

## Identification of Symptom Parameters For Failure Anticipation By Timed-Event Trend Analysis

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**Abstract:** This paper 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. The 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. Some faults, "unpredictable faults," are caused by unpredictable activities such as accidents and weather changes. However, the majority of the distribution faults are caused by natural degradation of distribution equipment. When some distribution equipment begins to deteriorate, intermittent incipient faults persist in the system from as little as several days to several months. Hence, the characterization of the equipment failure behavior is essential to allow distribution maintenance to schedule and execute remedial action aimed at replacing failing equipments prior to the occurrence of faults and service interruptions [1]. However, since an exact failure process of an equipment or system is not completely known, we usually monitor a large number of parameters to relate the behaviors 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 of distribution fault anticipator/locator was proposed. [5]. However, there has been no systematic method to isolate symptom parameters for fault anticipation, and these studies exemplify the importance of the evaluation and identification of the parameters.

This paper introduces a timed-event trend analysis method to evaluate and identify symptom

parameters. In timed event statistics, over a given observation length, while random events show its mean at the middle of the length, an event of a symptom parameter which 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 are occurring and an increasing rate of occurrence of such event [6]. Consider a situation where a fault occurred at time  $t_f$  and  $m$  events 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  $T_1, T_2, \dots, T_m$ . 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 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 are occurring 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  $\alpha$  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 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 paper is adopted from [8] and its brief description follows.

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

- Non-harmonic component (such as 30 Hz, 90Hz, 150Hz, and so on) of 5:00 AM data ("Non-Am" parameter)
- Non-harmonic component of 5:00 PM data ("Non-Pm" parameter)
- High-frequency component (above 1 kHz) of 5:00 AM data ("Hi-Am" parameter).
- High-frequency component of 5:00 PM 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 Fig.1 and Fig.2, the occurrences of the events of the four parameters and the faults are chronologically arranged for the records of July - August 1996 and December 1996 - 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.

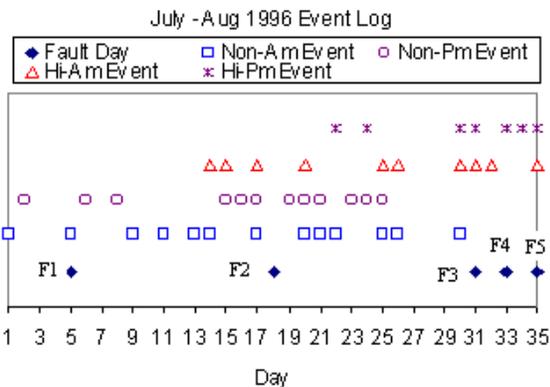


Figure 1. Event and Fault Occurrence in July 1, 1996 – August 4, 1996 (35 days)

**Application of Laplace Test Statistic:** A typical distribution feeder has hundreds of equipments and these equipments have been in service for varying periods of time and are in various states of health. At any one point in time, dozens or scores of them are at some stage of incipient failure

and generate "events," and it is likely that only one or a few of them will reach the point of fault. Therefore, even after the source of a particular fault is located and repaired, most of the partially failed equipments are still present on the system. In other words, an event observed before a fault may be a precursor of the fault or the one 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.

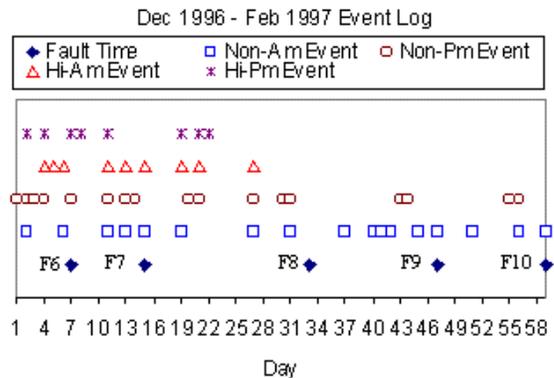


Figure 2. Event and Fault Occurrence in December 26, 1996 – February 22, 1997 (59 days)

Fig.3 traces the test statistics in the expanded observation scheme for the first record. None of the test statistics for "Non-Am" is 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.

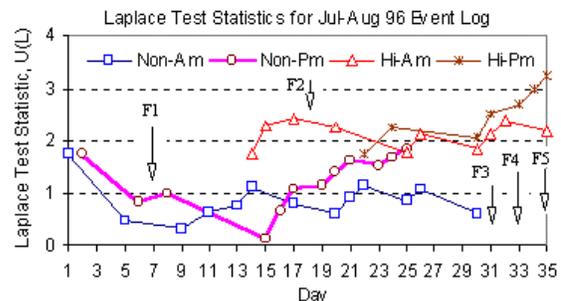


Figure 3. Traces of the Laplace test statistic for the record of Jul 96 - Aug 96

Fig.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.

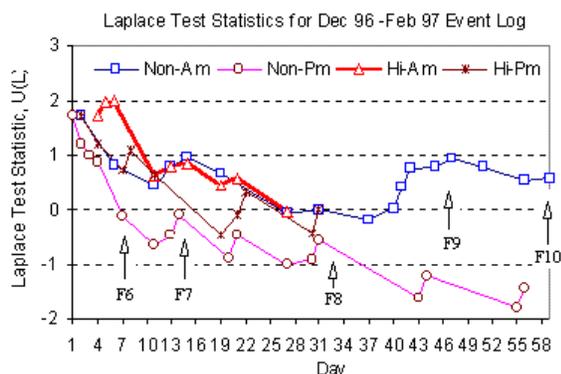


Fig.4. Traces of the Laplace test statistic for the record of Dec 96- Feb 97

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:** A critical need for condition monitoring and failure prediction is an effective scheme for identifying the symptom parameters. A trend-event analysis scheme based on the Laplace test statistic is introduced to isolate parameters that will give critical 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 non-harmonic components, even with more events in the observation length, are found not to be the symptom parameters. The timed event approach showed that the Laplace test statistic could be of great help in identification of the parameters for predictive maintenance and health monitoring applications. The proposed scheme has an excellent potential in the other fields of failure physics and failure trend analysis.

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