ELECTRICAL ENGINEERING

Effect of Fault Current Limiter in Reliability Assessment Of Power Systems

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دراسة تاثير "محدد تيار الخطأ" على حساب مؤشرات الأعتمادية في نظام القوى الكهربية

ملخص البحث:

تهتم هذه الدراسة أساسا بدراسة تأثير و خواص و مكان "محدد تيار الخطأ" في حساب مؤشرات الأعتمادية في نظام قوى كهربي معين. حيث أن الهدف الأساسي من تركيب محدد تيار الخطأ هو التحكم في أقصى تيار يمر عند حدوث عطل حتى يمكن لعناصر النظام أن تتحملها بأمان. و يتم ذلك بإدخال معاوقة محسوبة للتيار في حالة وجود عطل و تكفي هذه المعاوقه لتحدد التيار عند مستوى معين بحيث تعمل أجهزة الحماية و تفصل الجزء الذي به عطل.

هذه الدراسة تأخذ في الاعتبار كيفية تشغيل "محدد تيار الخطأ" عند حدوث عطل و تدرس أيضا احتمال عدم التعرف على العطل و تأثير ذلك على حساب مؤشرات الأعتماديه لنظام القوى.

يستفيد من هذا البحث مهندس تشغيل شبكات التوزيع للجهد المتوسط حيث يمكن دراسة تأثير و خواص و أماكن وضع محددات تيار الخطأ طبقا لشكل النظام و بيانات الأعتماديه للنظام و اختيار أنسب الأماكن لوضع هذه المحددات.

Abstract

This paper is concerned with the effect of fault current Limiter "FCL" characteristics, location and associated recognition on the reliability assessment of power systems.

The FCL "not recognizing probability" is very important factor since the failure of the FCL in recognizing the fault might result in serious damage to the extensive apparatus protected by it. Consequently the variation of the FCL characteristics affects intensively the reliability assessment of the power system.

In this paper, the state space transition models are employed to evaluate the reliability indices of the chosen power system which contains circuit breakers, bus-bars, power transformers, FCL, disconnecting switches and distribution feeders.

The results illustrate the significant effect of considering "not recognizing probability "Q"" of both the FCL and circuit breaker on the calculations of reliability indices of a power system.

1. Introduction

The main functions of the FCL are; limiting the peak of the first current loop to level no greater than the momentary capabilities of the component of the system, subsequent to the first loop of fault current, and insert sufficient impedance in the circuit to limit current to a level which is high enough to actuate appropriate relays but below the interrupting capabilities of circuit breakers on the load side of the FCL [1].

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The reliability evaluation of FCL requires more attention and discussion than it has been received [2]. As the need for the FCL is mainly to protect costly, under-rated equipment, therefore, the failure of the FCL presumably can cause serious damage to the extensive apparatus which is protected by the FCL. If the FCL is to become a practical reality and to take its place along with the surge suppresser as an integral part of complete power system, then a high level of reliability will be achieved.

Various design approaches of FCL's have been used to pursue the development of the FCL[3]. and since the FCL equipment options have been available to the user, a specific application will dictate the FCL concept which is mostly suitable for it.

An EPRI "Electric Power Research Institute" report covering the development of specific ratings, proofs tests of these designs, and demonstrations in utility applications. Also, a project of Edison Co. (PR 1140) has been initiated to develop a vacuum technology based FCL suitable for distribution circuit applications.

The components of the FCL are shown in Figure (1), while the chosen power system configuration is shown in figure (2) This paper is concerned with the assessment of reliability indices of a power system taking into consideration the presence and characteristics of the FCL. Also the probability of not recognizing the fault "Q" for the FCL switches is considered.

The state space transition model is used to describe the behavior of the power system when a fault occurs at different locations over the power system, and also to indicate the reliability indices as a function of the coordination of devices, anticipated fault recognition, failure rate and down times of system components as shown in figures(3 & 4).

The power system is prepared for using state-space technique by dividing it into protected areas and normalizing it into equivalent forms to assign the correct reliability indices. By the aid of state-apace transition models, the general equations can be written for both total failure rate and total down time per failure as function of component reliability indices and not recognizing probability "Q". The system areas reliability indices are drawn versus "Q" as shown in figures (1 - 3).

2. Case Study

In this paper, the chosen power system contains two step down transformers (400/220 KV), two 220 kv main feeders and a substation 400/220 KV. This system is provided with four current limiters as seen in figure (2) and coordinated with the circuit breakers.

The system is divided into zones in order to study the effect of the FCL on reliability assessment of the power system. The faults are assumed at different locations around the system, and the associated probable stares are drawn. By the aid of state-spaee states transition models [4], the reliability indices are calculated for each zone and for the power system as a whole. The reliability indices taken into consideration are; failure rate "λ" and down time per failure "r".

2.1. System Preparation (Normalizing Feeder Lengths)

As the reliability indices of feeders depend upon their lengths and types, so it is very important to normalize the main feeder lengths around the network to assign correct failure rate and down time per failure for the chosen power system.

In practice, neither the loads distribution nor the feeders are uniform. So it is convenient to treat a physical feeder as an equivalent uniform feeder of unity length [5]. This is accomplished in two processes as follows:

1. Suppose that there are "k" sections in physical feeders. Choose "r_j" as the resistance of the equivalent uniform feeder of the "j^{th}" section in ohm per km. Modify the physical length "L_i" of the "i^{th}" section as follows :

$$L_{ui} = L_i * r_i / r_j \qquad i = 1,2,\ldots\ldots,k$$

where "L_{ui}" is the length of the equivalent uniform feeder in km.

2. The total length of the equivalent uniform feeder "L_u" is defined by :

$$L_u = \sum_{i=0}^{k} L_i * r_i / r_j$$

Dividing each section length "L_{ui}" of the equivalent feeder by "L_u" to yield the normalized equivalent uniform feeder of unity length and unity resistance, where:

$$r = \sum_{i=0}^{k} L_i * r_i \qquad \text{Ohm per normalized length}$$

2.2. State-Space Transition Models

The state-space transition models are created according to the operation system protective devices sequence, when a fault takes place at any zone of the studied system. As an example, when a fault occurs at zone "3" as seen in figure (3), the system operating events will be as follows; As the system fault happens, the FCL will be actuated to operate and interrupt switches F2-1 & F2-2 to open partially within 0.002 sec, and at the same time the ground switch "GS", is closed for a time of 0.003 sec. By the time reaches 0.005 sec, the ground switch is closed and F2-1 & F2-2 are fully open, while the reactor is inserted fully in the route of the current. Finally, after a certain adjusted time the circuit breaker is reclosed and the system is in the steady state condition. Figures (3 & 4) illustrate the corresponding operating events.

3. System reliability Assessments

The proposed approach is summarized in the flow chart of figure (5). The first step i to identify the system under study that contains circuit breakers, FCL's , powe transformers, disconnecting switches, busbars and underground feeders. The secon step is to normalize the power system ,to divide it into protective areas and to draw it possible states allover the zone areas. From the state-space representation of th concerned system, the reliability equations can be written as functions of no recognizing probability "Q" of both FCL and circuit breakers.

3.1. List of Symbols

λ_S = Failure rate of supply

λ_t = Failure rate of power transformer

λ_i = Failure rate of zone "i" with enough current to operate the FCL

λ_i' = Failure rate of zone "i" with enough fault current to operate the circuit breaker

t_{g1} = Closing time of ground switch

t_{int2} = Operating time of interrupting switch

t_{b3} = Delay time needed for circuit breaker to operate after fault happens

t_{cb1} = Time needed to close the first circuit breaker in the faulty region

t_{cb2} = Time needed to close the second circuit breaker in the faulty region

t_{cb3} = Time needed to close the third circuit breaker in the faulty region

P_f = Probability of the FCL recognizing the fault

Q_f = Probability of not recognizing the fault of the FCL

P_{CB} = Probability of the circuit breaker recognizing the fault

Q_{CB} = Probability of not recognizing the fault of the circuit breaker

r_{ii} = Repair time, in hours, of section "ii" per fault

r_{ISO} = Time needed to isolate the fault

The following assumptions are taken into consideration during the study:

1. The load side protective equipment must clear the fault before the source device operates to lockout.

2. Permanent faults must be restricted to the smallest area of the system.

3. There is a complete coordination between the FCL and the circuit breaker; i.e. the minimum actuating current of the circuit breaker should equal 10 % of the minimum current that actuates the FCL [3].

4. The model is developed for a single contingency outage of all considered areas.

3.2. Total Failure Rate (λ_{it})

Considering the model illustrated in figure (2) and taken into account the fault events shown in figure (4), the corresponding state-space transition model can be easily obtained. When a fault happens in protected area FCL-1 in zone 1 as an example, the operating events leads to the following equations:

λ_{1t} = Total failure rate, when fault happens in zone 1 which equals the failure rate of both of zone 1 and supply. This zone is out of FCL protection as seen in figure (2).

$$\lambda_{1t} = \lambda_1 + \lambda_S \tag{1}$$

λ_{2t} = Total failure rate, when fault happens in zone 2

$$\lambda_{2t} = P_f(\lambda_2+\lambda_3+\lambda_4) + Q_f(\lambda_5+\lambda_6) + Q_f^2(\lambda_{11}+\lambda_{12}) + Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) + P_{CB}\lambda_2' + Q_{CB}\lambda_3' + Q_{CB}^2\lambda_4' + Q_{CB}^3\lambda_5' \tag{2}$$

Similarly,

$$\lambda_{3t} = P_f(\lambda_3+\lambda_4) + Q_f(\lambda_5+\lambda_6) + Q_f^2(\lambda_{11}+\lambda_{12}) + Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) + P_{CB}\lambda_3' + Q_{CB}\lambda_4' + Q_{CB}^2\lambda_5' + Q_{CB}^3\lambda_6' \tag{3}$$

$$\lambda_{4t} = P_f\lambda_4 + Q_f(\lambda_5+\lambda_6) + Q_f^2(\lambda_{11}+\lambda_{12}) + Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) + P_{CB}\lambda_4' + Q_{CB}\lambda_5' + Q_{CB}^2\lambda_6' + Q_{CB}^3\lambda_{12}' \tag{4}$$

$$\lambda_{5t} = P_f(\lambda_5+\lambda_6) + Q_f(\lambda_{11}+\lambda_{12}) + Q_f^2(\lambda_8+\lambda_9+\lambda_{10}) + P_{CB}\lambda_5' + Q_{CB}\lambda_6' + Q_{CB}^2\lambda_{12}' + Q_{CB}^3\lambda_{11}' \tag{5}$$

$$\lambda_{6t} = P_f(\lambda_5+\lambda_6) + Q_f(\lambda_{11}+\lambda_{12}) + Q_f^2(\lambda_8+\lambda_9+\lambda_{10}) + P_{CB}\lambda_6' + Q_{CB}\lambda_{12}' + Q_{CB}^2\lambda_{11}' + Q_{CB}^3\lambda_{10}' \tag{6}$$

Equations (1-6) are drawn in figure (6) by varying the values of Q_f & Q_{CB}.

3.3. Total Down Time " $(\lambda.r)_{it}$ "

Considering the model illustrated in figure (3) and assuming a fault at different zones then drawing the corresponding state-space transition models, the total down time for each zone can be calculated as follow:

$$(\lambda.r)_{1t} = \lambda_1 * r_{11} + \lambda_S * r_S \qquad (7)$$

where " r_S " is the repair time per fault of the supply.

$$\begin{aligned}(\lambda.r)_{2t} = {} & P_f(\lambda_2+\lambda_3+\lambda_4) * (t_{f1}+t_{f2}+t_{O}+0.005+r_{22}+0.003+r_{ISO}) + \\ & Q_f(\lambda_5+\lambda_6) * t_{f1} + Q_f^2(\lambda_{11}+\lambda_{12}) * t_{f2} + Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) * t_{f3} + \\ & P_{CB}\lambda_2' * (t_{CB1}+r_{22}) + Q_{CB}\lambda_3' * t_{CB1} + Q_{CB}^2\lambda_4' * t_{CB2} + \\ & Q_{CB}^3\lambda_5' * t_{CB3} \qquad (8)\end{aligned}$$

$$\begin{aligned}(\lambda.r)_{3t} = {} & P_f(\lambda_3+\lambda_4) * (t_{f1}+r_{33}) + \\ & Q_f(\lambda_5+\lambda_6) * t_{f1} + Q_f^2(\lambda_{11}+\lambda_{12}) * t_{f2} - Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) * t_{f3} + \\ & P_{CB}\lambda_3' * (t_{CB1}+r_{33}) + Q_{CB}\lambda_4' * t_{CB1} + Q_{CB}^2\lambda_5' * t_{CB2} + \\ & Q_{CB}^3\lambda_6' * t_{CB3} \qquad (9)\end{aligned}$$

$$\begin{aligned}(\lambda.r)_{4t} = {} & P_f\,\lambda_4 * (t_{f1}+r_{44}) + \\ & Q_f(\lambda_5+\lambda_6) * t_{f1} + Q_f^2(\lambda_{11}+\lambda_{12}) * t_{f2} + Q_f^3(\lambda_8+\lambda_9+\lambda_{10}) * t_{O} + \\ & P_{CB}\lambda_4' * (t_{CB1}+r_{44}) + Q_{CB}\lambda_5' * t_{CB1} + Q_{CB}^2\lambda_6' * t_{CB2} + \\ & Q_{CB}^3\lambda_{12}' * t_{CB3} \qquad (10)\end{aligned}$$

$$\begin{aligned}(\lambda.r)_{5t} = {} & P_f(\lambda_5+\lambda_6) * (t_{f1}+r_{55}) + \\ & Q_f(\lambda_{11}+\lambda_{12}) * t_{f1} + Q_f^2(\lambda_8+\lambda_9+\lambda_{10}) * t_{f2} + \\ & P_{CB}\lambda_5' * (t_{CB1}+r_{55}) + Q_{CB}\lambda_6' * t_{CB1} + Q_{CB}^2\lambda_{12}' * t_{CB2} + \\ & Q_{CB}^3\lambda_{11}' * t_{CB2} \qquad (11)\end{aligned}$$

$$\begin{aligned}(\lambda.r)_{6t} = {} & P_f(\lambda_5+\lambda_6) * (t_{f1}+r_{66}) + \\ & Q_f(\lambda_{11}+\lambda_{12}) * t_{f1} + Q_f^2(\lambda_8+\lambda_9+\lambda_{10}) * t_{f2} +\end{aligned}$$

$$Q_{CB}^{3}\ \lambda_{10}^{1} * t_{CB3} \tag{12}$$

Equations from (7 - 12) are drawn in figure (7) by varying both Q_f & Q_{CB}.

4. Results

The reliability indices has been calculated at different places. The first case when the efficiencies of both the circuit breakers and FCL are the same. i.e. when $Q_f = Q_{CB}$. The second case when the FCL's re ideal ($Q_f = 0$) while circuit breakers are not ideal ($0 < Q_{CB} < 1$). The third case when the circuit breakers are ideal ($Q_{CB} = 0$) and the FCL's are not ideal ($0 < Q_f < 1$). Figures (6 - 7) illustrate the system failure rate and total down time versus not recognizing probability. These figures demonstrate highly the effect of the reliability indices with " Q " of the FCL and circuit breakers. For higher values of " Q " lying between " 0.55 to 1.0 " the effect of " Q " is very clear.

Figures (8 - 9) illustrate the system failure rate and total down time per fault, versus not recognizing probability "Q" in the second case when ($Q_f = 0$). The figures demonstrates the effect of " Q_{CB} " on both of reliability indices, with the remark of their small increase rate in all system zones.Figures (10-11) illustrte also the system failure rate and total down time per fault in case of varying not recognizing probability of circuit breaker .

5-conclusions

This paper presents the effect of the FCL on the reliability indices assessment of a power system provided with circuit breakers, power transformers and transmission lines feeders.

The study show the importance of both FCL and circuit breakers quality . The planning engineer should be take the values of not recognizing probabilities of power system components on reliability assessment.

References

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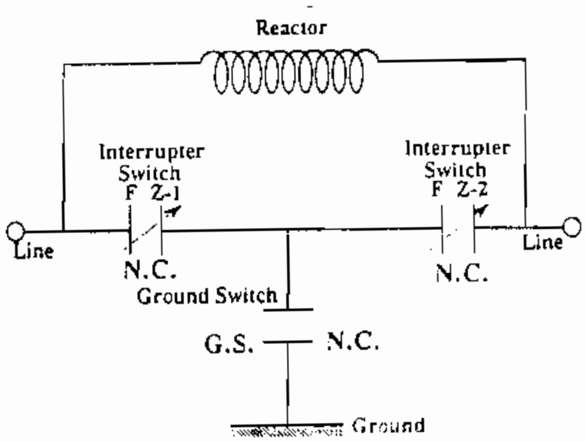

Figure (1)
Fault Current Limiter 'FCL' Components

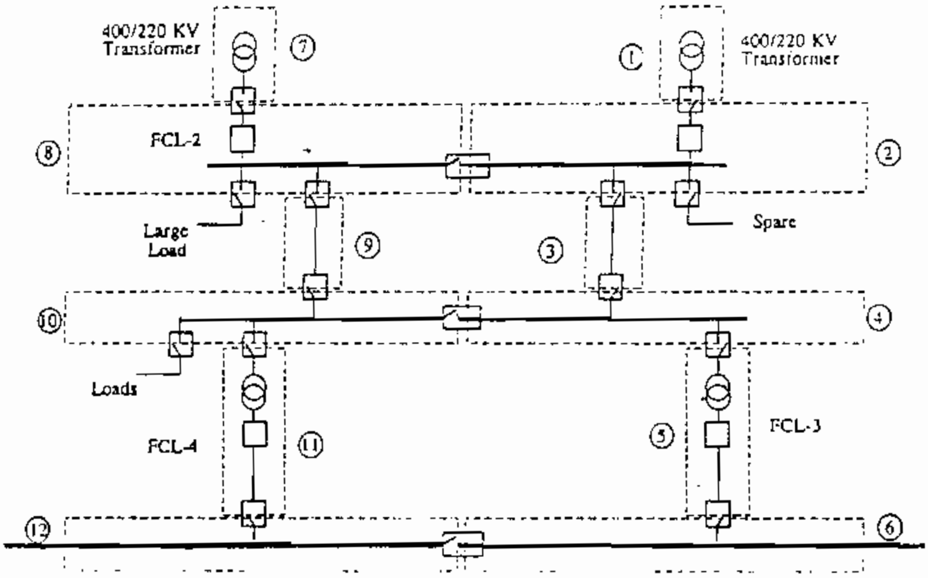

Figure (2)
The System Model Divided Into Distinct Regions

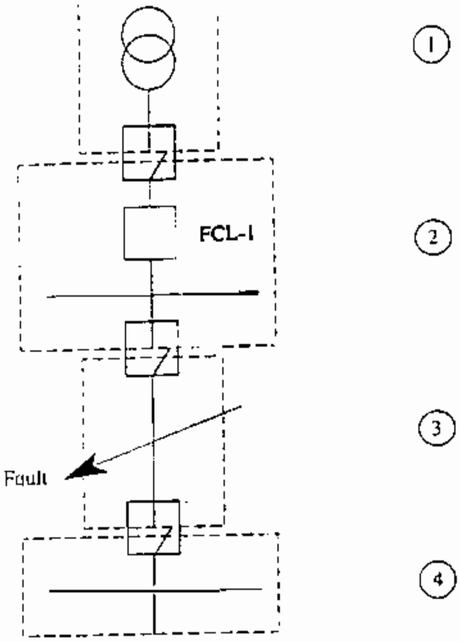

Figure (3)
Fault Location In Zone [3]

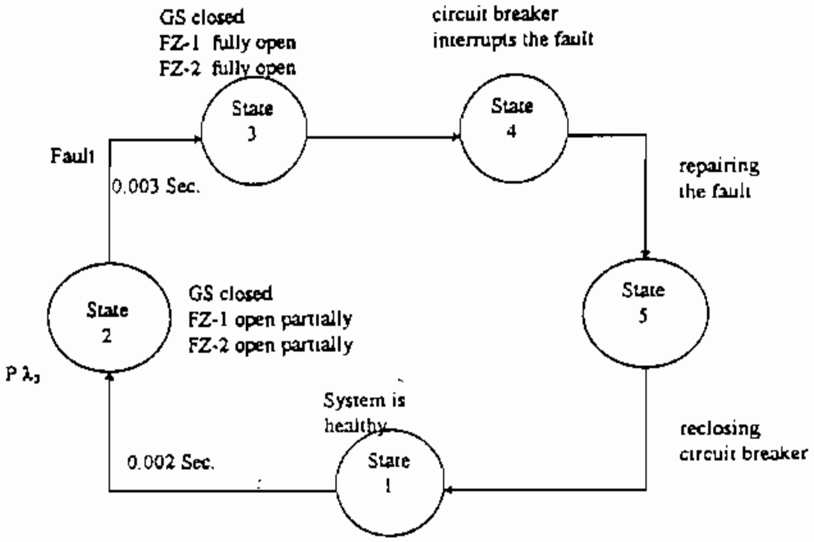

Figure (4)
Operating events of faulted system
when a fault happens in zone 3

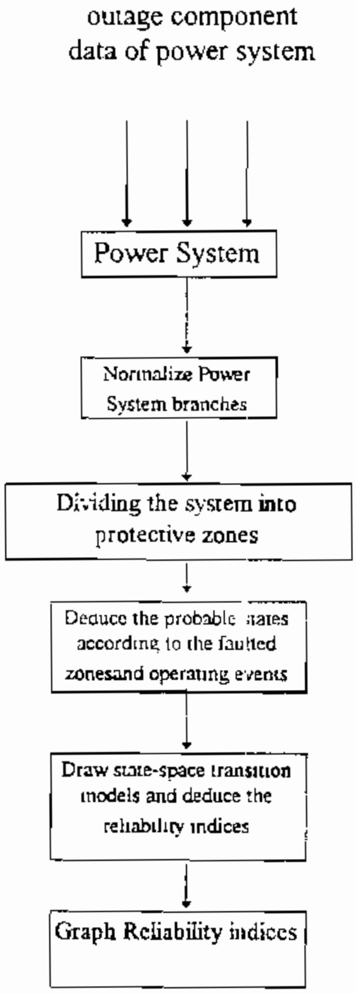

Fig (5) Flow chart representing the proposed approach

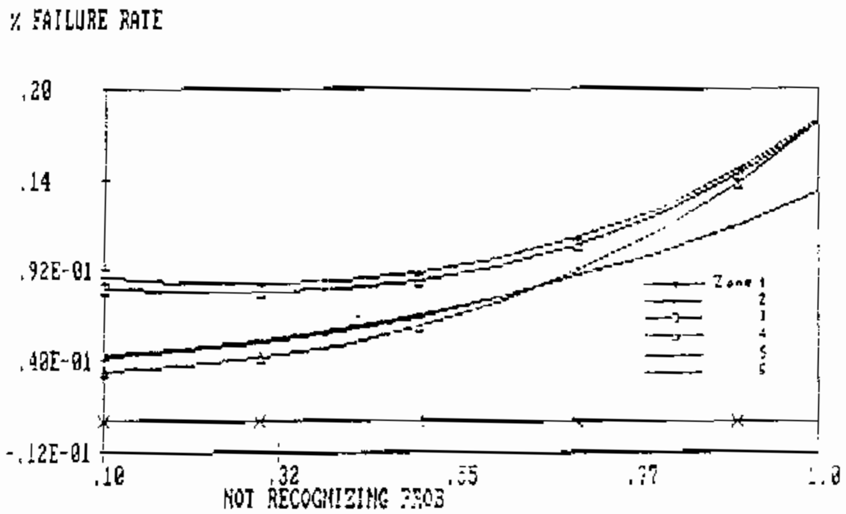

Figure (6)
System Failure Rate For Different Zone Faults as a Function of Q
(Q_f & Q_{c5} are varying)

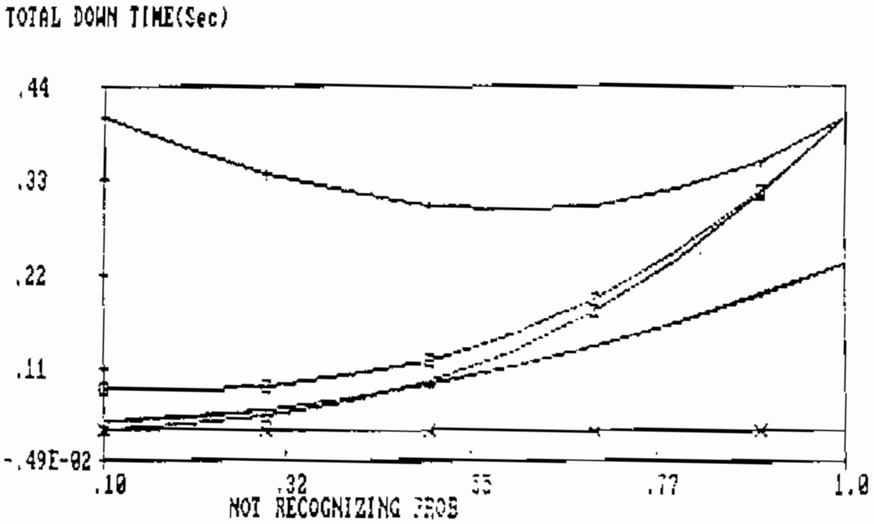

Figure (7)
Total Down Time/Year For Different Zone Faults as a Function of Q
(Q_f & Q_{c5} are varying)

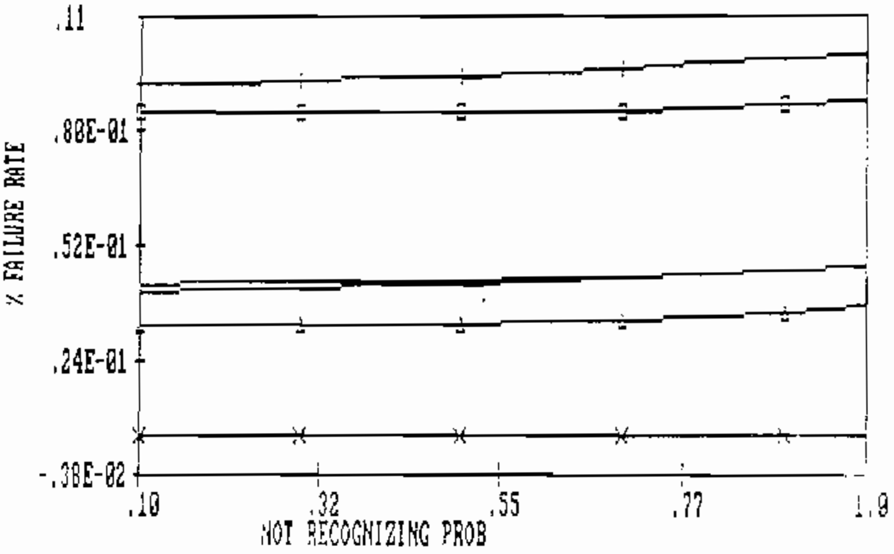

Figure (8)
System Failure Rate For Different Zone Faults asa Function of Q
($Q_f = 0$ & Q_{cb} is varying)

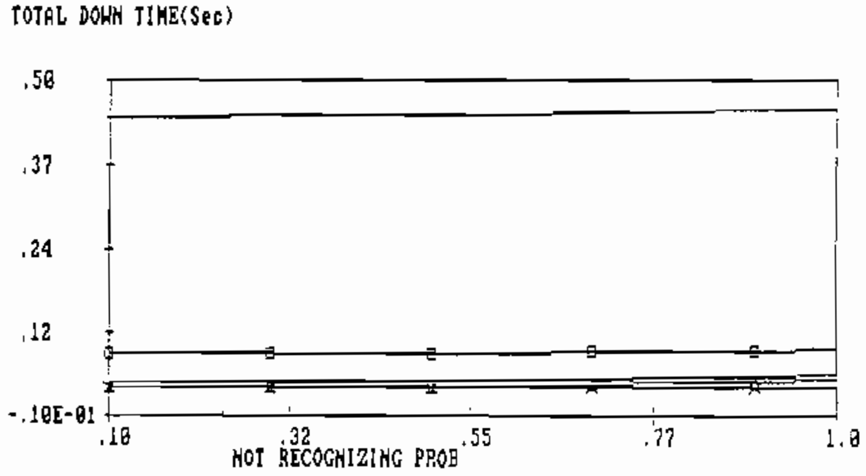

Figure (9)
Total Down Time/Year For Different Zone Faults as a Function of Q
($Q_f = 0$ & Q_{cb} is varying)

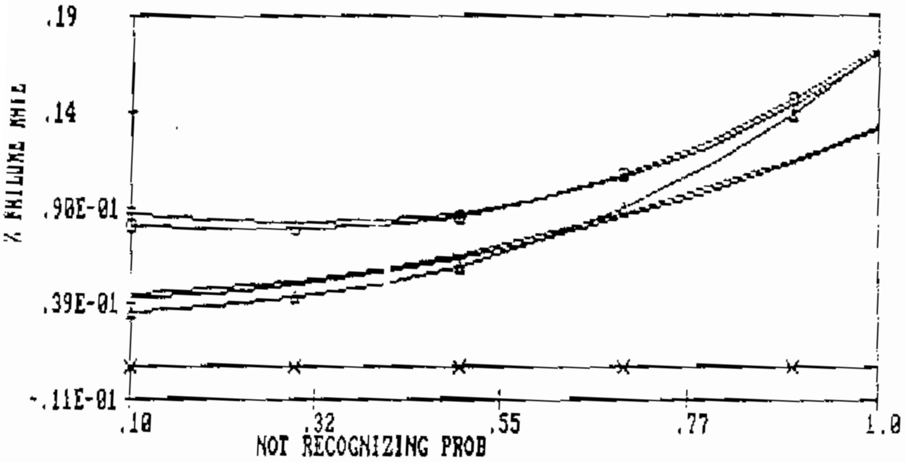

Figure (10)
System Failure Rate For Different Zone Faults as a Function of Q
(Q_{cb} = 0 & Q_f is varying)

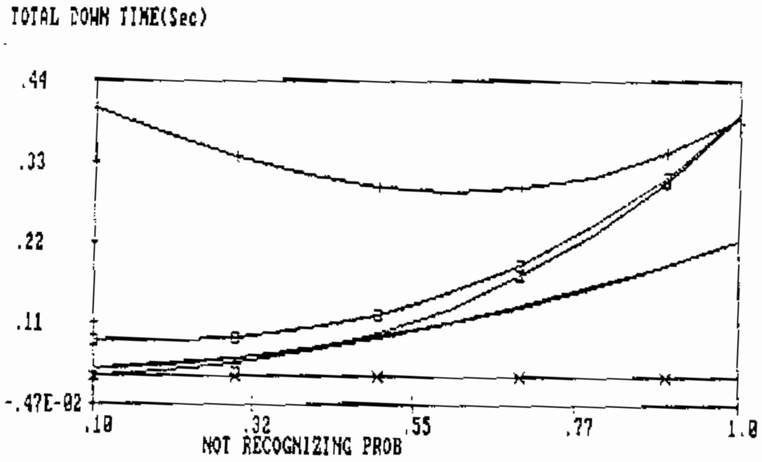

Figure (11)
Total Down Time/Year For Different Zone Faults as a Function of Q
(Q_{cb} = 0 & Q_f is varying)