Program

(Times and locations subject to change)

Power System Relaying Paper forum #3

Session Type:	Paper Forum
Time:	Wednesday, July 29, 2009 15:40-17:00
Room:	CTCC South - Glen 205
Track:	Please Choose an option below
Committee:	Power System Relaying
Co-Sponsoring Committee 1:	Power System Relaying
Co-Sponsoring Committee 2:	Unspecified
Chair 1:	Robert Pettigrew; TRC Inc
Chair 2:	
Summary:	

09GM1501-A Novel Fault-Dependent-Time-Settings Algorithm for Overcurrent Relays

Marija Prica; Carnegie Mellon University

Marija Ilic; Carnegie Mellon University

09GM0081-Neural Network-based Technique used for Recovery the CCVT Primary Signal

Saber Saleh; ministry of electricity and energy

Essam Aboul-Zahab; Cairo University

El Sayed Tag Eldin; Cairo University

D. K. Ibrahim; Cairo University

M. I. Gilany; College of Technological Studies

09GM0125-Reliability and Availability Analysis of IEC 61850 Based Substation Communication Architectures

Mitalkumar Kanabar; University of Western Ontario

Tarlochan Sidhu; University of Western Ontario

09GM0866-Considering Failure Probability for Back-up Relay in Determination of the Optimum Routine Test Interval in Protective System Using Markov Model

Yaser Damchi; Ferdowsi University of Mashhad

Javad Sadeh; Ferdowsi University of Mashhad

09GM1440-Evaluating the Role of Current Limiting Fuses for Wind Farm Protection Applications

Tamer Kawady; Faculty of Engineering, Minoufiya University

Naema Mansour; Faculty of Engineering, Minoufiya University

Abd El-Maksoud Taalab; Faculty of Engineering, Minoufiya University

09GM0019-Opportuities for Utilitiies as Innovators in the Area of Protection & Control Engineering

Shinichi Imai; Tokyo Electric Power Co.

Tomoo Ohmori; Tokyo Electric Power Co.

Hiroaki Kitajima; Tokyo Electric Power Co.
Hiroshi Okamura; Tokyo Electric Power Co.

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Considering Failure Probability for Back-up Relay in Determination of the Optimum Routine Test Interval in Protective System Using Markov Model

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***Abstract*--In order to enhance both dependability and security which are two aspects of relaying system, self- checking and monitoring facilities are usually considered along with routine test. In practice back-up relay can have mal trip when not required and may fail to trip when required and can cause power system blackout due to cascading failure. Generally, this situation is not taken into account in the previous studies, so in this paper, a Markov model is proposed for reliability analysis when back-up relay is not perfectly reliable. Results show that optimum routine test and reliability indices decrease if back-up relay is not perfectly reliable. In the proposed Markov model, for simplification of the suggested Markov model, we suppose that there is only self-checking facility with routine test and monitoring test is not considered.**

***Index Terms*--** Protection of power systems, Reliability**,** Routine Test, Self Checking, Back-up relay**.**

I. Nomenclature

The state abbreviation and transition rates are defined as follows:

C	Protected component
P	Primary relay
B	Back up relay
X	Additional equipment connected to component which isolated by manual switching
F_P	Primary relay failures(reciprocal of primary relay Main Time Between Failures(MTBF))
F_{BP}	Back up relay failures
ST	Self-checking test effectiveness index(per unit)
F_{ST}	Primary relay failures detected by self-checking test(failures/year)
F_{BST}	Back up relay failures detected by self-checking test(failures/year)
F_{PP}	Primary relay failures not detected by self-checking test(failures/year)
F_{BPP}	Back up relay failures not detected by self-checking test(failures/year)
F_C	Component failures (fault/year)
F_{CC}	Common case failures of the Primary relay and component failures (failures /year)
F_{BCC}	Common case failures of the Back up relay and component failures (failures /year)
F_{CCC}	Common case failures of the Primary, Back up relays and component failures (failures /year)
R_c	protected component repairs per hour
R_t	Primary relay inspection per hour
R_{Bt}	Back up relay inspection per hour
R_r	Primary relay repair per hour
R_{Br}	Back up relay repair per hour
S_n	Primary relay tripping per hour
S_{Bn}	Back up relay tripping per hour
S_m	manual switching per hour
θ_{pm}	Protection inspection rate(reciprocal protection inspection interval)

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II. Introduction

THE goal of protective relay testing is to minimize the availability of Protection system and minimize the risk of relay maloperation [1]. Self-checking and monitoring facilities have significantly enhanced the reliability of the protection system [2], [3]. Protection systems play a vital role in maintaining the high degree of service reliability in the power system. Failure to trip when required and mal-trip when not required are two main relay failure modes. Dependability and security are two important factors in the reliability analysis of protection systems. Dependability is defined as the probability that a relay will operate correctly and security is defined as the probability that a relay will not operate when tripping is not desired [2-4]. The self-checking facilities increase the optimum routine test of protection system [1-3].

A study by the North American Electric Reliability Council shows that the protection relays are involved in about 75 percent of major disturbances. Normally power system blackouts result from cascading failures. For example on August 10th in 1996, it was false tripping that caused 30000MW load and 27000MW generation loss and 7.5 million costumers were without power [6], [7]. Therefore it is necessary to analyze the reliability protection of power system.

Protection system reliability analysis has been investigated

in many papers. In [1] the optimum routine test intervals are determined when there are self-checking facilities; besides sensitivity of protection system to MTBF and failure per year are investigated. In [2] a Markov model has been proposed for protection system and transmission line. Optimum routine test interval and self checking interval are determined considering self-checking and monitoring facilities. In [3] a Markov model has been proposed for the protection system of power transformer. In [5] the impact of preventive maintenance of protection system on the reliability system of the power supply to customers had been determined. In [8] a Markov model has been introduced for the protection system by considering redundant protective system.

In all of the above mentioned papers, the back-up protection system is assumed to be perfectly reliable for reliability analysis, but this assumption is not correct in the operation. Therefore, in this paper a Markov model for protection system is proposed by considering failure probability for back up relay and also optimum routine test interval is determined. The results show that optimum routine test interval and power system protection reliability are decreased when back-up relay is not completely reliable.

III. Markov Model of Protection /Component System

A Markov model of protection/component system is shown Fig. 1, base on the assumption of failure probability for back-up relay. In this model the protected component is assumed to be transmission line.

In suggested model following assumptions are considered:

1- There is only possibility of self checking facilities.

2- Primary and backup relays must be taken out of service to be inspected.

3- The time required to test a relay is equal to the time required to repair or replace a failed relay.

4- There is not possibility for operation of back-up relay in duration operation of primary relay.

5- It is possible to repair for primary and back-up relays simultaneously.

The model in [1] is assumed that back-up relay is perfectly reliable but in model proposed in this paper it is assumed that there is failure probability for back-up relay. State 1 represents the normal operating condition where the line is energized and relay is operating properly. When a line fault occurs and primary relay operates properly, the component makes the transition to a down state represented by state 2, and the model transfers from state 1 to 13 when a primary relay failure occurs as well as a line fault. In state 2 primary relay is operating properly and signals the circuit breaker to trip. The normal switching transition takes the model system to state 6. The line is then required and reenergized, taking the model system back to state 1. The model transfers from state 6 to 7 when primary relay has false operation. In state 13 back-up relay is operating properly and signals the circuit breaker to and the faulted line is isolated and the model transfers to state 7. In states 3, 5 and 9 the line is energized and the primary relay is out of service but back-up relay is available.

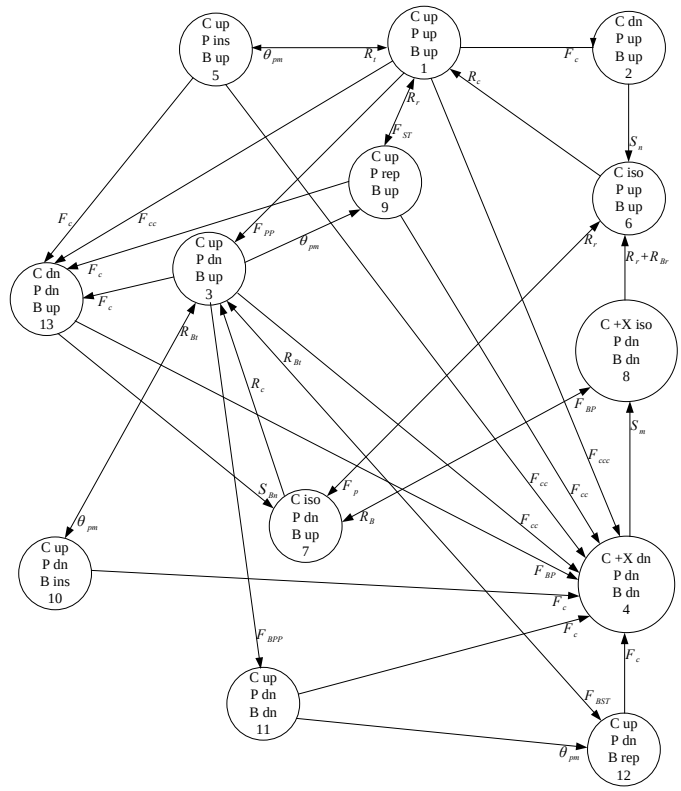

Fig. 1. Markov model of a protection/component system that account self-checking test and failure probability for back-up relay

In the state 5 the primary relay is out of service being inspected. The model system transfers from 1 to 3 when the primary relay failure is not detected by the relay self-checking test. The model system enters state 9 from 1 when the primary relay failure is detected by the self-checking test. In states 10, 11 and 12 the line is energized but the primary and back-up relays are not available. State 4 illustrates that the line is reenergized and the primary and back up relays are out of service. The model system transfers from 4 to 8 by manual switching.

In this study it is supposed that $F_{ST}=F_{BST}$ and $F_{PP}=F_{BPP}$ that are calculated using (1):

$$\begin{aligned} F_{ST}&=F_{BST}=F_P\times ST \\ F_{PP}&=F_{BPP}=F_P\times(1-ST) \end{aligned} \tag{1}$$

The probabilities associated with the different states of the Maerkov model are calculated using (2) to (3) where **S** is the stochastic transitional matrix and **p** is the vector of the state probabilities [9]:

$$\boldsymbol{pS}=\boldsymbol{p} \tag{2}$$

$$\mathrm{p}=[p_1, p_2, p_3, \ldots\ldots, p_{11}, p_{12}, p_{13}] \tag{3}$$

Finally the flowing equation is needed to overcome the singularity of (S-I) that is defined using (4):

$$\sum_{i=1}^{13} p_i = 1 \tag{4}$$

Dependability and security are two important factors in reliability analysis. For the analysis of these factors we can use correct operation of protection system probability (**P_d**) and mal-operation of protection system probability (**P_s**) as are defineded using (5):

$$P_d = p_2 + p_6 + p_{13}$$
$$P_s = p_7 \tag{5}$$

IV. STUDY RESULTS

In the results presented in this paper, the following transition rates are used except the ones mentioned in the article:

R_c =0.5component repairs per hour
R_t =1 primary relay routine test per hour
R_{Bt} =1 back-up relay routine test per hour
R_r =0.5 primary relay inspections per hour
R_{Br} =0.5 back-up relay inspections per hour
F_{CC} = 10^{-6} failure per hour
F_{BCC} = 10^{-6} Failure per hour
F_{CCC} =10^{-9} Failure per hour
S_n = 43200 Operations per hour
S_{Bn} =21600 Operations per hour
S_m =0.5 Operations per hour

A. Basic Condition

In this study the self-checking test is not considered. In the present case the mean time between failures of 50 years for primary and back-up relays and a line that is faulted twice per year are considered. Fig. 2, Shows correct operation of the probability protection system versus optimum routine test time interval and Fig. 3, presents the probability of mal-operation of protection system versus optimum routine test time interval.

Figs. 2 and 3 show that optimum routine test time interval considering the failure probability for back-up relay is 650 hours because in this time **P_d** is maximum and **P_s** is minimum but optimum routine test time interval by assuming that back-up relay is completely reliable is 780 hours [1]. This presents that optimum routine test time interval decreases when back-up relay is not fully reliable.

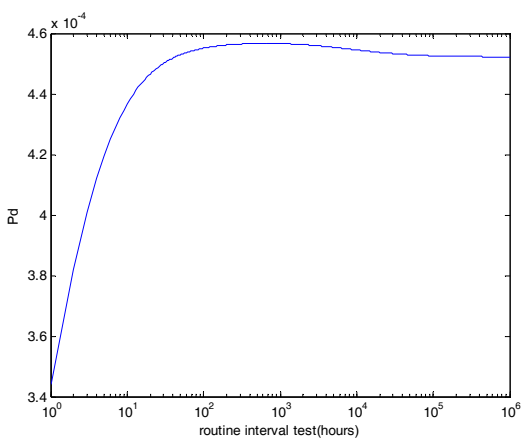

Fig. 2. Probability of correct operation of protection system without self-checking test

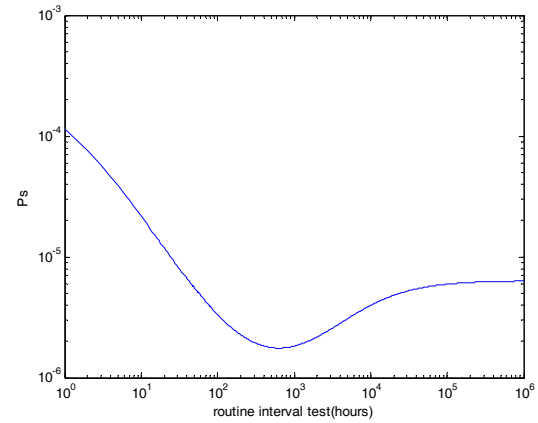

Fig. 3. Mal-operation of protection system probability without self-checking test

B. The Effect of Self-checking Test on Optimum Routine Test Interval

Figs. 4 and 5 show that the results of considering primary and back-up relays of self-checking test with different degrees of effectiveness on the correct operation probability and mal-operation probability of protection system for the same consideration on the pervious ones.

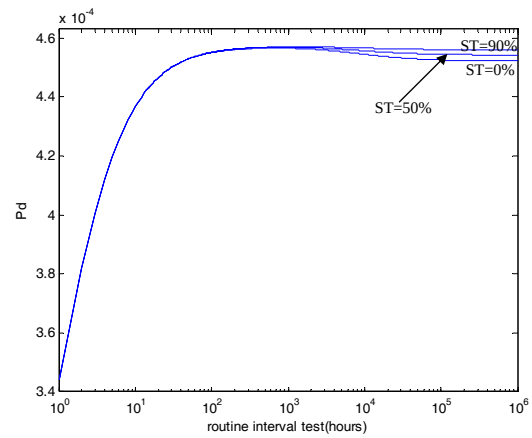

Fig. 4. The effect of self-checking effectiveness on the probability of correct operation protection system

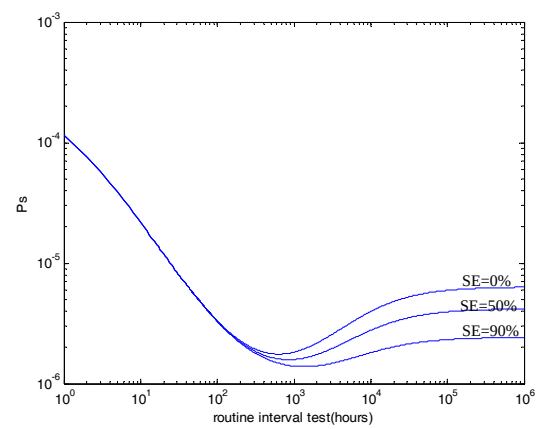

Fig. 5. The effect self-checking effectiveness on the probability of mal-operation protection system

Figs.4 and5 shows that increasing self-checking effectiveness enhances the optimum routine test time interval. As depicted in Fig. 4 increasing of **ST** leads to enhancing $\mathbf{P_d}$ which consequently results in rising dependability of the system. In according to Fig. 5, security of protection system increases by the decrease of mal-operation probability.

C. Comparison Between Suggested Model and Model [1]

In [1] for reliability analysis it is assumed that back-up relay is fully reliable and results are shown in table (1). But table (2) presents reliability analysis assuming the failure probability for back-up relay in the suggested model.

Table 1**.** Effect of self-checking effectiveness on the optimum routine test time interval by model presented in [1]

MTBF=50 (y) F_C=2 (f/y)	ST (%)	probability	Optimum time
P_d	0	4.5677423e-004	780
$_s$		1.6347319e-006	780
P_d	50	4.5697630e-004	1191
P_s		1.4345959e-006	1191
P_d	90	4.5724656e-004	4010
P_s		1.1669539e-006	4010

Table 2. Effect of self-checking effectiveness on the optimum routine test time interval by suggested model

MTBF=50 (y) F_C=2 (f/y)	ST (%)	probability	Optimum time
P_d	0	4.5666969e-004	650
P_s		1.7564672e-006	650
P_d	50	4.5684187e-004	865
P_s		1.5793738e-006	865
P_d	90	4.5703450e-004	1371
P_s		1.3840356e-006	1371

From Tables 1 and 2 it can be seem that by considering failures probability for back-up relay, **Pd** for suggested model is less than results of reference [1]. This subject presents that dependability decreases when back-up relay is not fully reliable. $\mathbf{P_s}$ in reference [1] is less than results of suggested model. This result shows that by considering of failure probability for back-up relay, security and optimum routine test time interval decrease.

D. The Effect of MTBF on Optimum Routine Test Time Interval

Figs. 6, 7 and Table (3) show the effect of MTBF on the optimum routine test time interval by assumption that there is not self-checking test and a line that is faulted twice per year.

Figs. 6, 7 and Table (3) illustrate that with the increase of MTBF, Pd increases and $\mathbf{P_s}$ decreases. This means that the rise of MTBF cause to increase of dependability and security. Furthermore optimum routine test tine interval enhances due to an increase of MTBF.

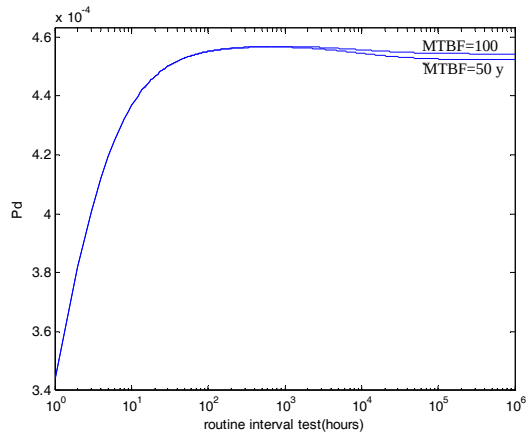

Fig. 6. Effect of MTBF on probabilitycorrect operation protection system

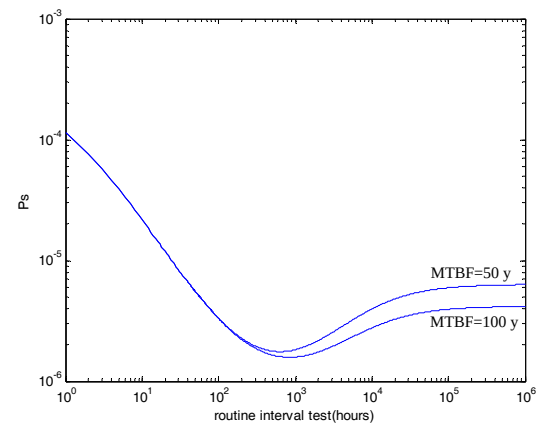

Fig. 7. Effect of MTBF on probability of mal-operation protection system

Table 3. Effect MTBF on optimum routine test time interval

F_C=2 (f/y) ST=0%	MTBF (y)	probability	Optimum time
P_d	50	4.5666969e-004	650
P_s		1.7564672e-006	650
P_d	100	4.5684472e-004	868
P_s		1.5796762e-006	868

E. Effect of Faults per year on Optimum Routine Test Time Interval

To investigate the effect of fault rate of protected component on optimum routine test time interval, security analysis has been done without self-checking test and by assuming that MTBF is 50 years for primary and back-up relays. As results are shown in Fig. 8, and table (4), according to results, optimum routine test time interval and $\mathbf{P_s}$ increase by enhancing faults per year, therefore, security decreases.

Table 4. Effect of faults per year on probability of mal-operation protection system

MTBF=50(y) ST=0%	F_C (f/y)	probability	Optimum time
P_s	1	1.3781373e-006	617
P_s	10	4.5614233e-006	1005

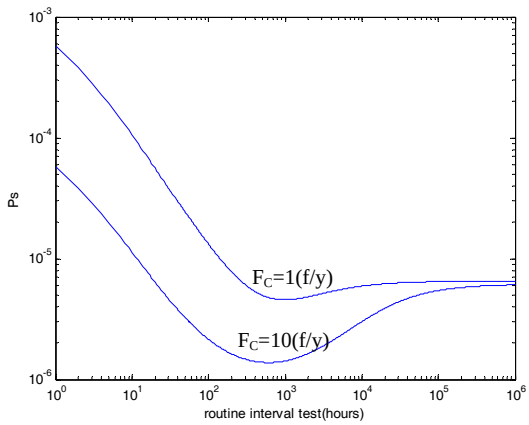

Fig. 8. Effect of faults per year on probability of mal-operation protection system

V. CONCLUSION

In this paper a Markov model is suggested for power system reliability analysis by considering failure probability for back-up relay. Presented results show that optimum routine test time interval and reliability decrease when back-up relay is not fully reliable. Also the effect of self-checking effectiveness, MTBF and fault rate protected component on optimum routine test time interval has been investigated. The results also show that by increment self-checking effectiveness and MTBF, optimum routine test time interval, security and dependability increase but increase of fault rate of protected component decreases the security.

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