BCTC-SPA-R003

Probability Distribution of HVDC Capacity and Impacts of Two Key Components

(Risk, Cost and Feasibility of Extending HVDC life to 2009)

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System Performance Assessment
BCTC

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(Executive Summary)

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This study is a portion of the Vancouver Island Supply Alternative Project [1,2]. HVDC Pole 1 has been retired and Pole 2 will be retired in 2007. BCUC agreed that the planning capacity of HVDC would be zero in 2007. One major alternative for Vancouver Island supply is the addition of the 230 kV AC line. However, the in-service date of the 230 kV AC line project will be in October 2008 as an accelerated plan or in October 2009 as a non-accelerated plan.

Conceptually, the retirement of HVDC does not mean that it can no longer be used in operation. Actually, like human beings, the retired HVDC can continue to serve supply with relatively high unavailability from an operation viewpoint. Also, replacements of some critical components can extend its life. The purpose of the study is to evaluate probability distribution of HVDC capacity and impacts of two key component replacements (Pole 2 reactor and filter capacitor at VIT) on HVDC reliability. The results provide answers to the following questions:

- If we continue to use HVDC as it is (i.e., without any replacement or refurbishment), what is the increased risk or unreliability of HVDC?
- If we replace each of the two key components, how much reliability improvement can be expected and for how long?
- Can HVDC be used as an alternative before the 230 kV line in-service?

The study does not intend to re-address HVDC life extension as a long-term solution to Vancouver Island supply. The previous studies have proved that HVDC life extension is not a competitive alternative for Vancouver Island long-term power supply in terms of economic effectiveness and long time unreliability. HVDC ageing is a basic fact. However, this does not lower the significance of investigating the risk, cost and feasibility of extending HVDC life to fill the gap before the 230 kV AC line in-service.

The following conclusions can be made from the assessment results:

(1) The evaluated results show that the availability of Pole 1 in 2004 is only 38.9% now and will be further decreased to 20% in 2007. The availability of Pole 2 in 2004 is 84% now, will be decreased to only 73% in 2007 and to 63% in 2009 due to ageing failure probability.
(2) By combining the poles 1 and 2 together, the availability of the whole HVDC in 2004 is 90.2%, will be 78.4% in 2007 and 66.9% in 2009. The failure event of HVDC can happen any time during the peak or off-peak period with the estimated probabilities in different years. If we can accept the relatively high risk from 2007 to 2009, HVDC without any refurbishment (doing nothing) could be used as an option before the 230 kV line in place in 2008 or 2009.
(3) The study shows that replacing the Pole 2 reactor at VIT in 2005 will provide HVDC life extension by two years. This means that replacing the Pole 2 reactor at VIT in 2005 will bring the HVDC failure probability in 2009 back to its failure probability level in 2007. Replacing the Pole 2 filter capacitor at VIT in 2005 will provide HVDC life extension by one year. In other words, replacing the Pole 2 filter capacitor at VIT in 2005 will bring the HVDC failure probability in 2008 back to its failure probability level in 2007.
(4) According to the cost estimate based on the Alstom Life Extension Report completed in June 2001, the Pole 2 reactor costs $2.0 million and the Pole 2 filter capacitor costs $1.7 million. If we want to keep the overall HVDC reliability in 2009 at the same level as its reliability status in 2007, replacing the Pole 2 reactor at VIT is an option with $2.0 million of investment. Replacing the Pole 2 filter capacitor at VIT can be used as an additional measure to get one more year of “reliability advance” with the cost of $1.7 million.

(5) It is important to appreciate that the assessment results are based on the probability analysis. The results should be viewed as the expected value of a random variable. Also, the input data always have some uncertainty. The input data used in this study are based on the same source that was used in the reliability evaluation of Vancouver Island in the VIGP project.

(6) In general, it can be concluded that HVDC can be used as an alternative before the 230 kV AC line in-service. If the 230kV line can be in place in 2008, replacing the Pole 2 filter capacitor at VIT may be a good option if a little bit (about 1%) higher risk is acceptable. If the 230kV line cannot be available until 2009, replacing the Pole 2 reactor at VIT is a potential option. Both of these options provide almost the same HVDC reliability level as that in 2007. The cost paid is $1.7 or $2.0 million. Replacing both the Pole 2 reactor and the filter capacitor at VIT can offer further improvement in HVDC reliability with the total cost of $3.7 million.

Probability Distribution of HVDC Capacity and Impacts of Two Key Components
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1. Introduction

This study is a portion of the Vancouver Island Supply Alternative Project [1,2]. HVDC Pole 1 has been retired and Pole 2 will be retired in 2007. BCUC agreed that the planning capacity of HVDC would be zero in 2007. One major alternative for Vancouver Island supply is the addition of the 230 kV AC line. However, the in-service date of the 230 kV AC line project will be in October 2008 as an accelerated plan or in October 2009 as a non-accelerated plan.

Conceptually, the retirement of HVDC does not mean that it can no longer be used in operation. Actually, like human beings, the retired HVDC can continue to serve supply with relatively high unavailability from an operation viewpoint. Also, replacements of some critical components can extend its life. The purpose of the study is to evaluate the probability distribution of HVDC capacity and impacts of two key component replacements (Pole 2 reactor and filter capacitor at VIT) on HVDC reliability. The results provide answers to the following questions:

- If we continue to use HVDC as it is (i.e., without any replacement or refurbishment), what is the increased risk or unreliability of HVDC?
- If we replace each of the two key components, how much reliability improvement can be expected and for how long?
- Can the HVDC be used as an alternative before the 230 kV line in-service?

The study does not intend to re-address HVDC life extension as a long-term solution to Vancouver Island supply. The previous studies have proved that HVDC life extension is not a competitive alternative for Vancouver Island long-term power supply in terms of economic effectiveness and long time unreliability. HVDC ageing is a basic fact. However, this does not lower the significance of investigating the risk, cost and feasibility of extending HVDC life to fill the gap before the 230 kV AC line in-service.

2. Assumptions and data

In the study, the following assumptions are considered:

- Both repairable and ageing failure modes of each component of the HVDC system are modelled.
- HVDC has been in the end-of-life stage and ageing failures must be considered. The basic feature of ageing failure is that the failure probability of components increases as the age.
- The time frame is from 2004 to 2010.
- According to the operation logic of HVDC, both poles 1 and 2 have two operation modes. The pole 1 can be operated at the full capacity of 312 MW if all the components are in service and at the half capacity of 156 MW if only one of the components with redundancy fails. The pole 1 has to be shut down if the reactor or filter capacitor at either VIT or ARN fails. The pole 2 can be operated at the full capacity of 476 MW if all the components are available and at the half capacity of 238 MW if only one of the components with redundancy fails. The pole 2 has to be shut down if the reactor or filter capacitor at either VIT or ARN fails.
- It can be judged from the reliability configuration of HVDC that the key components impacting HVDC reliability are the reactor and filter capacitor of Pole 2 at the VIT side. Only the reliability improvement due to replacement of each of the two key components is evaluated.
- The failure data of components are the same as those used in the reliability evaluation study of the VIGP project [3]. The data include the failure frequency and repair time for the repairable failure mode and the mean life and standard deviation of each component. These data are based on the expert's estimation [4].

3. Assessment Method

The assessment method includes the following steps:

(1) The unavailability due to the repairable and ageing failure of each component is calculated using the SPARE program [5].
(2) The state enumeration technique is used to evaluate the probability of each capacity level of pole 1 or pole 2. This is performed on a spreadsheet.
(3) The state enumeration technique is used to assess the probability distribution of whole HVDC capacity by combining the state probabilities of poles 1 and 2. This is also conducted on a spreadsheet.
(4) The above steps are repeated from 2004 to 2010.
(5) Step (1) to (4) are performed for the three cases: (a) base case (doing nothing); (b) replacement of Pole 2 reactor at VIT; (c) replacement of Pole 2 filter capacitor at VIT.

4. Results

4.1 Doing nothing

The unavailability values due to both repairable and ageing failures for all the components from 2004 to 2010, which were obtained from running the SPARE program, are listed in Appendix 1. The calculation process of the probability distributions for the poles 1 and 2 at different capacity levels is also given in Appendix 1.

The separate reliability probability distributions for the poles 1 and 2 are shown respectively in Tables 1 & 2 and Figures 1 & 2. The probability distribution of whole HVDC capacity, which is a combination of probability distributions of the poles 1 and 2, is shown in Table 3 and Figure 3.

Table 1 Reliability probability distribution of Pole 1 (doing nothing)

Year	Probability at 156 MW & above	Probability at 312 MW only	Failure probability
2004	0.185683187	0.389007903	0.610992097
2005	0.143281059	0.322473156	0.677526844
2006	0.106243735	0.258678238	0.741321762
2007	0.075725132	0.200479565	0.799520435
2008	0.051009050	0.148315626	0.851684374
2009	0.032753449	0.105080105	0.894919895
2010	0.019887959	0.070819540	0.929180460

Table 2 Reliability probability distribution of Pole 2 (doing nothing)

Year	Probability at 238 MW & above	Probability at 476 MW only	Failure probability
2004	0.629157259	0.840012783	0.159987217
2005	0.593907860	0.808170912	0.191829088
2006	0.554333069	0.771330493	0.228669507
2007	0.512838492	0.730082813	0.269917187
2008	0.463541606	0.682057124	0.317942876
2009	0.413689862	0.629911569	0.370088431
2010	0.362198344	0.573357887	0.426642113

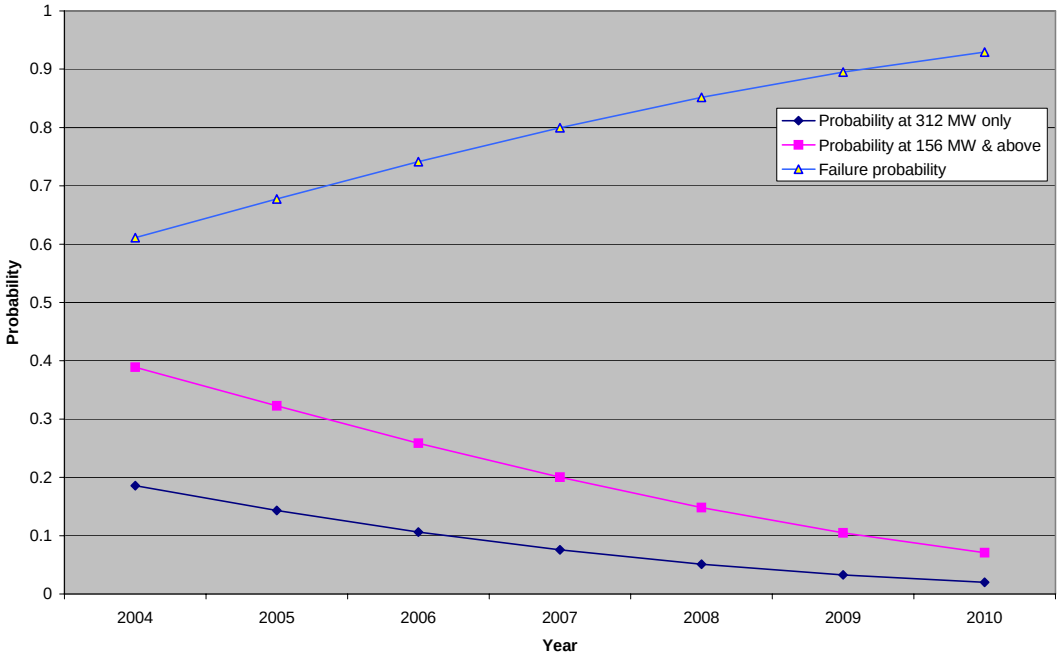

Figure 1 Reliability probability of Pole 1 (doing nothing)

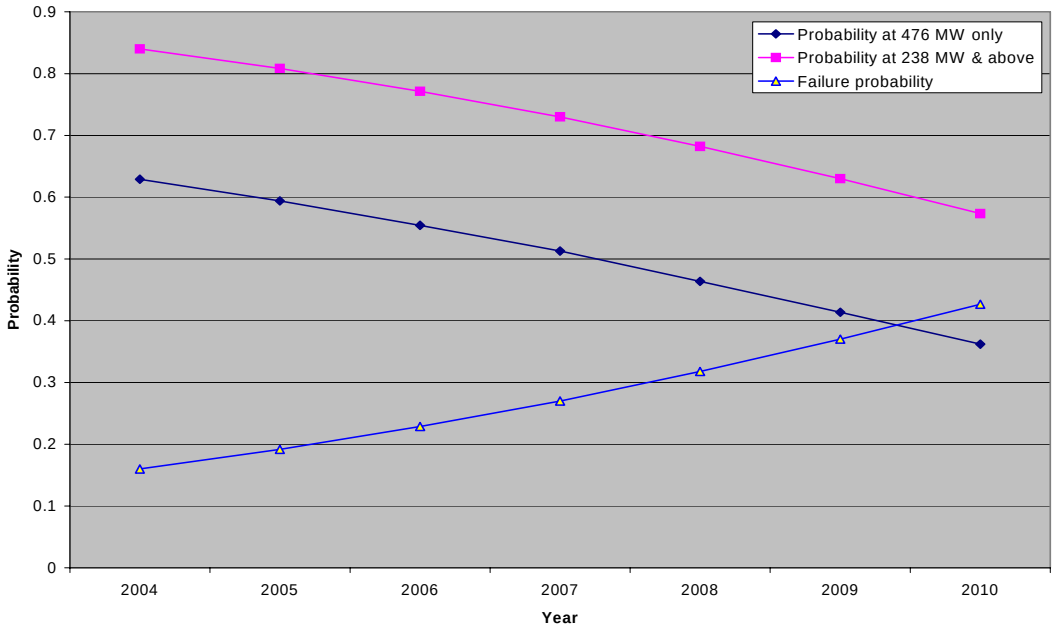

Figure 2 Reliability probability of Pole 2 (doing nothing)

Table 3 Cumulative probability distribution of HVDC capacity (doing nothing)

Capacity	2004	2005	2006	2007	2008	2009	2010
0 MW	0.097750925	0.129969357	0.169517682	0.215804307	0.270786979	0.331199500	0.396427514
156 MW up	0.902249075	0.870030643	0.830482318	0.784195693	0.729213021	0.668800500	0.603572486
238 MW up	0.869719720	0.835656386	0.795625195	0.750522328	0.698275088	0.642033242	0.581842928
312 MW up	0.740888660	0.690487417	0.634760283	0.576831053	0.512168836	0.448532134	0.385637607
394 MW up	0.711181724	0.663001943	0.610465580	0.556391539	0.495950872	0.436410461	0.377152566
476 MW up	0.668309585	0.624607697	0.577387686	0.529289347	0.474687875	0.420771868	0.366397876
550 MW up	0.283899472	0.222219179	0.166448518	0.119264493	0.079896732	0.050552581	0.029850253
632 MW up	0.244747146	0.191519342	0.143393901	0.102813638	0.068750464	0.043470574	0.025650720
788 MW	0.116823925	0.085095747	0.058894416	0.038834763	0.023644817	0.013549770	0.007203386

Note: “up” indicates the capacity and above. For example, “156 MW up” indicates “156 MW & above”.

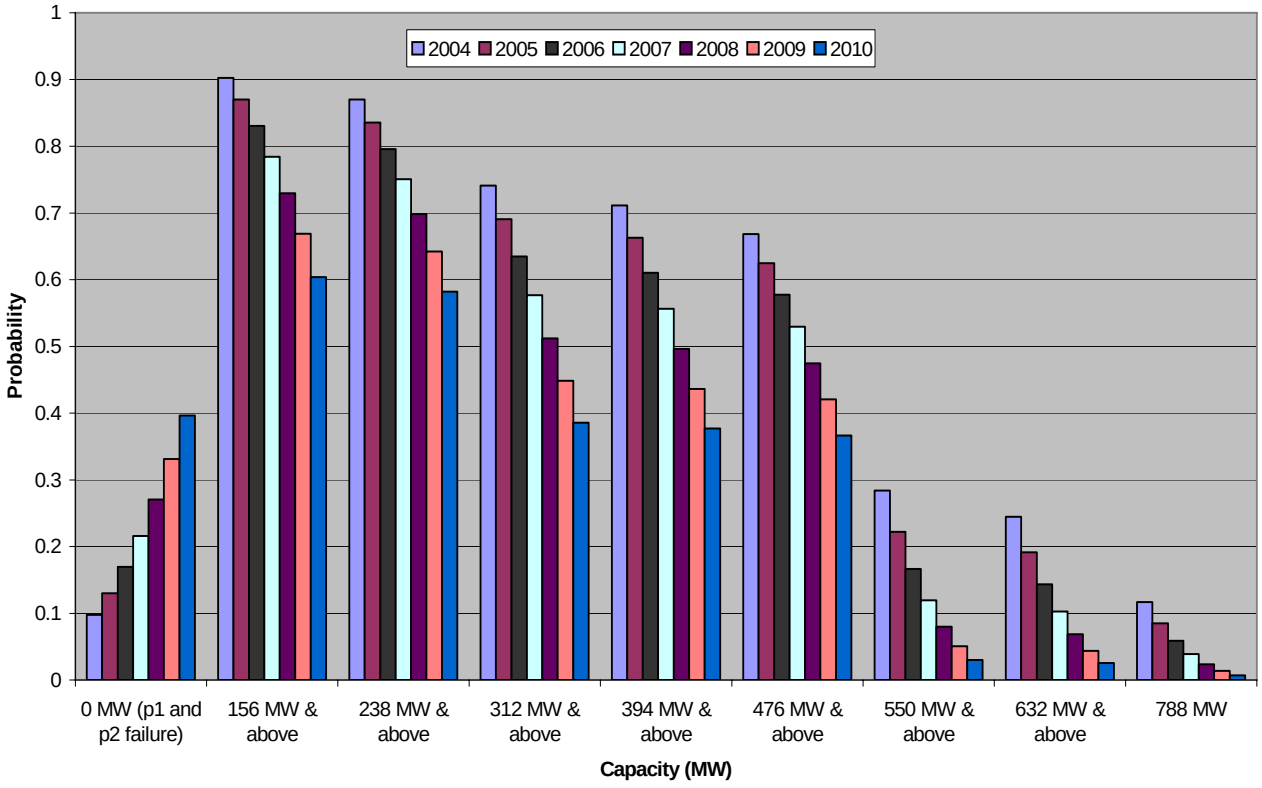

Figure 3 Cumulative probability distribution of HVDC capacity (doing nothing)

The following observations can be made:

- Although the pole 1 has retired, it can be still used as a stand-by source with a very high failure probability. Its unavailability is 61% in 2004 and will be up to 93% in 2010.
- The pole 2 is close to retire. Its unavailability in 2004 is 16% and will be up to 42.7% in 2010. By 2007, the total probability of pole 2 at the half (238 MW) or full (476 MW) capacity will be only about 73%. According to the criterion used in the VIGP project, a dependable source or a firm capacity should have availability of 95% or above. However, like the existing pole 1, the pole 2 will be still used with a relatively high failure probability after 2007 from a viewpoint of operation.
- The full unavailability of the whole HVDC (combined poles 1 and 2) in 2004 is 9.8%, will be increased to 21.6% in 2007 and reach 39.6% in 2010. This equivalently means that the probability that the HVDC has at least 156 MW is 90.2% in 2004, 78.4% in 2007 and 60.4% in 2010.

4.2 Replacement of Pole 2 reactor at VIT

There is no reason to consider any refurbishment on the pole 1 since it has been retired already. For Pole 2, the reactor is a key component due to the fact that it is in series with other components from a viewpoint of HVDC reliability configuration. In other words, once it fails, Pole 2 will fully lose its supply capacity. There is a spare reactor at the ARN side. This spare would have to be transported from ARN to VIT to be installed if the Pole 2 reactor at VIT fails. This results in long recovery time and thus a large negative impact on HVDC reliability. The reactor at VIT has been operated for 28 years while its mean life is estimated to be 30 years [4].

It is assumed that the Pole 2 reactor at VIT is replaced in 2005 and the old one can be used as a spare at VIT. The unavailability data of all the components including a new Pole 2 reactor at VIT from 2004 to 2010 are listed in Appendix 2. The calculation process of the probability distributions for the poles 1 and 2 at different capacity levels is also given in Appendix 2.

The comparison between the reliability probability distributions of Pole 2 with and without the replacement of the reactor at VIT is shown in Table 4 and Figure 4. The cumulative probability distribution of whole HVDC capacity with the replacement of the pole 2 reactor at VIT is shown in Table 5 and Figure 5. The comparison of HVDC reliability between doing nothing and the VIT reactor replacement is shown in Table 6 and Figure 6. In the last comparison, only three capacity levels (0 MW, 238 MW and 476 MW) corresponding to the pole 2 capacities are given.

Table 4 Comparison of Pole 2 reliability between doing nothing and replacement of Pole 2 reactor at VIT

	Doing nothing (Probability)			Replacement of Pole 2 reactor at VIT (Probability)			Failure
Year	476 MW only	238 MW & above	Failure	476 MW only	238 MW & above	Failure	probability reduction
2004	0.629157259	0.840012783	0.159987217	0.629157259	0.840012783	0.159987217	0
2005	0.593907860	0.808170912	0.191829088	0.634966667	0.864042429	0.135957571	0.055871517
2006	0.554333069	0.771330493	0.228669507	0.601807089	0.837388539	0.162611461	0.066058046
2007	0.512838492	0.730082813	0.269917187	0.566978784	0.807157560	0.192842440	0.077074747
2008	0.463541606	0.682057124	0.317942876	0.523576413	0.770392598	0.229607402	0.088335475
2009	0.413689862	0.629911569	0.370088431	0.479127858	0.729551795	0.270448205	0.099640226
2010	0.362198344	0.573357887	0.426642113	0.431899224	0.683693978	0.316306022	0.110336091

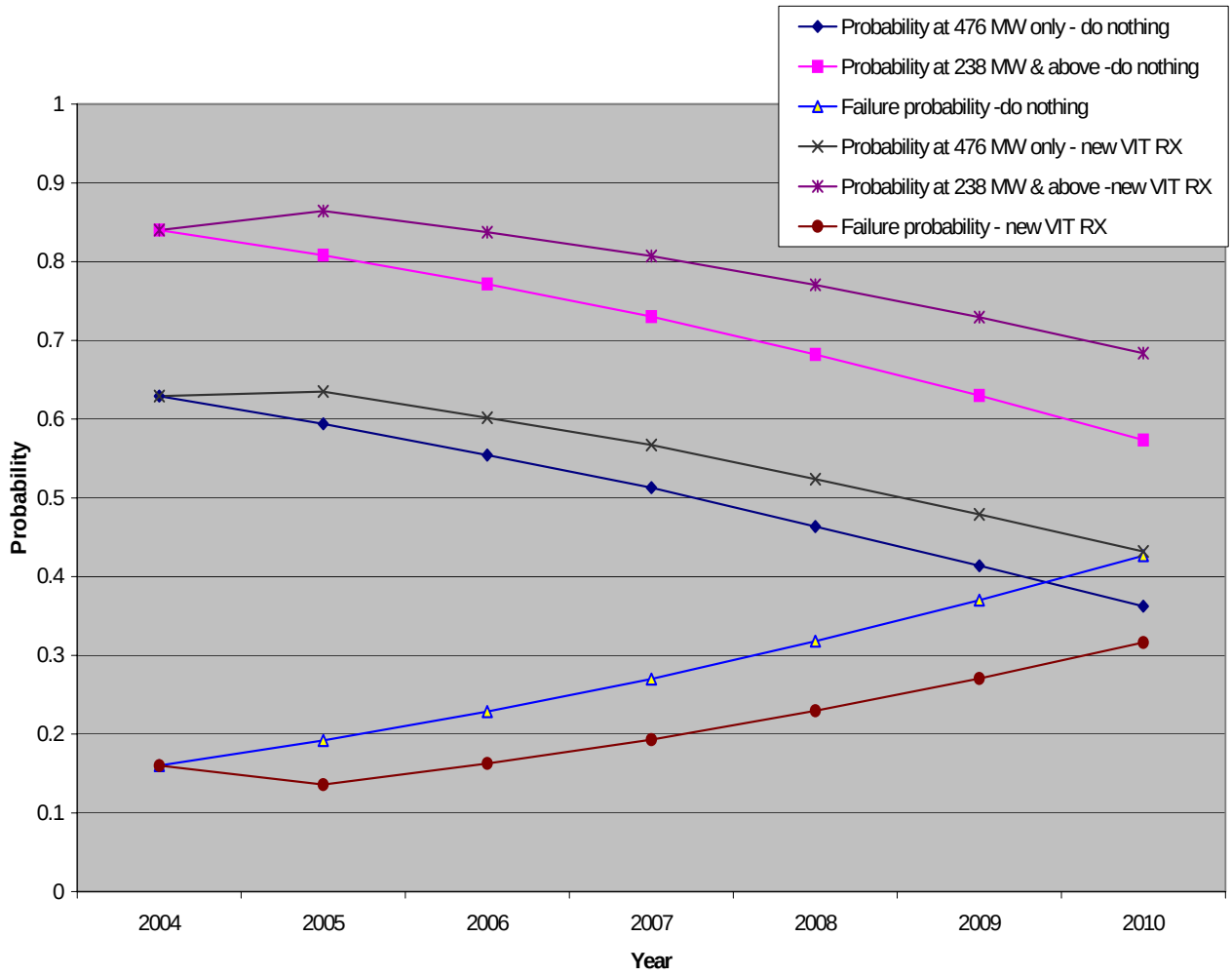

Figure 4 Comparison of Pole 2 reliability between doing nothing and replacement of Pole 2 reactor at VIT

Table 5 Cumulative probability distribution of HVDC capacity (replacement of Pole 2 reactor at VIT)

Capacity	2004	2005	2006	2007	2008	2009	2010
0 MW	0.097750925	0.092114904	0.120547415	0.154181472	0.195553036	0.242029479	0.293905375
156 MW up	0.902249075	0.907885096	0.879452585	0.845818528	0.804446964	0.757970521	0.706094625
238 MW up	0.86971972	0.883522574	0.854664988	0.821760579	0.782104654	0.738409906	0.689984659
312 MW up	0.74088866	0.728317596	0.680023332	0.62973274	0.571895166	0.514300543	0.456021894
394 MW up	0.711181724	0.708837451	0.662746883	0.615129721	0.56018311	0.505442432	0.449731213
476 MW up	0.668309585	0.667788885	0.626836142	0.585166354	0.536166272	0.487330106	0.436906908
550 MW up	0.283899472	0.237581923	0.18070345	0.13185523	0.090244423	0.058549053	0.035594588
632 MW up	0.244747146	0.204759705	0.155674397	0.11366766	0.077654564	0.050346806	0.030586904
788 MW	0.116823925	0.090978696	0.063938233	0.042934544	0.026707135	0.01569309	0.008589594

Note: “up” indicates the capacity and above. For example, “156 MW up” indicates “156 MW & above”.

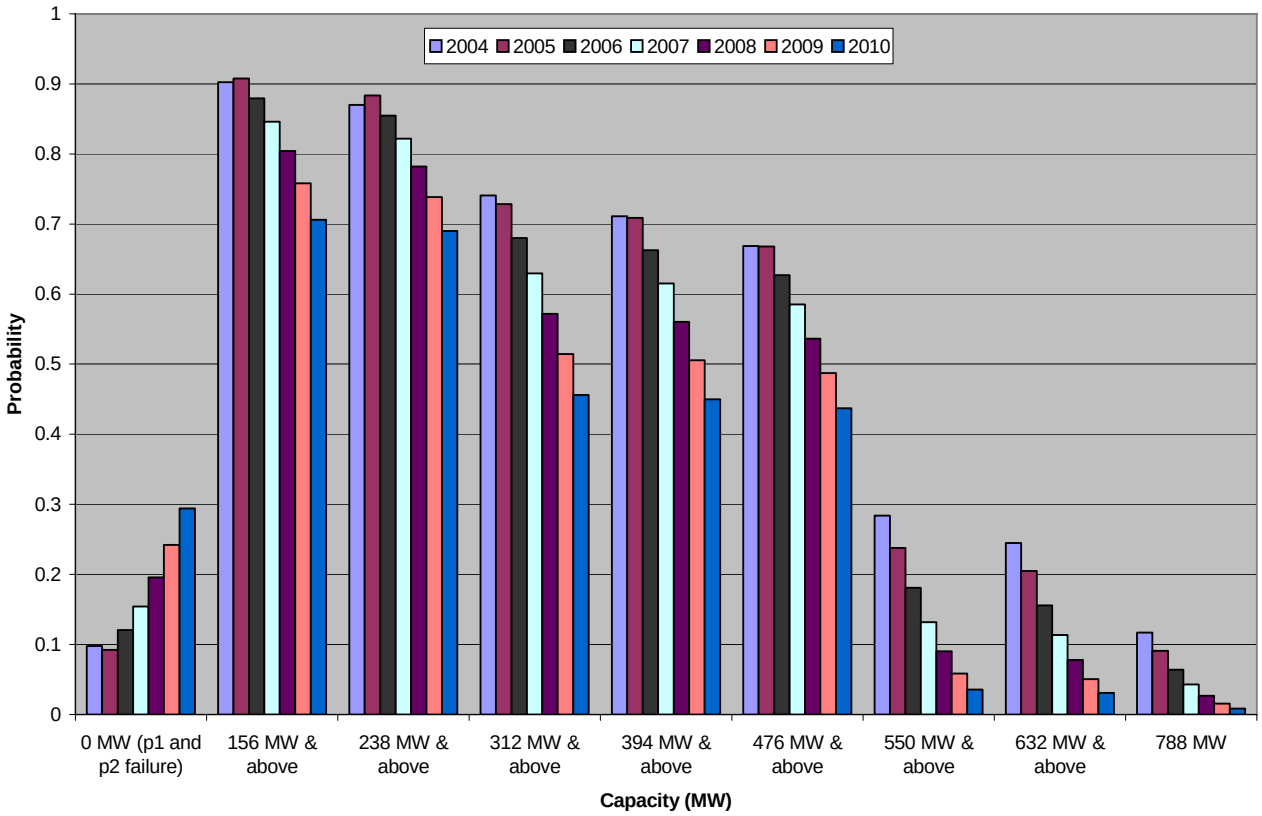

Figure 5 Cumulative probability distribution of HVDC capacity (replacement of Pole 2 reactor at VIT)

Table 6 Comparison of HVDC reliability between doing nothing and replacement of Pole 2 reactor at VIT

	Replacement of Pole 2 reactor at VIT (Probability)			Doing nothing (Probability)			Failure (0MW)
Year	0 MW	238 MW & above	476 MW & above	0 MW	238 MW & above	476 MW & above	probability reduction
2004	0.097750925	0.869719720	0.668309585	0.097750925	0.869719720	0.668309585	0
2005	0.092114904	0.883522574	0.667788885	0.129969357	0.835656386	0.624607697	0.037854453
2006	0.120547415	0.854664988	0.626836142	0.169517682	0.795625195	0.577387686	0.048970267
2007	0.154181472	0.821760579	0.585166354	0.215804307	0.750522328	0.529289347	0.061622835
2008	0.195553036	0.782104654	0.536166272	0.270786979	0.698275088	0.474687875	0.075233943
2009	0.242029479	0.738409906	0.487330106	0.331199500	0.642033242	0.420771868	0.089170020
2010	0.293905375	0.689984659	0.436906908	0.396427514	0.581842928	0.366397876	0.102522139

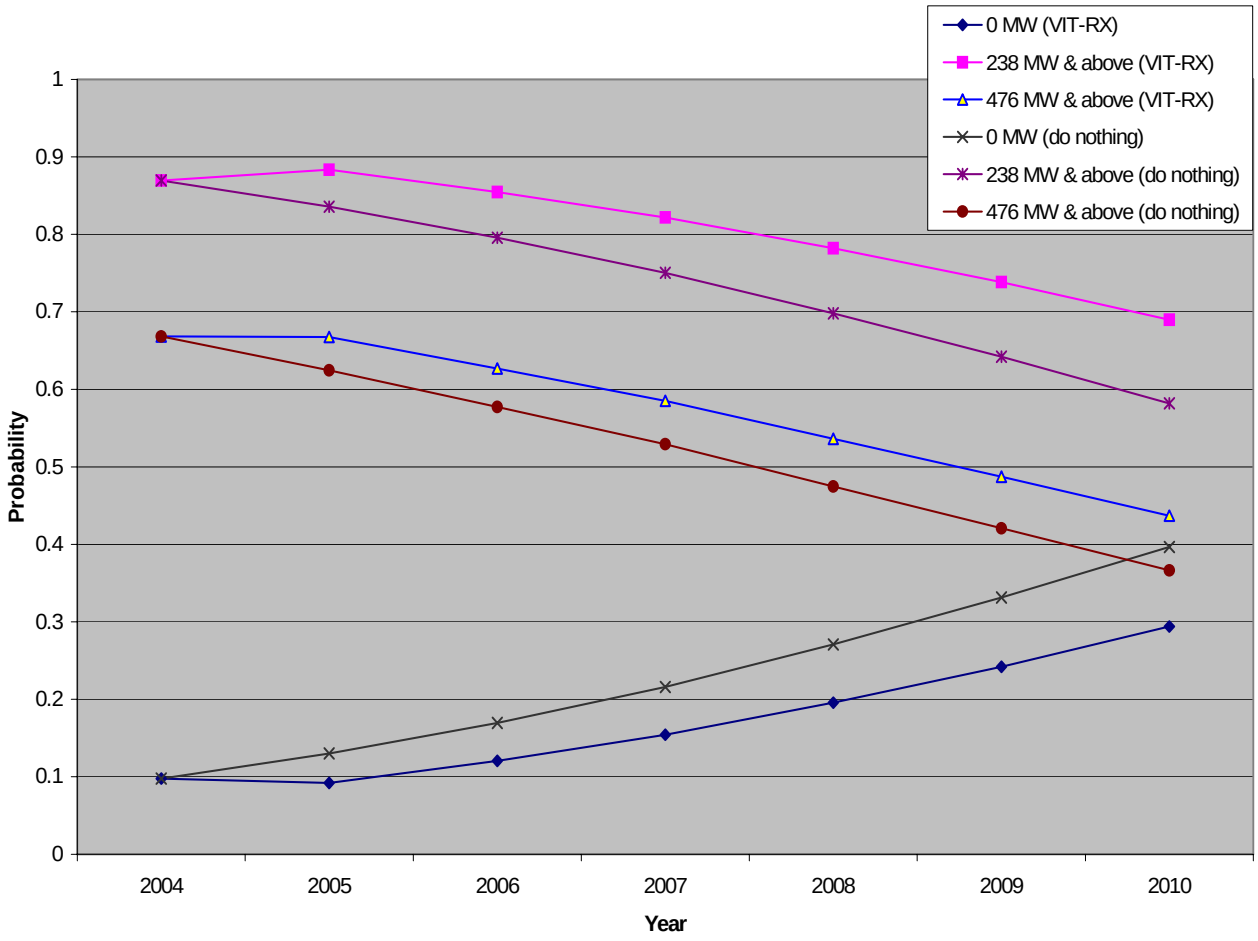

Figure 6 Comparison of HVDC reliability between doing nothing and replacement of Pole 2 reactor at VIT

The following observations can be made:

- With the replacement of Pole 2 reactor at VIT, the failure probability of Pole 2 is reduced by 5.6% in 2005 and by 11% in 2010. This reduction is equivalent to about a life extension of two years for Pole 2. The failure probability of Pole 2 in 2007 if doing nothing is basically the same as its failure probability in 2009 if the reactor at VIT is replaced in 2005.
- With the replacement of Pole 2 reactor at VIT, the failure probability of the whole HVDC is reduced by 3.8% in 2005 and by 10.3% in 2010. This reduction is equivalent to a life extension of 1.5 years for the whole HVDC. The failure probability of the whole HVDC in 2007 if doing nothing is close to its failure probability between 2008 and 2009 if the Pole 2 reactor at VIT is replaced in 2005. The reason why the relative effect of replacing Pole 2 reactor at VIT for the whole HVDC is slightly smaller than that for Pole 2 alone is due to the fact that the Pole 2 reactor does not have any effect on Pole 1. However, incorporation of Pole 1, even with its high unavailability, makes the failure probability of the whole HVDC lower than that of Pole 2 alone for both cases of doing nothing and replacing Pole 2 reactor at VIT.
- The full unavailability of the whole HVDC after replacing Pole 2 reactor at VIT in 2005 is 9.2%, will be increased to 15.4% in 2007 and reach 29.4% in 2010. This equivalently means that the probability that HVDC has at least a 156 MW capacity is 90.8% in 2005, 84.6% in 2007 and 70.6% in 2010.

4.3 Replacement of Pole 2 filter capacitor at VIT

Similarly, according to the reliability configuration of HVDC, the filter capacitor of Pole1 2 is another key component to improve HVDC reliability. The filter capacitor at ARN was replaced in 1996, which is relatively new. The filer capacitor at VIT has been operated for 28 years while its mean life is estimated to be 33 years.

It is assumed that the filter capacitor of Pole 2 is replaced in 2005. The unavailability data of all the components including the new filter capacitor of Pole 2 at VIT from 2004 to 2010 are listed in Appendix 3. The calculation process of the probability distributions for the poles 1 and 2 at different capacity levels is also given in Appendix 3.

The comparison between reliability probability distributions of Pole 2 with and without the replacement of the filter capacitor at VIT is shown in Table 7 and Figure 7. The cumulative probability distribution of whole HVDC capacity with the replacement of the filter capacitor of Pole 2 at VIT is shown in Table 8 and Figure 8. The comparison of HVDC reliability between doing nothing and the VIT filter capacitor replacement is shown in Table 9 and Figure 9. In the last comparison, only three capacity levels (0 MW, 238 MW and 476 MW) corresponding to the pole 2 capacities are given.

Table 7 Comparison of Pole 2 reliability between doing nothing and replacement of Pole 2 filter capacitor at VIT

	Doing nothing (Probability)			Replacement of Pole 2 filterCP at VIT (Probability)			Failure
Year	476 MW only	238 MW & above	Failure	476 MW only	238 MW & above	Failure	probability reduction
2004	0.629157259	0.840012783	0.159987217	0.629157259	0.840012783	0.159987217	0
2005	0.59390786	0.808170912	0.191829088	0.613541381	0.834887581	0.165112419	0.026716670
2006	0.554333069	0.771330493	0.228669507	0.57725614	0.803226954	0.196773046	0.031896461
2007	0.512838492	0.730082813	0.269917187	0.539194587	0.767603655	0.232396345	0.037520842
2008	0.463541606	0.682057124	0.317942876	0.49297235	0.725361647	0.274638353	0.043304523
2009	0.413689862	0.629911569	0.370088431	0.445945416	0.679026012	0.320973988	0.049114443
2010	0.362198344	0.573357887	0.426642113	0.396708348	0.627987025	0.372012975	0.054629138

Table 8 Cumulative probability distribution of HVDC capacity (replacement of Pole 2 filter capacitor at VIT)

Capacity	2004	2005	2006	2007	2008	2009	2010
0 MW	0.097750925	0.111868096	0.145872141	0.185805627	0.233905194	0.287246008	0.345667187
156 MW up	0.902249075	0.888131904	0.854127859	0.814194373	0.766094806	0.712753992	0.654332813
238 MW up	0.869719720	0.858545064	0.824132858	0.785201899	0.739370688	0.689539017	0.635385604
312 MW up	0.740888660	0.708577071	0.656615775	0.602584181	0.541448355	0.480950555	0.420485977
394 MW up	0.711181724	0.684919589	0.635709872	0.584985937	0.527439314	0.470437550	0.413087398
476 MW up	0.668309585	0.645256099	0.601264123	0.556490894	0.504826307	0.453579610	0.401308009
550 MW up	0.283899472	0.229565343	0.173331584	0.125393803	0.084969460	0.054494184	0.032694364
632 MW up	0.244747146	0.197850625	0.149323601	0.108097496	0.073115503	0.046859991	0.028094703
788 MW	0.116823925	0.087908858	0.061329848	0.040830582	0.025146051	0.014606251	0.007889719

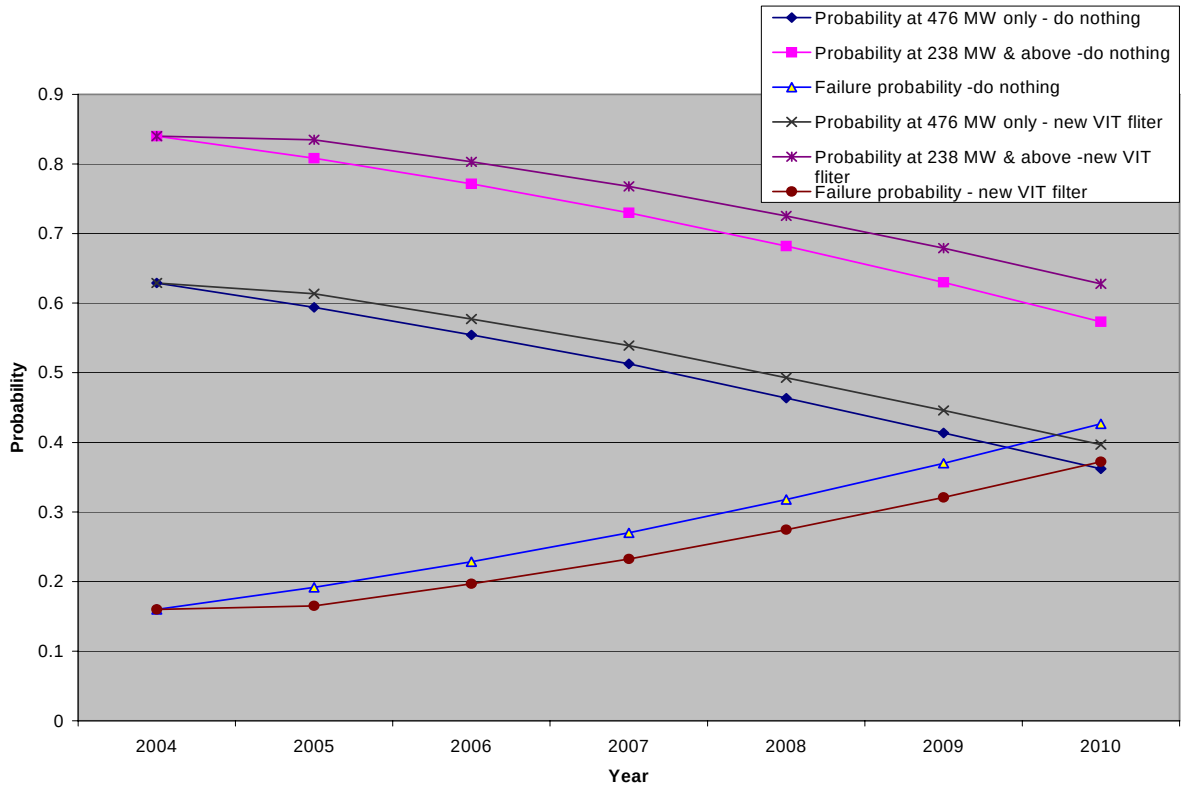

Figure 7 Comparison of Pole 2 reliability between doing nothing and replacement of Pole 2 filter capacitor at VIT

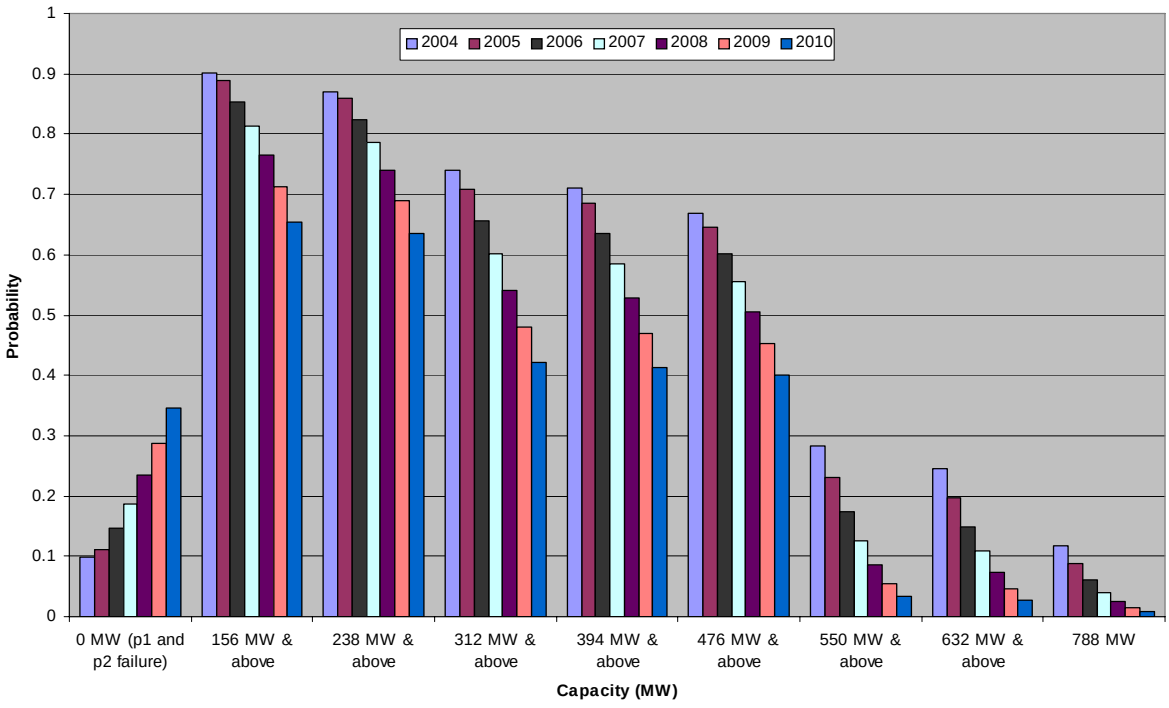

Figure 8 Cumulative probability distribution of HVDC capacity (replacement of Pole 2 filter capacitor at VIT)

Table 9 Comparison of HVDC reliability between doing nothing and replacement of Pole 2 filter capacitor at VIT

	Replacement of Pole 2 filterCp at VIT (Probability)			Doing nothing (Probability)			Failure (0MW)
Year	0 MW	238 MW & above	476 MW & above	0 MW	238 MW & above	476 MW & above	probability reduction
2004	0.097750925	0.869719720	0.668309585	0.097750925	0.86971972	0.668309585	0
2005	0.111868096	0.858545064	0.645256099	0.129969357	0.835656386	0.624607697	0.018101261
2006	0.145872141	0.824132858	0.601264123	0.169517682	0.795625195	0.577387686	0.023645541
2007	0.185805627	0.785201899	0.556490894	0.215804307	0.750522328	0.529289347	0.029998680
2008	0.233905194	0.739370688	0.504826307	0.270786979	0.698275088	0.474687875	0.036881786
2009	0.287246008	0.689539017	0.453579610	0.331199500	0.642033242	0.420771868	0.043953492
2010	0.345667187	0.635385604	0.401308009	0.396427514	0.581842928	0.366397876	0.050760327

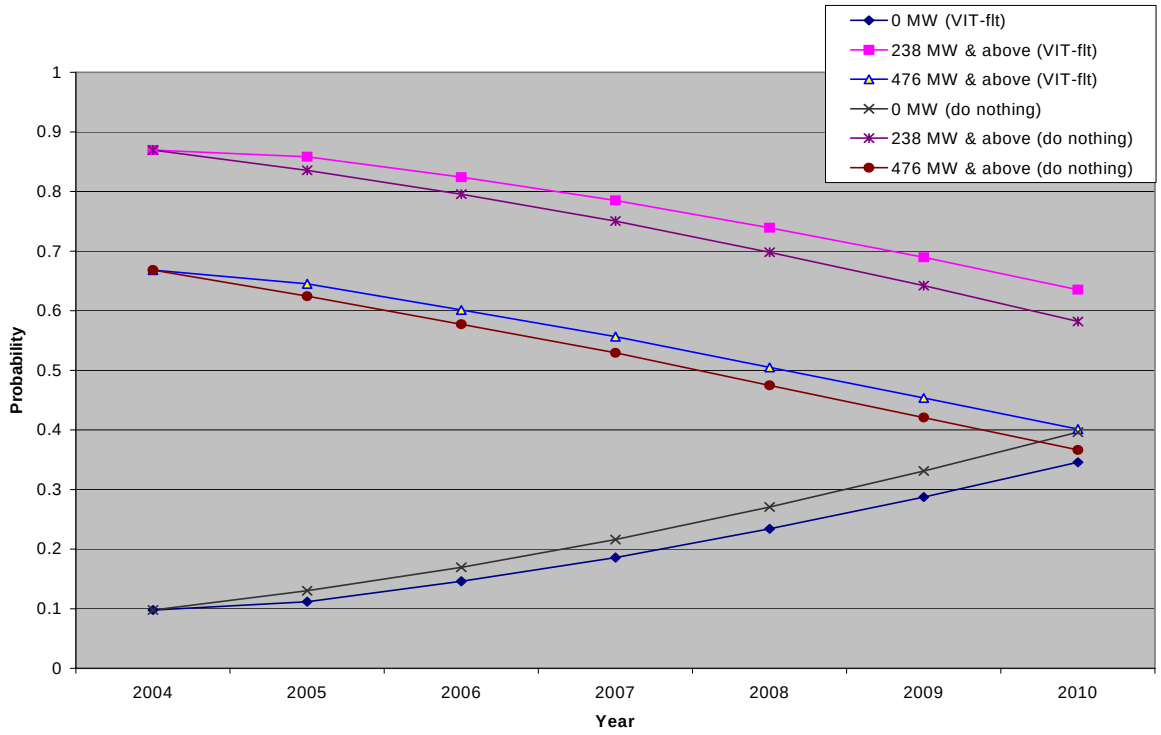

Figure 9 Comparison of HVDC reliability between doing nothing and replacement of Pole 2 filter capacitor at VIT

The following observations can be made:

- With the replacement of Pole 2 filter capacitor at VIT, the failure probability of Pole 2 is reduced by 2.7% in 2005 and by 5.5 in 2010. This reduction is equivalent to a life extension of one year for Pole 2. The failure probability of Pole 2 in 2007 if doing nothing is close to its failure probability in 2008 if the filter capacitor at VIT is replaced in 2005.
- With the replacement of Pole 2 filter capacitor at VIT, the failure probability of the whole HVDC is reduced by 1.8% in 2005 and by 5.1% in 2010. This reduction is equivalent to a life extension of less than one year for the whole HVDC.

- The full unavailability of the whole HVDC after replacing Pole 2 filter capacitor at VIT in 2005 is 11.2%, will be increased to 18.6% in 2007 and reach 34.6% in 2010. This equivalently means that the probability that HVDC has at least a 156 MW capacity is 88.8% in 2005, 81.4% in 2007 and 65.4% in 2010.

5. Conclusions

This study assessed the probability distribution of HVDC capacity from 2004 to 2010 and the impacts of two key component replacements (Pole 2 reactor and filter capacitor at VIT) on HVDC reliability. The following conclusions can be made:

(1) HVDC Pole 1 has been retired and Pole 2 will be retired in 2007. From an operation viewpoint, the retired poles can be still used with relatively high unavailability. The evaluated results show that the availability of Pole 1 in 2004 is only 38.9% and will be further decreased to 20% in 2007. The availability of Pole 2 in 2004 is 84%, will be decreased to only 73% in 2007 and to 63% in 2009 due to ageing failure probability.

(2) Combining the poles 1 and 2 together, the availability of the whole HVDC in 2004 is 90.2%, will be 78.4% in 2007 and 66.9% in 2009. The failure event of HVDC can happen any time during the peak or off-peak period with the estimated probabilities in different years. If we can accept the relatively high risk from 2007 to 2009, HVDC without any refurbishment (doing nothing) could be used as an option before the 230 kV line in place in 2008 or 2009.

(3) According to the reliability configuration of the HVDC system, the reactor and filter capacitor of Pole 2 at VIT are two key components to HVDC reliability. Also, both the components are 28 years old with the mean life of 30 years for the reactor and 33 years for the filter capacitor. In other words, they have a high ageing failure probability. The study shows that replacing the Pole 2 reactor at VIT in 2005 will provide HVDC life extension by two years. This means that replacing the Pole 2 reactor at VIT in 2005 will bring the HVDC failure probability in 2009 back to its failure probability level in 2007. Replacing the Pole 2 filter capacitor at VIT in 2005 will provide HVDC life extension by one year. In other words, replacing the Pole 2 filter capacitor at VIT in 2005 will bring the HVDC failure probability in 2008 back to its failure probability level in 2007.

(4) According to the cost estimate based on the Alstom Life Extension Report completed in June 2001 [6], the Pole 2 reactor costs $2.0 million and the Pole 2 filter capacitor costs $1.7 million. If we want to keep the overall HVDC reliability in 2009 at the same level as its reliability status in 2007, replacing the Pole 2 reactor at VIT is an option with $2.0 million of investment. Replacing the Pole 2 filter capacitor at VIT can be used as an additional measure to get one more year of "reliability advance" with the cost of $1.7 million.

(5) It is important to appreciate that the assessment results are based on the probability analysis. The results should be viewed as the expected value of a random variable. Also, the input data always have some uncertainty. The input data used in this study are based on the same source that was used in the reliability evaluation of Vancouver Island in the VIGP project.

(6) In general, it can be concluded that HVDC can be used as an alternative before the 230 kV AC line in-service. If the 230kV line can be in place in 2008, replacing the Pole 2 filter capacitor at VIT may be a good option if a little bit (about 1%) higher risk is acceptable. If the 230kV line cannot be available until 2009, replacing the Pole 2 reactor at VIT is a potential option. Both of these options provide almost the same HVDC reliability level as that in 2007. The cost paid is $1.7 or $2.0 million. Replacing both the Pole 2 reactor and the filter capacitor at VIT can offer further improvement in HVDC reliability with the total cost of $3.7 million.

6. References

[1] Fred Dennert, "Statement of Objectives – Vancouver Island Supply Solution Strategy", March 25, 2004

[2] Fred Dennert, "Vancouver Island Supply Alternatives Project – Task Managers Meeting Notes", March 19, 2004

[3] Wenyuan Li, "Reliability Evaluation of Three Scenarios for Vancouver Island Power Supply – An Expected Energy Not Served (EENS) Study", a study report for the VIGP project, submitted to the BCUC hearing, June 11, 2003

[4] Terry Treasure, "Estimated Life Expectancy of HVDC Components for the Purpose of Reliability Studies", March 15, 2002

[5] Wenyuan Li, SPARE Program User's Manual, April, 2001

[6] BCUC Staff IR No.1.20.3 (March 21, 2003), "Vancouver Island Transmission Supply – HVDC Pole 2 Life Extension Alternative 17 October, 2002"

Appendix 1

Input data (do-nothing)

Pole 2

	2004	2005	2006	2007	2008	2009	2010	
filter-VIT	0.02557	0.03201	0.03972	0.04889	0.05971	0.07234	0.087	
filter-ARN	0.00002	0.00003	0.00005	0.00008	0.00012	0.00019	0.0003	(ARN filter replaced in 1996)
Reactor-VIT	0.05278	0.06485	0.07907	0.09567	0.11484	0.13675	0.16155	
Reactor-ARN	0.05111	0.06321	0.07746	0.09408	0.11328	0.13524	0.16008	(spare is located at ARN side)
Common	0.00127	0.00149	0.00176	0.0021	0.00252	0.00302	0.00364	
T3	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T4	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T7	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T8	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
V3	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V4	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V7	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V8	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
Auxiliary-V3	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V4	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V7	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V8	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(MTTR assumed 4 months)
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(900 amp cable assumed less life expectancy)
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	(MTTR assumed 4 months)
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	

Pole 1

	2004	2005	2006	2007	2008	2009	2010
filter-VIT	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754
filter-ARN	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754
Reactor-VIT	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111
Reactor-ARN	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111
T1	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T2	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T5	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T6	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272

Probability calculations of capacities for Poles 1 and 2 in 2004 (do-nothing)							
Pole 2							
2004	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.02557	0.97443					
filter-ARN	0.00002	0.99998					
Reactor-VIT	0.05278	0.94722					
Reactor-ARN	0.05111	0.94889					
Common	0.00127	0.99873					
T3	0.01303	0.98697		0.008306148			
T4	0.01303	0.98697		0.008306148			
T7	0.01303	0.98697		0.008306148			
T8	0.01303	0.98697		0.008306148			
V3	0.01299	0.98701		0.008280314			
V4	0.01299	0.98701		0.008280314			
V7	0.01299	0.98701		0.008280314			
V8	0.01299	0.98701		0.008280314			
Auxiliary-V3	0.0011	0.9989		0.000692835			
Auxiliary-V4	0.0011	0.9989		0.000692835			
Auxiliary-V7	0.0011	0.9989		0.000692835			
Auxiliary-V8	0.0011	0.9989		0.000692835			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
			0.629157259	0.210855525	0.840012783	0.159987217	349.66247
Pole 1							
2004	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.10389	0.89611					
filter-ARN	0.10389	0.89611					
Reactor-VIT	0.18921	0.81079					
Reactor-ARN	0.18921	0.81079					
T1	0.08277	0.91723		0.016755882			
T2	0.08277	0.91723		0.016755882			
T5	0.08277	0.91723		0.016755882			
T6	0.08277	0.91723		0.016755882			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
			0.185683187	0.203324716	0.389007903	0.610992097	89.6518101

Probability calculations of capacities for Poles 1 and 2 in 2005 (do-nothing)							
Pole2							
2005	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.03201	0.96799					
filter-ARN	0.00003	0.99997					
Reactor-VIT	0.06485	0.93515					
Reactor-ARN	0.06321	0.93679					
Common	0.00149	0.99851					
T3	0.01644	0.98356		0.009927046			
T4	0.01644	0.98356		0.009927046			
T7	0.01644	0.98356		0.009927046			
T8	0.01644	0.98356		0.009927046			
V3	0.01458	0.98542		0.008787295			
V4	0.01458	0.98542		0.008787295			
V7	0.01458	0.98542		0.008787295			
V8	0.01458	0.98542		0.008787295			
Auxiliary-V3	0.00132	0.99868		0.000784995			
Auxiliary-V4	0.00132	0.99868		0.000784995			
Auxiliary-V7	0.00132	0.99868		0.000784995			
Auxiliary-V8	0.00132	0.99868		0.000784995			
Cable 900 amp	0.04842	0.95158		0.030220285			
Cable 900 amp	0.04842	0.95158		0.030220285			
Cable 600 amp	0.04082	0.95918		0.025275046			
Cable 600 amp	0.04082	0.95918		0.025275046			
Cable 600 amp	0.04082	0.95918		0.025275046			
			0.59390786	0.214263051	0.808170912	0.191829088	333.6947477
Pole 1							
2005	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.12309	0.87691					
filter-ARN	0.12309	0.87691					
Reactor-VIT	0.21992	0.78008					
Reactor-ARN	0.21992	0.78008					
T1	0.09373	0.90627		0.014818689			
T2	0.09373	0.90627		0.014818689			
T5	0.09373	0.90627		0.014818689			
T6	0.09373	0.90627		0.014818689			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
			0.143281059	0.179192098	0.322473156	0.677526844	72.65765748

Probability calculations of capacities for Poles 1 and 2 in 2006 (do-nothing)							
Pole 2							
2006	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.03972	0.96028					
filter-ARN	0.00005	0.99995					
Reactor-VIT	0.07907	0.92093					
Reactor-ARN	0.07746	0.92254					
Common	0.00176	0.99824					
T3	0.02058	0.97942		0.011647888			
T4	0.02058	0.97942		0.011647888			
T7	0.02058	0.97942		0.011647888			
T8	0.02058	0.97942		0.011647888			
V3	0.01641	0.98359		0.009248371			
V4	0.01641	0.98359		0.009248371			
V7	0.01641	0.98359		0.009248371			
V8	0.01641	0.98359		0.009248371			
Auxiliary-V3	0.00159	0.99841		0.000882793			
Auxiliary-V4	0.00159	0.99841		0.000882793			
Auxiliary-V7	0.00159	0.99841		0.000882793			
Auxiliary-V8	0.00159	0.99841		0.000882793			
Cable 900 amp	0.05019	0.94981		0.02929215			
Cable 900 amp	0.05019	0.94981		0.02929215			
Cable 600 amp	0.04111	0.95889		0.023765638			
Cable 600 amp	0.04111	0.95889		0.023765638			
Cable 600 amp	0.04111	0.95889		0.023765638			
			0.554333069	0.216997424	0.771330493	0.228669507	315.5079277
Pole 1							
2006	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.14478	0.85522					
filter-ARN	0.14478	0.85522					
Reactor-VIT	0.2535	0.7465					
Reactor-ARN	0.2535	0.7465					
T1	0.10637	0.89363		0.012646337			
T2	0.10637	0.89363		0.012646337			
T5	0.10637	0.89363		0.012646337			
T6	0.10637	0.89363		0.012646337			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
			0.106243735	0.152434503	0.258678238	0.741321762	56.92782777

Probability calculations of capacities for Poles 1 and 2 in 2007 (do-nothing)							
Pole 2							
2007	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.04889	0.95111					
filter-ARN	0.00008	0.99992					
Reactor-VIT	0.09567	0.90433					
Reactor-ARN	0.09408	0.90592					
Common	0.0021	0.9979					
T3	0.02557	0.97443		0.013457386			
T4	0.02557	0.97443		0.013457386			
T7	0.02557	0.97443		0.013457386			
T8	0.02557	0.97443		0.013457386			
V3	0.01852	0.98148		0.009676987			
V4	0.01852	0.98148		0.009676987			
V7	0.01852	0.98148		0.009676987			
V8	0.01852	0.98148		0.009676987			
Auxiliary-V3	0.00193	0.99807		0.000991692			
Auxiliary-V4	0.00193	0.99807		0.000991692			
Auxiliary-V7	0.00193	0.99807		0.000991692			
Auxiliary-V8	0.00193	0.99807		0.000991692			
Cable 900 amp	0.05023	0.94977		0.027122227			
Cable 900 amp	0.05023	0.94977		0.027122227			
Cable 600 amp	0.04143	0.95857		0.022165203			
Cable 600 amp	0.04143	0.95857		0.022165203			
Cable 600 amp	0.04143	0.95857		0.022165203			
			0.512838492	0.217244321	0.730082813	0.269917187	295.81527
Pole 1							
2007	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.16905	0.83095					
filter-ARN	0.16905	0.83095					
Reactor-VIT	0.28976	0.71024					
Reactor-ARN	0.28976	0.71024					
T1	0.12082	0.87918		0.010406413			
T2	0.12082	0.87918		0.010406413			
T5	0.12082	0.87918		0.010406413			
T6	0.12082	0.87918		0.010406413			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
			0.075725132	0.124754433	0.200479565	0.799520435	43.0879328

Probability calculations of capacities for Poles 1 and 2 in 2008 (do-nothing)							
Pole 2							
2008	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.05971	0.94029					
filter-ARN	0.00012	0.99988					
Reactor-VIT	0.11484	0.88516					
Reactor-ARN	0.11328	0.88672					
Common	0.00252	0.99748					
T3	0.03152	0.96848		0.015086353			
T4	0.03152	0.96848		0.015086353			
T7	0.03152	0.96848		0.015086353			
T8	0.03152	0.96848		0.015086353			
V3	0.02094	0.97906		0.009914164			
V4	0.02094	0.97906		0.009914164			
V7	0.02094	0.97906		0.009914164			
V8	0.02094	0.97906		0.009914164			
Auxiliary-V3	0.00234	0.99766		0.001087231			
Auxiliary-V4	0.00234	0.99766		0.001087231			
Auxiliary-V7	0.00234	0.99766		0.001087231			
Auxiliary-V8	0.00234	0.99766		0.001087231			
Cable 900 amp	0.05456	0.94544		0.026750328			
Cable 900 amp	0.05456	0.94544		0.026750328			
Cable 600 amp	0.0418	0.9582		0.020221289			
Cable 600 amp	0.0418	0.9582		0.020221289			
Cable 600 amp	0.0418	0.9582		0.020221289			
			0.463541606	0.218515517	0.682057124	0.317942876	272.652498
Pole 1							
2008	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.19596	0.80404					
filter-ARN	0.19596	0.80404					
Reactor-VIT	0.3284	0.6716					
Reactor-ARN	0.3284	0.6716					
T1	0.13724	0.86276		0.008114055			
T2	0.13724	0.86276		0.008114055			
T5	0.13724	0.86276		0.008114055			
T6	0.13724	0.86276		0.008114055			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
			0.05100905	0.097306577	0.148315626	0.851684374	31.0946494

Probability calculations of capacities for Poles 1 and 2 in 2009 (do-nothing)							
Pole 2							
2009	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.07234	0.92766					
filter-ARN	0.00019	0.99981					
Reactor-VIT	0.13675	0.86325					
Reactor-ARN	0.13524	0.86476					
Common	0.00302	0.99698					
T3	0.03858	0.96142		0.016600606			
T4	0.03858	0.96142		0.016600606			
T7	0.03858	0.96142		0.016600606			
T8	0.03858	0.96142		0.016600606			
V3	0.02369	0.97631		0.010038116			
V4	0.02369	0.97631		0.010038116			
V7	0.02369	0.97631		0.010038116			
V8	0.02369	0.97631		0.010038116			
Auxiliary-V3	0.00285	0.99715		0.001182386			
Auxiliary-V4	0.00285	0.99715		0.001182386			
Auxiliary-V7	0.00285	0.99715		0.001182386			
Auxiliary-V8	0.00285	0.99715		0.001182386			
Cable 900 amp	0.05722	0.94278		0.025108014			
Cable 900 amp	0.05722	0.94278		0.025108014			
Cable 600 amp	0.04223	0.95777		0.018240416			
Cable 600 amp	0.04223	0.95777		0.018240416			
Cable 600 amp	0.04223	0.95777		0.018240416			
			0.413689862	0.216221708	0.629911569	0.370088431	248.3771406
Pole 1							
2009	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.22549	0.77451					
filter-ARN	0.22549	0.77451					
Reactor-VIT	0.36902	0.63098					
Reactor-ARN	0.36902	0.63098					
T1	0.15575	0.84425		0.006042463			
T2	0.15575	0.84425		0.006042463			
T5	0.15575	0.84425		0.006042463			
T6	0.15575	0.84425		0.006042463			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
			0.032753449	0.072326656	0.105080105	0.894919895	21.5020344

Probability calculations of capacities for Poles 1 and 2 in 2010 (do-nothing)							
Pole 2							
2009	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.087	0.913					
filter-ARN	0.0003	0.9997					
Reactor-VIT	0.16155	0.83845					
Reactor-ARN	0.16008	0.83992					
Common	0.00364	0.99636					
T3	0.04689	0.95311		0.017819014			
T4	0.04689	0.95311		0.017819014			
T7	0.04689	0.95311		0.017819014			
T8	0.04689	0.95311		0.017819014			
V3	0.02682	0.97318		0.009981873			
V4	0.02682	0.97318		0.009981873			
V7	0.02682	0.97318		0.009981873			
V8	0.02682	0.97318		0.009981873			
Auxiliary-V3	0.00346	0.99654		0.001257557			
Auxiliary-V4	0.00346	0.99654		0.001257557			
Auxiliary-V7	0.00346	0.99654		0.001257557			
Auxiliary-V8	0.00346	0.99654		0.001257557			
Cable 900 amp	0.06024	0.93976		0.023217447			
Cable 900 amp	0.06024	0.93976		0.023217447			
Cable 600 amp	0.04272	0.95728		0.016163623			
Cable 600 amp	0.04272	0.95728		0.016163623			
Cable 600 amp	0.04272	0.95728		0.016163623			
			0.362198344	0.211159543	0.573357887	0.426642113	222.662383
Pole 1							
2010	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.25754	0.74246					
filter-ARN	0.25754	0.74246					
Reactor-VIT	0.41111	0.58889					
Reactor-ARN	0.41111	0.58889					
T1	0.17644	0.82356		0.004260809			
T2	0.17644	0.82356		0.004260809			
T5	0.17644	0.82356		0.004260809			
T6	0.17644	0.82356		0.004260809			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
			0.019887959	0.050931581	0.07081954	0.92918046	14.15036994

Reliability distribution results for Poles 1 and 2 (do-nothing)			
Pole 2			
	Probability at 476 MW only	Probability at 238 MW & above	Failure probability
2004	0.629157259	0.840012783	0.159987217
2005	0.59390786	0.808170912	0.191829088
2006	0.554333069	0.771330493	0.228669507
2007	0.512838492	0.730082813	0.269917187
2008	0.463541606	0.682057124	0.317942876
2009	0.413689862	0.629911569	0.370088431
2010	0.362198344	0.573357887	0.426642113
Pole 1			
	Probability at 312 MW only	Probability at 156 MW & above	Failure probability
2004	0.185683187	0.389007903	0.610992097
2005	0.143281059	0.322473156	0.677526844
2006	0.106243735	0.258678238	0.741321762
2007	0.075725132	0.200479565	0.799520435
2008	0.05100905	0.148315626	0.851684374
2009	0.032753449	0.105080105	0.894919895
2010	0.019887959	0.07081954	0.92918046

Cumulative probability distribution of HVDC capacity (do-nothing)										
Pole 2	(doing nothing)									
	Failure probability	Probability at 476 MW only	Probability at 238 MW	Probability at 238 MW & above						
2004	0.159987217	0.629157259	0.210855525	0.840012783						
2005	0.191829088	0.59390786	0.214263051	0.808170912						
2006	0.228669507	0.554333069	0.216997424	0.771330493						
2007	0.269917187	0.512838492	0.217244321	0.730082813						
2008	0.317942876	0.463541606	0.218515517	0.682057124						
2009	0.370088431	0.413689862	0.216221708	0.629911569						
2010	0.426642113	0.362198344	0.211159543	0.573357887						
Pole 1										
	Failure probability	Probability at 312 MW only	Probability at 156 MW	Probability at 156 MW & above						
2004	0.610992097	0.185683187	0.203324716	0.389007903						
2005	0.677526844	0.143281059	0.179192098	0.322473156						
2006	0.741321762	0.106243735	0.152434503	0.258678238						
2007	0.799520435	0.075725132	0.124754433	0.200479565						
2008	0.851684374	0.05100905	0.097306577	0.148315626						
2009	0.894919895	0.032753449	0.072326656	0.105080105						
2010	0.92918046	0.019887959	0.050931581	0.07081954						
Pole 1 &2 density distribution										
	0 MW (p1 and p2 failure)	156 MW (p1-156 & p2 zero)	238 MW (p1 zero & p2-238)	312 MW (p1-312 and p2 zero)	394 MW (p1-156 & p2-238)	476 MW (p1 zero & p2-476)	550 MW (p1-312 & p2-238)	632 MW (p1-156 & p2-476)	788 MW (p1-312 & p2-476)	Total
2004	0.097750925	0.032529355	0.128831059	0.029706936	0.04287214	0.384410113	0.039152326	0.127923221	0.116823925	1
2005	0.129969357	0.034374257	0.145168969	0.027485475	0.038394246	0.402388518	0.030699837	0.106423595	0.085095747	1
2006	0.169517682	0.034857123	0.160864913	0.024294703	0.033077894	0.410939167	0.023054617	0.084499486	0.058894416	1
2007	0.215804307	0.033673366	0.173691274	0.020439515	0.027102192	0.410024854	0.016450855	0.063978875	0.038834763	1
2008	0.270786979	0.030937933	0.186106252	0.016217964	0.021262997	0.394791143	0.011146269	0.045105647	0.023644817	1
2009	0.3311995	0.026767258	0.193501108	0.012121673	0.015638593	0.370219288	0.007082007	0.029920804	0.01354977	1
2010	0.396427514	0.021729557	0.196205322	0.008485041	0.010754689	0.336547624	0.004199532	0.018447334	0.007203386	1
Pole 1 &2 cumulative distribution										
	0 MW (p1 and p2 failure)	156 MW & above	238 MW & above	312 MW & above	394 MW & above	476 MW & above	550 MW & above	632 MW & above	788 MW	
2004	0.097750925	0.902249075	0.86971972	0.74088866	0.711181724	0.668309585	0.283899472	0.244747146	0.116823925	
2005	0.129969357	0.870030643	0.835656386	0.690487417	0.663001943	0.624607697	0.222219179	0.191519342	0.085095747	
2006	0.169517682	0.830482318	0.795625195	0.634760283	0.61046558	0.577387686	0.166448518	0.143393901	0.058894416	
2007	0.215804307	0.784195693	0.750522328	0.576831053	0.556391539	0.529289347	0.119264493	0.102813638	0.038834763	
2008	0.270786979	0.729213021	0.698275088	0.512168836	0.495950872	0.474687875	0.079896732	0.068750464	0.023644817	
2009	0.3311995	0.6688005	0.642033242	0.448532134	0.436410461	0.420771868	0.050552581	0.043470574	0.01354977	
2010	0.396427514	0.603572486	0.581842928	0.385637607	0.377152566	0.366397876	0.029850253	0.02565072	0.007203386	

Appendix 2

Input data (VIT-reactor replacement)

Pole 2

	2004	2005	2006	2007	2008	2009	2010	
filter-VIT	0.02557	0.03201	0.03972	0.04889	0.05971	0.07234	0.087	
filter-ARN	0.00002	0.00003	0.00005	0.00008	0.00012	0.00019	0.0003	(ARN filter replaced in 1996)
Reactor-VIT	0.05278	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	(Buy a new reactor in 2005)
Reactor-ARN	0.05111	0.06321	0.07746	0.09408	0.11328	0.13524	0.16008	(spare is located at ARN side)
Common	0.00127	0.00149	0.00176	0.0021	0.00252	0.00302	0.00364	
T3	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T4	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T7	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
T8	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689	
V3	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V4	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V7	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
V8	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682	
Auxiliary-V3	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V4	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V7	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Auxiliary-V8	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346	
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(MTTR assumed 4 months)
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(900 amp cable assumed less life expectancy)
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	(MTTR assumed 4 months)
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	

Pole 1

	2004	2005	2006	2007	2008	2009	2010
filter-VIT	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754
filter-ARN	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754
Reactor-VIT	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111
Reactor-ARN	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111
T1	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T2	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T5	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
T6	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272

Probability calculations of capacities for Poles 1 and 2 in 2004 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.02557	0.97443					
filter-ARN	0.00002	0.99998					
Reactor-VIT	0.05278	0.94722					
Reactor-ARN	0.05111	0.94889					
Common	0.00127	0.99873					
T3	0.01303	0.98697		0.008306148			
T4	0.01303	0.98697		0.008306148			
T7	0.01303	0.98697		0.008306148			
T8	0.01303	0.98697		0.008306148			
V3	0.01299	0.98701		0.008280314			
V4	0.01299	0.98701		0.008280314			
V7	0.01299	0.98701		0.008280314			
V8	0.01299	0.98701		0.008280314			
Auxiliary-V3	0.0011	0.9989		0.000692835			
Auxiliary-V4	0.0011	0.9989		0.000692835			
Auxiliary-V7	0.0011	0.9989		0.000692835			
Auxiliary-V8	0.0011	0.9989		0.000692835			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
			0.629157259	0.210855525	0.840012783	0.159987217	349.66247
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.10389	0.89611					
filter-ARN	0.10389	0.89611					
Reactor-VIT	0.18921	0.81079					
Reactor-ARN	0.18921	0.81079					
T1	0.08277	0.91723		0.016755882			
T2	0.08277	0.91723		0.016755882			
T5	0.08277	0.91723		0.016755882			
T6	0.08277	0.91723		0.016755882			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
			0.185683187	0.203324716	0.389007903	0.610992097	89.6518101

Probability calculations of capacities for Poles 1 and 2 in 2005 (VIT reactor replacement)							
Pole2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.03201	0.96799					
filter-ARN	0.00003	0.99997					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.06321	0.93679					
Common	0.00149	0.99851					
T3	0.01644	0.98356		0.010613335			
T4	0.01644	0.98356		0.010613335			
T7	0.01644	0.98356		0.010613335			
T8	0.01644	0.98356		0.010613335			
V3	0.01458	0.98542		0.00939479			
V4	0.01458	0.98542		0.00939479			
V7	0.01458	0.98542		0.00939479			
V8	0.01458	0.98542		0.00939479			
Auxiliary-V3	0.00132	0.99868		0.000839264			
Auxiliary-V4	0.00132	0.99868		0.000839264			
Auxiliary-V7	0.00132	0.99868		0.000839264			
Auxiliary-V8	0.00132	0.99868		0.000839264			
Cable 900 amp	0.04842	0.95158		0.032309513			
Cable 900 amp	0.04842	0.95158		0.032309513			
Cable 600 amp	0.04082	0.95918		0.027022393			
Cable 600 amp	0.04082	0.95918		0.027022393			
Cable 600 amp	0.04082	0.95918		0.027022393			
			0.634966667	0.229075762	0.864042429	0.135957571	356.7641648
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.12309	0.87691					
filter-ARN	0.12309	0.87691					
Reactor-VIT	0.21992	0.78008					
Reactor-ARN	0.21992	0.78008					
T1	0.09373	0.90627		0.014818689			
T2	0.09373	0.90627		0.014818689			
T5	0.09373	0.90627		0.014818689			
T6	0.09373	0.90627		0.014818689			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
			0.143281059	0.179192098	0.322473156	0.677526844	72.65765748

Probability calculations of capacities for Poles 1 and 2 in 2006 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.03972	0.96028					
filter-ARN	0.00005	0.99995					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.07746	0.92254					
Common	0.00176	0.99824					
T3	0.02058	0.97942		0.012645433			
T4	0.02058	0.97942		0.012645433			
T7	0.02058	0.97942		0.012645433			
T8	0.02058	0.97942		0.012645433			
V3	0.01641	0.98359		0.010040418			
V4	0.01641	0.98359		0.010040418			
V7	0.01641	0.98359		0.010040418			
V8	0.01641	0.98359		0.010040418			
Auxiliary-V3	0.00159	0.99841		0.000958397			
Auxiliary-V4	0.00159	0.99841		0.000958397			
Auxiliary-V7	0.00159	0.99841		0.000958397			
Auxiliary-V8	0.00159	0.99841		0.000958397			
Cable 900 amp	0.05019	0.94981		0.031800779			
Cable 900 amp	0.05019	0.94981		0.031800779			
Cable 600 amp	0.04111	0.95889		0.025800967			
Cable 600 amp	0.04111	0.95889		0.025800967			
Cable 600 amp	0.04111	0.95889		0.025800967			
			0.601807089	0.23558145	0.837388539	0.162611461	342.5285593
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.14478	0.85522					
filter-ARN	0.14478	0.85522					
Reactor-VIT	0.2535	0.7465					
Reactor-ARN	0.2535	0.7465					
T1	0.10637	0.89363		0.012646337			
T2	0.10637	0.89363		0.012646337			
T5	0.10637	0.89363		0.012646337			
T6	0.10637	0.89363		0.012646337			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
			0.106243735	0.152434503	0.258678238	0.741321762	56.92782777

Probability calculations of capacities for Poles 1 and 2 in 2007 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.04889	0.95111					
filter-ARN	0.00008	0.99992					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.09408	0.90592					
Common	0.0021	0.9979					
T3	0.02557	0.97443		0.01487808			
T4	0.02557	0.97443		0.01487808			
T7	0.02557	0.97443		0.01487808			
T8	0.02557	0.97443		0.01487808			
V3	0.01852	0.98148		0.010698585			
V4	0.01852	0.98148		0.010698585			
V7	0.01852	0.98148		0.010698585			
V8	0.01852	0.98148		0.010698585			
Auxiliary-V3	0.00193	0.99807		0.001096385			
Auxiliary-V4	0.00193	0.99807		0.001096385			
Auxiliary-V7	0.00193	0.99807		0.001096385			
Auxiliary-V8	0.00193	0.99807		0.001096385			
Cable 900 amp	0.05023	0.94977		0.029985517			
Cable 900 amp	0.05023	0.94977		0.029985517			
Cable 600 amp	0.04143	0.95857		0.024505181			
Cable 600 amp	0.04143	0.95857		0.024505181			
Cable 600 amp	0.04143	0.95857		0.024505181			
			0.566978784	0.240178776	0.80715756	0.19284244	327.04445
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.16905	0.83095					
filter-ARN	0.16905	0.83095					
Reactor-VIT	0.28976	0.71024					
Reactor-ARN	0.28976	0.71024					
T1	0.12082	0.87918		0.010406413			
T2	0.12082	0.87918		0.010406413			
T5	0.12082	0.87918		0.010406413			
T6	0.12082	0.87918		0.010406413			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
			0.075725132	0.124754433	0.200479565	0.799520435	43.0879328

Probability calculations of capacities for Poles 1 and 2 in 2008 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.05971	0.94029					
filter-ARN	0.00012	0.99988					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.11328	0.88672					
Common	0.00252	0.99748					
T3	0.03152	0.96848		0.017040237			
T4	0.03152	0.96848		0.017040237			
T7	0.03152	0.96848		0.017040237			
T8	0.03152	0.96848		0.017040237			
V3	0.02094	0.97906		0.01119818			
V4	0.02094	0.97906		0.01119818			
V7	0.02094	0.97906		0.01119818			
V8	0.02094	0.97906		0.01119818			
Auxiliary-V3	0.00234	0.99766		0.001228042			
Auxiliary-V4	0.00234	0.99766		0.001228042			
Auxiliary-V7	0.00234	0.99766		0.001228042			
Auxiliary-V8	0.00234	0.99766		0.001228042			
Cable 900 amp	0.05456	0.94544		0.030214851			
Cable 900 amp	0.05456	0.94544		0.030214851			
Cable 600 amp	0.0418	0.9582		0.022840215			
Cable 600 amp	0.0418	0.9582		0.022840215			
Cable 600 amp	0.0418	0.9582		0.022840215			
			0.523576413	0.246816185	0.770392598	0.229607402	307.964625
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.19596	0.80404					
filter-ARN	0.19596	0.80404					
Reactor-VIT	0.3284	0.6716					
Reactor-ARN	0.3284	0.6716					
T1	0.13724	0.86276		0.008114055			
T2	0.13724	0.86276		0.008114055			
T5	0.13724	0.86276		0.008114055			
T6	0.13724	0.86276		0.008114055			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
			0.05100905	0.097306577	0.148315626	0.851684374	31.0946494

Probability calculations of capacities for Poles 1 and 2 in 2009 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.07234	0.92766					
filter-ARN	0.00019	0.99981					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.13524	0.86476					
Common	0.00302	0.99698					
T3	0.03858	0.96142		0.019226512			
T4	0.03858	0.96142		0.019226512			
T7	0.03858	0.96142		0.019226512			
T8	0.03858	0.96142		0.019226512			
V3	0.02369	0.97631		0.011625958			
V4	0.02369	0.97631		0.011625958			
V7	0.02369	0.97631		0.011625958			
V8	0.02369	0.97631		0.011625958			
Auxiliary-V3	0.00285	0.99715		0.001369417			
Auxiliary-V4	0.00285	0.99715		0.001369417			
Auxiliary-V7	0.00285	0.99715		0.001369417			
Auxiliary-V8	0.00285	0.99715		0.001369417			
Cable 900 amp	0.05722	0.94278		0.029079633			
Cable 900 amp	0.05722	0.94278		0.029079633			
Cable 600 amp	0.04223	0.95777		0.021125708			
Cable 600 amp	0.04223	0.95777		0.021125708			
Cable 600 amp	0.04223	0.95777		0.021125708			
			0.479127858	0.250423937	0.729551795	0.270448205	287.6657575
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.22549	0.77451					
filter-ARN	0.22549	0.77451					
Reactor-VIT	0.36902	0.63098					
Reactor-ARN	0.36902	0.63098					
T1	0.15575	0.84425		0.006042463			
T2	0.15575	0.84425		0.006042463			
T5	0.15575	0.84425		0.006042463			
T6	0.15575	0.84425		0.006042463			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
			0.032753449	0.072326656	0.105080105	0.894919895	21.5020344

Probability calculations of capacities for Poles 1 and 2 in 2010 (VIT reactor replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.087	0.913					
filter-ARN	0.0003	0.9997					
Reactor-VIT	0.0002	0.9998					
Reactor-ARN	0.16008	0.83992					
Common	0.00364	0.99636					
T3	0.04689	0.95311		0.021248077			
T4	0.04689	0.95311		0.021248077			
T7	0.04689	0.95311		0.021248077			
T8	0.04689	0.95311		0.021248077			
V3	0.02682	0.97318		0.011902769			
V4	0.02682	0.97318		0.011902769			
V7	0.02682	0.97318		0.011902769			
V8	0.02682	0.97318		0.011902769			
Auxiliary-V3	0.00346	0.99654		0.00149956			
Auxiliary-V4	0.00346	0.99654		0.00149956			
Auxiliary-V7	0.00346	0.99654		0.00149956			
Auxiliary-V8	0.00346	0.99654		0.00149956			
Cable 900 amp	0.06024	0.93976		0.027685376			
Cable 900 amp	0.06024	0.93976		0.027685376			
Cable 600 amp	0.04272	0.95728		0.019274125			
Cable 600 amp	0.04272	0.95728		0.019274125			
Cable 600 amp	0.04272	0.95728		0.019274125			
			0.431899224	0.251794754	0.683693978	0.316306022	265.511182
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.25754	0.74246					
filter-ARN	0.25754	0.74246					
Reactor-VIT	0.41111	0.58889					
Reactor-ARN	0.41111	0.58889					
T1	0.17644	0.82356		0.004260809			
T2	0.17644	0.82356		0.004260809			
T5	0.17644	0.82356		0.004260809			
T6	0.17644	0.82356		0.004260809			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
			0.019887959	0.050931581	0.07081954	0.92918046	14.15036994

Comparison of Pole 2 reliability probability between doing nothing and replacement of Pole 2 reactor at VIT				
		Doing nothing		
	Probability at 476 MW only - do nothing	Probability at 238 MW & above -do nothing	Failure probability -do nothing	
2004	0.629157259	0.840012783	0.159987217	
2005	0.59390786	0.808170912	0.191829088	
2006	0.554333069	0.771330493	0.228669507	
2007	0.512838492	0.730082813	0.269917187	
2008	0.463541606	0.682057124	0.317942876	
2009	0.413689862	0.629911569	0.370088431	
2010	0.362198344	0.573357887	0.426642113	
		Reactor at VIT replaced by a new one		
	Probability at 476 MW only - new VIT RX	Probability at 238 MW & above -new VIT RX	Failure probability - new VIT RX	failure probability reduction
2004	0.629157259	0.840012783	0.159987217	0
2005	0.634966667	0.864042429	0.135957571	0.055871517
2006	0.601807089	0.837388539	0.162611461	0.066058046
2007	0.566978784	0.80715756	0.19284244	0.077074747
2008	0.523576413	0.770392598	0.229607402	0.088335475
2009	0.479127858	0.729551795	0.270448205	0.099640226
2010	0.431899224	0.683693978	0.316306022	0.110336091
	Probability at 312 MW only	Probability at 156 MW & above	Failure probability	
2004	0.185683187	0.389007903	0.610992097	
2005	0.143281059	0.322473156	0.677526844	
2006	0.106243735	0.258678238	0.741321762	
2007	0.075725132	0.200479565	0.799520435	
2008	0.05100905	0.148315626	0.851684374	
2009	0.032753449	0.105080105	0.894919895	
2010	0.019887959	0.07081954	0.92918046	

HVDC reliability comparison between doing nothing and VIT reactor replacement				
	0 MW (VIT-RX)	238 MW & above (VIT-RX)	476 MW & above (VIT-RX)	0 MW (do nothing)
2004	0.097750925	0.86971972	0.668309585	0.097750925
2005	0.092114904	0.883522574	0.667788885	0.129969357
2006	0.120547415	0.854664988	0.626836142	0.169517682
2007	0.154181472	0.821760579	0.585166354	0.215804307
2008	0.195553036	0.782104654	0.536166272	0.270786979
2009	0.242029479	0.738409906	0.487330106	0.3311995
2010	0.293905375	0.689984659	0.436906908	0.396427514
	238 MW & above (do nothing)	476 MW & above (do nothing)	0 MW probability reduction	
2004	0.86971972	0.668309585	0	
2005	0.835656386	0.624607697	0.037854453	
2006	0.795625195	0.577387686	0.048970267	
2007	0.750522328	0.529289347	0.061622835	
2008	0.698275088	0.474687875	0.075233943	
2009	0.642033242	0.420771868	0.08917002	
2010	0.581842928	0.366397876	0.102522139	

Cumulative probability distribution of HVDC capacity (VIT reactor replacement)										
Pole 2	(New VIT reactor)									
	Failure probability	Probability at 476 MW only	Probability at 238 MW	Probability at 238 MW & above						
2004	0.159987217	0.629157259	0.210855525	0.840012783						
2005	0.135957571	0.634966667	0.229075762	0.864042429						
2006	0.162611461	0.601807089	0.23558145	0.837388539						
2007	0.19284244	0.566978784	0.240178776	0.80715756						
2008	0.229607402	0.523576413	0.246816185	0.770392598						
2009	0.270448205	0.479127858	0.250423937	0.729551795						
2010	0.316306022	0.431899224	0.251794754	0.683693978						
Pole 1										
	Failure probability	Probability at 312 MW only	Probability at 156 MW	Probability at 156 MW & above						
2004	0.610992097	0.185683187	0.203324716	0.389007903						
2005	0.677526844	0.143281059	0.179192098	0.322473156						
2006	0.741321762	0.106243735	0.152434503	0.258678238						
2007	0.799520435	0.075725132	0.124754433	0.200479565						
2008	0.851684374	0.05100905	0.097306577	0.148315626						
2009	0.894919895	0.032753449	0.072326656	0.105080105						
2010	0.92918046	0.019887959	0.050931581	0.07081954						
Pole 1 &2 density distribution										
	0 MW (p1 and p2 failure)	156 MW (p1-156 & p2 zero)	238 MW (p1 zero & p2-238)	312 MW (p1-312 and p2 zero)	394 MW (p1-156 & p2-238)	476 MW (p1 zero & p2-476)	550 MW (p1-312 & p2-238)	632 MW (p1-156 & p2-476)	788 MW (p1-312 & p2-476)	Total
2004	0.097750925	0.032529355	0.128831059	0.029706936	0.04287214	0.384410113	0.039152326	0.127923221	0.116823925	1
2005	0.092114904	0.024362522	0.155204978	0.019480145	0.041048566	0.430206962	0.032822218	0.113781009	0.090978696	1
2006	0.120547415	0.024787597	0.174641655	0.017276449	0.035910741	0.446132692	0.025029053	0.091736164	0.063938233	1
2007	0.154181472	0.024057949	0.192027839	0.014603019	0.029963367	0.453311124	0.01818757	0.070733117	0.042934544	1
2008	0.195553036	0.02234231	0.210209488	0.011712055	0.024016838	0.44592185	0.012589859	0.050947428	0.026707135	1
2009	0.242029479	0.019560614	0.224109363	0.008858112	0.018112326	0.428781053	0.008202248	0.034653716	0.01569309	1
2010	0.293905375	0.016109966	0.233962765	0.006290681	0.012824305	0.401312319	0.005007684	0.02199731	0.008589594	1
Pole 1 &2 cumulative distribution										
	0 MW (p1 and p2 failure)	156 MW & above	238 MW & above	312 MW & above	394 MW & above	476 MW & above	550 MW & above	632 MW & above	788 MW	
2004	0.097750925	0.902249075	0.86971972	0.74088866	0.711181724	0.668309585	0.283899472	0.244747146	0.116823925	
2005	0.092114904	0.907885096	0.883522574	0.728317596	0.708837451	0.667788885	0.237581923	0.204759705	0.090978696	
2006	0.120547415	0.879452585	0.854664988	0.680023332	0.662746883	0.626836142	0.18070345	0.155674397	0.063938233	
2007	0.154181472	0.845818528	0.821760579	0.62973274	0.615129721	0.585166354	0.13185523	0.11366766	0.042934544	
2008	0.195553036	0.804446964	0.782104654	0.571895166	0.56018311	0.536166272	0.090244423	0.077654564	0.026707135	
2009	0.242029479	0.757970521	0.738409906	0.514300543	0.505442432	0.487330106	0.058549053	0.050346806	0.01569309	
2010	0.293905375	0.706094625	0.689984659	0.456021894	0.449731213	0.436906908	0.035594588	0.030586904	0.008589594	

Appendix 3

Input data (VIT-filter replacement)												
Pole 2												
	2004	2005	2006	2007	2008	2009	2010					
filter-VIT	0.02557	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	(buy a new filter in 2005)				
filter-ARN	0.00002	0.00003	0.00005	0.00008	0.00012	0.00019	0.0003	(ARN filter replaced in 1996)				
Reactor-VIT	0.05278	0.06485	0.07907	0.09567	0.11484	0.13675	0.16155					
Reactor-ARN	0.05111	0.06321	0.07746	0.09408	0.11328	0.13524	0.16008	(spare is located at ARN side)				
Common	0.00127	0.00149	0.00176	0.0021	0.00252	0.00302	0.00364					
T3	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689					
T4	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689					
T7	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689					
T8	0.01303	0.01644	0.02058	0.02557	0.03152	0.03858	0.04689					
V3	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682					
V4	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682					
V7	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682					
V8	0.01299	0.01458	0.01641	0.01852	0.02094	0.02369	0.02682					
Auxiliary-V3	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346					
Auxiliary-V4	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346					
Auxiliary-V7	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346					
Auxiliary-V8	0.0011	0.00132	0.00159	0.00193	0.00234	0.00285	0.00346					
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(MTTR assumed 4 months)				
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024	(900 amp cable assumed less life expectancy)				
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272	(MTTR assumed 4 months)				
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272					
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272					
Pole 1												
	2004	2005	2006	2007	2008	2009	2010					
filter-VIT	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754					
filter-ARN	0.10389	0.12309	0.14478	0.16905	0.19596	0.22549	0.25754					
Reactor-VIT	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111					
Reactor-ARN	0.18921	0.21992	0.2535	0.28976	0.3284	0.36902	0.41111					
T1	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644					
T2	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644					
T5	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644					
T6	0.08277	0.09373	0.10637	0.12082	0.13724	0.15575	0.17644					
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496					
MAV-VIT	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496					
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496					
MAV-ARN	0.11284	0.13185	0.15332	0.17735	0.20399	0.23322	0.26496					
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024					
Cable 900 amp	0.04689	0.04842	0.05019	0.05023	0.05456	0.05722	0.06024					
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272					
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272					
Cable 600 amp	0.04058	0.04082	0.04111	0.04143	0.0418	0.04223	0.04272					

Probability calculations of capacities for Poles 1 and 2 in 2004 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.02557	0.97443					
filter-ARN	0.00002	0.99998					
Reactor-VIT	0.05278	0.94722					
Reactor-ARN	0.05111	0.94889					
Common	0.00127	0.99873					
T3	0.01303	0.98697		0.008306148			
T4	0.01303	0.98697		0.008306148			
T7	0.01303	0.98697		0.008306148			
T8	0.01303	0.98697		0.008306148			
V3	0.01299	0.98701		0.008280314			
V4	0.01299	0.98701		0.008280314			
V7	0.01299	0.98701		0.008280314			
V8	0.01299	0.98701		0.008280314			
Auxiliary-V3	0.0011	0.9989		0.000692835			
Auxiliary-V4	0.0011	0.9989		0.000692835			
Auxiliary-V7	0.0011	0.9989		0.000692835			
Auxiliary-V8	0.0011	0.9989		0.000692835			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 900 amp	0.04689	0.95311		0.030952549			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
Cable 600 amp	0.04058	0.95942		0.026611079			
			0.629157259	0.210855525	0.840012783	0.159987217	349.66247
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.10389	0.89611					
filter-ARN	0.10389	0.89611					
Reactor-VIT	0.18921	0.81079					
Reactor-ARN	0.18921	0.81079					
T1	0.08277	0.91723		0.016755882			
T2	0.08277	0.91723		0.016755882			
T5	0.08277	0.91723		0.016755882			
T6	0.08277	0.91723		0.016755882			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-VIT	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
MAV-ARN	0.11284	0.88716		0.023617488			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 900 amp	0.04689	0.95311		0.009135026			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
Cable 600 amp	0.04058	0.95942		0.007853728			
			0.185683187	0.203324716	0.389007903	0.610992097	89.6518101

Probability calculations of capacities for Poles 1 and 2 in 2005 (VIT filter replacement)							
Pole2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.00003	0.99997					
Reactor-VIT	0.06485	0.93515					
Reactor-ARN	0.06321	0.93679					
Common	0.00149	0.99851					
T3	0.01644	0.98356		0.010255216			
T4	0.01644	0.98356		0.010255216			
T7	0.01644	0.98356		0.010255216			
T8	0.01644	0.98356		0.010255216			
V3	0.01458	0.98542		0.009077787			
V4	0.01458	0.98542		0.009077787			
V7	0.01458	0.98542		0.009077787			
V8	0.01458	0.98542		0.009077787			
Auxiliary-V3	0.00132	0.99868		0.000810945			
Auxiliary-V4	0.00132	0.99868		0.000810945			
Auxiliary-V7	0.00132	0.99868		0.000810945			
Auxiliary-V8	0.00132	0.99868		0.000810945			
Cable 900 amp	0.04842	0.95158		0.031219313			
Cable 900 amp	0.04842	0.95158		0.031219313			
Cable 600 amp	0.04082	0.95918		0.026110594			
Cable 600 amp	0.04082	0.95918		0.026110594			
Cable 600 amp	0.04082	0.95918		0.026110594			
			0.613541381	0.221346201	0.834887581	0.165112419	344.726093
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.12309	0.87691					
filter-ARN	0.12309	0.87691					
Reactor-VIT	0.21992	0.78008					
Reactor-ARN	0.21992	0.78008					
T1	0.09373	0.90627		0.014818689			
T2	0.09373	0.90627		0.014818689			
T5	0.09373	0.90627		0.014818689			
T6	0.09373	0.90627		0.014818689			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-VIT	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
MAV-ARN	0.13185	0.86815		0.021760764			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 900 amp	0.04842	0.95158		0.007290684			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
Cable 600 amp	0.04082	0.95918		0.006097638			
			0.143281059	0.179192098	0.322473156	0.677526844	72.65765748

Probability calculations of capacities for Poles 1 and 2 in 2006 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.00005	0.99995					
Reactor-VIT	0.07907	0.92093					
Reactor-ARN	0.07746	0.92254					
Common	0.00176	0.99824					
T3	0.02058	0.97942		0.012129558			
T4	0.02058	0.97942		0.012129558			
T7	0.02058	0.97942		0.012129558			
T8	0.02058	0.97942		0.012129558			
V3	0.01641	0.98359		0.009630815			
V4	0.01641	0.98359		0.009630815			
V7	0.01641	0.98359		0.009630815			
V8	0.01641	0.98359		0.009630815			
Auxiliary-V3	0.00159	0.99841		0.000919299			
Auxiliary-V4	0.00159	0.99841		0.000919299			
Auxiliary-V7	0.00159	0.99841		0.000919299			
Auxiliary-V8	0.00159	0.99841		0.000919299			
Cable 900 amp	0.05019	0.94981		0.030503454			
Cable 900 amp	0.05019	0.94981		0.030503454			
Cable 600 amp	0.04111	0.95889		0.024748407			
Cable 600 amp	0.04111	0.95889		0.024748407			
Cable 600 amp	0.04111	0.95889		0.024748407			
			0.57725614	0.225970815	0.803226954	0.196773046	328.5549763
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.14478	0.85522					
filter-ARN	0.14478	0.85522					
Reactor-VIT	0.2535	0.7465					
Reactor-ARN	0.2535	0.7465					
T1	0.10637	0.89363		0.012646337			
T2	0.10637	0.89363		0.012646337			
T5	0.10637	0.89363		0.012646337			
T6	0.10637	0.89363		0.012646337			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-VIT	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
MAV-ARN	0.15332	0.84668		0.019239015			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 900 amp	0.05019	0.94981		0.005614147			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
Cable 600 amp	0.04111	0.95889		0.004554933			
			0.106243735	0.152434503	0.258678238	0.741321762	56.92782777

Probability calculations of capacities for Poles 1 and 2 in 2007 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.00008	0.99992					
Reactor-VIT	0.09567	0.90433					
Reactor-ARN	0.09408	0.90592					
Common	0.0021	0.9979					
T3	0.02557	0.97443		0.014148995			
T4	0.02557	0.97443		0.014148995			
T7	0.02557	0.97443		0.014148995			
T8	0.02557	0.97443		0.014148995			
V3	0.01852	0.98148		0.010174312			
V4	0.01852	0.98148		0.010174312			
V7	0.01852	0.98148		0.010174312			
V8	0.01852	0.98148		0.010174312			
Auxiliary-V3	0.00193	0.99807		0.001042658			
Auxiliary-V4	0.00193	0.99807		0.001042658			
Auxiliary-V7	0.00193	0.99807		0.001042658			
Auxiliary-V8	0.00193	0.99807		0.001042658			
Cable 900 amp	0.05023	0.94977		0.028516108			
Cable 900 amp	0.05023	0.94977		0.028516108			
Cable 600 amp	0.04143	0.95857		0.02330433			
Cable 600 amp	0.04143	0.95857		0.02330433			
Cable 600 amp	0.04143	0.95857		0.02330433			
			0.539194587	0.228409068	0.767603655	0.232396345	311.017981
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.16905	0.83095					
filter-ARN	0.16905	0.83095					
Reactor-VIT	0.28976	0.71024					
Reactor-ARN	0.28976	0.71024					
T1	0.12082	0.87918		0.010406413			
T2	0.12082	0.87918		0.010406413			
T5	0.12082	0.87918		0.010406413			
T6	0.12082	0.87918		0.010406413			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-VIT	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
MAV-ARN	0.17735	0.82265		0.016325111			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 900 amp	0.05023	0.94977		0.004004836			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
Cable 600 amp	0.04143	0.95857		0.003272888			
			0.075725132	0.124754433	0.200479565	0.799520435	43.0879328

Probability calculations of capacities for Poles 1 and 2 in 2008 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.00012	0.99988					
Reactor-VIT	0.11484	0.88516					
Reactor-ARN	0.11328	0.88672					
Common	0.00252	0.99748					
T3	0.03152	0.96848		0.016044202			
T4	0.03152	0.96848		0.016044202			
T7	0.03152	0.96848		0.016044202			
T8	0.03152	0.96848		0.016044202			
V3	0.02094	0.97906		0.010543625			
V4	0.02094	0.97906		0.010543625			
V7	0.02094	0.97906		0.010543625			
V8	0.02094	0.97906		0.010543625			
Auxiliary-V3	0.00234	0.99766		0.001156261			
Auxiliary-V4	0.00234	0.99766		0.001156261			
Auxiliary-V7	0.00234	0.99766		0.001156261			
Auxiliary-V8	0.00234	0.99766		0.001156261			
Cable 900 amp	0.05456	0.94544		0.028448734			
Cable 900 amp	0.05456	0.94544		0.028448734			
Cable 600 amp	0.0418	0.9582		0.02150516			
Cable 600 amp	0.0418	0.9582		0.02150516			
Cable 600 amp	0.0418	0.9582		0.02150516			
			0.49297235	0.232389297	0.725361647	0.274638353	289.963491
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.19596	0.80404					
filter-ARN	0.19596	0.80404					
Reactor-VIT	0.3284	0.6716					
Reactor-ARN	0.3284	0.6716					
T1	0.13724	0.86276		0.008114055			
T2	0.13724	0.86276		0.008114055			
T5	0.13724	0.86276		0.008114055			
T6	0.13724	0.86276		0.008114055			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-VIT	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
MAV-ARN	0.20399	0.79601		0.013071866			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 900 amp	0.05456	0.94544		0.00294366			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
Cable 600 amp	0.0418	0.9582		0.002225191			
			0.05100905	0.097306577	0.148315626	0.851684374	31.0946494

Probability calculations of capacities for Poles 1 and 2 in 2009 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.00019	0.99981					
Reactor-VIT	0.13675	0.86325					
Reactor-ARN	0.13524	0.86476					
Common	0.00302	0.99698					
T3	0.03858	0.96142		0.017894962			
T4	0.03858	0.96142		0.017894962			
T7	0.03858	0.96142		0.017894962			
T8	0.03858	0.96142		0.017894962			
V3	0.02369	0.97631		0.010820791			
V4	0.02369	0.97631		0.010820791			
V7	0.02369	0.97631		0.010820791			
V8	0.02369	0.97631		0.010820791			
Auxiliary-V3	0.00285	0.99715		0.001274577			
Auxiliary-V4	0.00285	0.99715		0.001274577			
Auxiliary-V7	0.00285	0.99715		0.001274577			
Auxiliary-V8	0.00285	0.99715		0.001274577			
Cable 900 amp	0.05722	0.94278		0.027065696			
Cable 900 amp	0.05722	0.94278		0.027065696			
Cable 600 amp	0.04223	0.95777		0.019662628			
Cable 600 amp	0.04223	0.95777		0.019662628			
Cable 600 amp	0.04223	0.95777		0.019662628			
			0.445945416	0.233080596	0.679026012	0.320973988	267.7431999
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.22549	0.77451					
filter-ARN	0.22549	0.77451					
Reactor-VIT	0.36902	0.63098					
Reactor-ARN	0.36902	0.63098					
T1	0.15575	0.84425		0.006042463			
T2	0.15575	0.84425		0.006042463			
T5	0.15575	0.84425		0.006042463			
T6	0.15575	0.84425		0.006042463			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-VIT	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
MAV-ARN	0.23322	0.76678		0.009962127			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 900 amp	0.05722	0.94278		0.0019879			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
Cable 600 amp	0.04223	0.95777		0.001444165			
			0.032753449	0.072326656	0.105080105	0.894919895	21.5020344

Probability calculations of capacities for Poles 1 and 2 in 2010 (VIT filter replacement)							
Pole 2							
	failure prob.	success prob	476 MW prob	238 MW prob	above 238 MW prob	zero MW prob	average MW
filter-VIT	0.00001	0.99999					
filter-ARN	0.0003	0.9997					
Reactor-VIT	0.16155	0.83845					
Reactor-ARN	0.16008	0.83992					
Common	0.00364	0.99636					
T3	0.04689	0.95311		0.019516797			
T4	0.04689	0.95311		0.019516797			
T7	0.04689	0.95311		0.019516797			
T8	0.04689	0.95311		0.019516797			
V3	0.02682	0.97318		0.010932939			
V4	0.02682	0.97318		0.010932939			
V7	0.02682	0.97318		0.010932939			
V8	0.02682	0.97318		0.010932939			
Auxiliary-V3	0.00346	0.99654		0.001377377			
Auxiliary-V4	0.00346	0.99654		0.001377377			
Auxiliary-V7	0.00346	0.99654		0.001377377			
Auxiliary-V8	0.00346	0.99654		0.001377377			
Cable 900 amp	0.06024	0.93976		0.025429589			
Cable 900 amp	0.06024	0.93976		0.025429589			
Cable 600 amp	0.04272	0.95728		0.017703682			
Cable 600 amp	0.04272	0.95728		0.017703682			
Cable 600 amp	0.04272	0.95728		0.017703682			
			0.396708348	0.231278677	0.627987025	0.372012975	243.8774988
Pole 1							
	failure prob.	success prob	312 MW prob	156 MW prob	above 156 MW prob	zero MW prob	average MW
filter-VIT	0.25754	0.74246					
filter-ARN	0.25754	0.74246					
Reactor-VIT	0.41111	0.58889					
Reactor-ARN	0.41111	0.58889					
T1	0.17644	0.82356		0.004260809			
T2	0.17644	0.82356		0.004260809			
T5	0.17644	0.82356		0.004260809			
T6	0.17644	0.82356		0.004260809			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-VIT	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
MAV-ARN	0.26496	0.73504		0.007169016			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 900 amp	0.06024	0.93976		0.001274847			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
Cable 600 amp	0.04272	0.95728		0.000887529			
			0.019887959	0.050931581	0.07081954	0.92918046	14.15036994

	Reliability distribution results for Poles 1 and 2 (VIT filter replacement)			
		Doing nothing		
	Probability at 476 MW only	Probability at 238 MW & above -do nothing	Failure probability -do nothing	
2004	0.629157259	0.840012783	0.159987217	
2005	0.59390786	0.808170912	0.191829088	
2006	0.554333069	0.771330493	0.228669507	
2007	0.512838492	0.730082813	0.269917187	
2008	0.463541606	0.682057124	0.317942876	
2009	0.413689862	0.629911569	0.370088431	
2010	0.362198344	0.573357887	0.426642113	
		Filter at VIT replaced by a new one		
	Probability at 476 MW only	Probability at 238 MW & above -new VIT fliter	Failure probability - new VIT filter	failure probability reduction
2004	0.629157259	0.840012783	0.159987217	0
2005	0.613541381	0.834887581	0.165112419	0.02671667
2006	0.57725614	0.803226954	0.196773046	0.031896461
2007	0.539194587	0.767603655	0.232396345	0.037520842
2008	0.49297235	0.725361647	0.274638353	0.043304523
2009	0.445945416	0.679026012	0.320973988	0.049114443
2010	0.396708348	0.627987025	0.372012975	0.054629138
	Probability at 312 MW only	Probability at 156 MW & above	Failure probability	
2004	0.185683187	0.389007903	0.610992097	
2005	0.143281059	0.322473156	0.677526844	
2006	0.106243735	0.258678238	0.741321762	
2007	0.075725132	0.200479565	0.799520435	
2008	0.05100905	0.148315626	0.851684374	
2009	0.032753449	0.105080105	0.894919895	
2010	0.019887959	0.07081954	0.92918046	

HVDC reliability distribution (VIT filter replacement)				
	0 MW (VIT-flt)	238 MW & above (VIT-flt)	476 MW & above (VIT-flt)	0 MW (do nothing)
2004	0.097750925	0.86971972	0.668309585	0.097750925
2005	0.111868096	0.858545064	0.645256099	0.129969357
2006	0.145872141	0.824132858	0.601264123	0.169517682
2007	0.185805627	0.785201899	0.556490894	0.215804307
2008	0.233905194	0.739370688	0.504826307	0.270786979
2009	0.287246008	0.689539017	0.45357961	0.3311995
2010	0.345667187	0.635385604	0.401308009	0.396427514
	238 MW & above	476 MW & above (do nothing)	0MW probability reduction	
2004	0.86971972	0.668309585	0	
2005	0.835656386	0.624607697	0.018101261	
2006	0.795625195	0.577387686	0.023645541	
2007	0.750522328	0.529289347	0.02999868	
2008	0.698275088	0.474687875	0.036881786	
2009	0.642033242	0.420771868	0.043953492	
2010	0.581842928	0.366397876	0.050760327	

Cumulative probability distribution fo HVDC capacity (VIT filter replacement)										
Pole 2	(New VIT filter)									
	Failure probability	Probability at 476 MW only	Probability at 238 MW	Probability at 238 MW & above						
2004	0.159987217	0.629157259	0.210855525	0.840012783						
2005	0.165112419	0.613541381	0.221346201	0.834887581						
2006	0.196773046	0.57725614	0.225970815	0.803226954						
2007	0.232396345	0.539194587	0.228409068	0.767603655						
2008	0.274638353	0.49297235	0.232389297	0.725361647						
2009	0.320973988	0.445945416	0.233080596	0.679026012						
2010	0.372012975	0.396708348	0.231278677	0.627987025						
Pole 1										
	Failure probability	Probability at 312 MW only	Probability at 156 MW	Probability at 156 MW & above						
2004	0.610992097	0.185683187	0.203324716	0.389007903						
2005	0.677526844	0.143281059	0.179192098	0.322473156						
2006	0.741321762	0.106243735	0.152434503	0.258678238						
2007	0.799520435	0.075725132	0.124754433	0.200479565						
2008	0.851684374	0.05100905	0.097306577	0.148315626						
2009	0.894919895	0.032753449	0.072326656	0.105080105						
2010	0.92918046	0.019887959	0.050931581	0.07081954						
Pole 1 &2 density distribution										
	0 MW (p1 and p2 failure)	156 MW (p1-156 & p2 zero)	238 MW (p1 zero & p2-238)	312 MW (p1-312 and p2 zero)	394 MW (p1-156 & p2-238)	476 MW (p1 zero & p2-476)	550 MW (p1-312 & p2-238)	632 MW (p1-156 & p2-476)	788 MW (p1-312 & p2-476)	Total
2004	0.097750925	0.032529355	0.128831059	0.029706936	0.04287214	0.384410113	0.039152326	0.127923221	0.116823925	1
2005	0.111868096	0.029586841	0.149967993	0.023657482	0.03966349	0.415690755	0.031714718	0.109941767	0.087908858	1
2006	0.145872141	0.029995001	0.167517083	0.020905903	0.034445749	0.427932539	0.024007983	0.087993753	0.061329848	1
2007	0.185805627	0.028992474	0.182617717	0.017598244	0.028495044	0.431097091	0.017296307	0.067266915	0.040830582	1
2008	0.233905194	0.026724118	0.197922333	0.014009041	0.022613007	0.419856847	0.011853957	0.047969452	0.025146051	1
2009	0.287246008	0.023214975	0.208588462	0.010513005	0.01685794	0.399085425	0.007634193	0.032253741	0.014606251	1
2010	0.345667187	0.018947209	0.214899627	0.007398579	0.011779389	0.368613645	0.004599661	0.020204983	0.007889719	1
Pole 1 &2 cumulative distribution										
	0 MW (p1 and p2 failure)	156 MW & above	238 MW & above	312 MW & above	394 MW & above	476 MW & above	550 MW & above	632 MW & above	788 MW	
2004	0.097750925	0.902249075	0.86971972	0.74088866	0.711181724	0.668309585	0.283899472	0.244747146	0.116823925	
2005	0.111868096	0.888131904	0.858545064	0.708577071	0.684919589	0.645256099	0.229566343	0.197850625	0.087908858	
2006	0.145872141	0.854127859	0.824132858	0.656615775	0.635709872	0.601264123	0.173331584	0.149323601	0.061329848	
2007	0.185805627	0.814194373	0.785201899	0.602584181	0.584985937	0.556490894	0.125393803	0.108097496	0.040830582	
2008	0.233905194	0.766094806	0.739370688	0.541448355	0.527439314	0.504826307	0.08496946	0.073115503	0.025146051	
2009	0.287246008	0.712753992	0.689539017	0.480950555	0.47043755	0.45357961	0.054494184	0.046859991	0.014606251	
2010	0.345667187	0.654332813	0.635385604	0.420485977	0.413087398	0.401308009	0.032694364	0.028094703	0.007889719	