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Incorporating Station Related Aging Failures in Bulk System Reliability Analysis

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Abstract - This paper proposes methods to incorporate station related aging failures in composite system reliability assessment. Aging failures of station components, such as circuit breakers and bus bars, are a major concern in composite power system planning and operation as an increasing number of station components approach the wear-out phase. This paper presents probabilistic models for circuit breakers involving aging failures and relevant evaluation techniques to examine the effects of station related aging outages. The technique developed to incorporate station related aging failures are illustrated by application to a small composite test system.

The paper illustrates the effects of circuit breaker aging outages on bulk system reliability evaluation and examines the relative effects of variations in component age. System sensitivity analysis is illustrated by varying selected component parameters. The results show the implications of including component aging failure considerations in the overall analysis of a composite system.

Keywords: Bulk system reliability evaluation, aging, hazard rate, sensitivity

1. Introduction

A bulk electric system is generally composed of generating units, transmission lines and switching and transformer stations. The overall system reliability is dependent on the individual component reliabilities. Power system component failures can generally be divided into the two categories of random failures and those arising as a consequence of deterioration (aging) [2]. Most studies are focused on the influence of component random failures on bulk system reliability [3-5]. Aging failures of system components are, however, a growing issue in modern electric power systems as an increasing number of components approach the wear-out phase.

The failure events of a component can be grouped into the two categories of repairable and nonrepairable. A component can normally be restored to service after being repaired when it fails during its useful life, during which failures are assumed to occur randomly. A component cannot usually be repaired and must be replaced when it fails due to aging. A method to consider aging failures of system components such as cables and transformers in predictive reliability assessment is presented and illustrated by application in [6, 7]. In this method, a component effectively disappears for the remainder of the year under consideration when it fails due to aging as aging failures are considered to be nonrepairable. This is not always the case, however, for some important components. Station components such as circuit breakers and bus bars are relatively easy to replace compared to underground cables and transformers. An approach is therefore developed to recognize this in this paper.

This paper focuses on the development of a technique to incorporate station component aging failures in bulk system reliability evaluation. Circuit breakers are major station components and it is possible to replace them in most situations when required. An approximate evaluation approach is also developed to simply the analysis involved in including circuit breaker aging failures. The developed techniques are illustrated by application to the reliability evaluation of a small composite system designated as the RBTS [8].

2. System Applications

The test system used in the studies described in this paper is known as the RBTS [8]. This system was modified slightly by removing the radial line supplying Bus 6 and adding this load at Bus 5 in the original system. The modified system designated as the MRBTS is shown in Fig. 1.

This system has an installed capacity of 240 MW and a peak load of 185 MW. There are eleven generators located at two generator buses and eight transmission lines. The basic single line diagram of the test system in Fig. 1 is extended in Fig. 2 to include the station configurations. All the stations use ring bus configurations in the application

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illustrated in this paper.

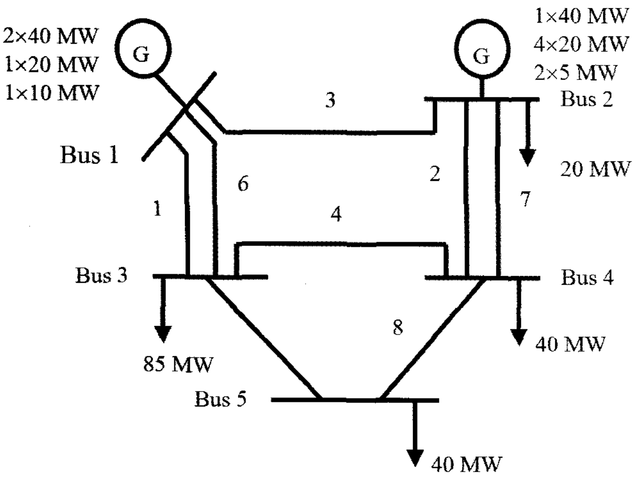

Fig. 1 Single line diagram of the MRBTS

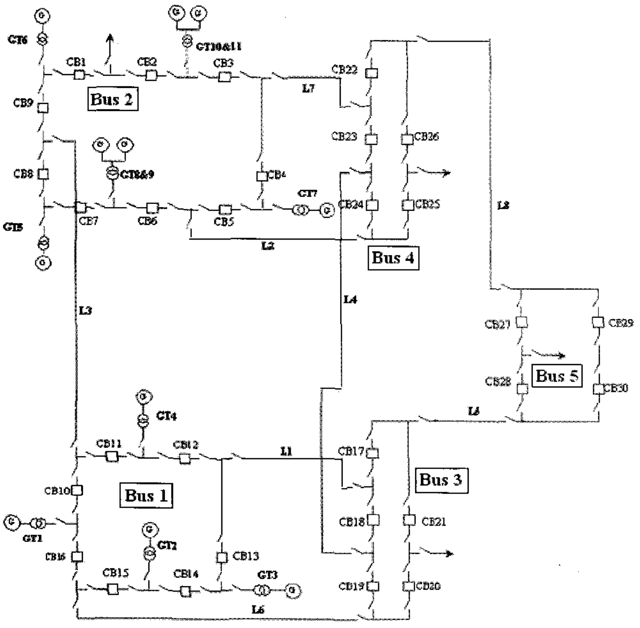

Fig. 2 Single line diagram of the MRBTS with ring bus configurations

The basic data for the RBTS are given in [8]. The circuit breaker reliability data was taken from [11] and the ratio of active to passive failures was derived from data shown in a CIGRE report [12]. The circuit breaker and bus bar reliability data used in this base case analysis are as follows.

Circuit breaker

Active failure rate = 0.00963 failures per year
Passive failure rate = 0.00107 failures per year
Total failure rate=0.0107 failures per year
Average outage duration = 93.62 hours
Switching time = 1 hour
Maintenance outage rate = 0.2 outages per year
Maintenance time = 108 hours

Bus bar

Failure rate = 0.025 failures per year
Outage duration = 10 hours

Each station shown in Fig. 2 was analyzed using the minimal cut set technique described in [9, 10]. This method is described and illustrated using a simple ring bus station. Fig. 3 shows a ring bus configuration, in which CB is the abbreviation for circuit breaker. The four terminal elements in the Figure can be transmission lines, feeders, transformers or loads. There are two kinds of minimal cut sets: independent minimal cut sets which cause the failure of only one terminal and common minimal cut sets which cause the failure of two or more terminals simultaneously. The reliability indices of the first group of minimal cut sets can be combined with those of the connected terminal. The reliability indices of the second group of minimal cut sets are treated as separate input data in the composite system reliability evaluation.

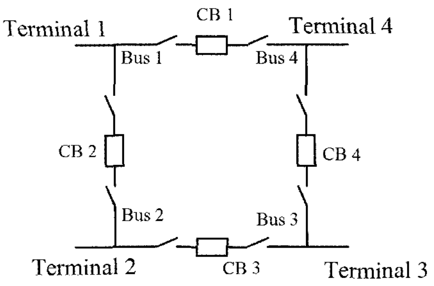

Fig. 3 Ring bus configuration

The independent minimal cut sets for Terminal 1 of the ring bus scheme are shown in Table 1. The common minimal cut sets for the four terminals are shown in Table 2. There are six common minimal cut sets. The first one is the active failure of CB2 which cause terminals 1 and 2 to be removed from service.

Table 1 Independent minimal cut sets for Terminal 1

Minimal cut set types	Forced outages	Maintenance outages
Independent minimal cut sets	Bus 1	
	CB1(T)+CB2(T)	CB2(M)+CB1(T)
	Bus 2+CB1(T)	CB1(M)+CB2(T)
	Bus 2+CB4(A)	CB1(M)+Bus 2
	Bus 4+CB2(T)	CB2(M)+Bus 4
	Bus 4+CB3(A)	
Cut set group name	Set 1	Set 2

(T=total failure, A=active failure, M=maintenance outage)

Table 2 Common minimal cut sets for the four station terminals.

Terminal 1	Terminal 2	Terminal 3	Terminal 4
CB1 (A)$_1$	CB2 (A)$_2$	CB3 (A)$_3$	CB1 (A)$_1$
CB2 (A)$_2$	CB3 (A)$_3$	CB4 (A)$_4$	CB4 (A)$_4$
Bus2 + Bus4$_6$	Bus1 + Bus3$_5$	Bus2 + Bus4$_6$	Bus1 + Bus3$_5$

The modified reliability data of Terminal 1 can be obtained by combining the data from its independent minimal cut sets. The required equations including station related forced and maintenance outages are as follows.

$$\begin{aligned} \lambda_1' &= \lambda_1 + \lambda_{set1} + \lambda_{set2} \\ U_1' &= U_1 + U_{set1} + U_{set2} \\ r_1' &= \frac{U_1'}{\lambda_1'} \end{aligned} \tag{1}$$

Where,

λ_1' is the modified failure rate of Terminal 1,

U_1' is the modified unavailability of Terminal 1,

r_1' is the modified average outage time of Terminal 1,

λ_1 is the original failure rate of Terminal 1,

λ_{set1} is the total failure rate of Set 1 due to station forced outages,

λ_{set2} is the total failure rate of Set 2 due to station maintenance outages,

U_1 is the original unavailability of Terminal 1,

U_{set1} is the total unavailability of Set 1,

U_{set2} is the total unavailability of Set 2.

Terminal 1 could be a transmission line or a transmission transformer and connected to two stations. The transmission element designated as Terminal 1 should therefore incorporate the associated independent minimal cut sets in both connected stations.

The MRBTS including the station related parameters was analyzed using the MECORE program. The MECORE program is a composite generation and transmission system reliability evaluation tool based on Monte Carlo simulation. This software was initially developed at the University of Saskatchewan and enhanced at BC Hydro. It can be utilized to perform reliability and reliability worth evaluation of generating systems, transmission systems or bulk power systems. The MECORE software can provide a wide range of reliability indices at the individual load points and for the overall composite system, as well as unreliability cost indices, which reflect reliability worth. The indices created by the program provide useful information when comparing different planning alternatives from a reliability point of view. The program is based on a combination of state sampling Monte Carlo simulation and enumeration techniques. The Monte Carlo technique is used to simulate the system component states and to calculate annualized indices at the system peak load level. A hybrid method utilizing an enumeration approach for aggregated load states is used to calculate annual indices.

The load point and system reliability indices for the MRBTS with ring bus schemes are shown in Tables 3 and 4.

Table 3 Annual load point indices for the MRBTS with ring bus schemes

Bus No.	PLC	ENLC (1/yr)	ELC (MW/yr)	EDNS (MW)	EENS (MWh/yr)
2	0.00004	0.10850	1.388	0.00048	4.202
3	0.00027	0.39032	9.890	0.00418	36.621
4	0.00003	0.10792	2.741	0.00077	6.759
5	0.00004	0.12130	2.987	0.00091	7.992

Table 4 Annual system indices for the MRBTS with ring bus schemes

Annual Indices	Results
ENLC (1/yr)	0.72091
ADLC (hrs/disturbance)	4.544
EDLC (hrs/yr)	3.28
PLC	0.00037
EDNS (MW)	0.00634
EENS (MWh/yr)	55.57458
EDC (k$/yr)	245.64
SI (system minutes/yr)	18.024

As shown in Tables 3 and 4, MECORE is capable of producing a wide range of system and load point indices. The abbreviations used in Tables 3 and 4 are listed below.

PLC - Probability of Load Curtailment
ENLC - The Expected Number of Load Curtailments
ELC - Expected Load Curtailments
EDNS - Expected Demand Not Supplied
EENS - Expected energy not supplied
ADLC - Average Duration of Load Curtailment
EDLC - Expected Duration of Load Curtailment
EDC - Expected damage cost
SI - Severity Index

The MRBTS at the 185 MW peak load level is a reasonably balanced system with no generation or transmission deficiencies. The analysis assumes that each component in the system is operating within its useful life during which failures are assumed to occur at random, and that preventive maintenance is being performed at assigned intervals.

The following section introduces the concept of component aging and the accompanying increase in failure rate associated with this phenomenon. The effect of the phenomenon on the reliability of the MRBTS is illustrated in a subsequent section.

3. Evaluation Method to Incorporate Aging Failures

The failure characteristics of electrical equipment generally follow the well-known bathtub curve shown in Fig. 4 [1]. Region I is known as the de-bugging or infant mortality period and is not considered in this paper. During Region II, which is known as the component useful life, the failure rate is constant and the failure density function follows an exponential distribution. When the component reaches Region III, which is designated as the wear-out period, the component failure rate gradually increases. The component reliability degrades after it leaves the useful life period.

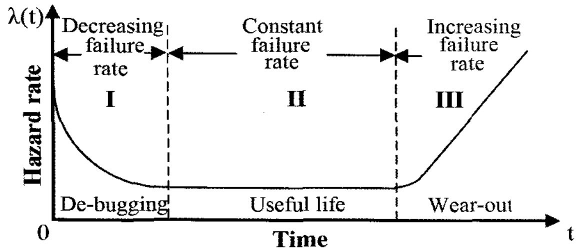

Fig. 4 Component hazard rate as a function of age

It is assumed in this analysis that aging failure rates of circuit breakers increase linearly with time. The failure density function in this case is a Weibull distribution with a shape factor of two. The time-dependent failure rate function for a circuit breaker is expressed by Equation (2) and shown in Fig. 5. In this equation, k is the slope factor and t_u is the useful life. The value of the slope factor is affected by a variety of factors such as mechanical design, loading, maintenance policies and environmental issues.

$$\lambda = \begin{cases} \lambda & (t \le t_u) \\ \lambda + \dfrac{\lambda \cdot k \cdot (t - t_u)}{t_u} & (t \ge t_u, k > 0) \end{cases} \tag{2}$$

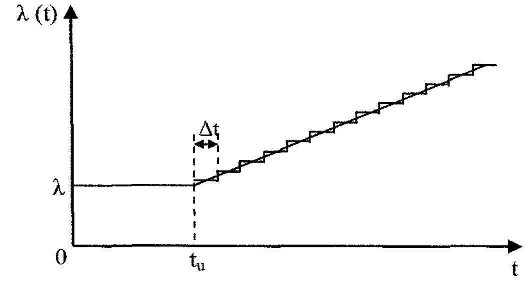

Fig. 5 Failure rate function of a circuit breaker

The reliability of a composite system is usually evaluated on a yearly basis and the annual reliability indices are used to express the system reliability performance. A one-year period can be divided into N equal intervals, each with a length Δt. It is assumed that Δt is small enough that the failure rate within Δt is a constant. If the age of the component is T years and greater than t_u, then the aging failure rate in the nth interval is given by

$$\lambda_{an} = \frac{\lambda \cdot k \cdot (t - t_u)}{t_u} = \frac{\lambda \cdot k \cdot (T + (n - 1/2) \cdot \Delta t - t_u)}{t_u} \qquad (n = 1, 2, \ldots, N) \tag{3}$$

The interval Δt can be varied as required. In the following analyses, it is assumed that a single average failure rate can be used to represent the failure rate over each one year period. Smaller intervals could be used if necessary.

The component aging failure rate increases linearly when the age is greater than t_u. The representative aging failure rate (λ_a) in the (T+1) year for the T-year component is equal to the average value for the year.

$$\begin{aligned} \lambda_a &= \frac{1}{N} \cdot \sum_{i=1}^{N} \frac{\lambda \cdot k \cdot (T + (i - 1/2) \cdot \Delta t - t_u)}{t_u} \\ &= \frac{\lambda \cdot k \cdot (T - 1/2 - t_u)}{t_u} \end{aligned} \tag{4}$$

3.1 The basic evaluation process

The state space model for a circuit breaker is shown in Fig. 6. In this model, the transition rate λ_a is the active failure rate and the transition rate λ_p is the passive failure rate. The transition rate μ_{sw} is the switching rate and is the reciprocal of the switching time. The transition rate μ from state 3 to state 1 is the repair rate of the circuit breaker and is the reciprocal of the average duration required to restore a failed breaker back to service.

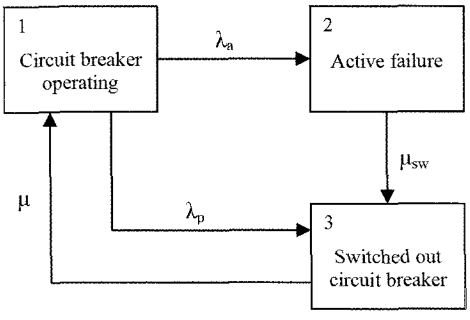

Fig. 6 State space model of a circuit breaker

The basic model in Fig. 6 is extended in Fig. 7 to consider the random and aging failures shown in Fig. 5. As shown in Equation (4), the component aging failure rate in each year can be represented by a constant value when the component age T is greater than the useful life t_u. The state space model for a circuit breaker in the ith year is shown in Fig. 7. The transition rates λ_{aai} and λ_{api} are the active failure rate and passive failure rate due to aging in the ith year respectively. The transition rate μ_a is the replacement rate of the circuit breaker and μ_{asw} is the switching rate, which is assumed to equal μ_{sw}.

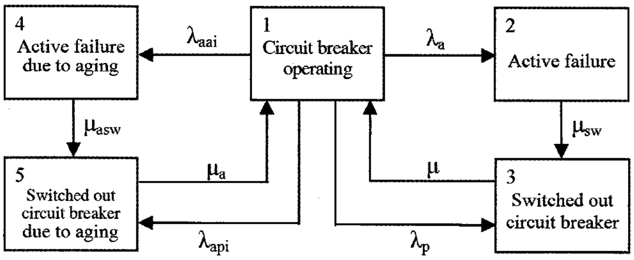

Fig. 7 Model of a circuit breaker in the ith year

The aging failure rate λ_{ai} in the ith year can be obtained using Equation (4). The ratio of active failures of a circuit breaker due to aging over related passive failures is assumed to be nine, which is the same as that used under normal conditions [12].

The active failure rate λ_{aai} and passive failure rate λ_{api} are therefore as follows.

$$\lambda_{aai} = 0.9 \cdot \lambda_{ai}, \quad \lambda_{api} = 0.1 \cdot \lambda_{ai} \tag{5}$$

The state probabilities in Fig. 7 can be calculated using the frequency balance approach [1].

$$\begin{aligned}
P_1 &= \frac{\mu \cdot \mu_a \cdot \mu_{sw} \cdot \mu_{asw}}{D} \\
P_2 &= \frac{\lambda_a \cdot \mu \cdot \mu_a \cdot \mu_{asw}}{D} \\
P_3 &= \frac{(\lambda_a + \lambda_p) \cdot \mu_a \cdot \mu_{sw} \cdot \mu_{asw}}{D} \\
P_4 &= \frac{\lambda_{aai} \cdot \mu \cdot \mu_a \cdot \mu_{sw}}{D} \\
P_5 &= \frac{(\lambda_{aai} + \lambda_{api}) \cdot \mu \cdot \mu_{sw} \cdot \mu_{asw}}{D}
\end{aligned} \tag{6}$$

where

$$\begin{aligned}
D = {} & \lambda_a(\mu \cdot \mu_a \cdot \mu_{asw} + \mu_a \cdot \mu_{sw} \cdot \mu_{asw}) + \lambda_{aai}(\mu \cdot \mu_a \cdot \mu_{sw} + \mu \cdot \mu_{sw} \cdot \mu_{asw}) \\
& + \lambda_p \cdot \mu_a \cdot \mu_{sw} \cdot \mu_{asw} + \lambda_{api} \cdot \mu \cdot \mu_{sw} \cdot \mu_{asw} + \mu \cdot \mu_a \cdot \mu_{sw} \cdot \mu_{asw}
\end{aligned}$$

The five-state model can be reduced to the three-state model shown in Fig. 8 by combining states 2 and 4, and states 3 and 5. The transition rates λ_{at} and λ_{pt} are the equivalent active failure rate and passive failure rate in the ith year respectively. The transition rate μ_t is the equivalent repair rate of the circuit breaker and μ_{swt} is the equivalent switching rate in the ith year.

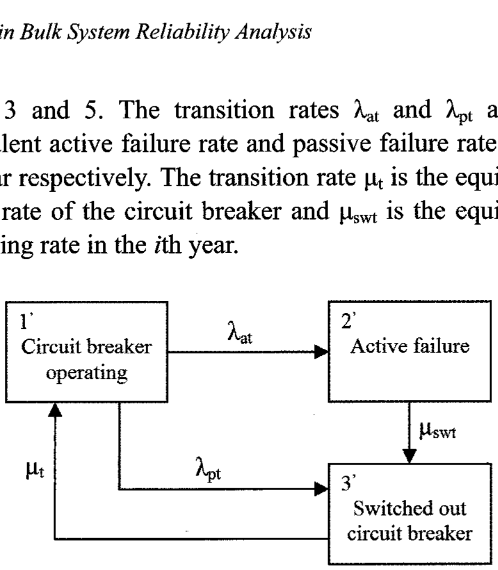

Fig. 8 Reduced model of a circuit breaker in the ith year

The total unavailability of the circuit breaker in Fig. 8 is

$$U_t = 1 - P_1' = 1 - P_1 = 1 - \frac{\mu \cdot \mu_a \cdot \mu_{sw} \cdot \mu_{asw}}{D} \tag{7}$$

Using the frequency balance approach, the equivalent active and passive failure rates in the ith year are as follows:

$$\lambda_{at} = \lambda_a + \lambda_{aai}, \quad \lambda_{pt} = \lambda_p + \lambda_{api} \tag{8}$$

The equivalent repair time in the ith year is

$$r_t = \frac{1}{\mu_t} = \frac{(\lambda_a + \lambda_p) \cdot \mu_a + (\lambda_{aai} + \lambda_{api}) \cdot \mu}{(\lambda_a + \lambda_p + \lambda_{aai} + \lambda_{api}) \cdot \mu \cdot \mu_a} \tag{9}$$

The equivalent switching time in the ith year is

$$r_{swt} = \frac{1}{\mu_{swt}} = \frac{\lambda_a \cdot \mu_{asw} + \lambda_{aai} \cdot \mu_{sw}}{(\lambda_a + \lambda_{aai}) \cdot \mu_{sw} \cdot \mu_{asw}} \tag{10}$$

3.2 Approximate evaluation process

The approximate method was developed in order to more easily evaluate the circuit breaker reliability parameters. In this procedure, the active failures and the passive failures of a circuit breaker due to random failures or aging are grouped separately. The switching action of the circuit breaker is not considered, since the switching time is very short. The five-state model is then reduced to the three-state model shown in Fig. 9 by grouping States 2 and 3 and states 4 and 5 in Fig. 7. The transition rates λ_{ai} and μ_a are the total failure rate and replacement rate of the circuit breaker due to aging in the ith year respectively. The transition rate λ and μ are the total forced outage rate and repair rate of the circuit breaker respectively. The model shown in Fig. 9 is directly applicable to bus bar outages due to random and aging failures. The normal model for a bus bar with a constant failure rate is the two-state representation shown in Fig. 10.

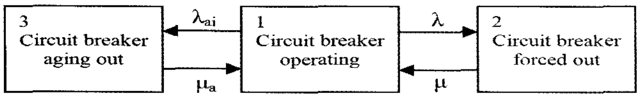

Fig. 9 Approximate model of a circuit breaker in the *i*th year

The three-state model can be reduced to the two-state model shown in Fig. 10 by combining states 2 and 3.

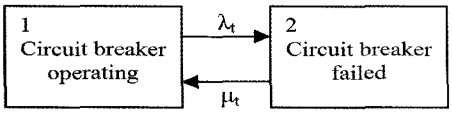

Fig. 10 Reduced approximate model of a circuit breaker in the *i*th year

The total failure rate of the circuit breaker is

$$\lambda_t = \lambda + \lambda_{ai} \tag{11}$$

The total unavailability of the breaker is

$$U_t = \lambda \cdot \frac{1}{\mu} + \lambda_{ai} \cdot \frac{1}{\mu_a} \tag{12}$$

The equivalent repair time is

$$r_t = \frac{U_t}{\lambda_t} = \frac{\lambda \cdot \frac{1}{\mu} + \lambda_{ai} \cdot \frac{1}{\mu_a}}{\lambda + \lambda_{ai}} = \frac{\lambda \cdot \mu_a + \lambda_{ai} \cdot \mu}{(\lambda + \lambda_{ai}) \cdot \mu \cdot \mu_a} \tag{13}$$

Once these reliability parameters are obtained, the next step is to separate the active and passive failures of the circuit breaker. The switching action of a circuit breaker is now taken into consideration. The state space model is the same as in Fig. 8 but the transition rates are different.

The total active failure rate and passive failure rate of the circuit breaker are as follows.

$$\begin{aligned} \lambda_{at} &= 0.9 \cdot \lambda_t = 0.9 \cdot (\lambda + \lambda_{ai}) = \lambda_a + \lambda_{aai} \\ \lambda_{pt} &= 0.1 \cdot \lambda_t = 0.1 \cdot (\lambda + \lambda_{ai}) = \lambda_p + \lambda_{api} \end{aligned} \tag{14}$$

The equivalent repair rate μ_t is assumed to equal the repair rate in Fig. 10. The equivalent repair time in the *i*th year is therefore equal to

$$r_t = \frac{\lambda \cdot \mu_a + \lambda_{ai} \cdot \mu}{(\lambda + \lambda_{ai}) \cdot \mu \cdot \mu_a} = \frac{(\lambda_a + \lambda_p) \cdot \mu_a + (\lambda_{aai} + \lambda_{api}) \cdot \mu}{(\lambda_a + \lambda_p + \lambda_{aai} + \lambda_{api}) \cdot \mu \cdot \mu_a} \tag{15}$$

The equivalent switching rate is assumed to be equal to the switching rate in the normal condition.

$$\mu_{swt} = \mu_{sw}, \qquad r_{swt} = r_{sw} \tag{16}$$

The equivalent reliability parameters of a circuit breaker, such as the active failure rate, passive failure rate, repair time and switching time are used to incorporate station related outages in the minimal cut set evaluation of each station [9, 10]. The equations developed in the approximate approach and those obtained by the accurate approach to calculate the equivalent active failure rate, passive failure rate and repair time are basically the same. The equations developed to calculate the circuit breaker unavailability are different. The equations used to calculate the circuit breaker parameters are developed under the assumption that the switching rate of circuit breaker due to aging is the same as that due to a forced outage. The equivalent switching time cannot be obtained using the approximate method.

4. MRBTS Analysis with Aging Failures

The effects of circuit breaker aging failures were incurporated in a series of studies of the MRBTS with ring bus configurations. The base case analysis of the system is shown in Tables 3 and 4. The useful life of a circuit breaker is assumed to be ten years and the average replacement time following an aging failure is considered to be six days. The series of studies were conducted assuming that all the circuit breakers were at the same point in their lives. Similar analyses could be conducted with each breaker at different points in their individual lives if required.

Fig. 4 assumes that the failure rate increases linearly with time in the wear-out region. The slope of this linear increase can vary considerably. The following studies on the MRBTS consider three cases in which the slope $k = 0.5$, 5 and 10. Incorporating aging failures of the station circuit breakers will impact all the reliability indices shown in Tables 3 and 4. The following Figure show the effects of aging failures on the system Expected Energy Not Supplied (EENS) for the MRBTS. The circuit breaker ages are shown in Table 5 and Fig.s 11-13.

Table 5 shows the circuit breaker reliability data includeing random and aging failures using the accurate and approximate approaches. The slope factor k is 0.5 in this case. It can be seen from Table 5 that the error in the unavailability obtained using the approximate approach is less than 1%. The approximate approach is used in the following reliability analyses. The load point and system EENS as a function of the circuit breaker age are shown in Fig. 11. This Fig. shows that the load point and system EENS increase slowly with increase in the circuit breaker age when the slope factor *k* is small.

Two additional cases were analyzed in which *k* equals 5 and 10. The total unavailability of a circuit breaker obtained using the accurate method is a little larger than that obtained using the approximate method. Fig.s 12 and 13 respectively show the load point and system EENS as a function of the circuit breaker age when *k* equals 5 and 10. These two Figure show that the load point and system EENS increase rapidly with increase in the circuit breaker age. The major contribution to the increase in the system EENS is from the load point at Bus 3, which carries the heaviest load in the system.

Table 5 Reliability data for the circuit breakers in the MRBTS (*k*=0.5)

Circuit breaker age (yr)	Equivalent active failure rate (f/yr)	Equivalent passive failure rate (f/yr)	Equivalent repair time (hr)	Unavailability (hr/yr) (accurate)	Unavailability (hr/yr) (approximate)
<10	0.00963	0.00107	93.62	1.011254	1.001734
10	0.009871	0.001097	94.848780	1.049999	1.040254
20	0.014686	0.001632	110.963934	1.824959	1.810654
30	0.019501	0.002167	119.120988	2.599783	2.581054
40	0.024316	0.002702	124.047525	3.374469	3.351454
50	0.029131	0.003237	127.345455	4.149019	4.121854

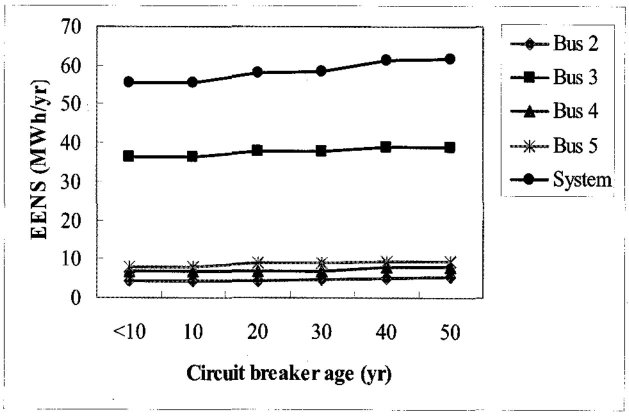

Fig. 11 Load point and the MRBTS EENS as a function of the circuit breaker age

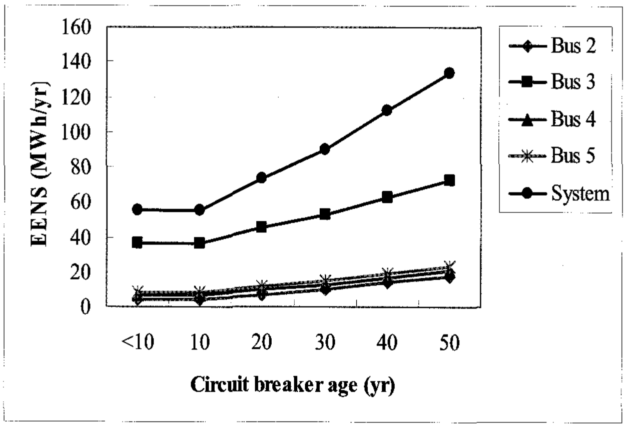

Fig. 12 Load point and the MRBTS EENS as a function of the circuit breaker age (*k*=5)

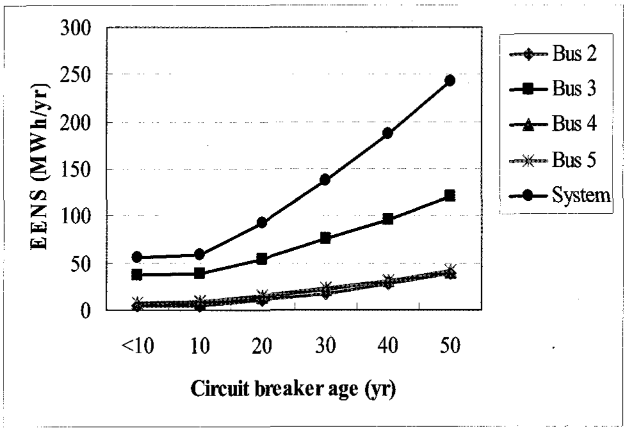

Fig. 13 Load point and MRBTS EENS as a function of the circuit breaker age (*k*=10)

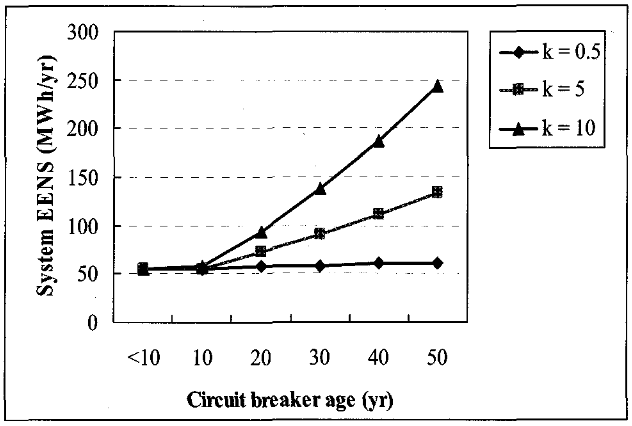

Fig. 14 Modified RBTS EENS comparison for three different circuit breaker slope factors

Fig. 14 shows a comparison of the system EENS for the modified RBTS with the three different slope factors. It can be seen from Fig. 13 that the load point and system EENS increase rapidly after the circuit breakers enter the wear-out period when the slope factor k is large. Circuit breaker aging failures can have significant impacts on the load point and system reliability in these cases.

5. Summary and Conclusions

This paper presents an analytical technique to incorporate circuit breaker aging failures in bulk system reliability evaluation. Circuit breaker models together with accurate and approximate evaluation processes are presented to incorporate aging failures in circuit breaker reliability parameters. The unavailability of a circuit breaker obtained using the accurate method is a little larger than that obtained using the approximate method. The approximate evaluation approach is considered to be acceptable and can be easily used in a reliability study.

The circuit breaker reliability parameters are used as input data to examine the aging effects on the modified RBTS with ring bus schemes. The results show that station component aging failures can have a significant impact on the load point and system reliability of a composite system. The impacts of component aging failures become larger with increase in component age. It is therefore important to recognize and incorporate station component aging effects in the reliability assessment of a bulk system, especially when the system components have been in operation for some time.

The effects on composite system reliability due to station component aging failures are dominated by the component slope factors, which are affected by the system maintenance policies. Aging effects on the load point and system EENS are relatively small when the component slope factors are small. These effects, however, increase rapidly as the slope factors increase. Inadequate maintenance can result in a large slope factor and it is important to conduct appropriate preventive maintenance on the station components in order to prolong their useful life and to keep their failure rates from increasing.

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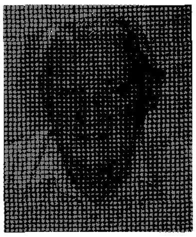

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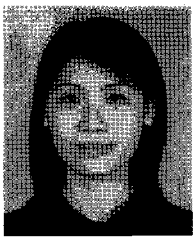

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