Computer Relaying Software Reliability Evaluation Using Event Tree

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***Abstract-* Software reliability evaluation has emerged as an area of importance in recent times with the proliferation of software based systems. But highly dependable software systems used for safety critical application, such as computer relays for power system transmission line protection produce little failure data. Hence a statistical method known as statistics of extreme is used for reliability evaluation. This paper deals with calculation of exceedance probability of computer relay and using this data an event tree of computer relay has been drawn.**

I. INTRODUCTION

The reliability evaluation of software based systems has become a major concern. Hardware reliability can be resolved much consistently compared to software reliability, which is a rather less explored field until recent times [1]. The reliability assessment of software requires the previous history of failure data based on which a statistical estimation is put forward. Nevertheless for novel and highly dependable software systems, such failure data is scarcely available and thus formulation of statistical estimation of reliability index from such meager available data does not seem viable [2].

Statistics of the extremes is a special branch of statistics which deals with scenarios involving extreme events and can model distribution of rare events, those for which very few or no available data is present to work with as in the case of computer relay's software evaluation where the failure data is very less.

For determining the design, procedural weakness & various hazardous consequences due to faults (initiating accidental event) event tree is developed for computer relay's software. An event tree is an inductive procedure that shows all the possible outcomes, resulting from an accidental or initiating event, taking into account whether all the safety barrier are functioning or not.

In this paper, the software reliability evaluation of a computer relay is investigated, whose algorithm is based on the use of wavelet-fuzzy combined approach for detection, classification and location of faults on a transmission line. With the extensive use of fast and accurate digital signal processing techniques such as the wavelet transform, detection and classification of different faults have been done very easily [3]–[4].

II. SOFTWARE RELIABILITY EVALUATION

Computers have pervaded to all aspects of modern society. Practically speaking, the existence of software based systems in our lives is omnipresent and the size and complexity of computer-intensive systems are growing day-by-day. Thus the reliability evaluation of software based systems has become a major concern. Especially for safety critical system like computer relay, reliability evaluation is extremely necessary. But as the number of fault found in the different modules of software is very rare, hence for reliability evaluation statistics of extreme is used.

In this paper, the software reliability evaluation of a computer relay has been obtained, the computer relay has three modules and Monte Carlo simulation was employed for incorporating the stochastic nature of fault occurrence in the system. Using this data, the failure probability and the corresponding Cdf for each of the three module of computer relay were calculated. By using the principles of statistics of extreme failure probability and exceedance probability were found out.

A. Statistics of Extreme

Software reliability modeling is a long-established approach, wherein a system's past failure data is analyzed for prediction of future behavior [5]. But software systems that are supposed to be built for highly dependable applications is difficult to analyze using conventional software reliability growth models owing to reasons such as the novelty of the software to be developed, sparingly few available failure data.

Statistics of extremes offers a modeling scheme that is independent of the test sampling order, the amount of available data and furthermore it does not require a priori knowledge about the underlying distribution of any parameter. a distribution F converges to some asymptotic form in its extreme tails [5]. Condition that a distribution F converges to an asymptotic form in its maximum tail if

$$\lim_{n\to\infty} F_X^n(a_n + b_n x) = H(x) \quad (1)$$

For applying statistics of extremes, the first step is to plot the empirical cumulative distribution function (Cdf) of available failure data in a Gumbel type probability paper [6] to find out its domain of attraction. Reference [7] shows that for most distributions the domain to attraction belongs to any one of the three Gumbel type asymptotic families, namely the Gumbel Type I, Gumbel Type II or Gumbel Type III [6]. The next step is to determine the software reliability estimate for highly dependable system employing a graphical based analysis using the form of empirical Cdf plot.

For obtaining the reliability indices needed for software evaluation, failure probability and exceedance probability is needed. These indices are calculated using the following equations [8]:

$$F_S\,(s) = \exp\left(-\exp\left(-s\right)\right) \quad (2)$$

Where $s = -k\,\ln\left(\dfrac{x-\varepsilon}{w-\varepsilon}\right) = -\ln[-\ln[F_S\,(s)]]$ (3)

$$K = \frac{-s}{\ln(x-\varepsilon)-(\omega-\varepsilon)} \quad (4)$$

$$F_S\,(s) = F_{X1}\,(X1 \le x) = 1-\exp[-(\frac{x-\varepsilon}{\omega-\varepsilon})^K\,] \quad (5)$$

$$P_{X1}\,(X1 \ge x) = [1-F_{X1}\,(X1 \le x)\,] \quad (6)$$

Where ω is the characteristic smallest variable of initial variate x, ε is the lower bound which is assumed to be 1 in this case and k is the inverse measure of dispersion of initial variate x. $F_{X1}\,(X1 \le x)$ is the probability that the number of failure is less than x (failure probability). Whereas $P_{X1}\,(X1 \ge x)$ gives the exceedance probability of the software.

III. CASE STUDY AND RESULT

Fault data is obtained from the Monte Carlo simulation result, from this fault data corresponding Cdf has been calculated for each of the three modules of the computer relay. Here detail calculations of detection module have been shown.

From the Cdf plot shown in "Fig.(1)" characteristic smallest value ω has been calculated which comes out to be 38 for detection module. Therefore (x-ε) is 37. The value of S can be extrapolated using "Fig. (1)". The probability of having less than (x - ε) = 24 software failure is approximately = 0.80. i.e., $F_s(s)$ = 0.80 as shown in table 1. Calculating S for (x - ε) = 24 gives S = 1.5. K is calculated using eqn. (4), which comes out to be 3.47. Therefore the failure probability expression for detection module is given as $F_{X1}\,(X1 \le x) = 1-\exp\left[-\left(\dfrac{x-\varepsilon}{37}\right)^{3.47}\right]$ from this expression by putting different values of x; failure probability for different potential software failure for detection module can be obtained and using eqn. (6) exceedance probability is calculated for different number of software failures and tabulated in table 2.

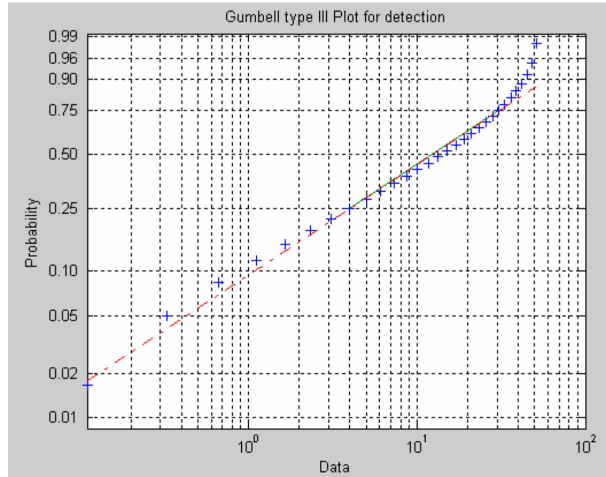

Figure 1. Gumbell Type III (Empirical Cdf) plot for Detection Module

TABLE 1 Cdf data of Detection Module

Fault type	Fault #	Probability	CDF
AG (LI)	1	.033	.0011
AG (MI)	2	.066	.003
AG (HI)	3	0.1	.0066
BG(LI)	4	0.133	.0111
BG(MI)	5	0.166	.0166
BG (HI)	6	0.2	.0233
CG (LI)	7	.233	.0310
CG (MI)	8	.266	.0399
CG (HI)	9	.300	.0499
ABG (LI)	10	.333	.0610
ABG (MI)	11	.366	.0732
ABG (HI)	12	.40	.0865
BCG (LI)	13	.433	.1010
BCG (MI)	14	.466	.1165
BCG (HI)	15	.500	.1332
CAG (LI)	16	.533	.1509
CAG (MI)	17	.566	.1698
CAG (HI)	18	.600	.1898
AB (LI)	19	.633	.2109
AB (MI)	20	.666	.2331
AB (HI	21	0.7	.2564
BC (LI)	22	0.733	.2809
BC (MI)	23	0.766	.3064
BC (HI)	24	0.80	.3331
CA (LI)	25	0.833	.3608
CA (MI)	26	0.866	.3897
CA (HI)	27	0.90	.4197
ABC (LI)	28	0.933	.4508
ABC (MI)	29	0.966	.4830
ABC (HI)	30	1	.5163

Table 2.Exceedance Probability of Detection Module

Exceedance Probability	Z : No. of Potential lifetime software failure				
P_x (X $\geq$ x)	2	5	9	12	15
	0.99999	0.9996	0.9951	0.9853	0.9663

For fault classification modules, from the Cdf plot in “fig. 2”, the smallest characteristic value, ω comes out to be 31 & (x - ε) =30. As in the previous calculation for detection module, from the Cdf data, and the Cdf plot shown in “Fig. 2” a value of S is extrapolated. The probability of having less than (x - ε) = 32 software failure is approximately 0.3299. Calculating S for (x - ε) = 32 gives S = -0.1034. Thereafter from eqn. (4), K is found out to be 1.603. Thus, the analytical expression for the failure probability for classification module is $F_{X1}(X1 \leq x) = 1 - \exp\left[-\left(\frac{x-\varepsilon}{30}\right)^{1.603}\right]$

Using the eqn.(6) exceedance probability values are tabulated in table 3.

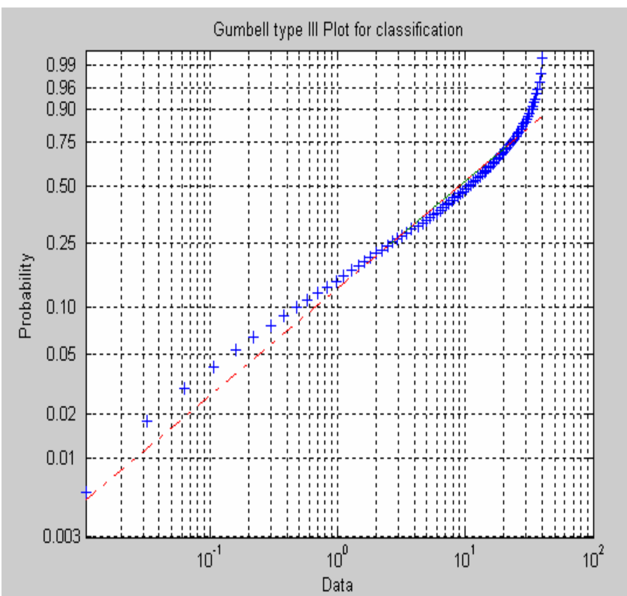

Figure 2. Gumbell Type III (Empirical Cdf) plot for classification Module

Table 3.Exceedance Probability of classification Module

Exceedance Probability	Z : No. of Potential lifetime software failure				
P_x (X $\geq$ x)	2	8	14	27	36
	0.9957	0.9158	0.7808	0.4550	0.2743

In “Fig. 3” the Cdf plot for fault location module is shown. The extrapolated value of S is 0.66 and k comes out to be 1.741. Therefore the final expression obtained for failure probability for fault location modules comes out to be

$F_{X1}(X1 \leq x) = 1 - \exp\left[-\left(\frac{x-\varepsilon}{33}\right)^{1.74}\right]$. Using eqn. (6) the exceedance probability for fault location is tabulated in table 4.

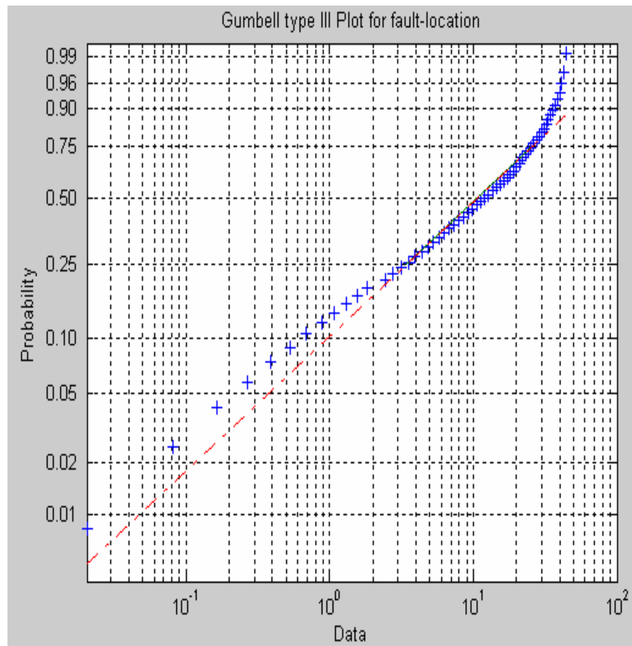

Figure 3. Gumbell Type III (Empirical Cdf) plot for fault location Module

Table 4.Exceedance Probability of fault location Module

Exceedance Probability	Z : No. of Potential lifetime software failure				
P_x (X $\geq$ x)	2	8	15	23	31
	0.9977	0.9349	0.7986	0.6103	0.4286

For software reliability evaluation of computer relay’s software, event tree is used, as shown in “fig (4)”. Event tree gives us the insight knowledge of the consequences, due to initiating fault [9]. These consequences will depend upon the functioning of the safety barriers. Here in this case for a computer relaying, its three modules namely detection, classification and fault location are the safety barriers.

Therefore, if all the three safety barriers are working, then the system will be considered as a Risk free or healthy system. The main job of a relay is to detect the faults. Hence if the first safety barrier, which is detection module of a computer relay, fails then the consequence will be termed as Risky, even if the other two modules are operational. And if first safety barrier is working and other two or one of the two is non-functional then the system is in marginal state.

From the event tree, the probability that the accidental event (fault) will lead to unwanted consequences if the safety-barriers are non functional is computed. Also probability of 'Risk free state' of computer relay is calculated. These values are tabulated in table 5.

For getting these probability values the exceedance probability for two numbers of failures has been taken for each of the three modules from table 2, 3 & 4 respectively. Therefore when all the modules are in 'Up state' the reliability comes out to be 0.9935 and the relay is said to be in Risk Free state & when all are in 'down state' reliability is $9.89*10^{-11}$.

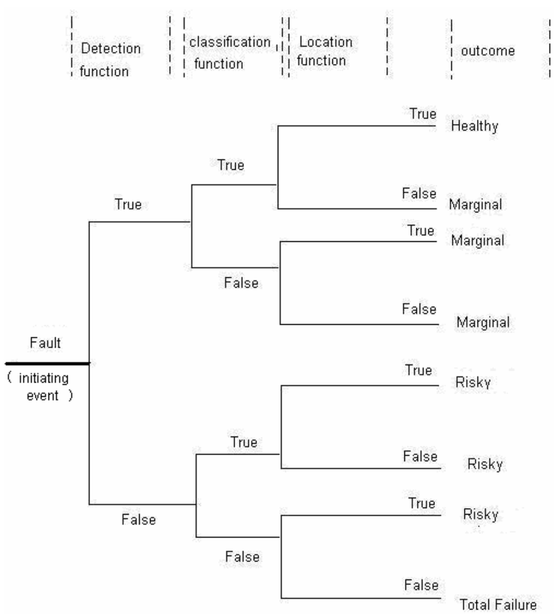

Figure 4 Event Tree of Computer Relay

Table 5 State Probability of Event Tree

State	Fault Detection	Fault Classification	Fault location	Probability
1	Down	Down	Down	$9.89*10^{-11}$
2	Down	Down	Up	$4.29*10^{-8}$
3	Down	Up	Down	$2.29*10^{-8}$
4	Down	Up	Up	$9.93*10^{-6}$
5	Up	Down	Down	$9.88*10^{-6}$
6	Up	Down	Up	$4.29*10^{-3}$
7	Up	Up	Down	$2.29*10^{-3}$
8	Up	Up	Up	0.9935

IV. CONCLUSION

The reliability evaluation for computer relaying demonstrates the efficacy of the proposed approach for assessing the risk associated with such software which rarely fails, but whose failures lead to catastrophic consequences such as blackouts. By using event tree, various state probabilities are evaluated for system planning. Also the least risk state probability serves as an indicator regarding the system reliability involving safety critical applications such as computer relay.

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