be a precursor of the fault or the one that comes later. Therefore, for a continuous and on-line identification of the symptom parameters, the observation length should be expanded to include all the events from the first to the latest one.

Figure 3 traces the test statistics in the expanded observation scheme for the first record. None of the test statistics for "Non-Am" are above 1.96, and only one for "Non-Pm" exceeds 1.96 before F3. However, the test statistics of "Hi-Am" exceed 1.96 for all four faults, and those of "Hi-Pm" exceed 1.96 for all three faults in the latter part of the observation length. This trace clearly indicates that "Hi-Am" and "Hi-Pm" are good symptom parameters for incipient fault detection.

Figure 4 traces test statistics for the second record. Since the event log for "Hi-Am" and "Hi-Pm" discontinued after F7, the evaluation of "Hi-Am" and "Hi-Pm" for the incipient faults is impossible. For the unpredictable faults, the test statistics of the parameters are below 1.96 for all the faults that were observed in the early part of the record. This fact is not unfavorable to "Hi-Am" and "Hi-Pm" as being the symptom parameters, since the test statistics correctly indicate the faults are random, not gradual.

However, "Non-Am" and "Non-Pm," whose test statistics for all the unpredictable faults are below 1.96, which is not unfavorable as being the symptom parameters, fail to indicate their relevance to the incipient faults. The test statistics of the "Non-Am" and "Non-Pm" are much lower than 1.96 for the two incipient faults (F9 and F10).

Conclusions: An effective scheme for identifying symptom parameters is needed for condition monitoring and failure prediction. A trend-event analysis scheme based on the Laplace test statistic is introduced to isolate parameters that will help to predict and anticipate faults. In the application of the Laplace test statistic using an event log, high-frequency components are found to be symptom parameters of the incipient faults. Also, the nonharmonic components, even with more events in the observation length, are found not to be the symptom parameters. The timed-event approach shows that the Laplace test statistic could be helpful in the identification of parameters for predictive maintenance and health-monitoring applications. The proposed scheme has potential in the other fields of failure physics and failure trend analysis.

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