APPLICATION OF AGING FAILURE MODELS IN POWER SYSTEM RELIABILITY EVALUATION

By Wenyuan Li

There are two failure modes for power system components: repairable and aging failures. The repairable failures are characterized by average failure frequency and repair time. Almost all methods and tools for power system reliability evaluation presented so far have only considered the repairable failure mode. In other words, aging failures, although an important failure mode, have not been modeled in power system reliability assessment.

The aging failure is a non-repairable failure event. Once a component fails due to aging, it will die forever. The aging failures of system components such as transformers, cables, breakers, capacitors and reactors, etc. have been a major concern and a driving factor in system planning of many utilities since more and more system components are approaching their end-of-life stage.

In fact, aging is a general phenomenon in the real life. Excluding aging failures in power system reliability evaluation will definitely lead to underestimation of the system risk. If some key components in a system are aged, aging failures could become a dominant factor of system unreliability. In this case, ignoring aging failures will most likely result in a misleading conclusion in system planning.

British Columbia Transmission Corporation (BCTC) has developed aging failure models for power system components and incorporated the models into the system reliability evaluation. The models are based on either normal or Weibull distribution and can be used to predict unavailability of a component due to aging failure in any specified period. The defined concept of unavailability due to aging failures is consistent with that for repairable failures. This allows aging failures to be easily included in the existing reliability evaluation techniques and tools.

Two computer programs have been completed for this purpose. The first one called SPARE is used to evaluate unavailability of components due to aging failures and conduct an equipment spare analysis. The second one named MECORE is used to perform transmission system reliability assessment.

This article presents an example to demonstrate an application of the aging failure model in predicting unavailability of underground cables due to aging failures and their impacts on a BC Hydro regional system reliability.

UNAVAILABILITY OF CABLES DUE TO AGING FAILURE

There are eight 230 kV underground cables in a BC Hydro regional system. The unavailability of repairable failures of the eight cables and their natural ages are given in Table 1. Repairable failure data is based on statistics in the past 15 years. The mean life for the cables was estimated to be 45 years with a standard deviation of 15 years. The SPARE program was used to calculate unavailability of the cables due to aging failures using the developed models.

Unavailability values due to aging failures for the eight cables from 2001 to

2006 using the normal and Weibull models are shown in Tables 2 and 3 respectively. In order to show a more clear comparison between the unavailability values of repairable failures and aging failures as well as those between normal and Weibull models, annual unavailability values of the three cables with typical ages from 2001 to 2006 have been plotted in Figures 1, 2 and 3.

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The following observations can be made from Tables 1-3 and Figures 1-3:

- The unavailability of aging failures increases with the age while the unavailability of repairable failures keeps constant.
- The unavailability of aging failures at a "young" age is smaller than the unavailability of repairable failures. The unavailability of aging failures at a "mid age" is in an order of magnitude comparable with the unavailability of repairable failures. The unavailability of aging failures at an "old age" is much larger than the unavailability of repairable failures.
- The normal distribution model provides a lower estimation of unavailability at a "young or mid age" but a higher estimation at an "old age" compared to the Weibull model if they have the same mean life and standard deviation. However, more investigations indicate that when the age is "very old", the situation will change - the Weibull model will lead to a higher estimation of unavailability than the normal model, particularly in the case of a small standard deviation. In other words, there are two intersection points on the two curves of unavailability vis-à-vis age for the normal and Weibull models.

RELIABILITY EVALUATION OF A BC HYDRO REGIONAL SYSTEM

The eight cables mentioned above are located in a BC Hydro regional system. The MECORE program using Monte Carlo state sampling method was utilized to assess reliability of the regional system from 2001 to 2006. It was assumed that each year had 2% of load growth with the same shape of an annual load curve. The Expected Energy Not Supplied (EENS) indices for two cases are shown in Tables 4 and 5 and Figure 4. In Case 1, only repairable failures for all system components were considered and in Case 2, aging failures for the eight cables were also considered on top of Case 1.

It can be seen that the system EENS indices of incorporating cable aging failures are much larger than those of only considering repairable failures. The contributions due to aging failures of the eight cables are dominant on the results in this case. This is because the cables are the main transmission links in the system and four of them are close to end-of-life with high aging failure unavailability. This suggests that for an aged system, if aging failures are ignored in modeling as is

Table 1 Age and unavailability of repairable failure

Cable	Age (years)	Unavailability
Cable 1	16	0.00152
Cable 2	27	0.01142
Cable 3	28	0.00152
Cable 4	28	0.00647
Cable 5	41	0.00342
Cable 6	43	0.01332
Cable 7	44	0.01027
Cable 8	44	0.01449

Table 2 Unavailability of aging failure (normal model)

Cable	Year					
	2001	2002	2003	2004	2005	2006
Cable1	0.00001	0.00002	0.00003	0.00005	0.00008	0.00012
Cable2	0.00136	0.00191	0.00262	0.00353	0.00468	0.00609
Cable3	0.00191	0.00262	0.00353	0.00468	0.00609	0.00781
Cable4	0.00191	0.00262	0.00353	0.00468	0.00609	0.00781
Cable5	0.03426	0.03914	0.04431	0.04976	0.05544	0.06134
Cable6	0.04431	0.04976	0.05544	0.06134	0.06744	0.07370
Cable7	0.04976	0.05544	0.06134	0.06744	0.07370	0.08010
Cable8	0.04976	0.05544	0.06134	0.06744	0.07370	0.08010

Table 3 Unavailability of aging failure (Weibull model)

Cable	Year					
	2001	2002	2003	2004	2005	2006
Cable1	0.00039	0.00051	0.00066	0.00084	0.00106	0.00132
Cable2	0.00406	0.00479	0.00560	0.00652	0.00756	0.00871
Cable3	0.00479	0.00560	0.00652	0.00756	0.00871	0.01000
Cable4	0.00479	0.00560	0.00652	0.00756	0.00871	0.01000
Cable5	0.02637	0.02935	0.03257	0.03605	0.03981	0.04385
Cable6	0.03257	0.03605	0.03981	0.04385	0.04818	0.05283
Cable7	0.03605	0.03981	0.04385	0.04818	0.05283	0.05779
Cable8	0.03605	0.03981	0.04385	0.04818	0.05283	0.05779

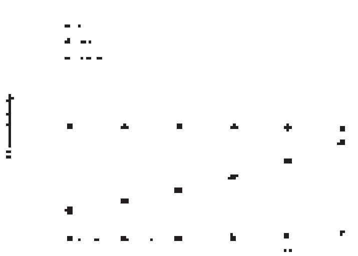

Figure 1: Unavailability of Cable 1 (age=16 years)

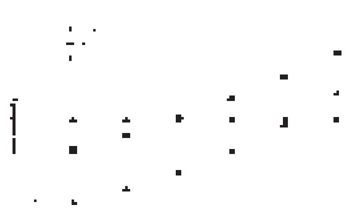

Figure 2: Unavailability of Cable 4 (age=28 years)

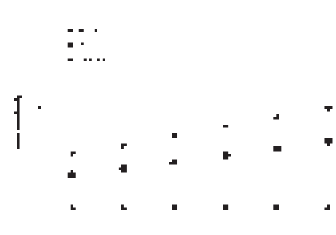

Figure 3: Unavailability of Cable 8 (age=44 years)

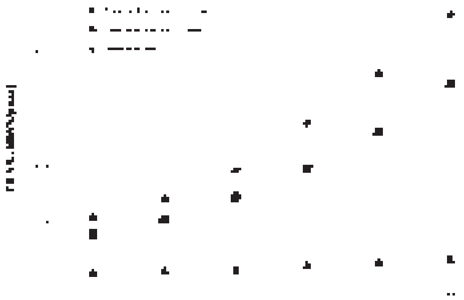

Figure 4: EENS of a BC Hydro regional system with and without cable aging failures

usually the case, reliability indices will be overly underestimated and this will most likely lead to a misleading conclusion in system planning. The EENS index for the case of only considering repairable failures has a slight increase with the years because of the assumption of 2% load growth each year. On the other hand, the EENS index for the case of incorporating cable aging failures increases dramatically as the time advances. This is due to the fact that the unavailability of cable aging failures has a relatively large increase over the years.

Table 4 System EENS (MWh/year) - Normal model for Case 2

Year	Case 1	Case 2 (normal model)	Contrib. due to aging failures	Contrib. %
2001	766	5515	4749	86
2002	906	7113	6207	87
2003	1054	9682	8628	89
2004	1359	13780	12421	90
2005	1690	18084	16394	91
2006	2039	23251	21212	91

Table 5 System EENS (MWh/year) - Weibull model for Case 2

Year	Case 1	Case 2 (Weibull model)	Contrib. due to aging failures	Contrib. %
2001	766	4128	3362	81
2002	906	5384	4478	83
2003	1054	7299	6245	86
2004	1359	9737	8378	86
2005	1690	13075	11385	87
2006	2039	17308	15269	88

CONCLUSIONS

This article describes an application of aging failure model in power system reliability evaluation. The defined unavailability of aging failures has a consistent form as that for repairable failures and therefore it is simple and straightforward to include it in the existing reliability evaluation techniques and tools.

The unavailability due to aging failures can be modeled using either normal or Weibull distribution. Generally, the normal model provides a lower estimation of unavailability at a young or mid age and a higher estimation at an age around the mean life compared to the Weibull model. Which model should be used in an actual application depends on the match between the parameters of the model and failure data statistics.

The results applied to a BC Hydro regional system reliability assessment indicate that aging failures have significant impacts on the system reliability, particularly for an "aged" system. Ignoring aging failures in reliability evaluation of an aged power system will result inconsiderable underestimation of system risk and most likely a misleading conclusion in system planning.

Dr. Wenyuan Li is a Specialist Engineer of System Operation and Asset Management at BCTC, Vancouver. He is also an IEEE Fellow; co-author of the book "Reliability Assessment of Electrical Power Systems Using Monte Carlo Methods", Plenum Press, New York, 1994; the winner of 1996 "Outstanding Engineer Award" of IEEE Canada for "contributions in power system reliability and probabilistic planning". **ET**.