Computation of the Value of Security
Final Report – Volume II -

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1 INTRODUCTION

The Volume I of this final report has presented the theorical aspects involved in the computation of the Value of Security using a probabilistic method based on Monte Carlo simulations proposed under the Value of Security Project –EPSRC/ERCOS grant reference no GR/K 80310.

The proposed probabilistic method allows the computation of the Value of Security of operational plans on the basis of the sum of the production cost of the scheduled plant configuration and the expected cost (in terms of necessary redispatch of generation and the impact of load shedding) of unplanned outages.

A Monte Carlo sample simulation computes the Value of Security from a number of trials. The individual trial's simulation starts from a known state of the system, which results from the implementation of the plan.

Individual trials are generated by random contingency conditions based on this state and the system's evolution over the analysis period (for example, several hours). The simulation period is broken down into intervals or snapshots to model random outages at different moments over this period.

The initial state of the following interval is derived from the current interval taking into account the contingencies presented and the corrective actions taken by the operators. The new interval starting state considers also the changes in load and in planned schedule generation.

Figure 1.1 shows the simulation of disturbance events for each snapshot in a Monte Carlo trial simulation used for computing the Value of Security. The sequence of events is divided in three parts:

- Generation of disturbances.

- Computation of an equilibrium point.

- Corrective actions and cost evaluation.

The initial system state given by network topology, load demand and generation schedule is modified by random disturbances (outages of lines, transformers, busbars, compensation and generation equipment). These disturbances could also produce other disturbances such as sympathetic and transient instability trips.

After restoring the generation-load balance, the equilibrium point of the new system's state must be calculated using a load flow. Two outcomes are possible for this computation:

- The power flow converges.

- The power flow diverges. This indicates that the occurrence of this contingency state would result in voltage stability problems. A heuristic technique has been developed to determine how much load must be dropped to restore the feasibility of the power flow. If the load flow diverges, it is assumed that the system or a part of the system (an island) would have suffered a voltage collapse were the operator not have taken action. It is further assumed that the operator's response to an impeding collapse would have been to shed load in 5% blocks in the area of the biggest mismatch until convergence is achieved. If convergence has still not been achieved after all load has been shed, the island or the system is deemed to have collapsed.

When the system has reached an equilibrium point (EP1, convergence of the load flow), a series of cascade tripping events may occur. In this case, a new load flow computation is required. A divergence of this new load flow indicates a severe problem (voltage collapse) has been caused by events occurred after EP1. As in the computation of EP1, a load shedding is realised until a new equilibrium point (EP2) is reached.

As Figure 1.1 shows, a sequence of load flow calculations and disturbance events may be established in an iterative way. This succession of calculation of EP(i)-disturbances-EP(i+1) can be interpreted as a modelling of successive slow events that provokes a voltage collapse in the system.

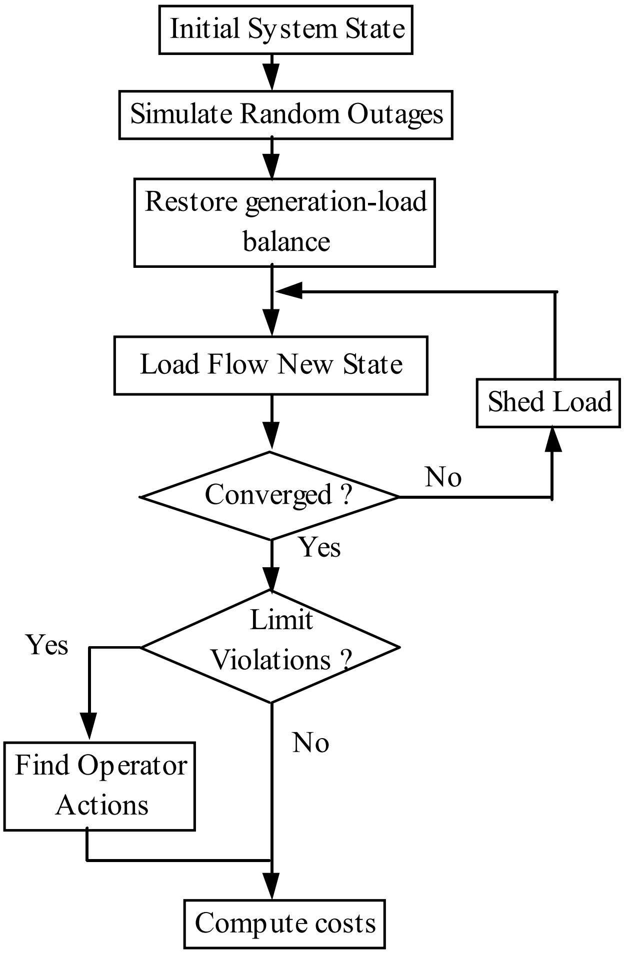

Figure 1.1 Simulation of one snapshot in a trial

Finally, the system reaches a last equilibrium point (EP). The system has a converged load flow with two possible outcomes:

- The resulting state of the system does not exhibit any major violation of normal operating limits. This state does not require any corrective action and has a cost of zero.

- The resulting state has some violations of normal operating constraints. Corrective actions must be taken to bring the system back within acceptable limits. The cost of these actions is computed and tallied.

In response to violations of system operating limits, operators can reschedule generation, change voltage set-points and tap ratios, and, as a last resort, shed load. Since operators reach decisions about what actions to take based on advice given by planners, information gleaned from “what-if” load flow studies, and experience, their actions are represented for the value of security computation by a fuzzy expert system with embedded load flow and linear sensitivity analysis. Three types of corrective actions are modelled:

- Active dispatch: dispatches settings of active power generation, shedding of load (active and reactive components in proportion) and changes to phase shifter settings in order to relieve overloads of transmission lines and cables.

- Reactive dispatch: dispatches settings of reactive control devices in order to correct violations of voltage limits.

- Dispatch of active controls for correction of voltage problems: this is activated to change the active generation and, if necessary, shed load in order to remove any outstanding violations of voltage limits.

Finally, the Value of Security is computed from the rescheduled generation, valued at the system marginal price, and from the interrupted load using the value of lost load (VOLL).

Volume II of this final report presents tests of the Value of Security Assessor program (Assessor) developed under the Value of Security Project –EPSRC/ERCOS grant reference no GR/K 80310 on both a small and a large power system. The south-west portion of the England and Wales system has been used as the small test power system, while a full model of the NGC transmission system for 1996/97 has been employed as the large test power system.

The objectives of these tests were to:

- Test the sequential simulation method that makes possible the computation of the value of security over a time interval (for example, 1 hour or 1 day).
- Test the variance reduction methods developed previously in the context of this sequential simulation
- Test the various methods for computing the value of lost load [5].
- Test the modelling of weather effects [7].
- Test the modelling of the time dependent phenomena [6, Appendix A]
- Develop improvements to the Assessor for the computation of the Value of Security for large power systems.

Chapter 2 presents the study cases and the results of the simulations based on the South-West England-Wales system.

Chapter 3 presents a previous study concerning the selection of simulation parameters and some important aspects related to the application of Value of Security Assessor to large power systems.

Chapter 4 presents the study cases and the results of the simulations based on the NGC System.

Chapter 5 discusses and proposes a method to consider severe outages in the computation of the Value of Security for large power systems, which allows that the Value of Security computation be faster.

Chapter 6 discusses the test results, presents conclusions and perspectives on future work in the value of security.

APPENDIX A – South West England-Wales System data gives the data of the south-west England-Wales test system, while APPENDIX B – NGC System data gives some data of the large test system of the NGC.

2 TESTING THE ASSESSOR OF VALUE OF SECURITY ON A SMALL POWER SYSTEM - THE ENGLAND AND WALES SOUTH-WEST SYSTEM

Firstly, the Value of Security Assessor program has been tested using a model representing the south-western portion of the transmission system of England and Wales (SW System).

Table 2.1 shows the main characteristics of the system. Two scenarios (the presence or absence of generation at Fawley station) have been used for testing. Figure 2.1 shows the load demand for a period of 24 hours. Generation dispatches for each scenario based on this load demand profile have been used. Detailed data is provided in APPENDIX A – South West England-Wales System data.

Table 2.1 Main characteristics South West System

Characteristic	Value
Maximum load [MW]	5566
Number of buses	53
Number of branches	115
Number of generators	25
Number of areas	1

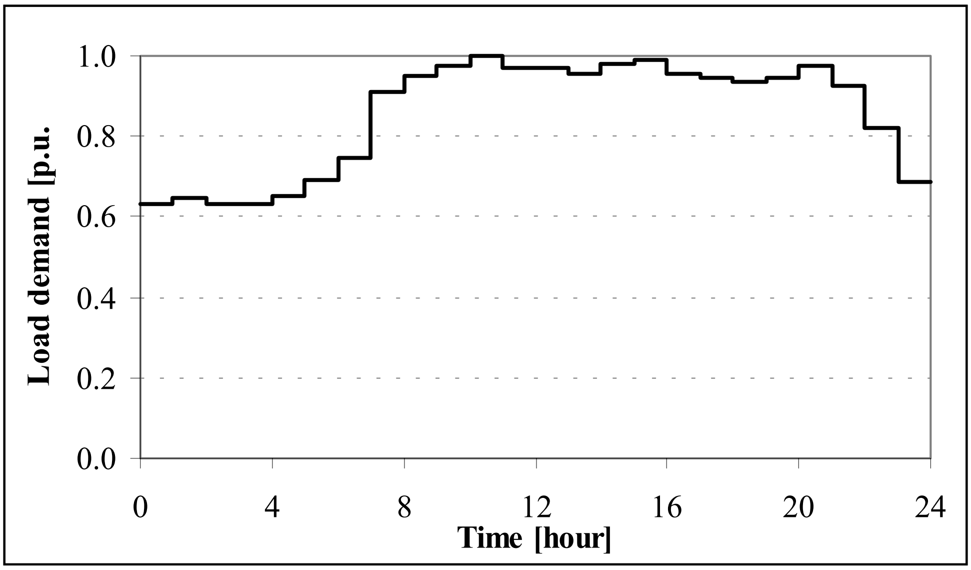

Figure 2.1 Load demand, South-West System

The data on reliability of transmission equipment provided by [1] has been used as typical data for this system. Failure rates of transmission lines have been computed using their length (See appendix B of [2]). Failure rates of generators have been computed from forced outage rates (FOR) provided in [3] and assuming mean time to repair (MTTR) values given by [4]. The generation prices associated with each generator are given in appendix D of [2].

The same load restoration process has been assumed in all cases. This process corresponds to the restoration by steps described in Figure 5b of [6]. Each step was given a duration of 30 minutes. The simulation therefore takes 2 subintervals for each period of constant load.

In the tables that follow in this chapter, the confidence that can be associated with the results is given in terms of the ratio of the standard deviation to the mean value of the total cost of value of security (σ/μ). Table 2.2 gives the value of this ratio associated with five combinations of degrees of confidence and confidence interval.

Table 2.2 σ / μ relations

Confidence degree [%]	Confidence interval [%]	σ / μ [%]
80.0	5.0	3.90
85.0	5.0	3.47
90.0	5.0	3.04
95.0	5.0	2.55
99.0	5.0	1.94
95.0	1.0	0.51
99.0	1.0	0.39

It is important to remember that the confidence interval is defined as a function of the mean (μ) and standard deviation (σ) values and the degree of confidence. Thus,

$$Confidence\ \ Interval = \left[\mu - \alpha \times \sigma, \mu + \alpha \times \sigma\right] \qquad (2.1)$$

where α is equal to 1.96 for a 95% degree of confidence and 1.645 for a 90% degree of confidence. The confidence interval in Table 2.2 is defined as an interval around the mean value expressed as a percentage of the mean value.

On the other hand, the standard deviation value mentioned here is not the standard deviation of the population sampling but it is the standard deviation of the mean value interpreted as another random variable.

2.1 Case 1

This is the base case where:

- VOLL has a constant value (2.5 £/kWh).
- No weather effect is considered, i.e. the failure rates for average weather conditions are used.
- Cascade and sympathetic tripping are not simulated.
- The simulation extends over 24 hours.

Table 2.3 presents the results obtained for case 1 using the naïve Monte Carlo simulation, without any variance reduction method. 100000 trials were used as the maximum number of trials for each sample. A convergence criterion of 5% of the mean value for a 95% degree of confidence was used. These simulations require a relative low consumption of CPU time (a SUN ULTRA SPARC 1 workstation was used).

The estimated total cost or value of security is given in the total row of each scenario in Table 2.3 with a degree of confidence higher than 99%. Statistically the total cost is given as an interval and the probability that the true value is in the interval. The interval is defined by equation (2.1) and the probability is equal to the degree of confidence. Table 2.4 gives the confidence intervals for both scenarios. The interval of confidence for the Fawley scenario includes the interval of confidence for the No-Fawley scenario. The best scenario therefore cannot be determined from this analysis.

Table 2.3 Monte Carlo Simulation Case 1 SW System

CASE 1- SCENARIO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	300	3250	160	3090	81	2.48	2.6
2	300	3182	94	3088	47	1.47	3.5
3	692	3363	276	3088	86	2.55	7.7
4	300	3296	205	3092	65	1.98	3.4
5	465	3308	217	3091	84	2.54	5.7
6	479	3393	302	3091	86	2.54	6.9
Total	2536	3316	226	3090	35	1.06	
CASE 1- SCENARIO NO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	4517	3309	293	3016	84	2.55	51.2
2	300	3121	100	3021	36	1.17	3.6
3	300	3151	133	3019	58	1.83	3.5
4	300	3086	70	3017	47	1.54	2.7
5	4856	3360	344	3016	86	2.55	55.9
6	427	3264	247	3018	83	2.54	5.6
Total	10700	3315	298	3017	53	1.60	

1- The maximum number of trials was 100000. Convergence criterion of 95% of degree of confidence and 5% of confidence interval

Table 2.4 Case 1 SW System - Total Costs Intervals

Probability [%]	Fawley [k£]	No-Fawley [k£]
95.0	[3211, 3418]	[3247, 3385]

In order to determine the best scenario, the correlated sampling method was used [8]. This method computes the differences between scenarios without computing the total cost of each scenario with a high degree of confidence. Table 2.5 shows the results obtained for this case. A 95% degree of confidence criterion on the difference in cost was used.

Using correlated sampling allows the selection of the best scenario. The simulation's stopping criterion establishes that the interval of confidence is less than the mean value, i.e. the interval of confidence does not include the zero value. The Assessor can therefore predict the best scenario. In this case, the No-Fawley scenario has the smaller total cost.

Table 2.5 Case 1 SW System – Correlation Sampling

CASE 1- SCENARIO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	300	3194	102	3092	42	1.32	7.1
2	300	3269	179	3089	76	2.33	6.9
3	659	3331	239	3091	82	2.47	14.7
4	300	3358	265	3093	112	3.34	5.9
5	300	3293	201	3092	71	2.16	8.3
6	300	3354	262	3092	103	3.07	7.1
7	300	3242	153	3089	57	1.74	6.3
8	300	3194	101	3092	33	1.02	5.5
Total	2759	3286	194	3091	29	0.89	
CASE 1- SCENARIO NO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	300	3121	102	3019	42	1.35	7.1
2	300	3196	179	3017	76	2.38	6.9
3	659	3283	264	3018	103	3.14	14.7
4	300	3285	266	3019	112	3.41	5.9
5	300	3221	202	3019	71	2.22	8.3
6	300	3291	273	3018	111	3.37	7.1
7	300	3185	168	3017	67	2.10	6.3
8	300	3121	101	3020	32	1.03	5.5
Total	2759	3222	204	3018	33	1.04	

1- The maximum number of trials was 100000

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Fawley Scenario - No Fawley Scenario						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	72.8	-0.5	73.3	0.4	0.5	No Fawley
2	72.6	-0.1	72.7	0.4	0.6	No Fawley
3	47.8	-25.2	73.0	24.3	50.8	No Fawley
4	72.6	-0.8	73.4	0.5	0.7	No Fawley
5	72.0	-1.2	73.2	0.7	1.0	No Fawley
6	62.6	-11.2	73.8	10.5	16.8	No Fawley
7	57.8	-14.6	72.4	14.6	25.3	No Fawley
8	72.7	-0.1	72.8	0.6	0.8	No Fawley
Total	63.9	-9.1	73.1			No Fawley

2.2 Case 2

This case considers the following:

- VOLL is a function of duration of interruption (Data from [5]). A consumer distribution of 35% residential consumers, 27% commercial consumers, 34% industrial consumers and 4% large users is assumed. The assumed busbar's load factor is 0.65.
- No weather effect is considered, i.e. the failure rates for average weather conditions are used.

- Cascade and sympathetic tripping are not simulated.
- The simulation extends over 24 hours

Table 2.6 Monte Carlo Simulation Case 2 SW System

CASE 2- SCENARIO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	15205	4187	1097	3089	107	2.55	150.0
2	19335	4405	1316	3089	112	2.55	207.5
3	16304	4531	1441	3090	116	2.55	174.9
4	23437	4487	1398	3089	115	2.55	251.7
5	13006	4178	1088	3090	107	2.55	160.3
6	14628	4335	1246	3089	111	2.55	171.9
Total	101915	4372	1283	3089	47	1.07	
CASE 2- SCENARIO NO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	24382	4394	1378	3016	112	2.55	268.2
2	27480	4482	1466	3016	114	2.55	308.4
3	25135	4525	1509	3016	115	2.55	281.3
4	21197	4283	1266	3017	109	2.55	236.1
5	27405	4511	1496	3016	115	2.55	299.3
6	14478	4339	1322	3017	111	2.55	172.4
Total	140077	4435	1419	3016	47	1.06	

1- The maximum number of trials was 100000. Convergence criterion of 95% of degree of confidence and 5% of confidence interval

Table 2.6 shows the results obtained for this case using the naive Monte Carlo simulation (i.e. without any of the variance reduction methods available in the program). As in case 1, the maximum number of trials was set at 100000 for each sample. A convergence criterion of 5% of the mean value for the 95% degree of confidence was used.

The estimated total cost or value of security is given in the total row of each scenario in Table 2.6 with a degree of confidence higher than 99%. Table 2.7 gives the confidence intervals for both scenarios under the case 2 assumptions. Note that these confidence intervals intersect and the interval for one case includes the average value of the other case. The best scenario therefore cannot be determined from this analysis.

Table 2.7 Case 2 SW System - Total Costs Intervals

Probability [%]	Fawley [k£]	No-Fawley [k£]
95.0	[4281, 4464]	[4343, 4528]

The expected generation cost of case 2 is the same as in case 1 (Table 2.3). The cost variation from case 1 to case 2 is less than 0.03%. This result is not surprising since the modelling of VOLL does not modify computation of generation cost.

The interruption cost computed with a VOLL function of the duration of interruption is higher than the interruption cost computed with a constant VOLL. This result was also expected because the lowest VOLL value (see section 9.3) is 5.6£/kWh (for an interruption of 24 hr) which is 2.24 times higher than the constant VOLL that was used (2.5 £/kWh).

The ratio of the interruption costs computed with the variable VOLL (case 2) and the constant VOLL (case 1) is 5.68 for the Fawley scenario and 4.76 for the No-Fawley scenario. These ratios imply an average VOLL, in case 2, of 14.21£/kWh for the first scenario and 11.90 £/kWh for No-Fawley scenario.

Comparison of these average VOLL with the variable VOLL function (see section 9.3) indicates that when an interruption occurs its average duration is around 4 hours with the Fawley scenario, while in No-Fawley scenario this average duration is around 8 hours. However, note that the events in case 2 and case 1 are different.

2.2.1 Selection of the Best Scenario

Correlated sampling was used to determine the best scenario. Table 2.8 shows results of different samples that use the quick comparison option. A 95% confidence degree criterion was used in the simulation. The general conclusion is that the best scenario is the No-Fawley scenario.

As shown in Table 2.8, correlated sampling gives an estimate of the total cost with a high standard deviation and, hence, a low degree of confidence is obtained (71 %). This is explained by two facts: correlated sampling uses a small number of trials and the purpose of analysis is different. The method compares different scenarios using the same trial in each one. The trial can be either of low cost or of high cost and the purpose is to define the cheapest scenario. That is the reason also of the high value of the σ/μ ratio.

The interruption cost is lower in the No-Fawley scenario, under the system conditions specified in this study case. However, there are samples from which the opposite conclusion could be drawn (Sample 4).

Table 2.8 Case 2 SW System – Correlation Sampling

CASE 2- SCENARIO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	588	4688	1599	3089	689	14.69	14.5
2	300	5590	2500	3090	1042	18.63	8.6
3	300	4336	1246	3090	461	10.63	6.3
4	887	4090	1000	3090	212	5.18	15.8
5	300	3747	658	3090	268	7.16	5.1
6	300	3794	704	3090	266	7.00	5.9
7	2080	3993	903	3090	208	5.21	58.8
8	300	6649	3568	3082	2527	38.01	8.1
Total	5055	4337	1248	3089	207	4.76	

CASE 2- SCENARIO NO FAWLEY							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	588	4511	1494	3016	630	13.96	14.5
2	300	5369	2353	3016	1015	18.90	8.6
3	300	4239	1222	3017	460	10.86	6.3
4	887	4032	1015	3017	224	5.55	15.8
5	300	3675	657	3017	268	7.29	5.1
6	300	3722	704	3017	266	7.14	5.9
7	2080	3911	894	3017	198	5.07	58.8
8	300	6512	3504	3009	2517	38.65	8.1
Total	5055	4237	1220	3016	202	4.76	

1- The maximum number of trials was 100000

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Fawley Scenario - No Fawley Scenario						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	177.6	104.8	72.8	82.7	46.6	No Fawley
2	221.1	147.8	73.3	85.3	38.6	No Fawley
3	97.3	24.2	73.1	25.5	26.2	No Fawley
4	58.5	-14.7	73.2	29.8	50.9	No Fawley
5	72.5	0.1	72.4	0.7	1.0	No Fawley
6	72.2	-0.3	72.5	0.7	1.0	No Fawley
7	82.1	9.1	73.0	41.9	51.0	No Fawley
8	137.1	63.9	73.2	52.3	38.1	No Fawley
Total	100.3	27.3	73.0			No Fawley

2.2.2 Computing the Value of Security using Variance Reduction Methods

While the correlated sampling approach identifies the best scenario, it does not provide a reliable estimate of the total cost of this scenario. The naive Monte Carlo simulation (Table 2.6) provides such an answer but requires an excessive amount of CPU time.

The following variance reduction methods were thus tested to see if they appreciably reduce the necessary CPU time:

- MVA stratified sampling (Table 2.9).

- MW/MVAr stratified sampling (Table 2.10).
- Adaptive stratified (Table 2.11).
- Auto cycle dagger (Table 2.12).
- Fast cycle dagger (Table 2.13).

A 95 % degree of confidence and a 5 % interval of confidence were used for these studies.

Figure 2.2 compares the total and interruption costs obtained for the Fawley scenario using different stratified variance reduction methods, while Figure 2.3 makes the same comparison for the No-Fawley scenario. Figure 2.4 compares the required number of trials by stratified methods as a percentage of the number of trials employed by the naïve Monte Carlo Simulation.

Table 2.9 Case 2 SW System - Variance Reduction: MVA Stratified -

CASE 2- SCENARIO FAWLEY - Variance Reduction Methods Application							
Method	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
MVA Strat	8708	4332	1242	3090	111	2.55	84.2
MVA Strat	1416	4050	958	3092	103	2.55	13.5
MVA Strat	5743	4225	1135	3090	108	2.55	71.1
MVA Strat	4736	4113	1022	3091	105	2.55	49.8
MVA Strat	14751	4463	1373	3090	114	2.55	160.8
Total	35354	4328	1239	3090	59	1.37	
CASE 2- SCENARIO NO FAWLEY - Variance Reduction Methods Application							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
MVA Strat	19289	4683	1667	3016	119	2.55	214.8
MVA Strat	17676	4549	1533	3016	116	2.55	202.8
MVA Strat	17389	4506	1490	3016	115	2.55	191.7
MVA Strat	4152	4089	1072	3017	104	2.55	45.1
MVA Strat	14738	4382	1366	3016	112	2.55	159.1
Total	73244	4514	1498	3016	55	1.22	

1- The maximum number of trials was 100000

2- Covergence criterion of 95% degree of confidence and 5% confidence interval

The following observations can be made on the application of stratified sampling:

- The different types of stratified sampling methods give an accurate estimation of the total and interruption costs, based on a comparison with the naïve Monte Carlo simulation.

- The CPU time consumption can be greatly reduced (around 45% to 65%). In some cases, the reduction can be very significant.

- The range of interruption costs obtained by the different stratified methods is very similar to the range obtained with the naïve Monte Carlo. The dispersion is also very similar.

- The total cost mean obtained by naïve Monte Carlo simulation is included in all total cost intervals associated with the stratified sampling methods. Reciprocally, the total cost interval associated with naïve Monte Carlo simulation includes all the mean values obtained by each alternative of stratified sampling method.

Table 2.10 Case 2 SW System - Variance Reduction: MW/MVAr Stratified -

CASE 2- SCENARIO FAWLEY - Variance Reduction Methods Application							
Method	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
MW/MVAr Strat	2050	4216	1125	3091	108	2.55	23.6
MW/MVAr Strat	15391	4488	1400	3089	115	2.55	183.8
MW/MVAr Strat	19347	4587	1499	3089	117	2.55	219.7
MW/MVAr Strat	5982	4419	1330	3089	113	2.55	61.8
MW/MVAr Strat	2005	4197	1107	3090	107	2.55	21.2
Total	44775	4496	1408	3089	66	1.47	
CASE 2- SCENARIO NO FAWLEY - Variance Reduction Methods Application							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
MW/MVAr Strat	14035	4644	1628	3016	118	2.55	161.4
MW/MVAr Strat	19918	4592	1576	3016	117	2.55	223.6
MW/MVAr Strat	6833	4270	1253	3017	109	2.55	75.9
MW/MVAr Strat	17691	4503	1487	3016	115	2.55	196.2
MW/MVAr Strat	11909	4316	1299	3017	110	2.55	131.3
Total	70386	4502	1486	3016	54	1.21	

1- The maximum number of trials was 100000

2- Covergence criterion of 95% degree of confidence and 5% confidence interval

Table 2.11 Case 2 SW System- Variance Reduction: Adaptive Stratified -

CASE 2- SCENARIO FAWLEY - Variance Reduction Methods Application							
Method	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Adaptive Strat.	1201	4205	1115	3090	96	2.29	14.4
Adaptive Strat.	11298	4282	1193	3089	108	2.53	130.6
Adaptive Strat.	8834	4219	1128	3090	107	2.53	104.2
Adaptive Strat.	1985	3987	897	3090	99	2.48	23.2
Adaptive Strat.	15001	4552	1463	3089	97	2.13	164.0
Total	38319	4356	1266	3089	56	1.28	
CASE 2- SCENARIO NO FAWLEY - Variance Reduction Methods Application							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Adaptive Strat.	1272	4088	1069	3019	99	2.42	15.3
Adaptive Strat.	14000	4511	1494	3016	90	1.98	158.4
Adaptive Strat.	2246	4125	1107	3018	76	1.83	27.0
Adaptive Strat.	1550	3767	749	3018	92	2.45	16.6
Adaptive Strat.	4235	4408	1391	3017	99	2.24	48.1
Total	23303	4382	1365	3017	58	1.32	

1- The maximum number of trials was 100000

2- Covergence criterion of 95% degree of confidence and 5% confidence interval

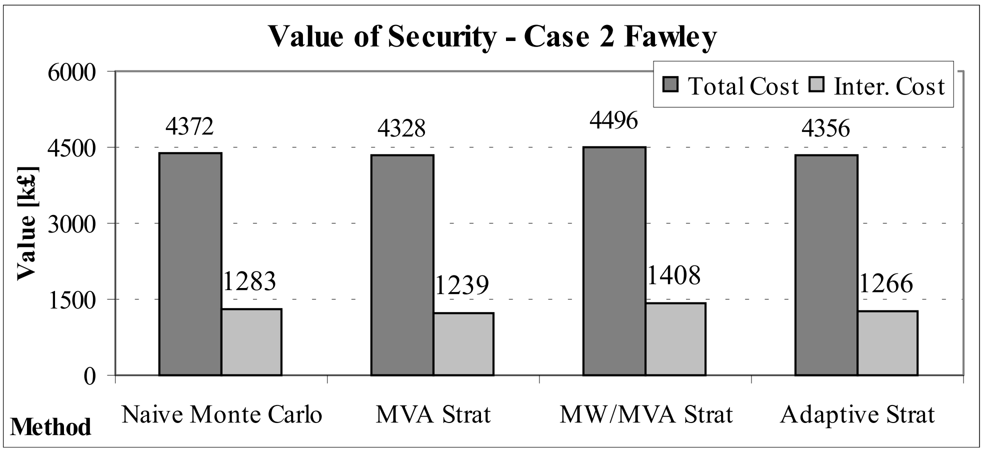

Figure 2.2 Case 2 SW System, Fawley – Comparison of Variants of the Stratified Sampling Variance Reduction Method

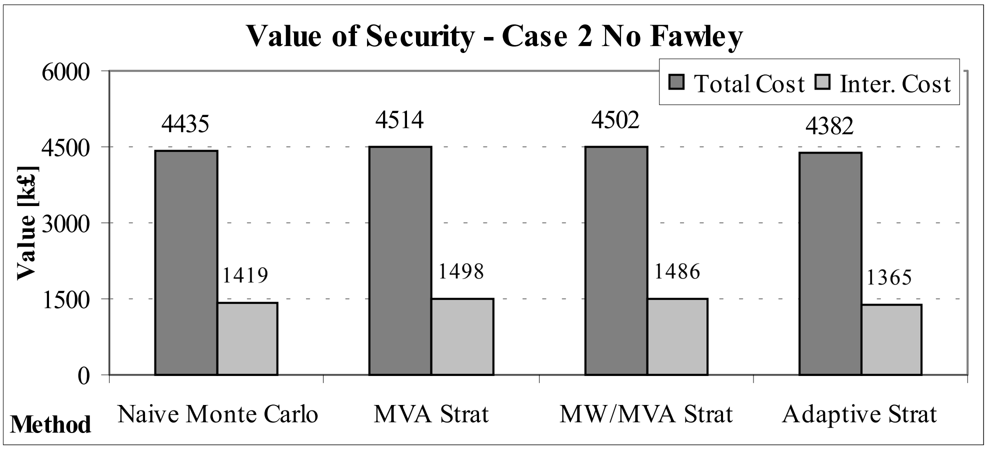

Figure 2.3 Case 2 SW System, No Fawley –Comparison of Variants of the Stratified Sampling Variance Reduction Method

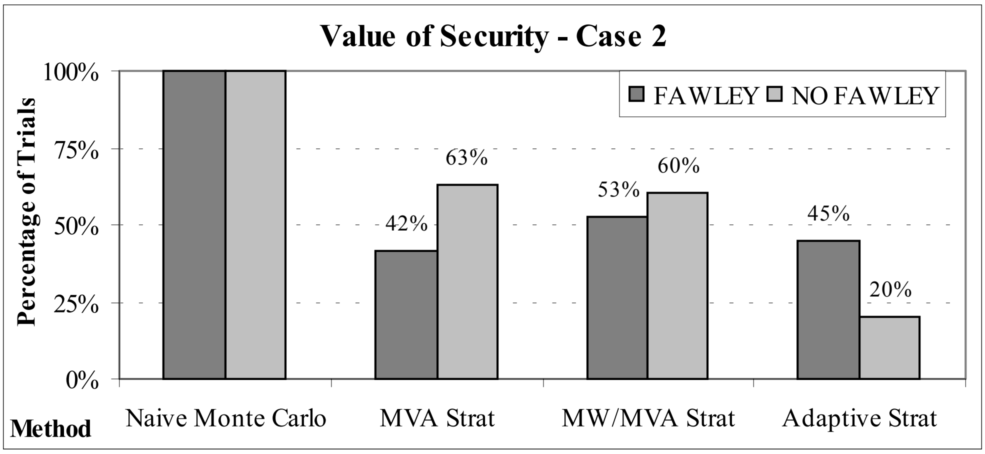

Figure 2.4 Case 2 SW System– Number of Trials required for the Variants of the Stratified Sampling Variance Reduction Method

Figure 2.5 compares the total and interruption costs obtained for the two scenarios using two variants of dagger sampling method of variance reduction. Figure 2.6 compares the required number of trials by dagger sampling variants as a percentage of the number of trials required by the naïve Monte Carlo Simulation.

The following observations can be made about the dagger sampling variance reduction method:

- The different variants of dagger sampling give an accurate estimate of the total and interruption costs based on a comparison with naïve Monte Carlo simulation.

- The reduction of CPU time consumption is small (5 % to 25 %).

- The slow cycle dagger option requires a number of trials higher than the maximum number of trials (100000). For this reason, this variant has not been tested.

- The total cost mean obtained by naïve Monte Carlo simulation is included in all the total cost intervals associated with the dagger variants. On the other hand, the total cost intervals associated with the naïve Monte Carlo simulation includes, with only one exception that is to close to the superior limit, the mean values obtained by the variants of the dagger sampling method.

Table 2.12 Case 2 SW System– Variance Reduction: Auto Cycle Dagger –

CASE 2- SCENARIO FAWLEY - Variance Reduction Methods Application							
Method	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Auto Cycle Dagger	680	3438	350	3088	80	2.31	8.4
Auto Cycle Dagger	10720	4363	1273	3090	111	2.54	127.1
Auto Cycle Dagger	18440	4360	1271	3090	111	2.54	203.2
Auto Cycle Dagger	5920	4319	1229	3090	109	2.53	61.9
Auto Cycle Dagger	28560	4536	1447	3089	116	2.55	321.0
Total	64320	4425	1336	3089	64	1.44	

CASE 2- SCENARIO NO FAWLEY - Variance Reduction Methods Application							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Auto Cycle Dagger	24520	4582	1566	3016	117	2.54	281.7
Auto Cycle Dagger	20920	4398	1382	3016	112	2.54	227.6
Auto Cycle Dagger	19160	4301	1284	3017	109	2.54	204.1
Auto Cycle Dagger	1320	3650	632	3018	87	2.39	11.8
Auto Cycle Dagger	21200	4361	1344	3016	111	2.55	245.2
Total	87120	4408	1392	3016	56	1.27	

1- The maximum number of trials was 100000

2- Covergence criterion of 95% degree of confidence and 5% confidence interval

Table 2.13 Case 2 SW System – Variance Reduction: Fast Cycle Dagger –

CASE 2- SCENARIO FAWLEY - Variance Reduction Methods Application							
Method	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Fast Cycle Dagger	19960	4562	1472	3089	116	2.54	235.3
Fast Cycle Dagger	1560	3906	815	3091	96	2.46	15.4
Fast Cycle Dagger	21160	4548	1459	3089	116	2.55	222.1
Fast Cycle Dagger	5720	4051	960	3090	102	2.53	57.6
Fast Cycle Dagger	17480	4469	1379	3090	114	2.54	188.4
Total	65880	4473	1383	3089	60	1.34	
CASE 2- SCENARIO NO FAWLEY - Variance Reduction Methods Application							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Fast Cycle Dagger	8080	4285	1267	3017	109	2.53	87.9
Fast Cycle Dagger	28400	4500	1483	3016	115	2.54	332.9
Fast Cycle Dagger	23680	4499	1482	3016	115	2.55	270.1
Fast Cycle Dagger	20880	4563	1547	3016	114	2.50	236.7
Fast Cycle Dagger	26320	4615	1599	3016	118	2.55	298.0
Total	107360	4524	1508	3016	54	1.20	

1- The maximum number of trials was 100000

2- Covergence criterion of 95% degree of confidence and 5% confidence interval

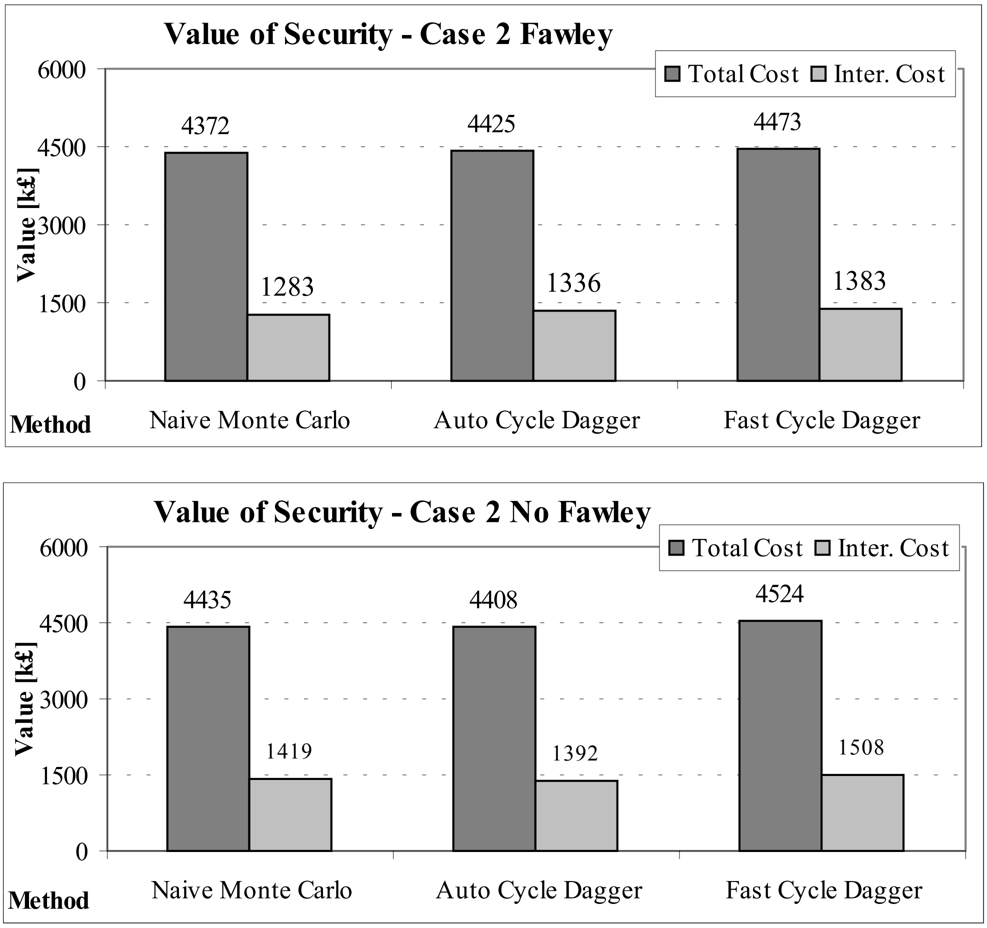

Figure 2.5 Case 2 SW System - Comparison of Variants of the Dagger Sampling Variance Reduction Method

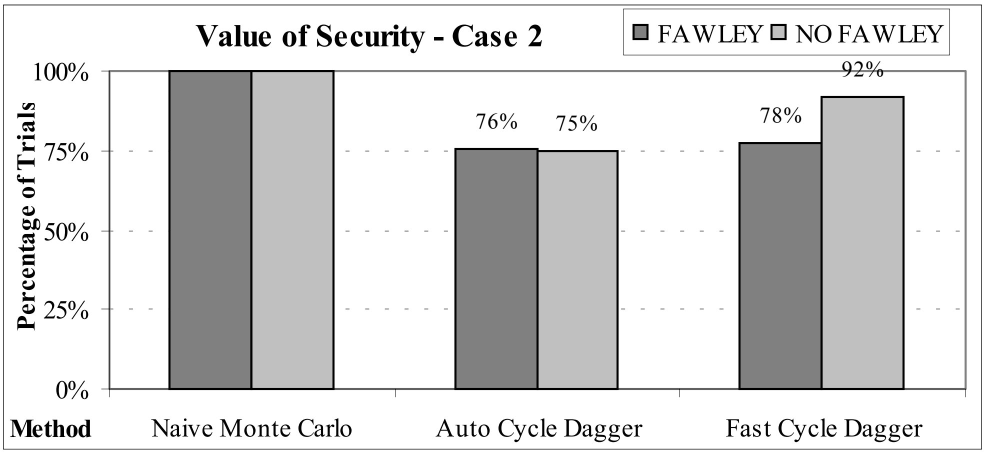

Figure 2.6 Case 2 SW System – Number of trials required for the Variants of the Dagger Sampling Variance Reduction Method

Table 2.14 Case 2 SW System – Total costs intervals by scenario (95% of confidence)

Method	Fawley [k£]	No-Fawley [k£]
Naïve Monte Carlo	[4281, 4464]	[4343, 4528]
MVA Strat	[4212, 4444]	[4406, 4623]
MW/MVAr Strat	[4367, 4626]	[4395, 4608]
Adaptive Stratified	[4215, 4433]	[4269, 4495]
Dagger Fast Cycle	[4355, 4591]	[4417, 4630]
Dagger AutoCycle	[4300, 4550]	[4299, 4517]

Table 2.14 compares the intervals of confidence for the total cost in both scenarios. It is important to mention that the simulations of both scenarios with the same method and criterion did not use the same simulated events.

2.3 Case 3

This case uses the following modelling characteristics:

- VOLL is a function of the duration of interruption defined as in Case 2.
- Adverse weather conditions between 17 and 21 hours.
- Cascade and sympathetic tripping are not simulated.
- The simulation extends over 24 hours

This case differs from case 2 only in the consideration of adverse weather effects.

The last two sections (sections 2.1 and 2.2) have shown that correlated sampling is a quick way to determine the best scenario in a set of possible dispatches. However, it gives an estimate of the total cost with only a low degree of confidence. Hence, another method must be used to compute the value of security, but only for the best scenario.

This strategy is used in the analysis of case 3. Table 2.15 presents the application of correlated sampling for selection of the best scenario. 7 out of 8 samples suggest that the best scenario is the Fawley scenario.

Table 2.15 Case 3 SW System– Correlated Sampling – Selection of the Best Scenario

CASE 3- SCENARIO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	505	6474	3386	3088	727	11.23	13.4
2	300	4995	1905	3090	612	12.26	6.7
3	3151	6469	3380	3090	313	4.84	81.3
4	6672	5948	2859	3090	184	3.09	165.5
5	3311	5941	2851	3090	250	4.21	91.2
6	12692	5738	2648	3090	124	2.16	318.7
7	2548	5997	2907	3090	260	4.34	90.0
8	2650	6177	3090	3088	319	5.16	96.0
Total	31829	5937	2848	3089	83	1.40	

CASE 3- SCENARIO NO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	505	6675	3660	3015	762	11.42	13.4
2	300	4919	1902	3017	614	12.49	6.7
3	3151	6584	3568	3016	332	5.05	81.3
4	6672	6044	3028	3016	197	3.25	165.5
5	3311	6029	3013	3016	265	4.39	91.2
6	12692	5802	2785	3016	133	2.29	318.7
7	2548	6083	3067	3016	273	4.49	90.0
8	2650	6249	3234	3014	326	5.22	96.0
Total	31829	6019	3003	3016	88	1.46	

1- The maximum number of trials was 100000

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Fawley Scenario - No Fawley Scenario

Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	-200.6	-274.4	73.8	100.9	-50.3	Fawley
2	76.8	3.7	73.1	8.4	10.9	No Fawley
3	-114.7	-188.5	73.8	57.2	-49.9	Fawley
4	-96.3	-169.9	73.6	49.1	-51.0	Fawley
5	-88.2	-161.7	73.5	42.9	-48.6	Fawley
6	-63.8	-137.3	73.5	32.6	-51.1	Fawley
7	-86.6	-160.3	73.7	43.8	-50.6	Fawley
8	-71.3	-144.6	73.3	35.4	-49.6	Fawley
Total	-81.5	-155.0	73.6			Fawley

Correlated sampling requires a large number of trials (see total rows) in this case. Hence, the σ/μ ratio satisfies the 95% degree of confidence criterion for the 5% confidence interval. This observation is used in Table 2.16, which shows the interval of confidence for total costs for both scenarios. Note that sample 6 also satisfies the convergence criterion.

The following conclusions can be drawn from this test:

- A 95% degree of confidence is not the same thing as a certainty. In some cases, the conclusions shown by a sample will be contradicted by other samples.

- Adverse weather conditions can change the best operating condition and the Assessor of Value of Security program can detect this change. Under the condition of case 2, the No Fawley scenario has a lower total cost that the Fawley scenario. Under the conditions of case 3, this conclusion is reversed.

- The total cost can be obtained directly from correlated sampling if and only if the ratio σ/μ satisfies the specified convergence criterion. In such a case, an additional computation of total cost by other method is not necessary.

Table 2.16 Case 3 SW System - Total Costs Intervals

Probability [%]	Fawley [k£]	No-Fawley [k£]
95.0	[5776, 6100]	[5847, 6191]

2.4 Case 4

This case considers the following conditions:

- VOLL is a function of the duration of interruptions as defined in Case 2.
- Average weather conditions hold during the full 24 hours period.
- Cascade and sympathetic tripping are simulated.
- The simulation extends over 24 hours

This case differs from study case 2 only in the consideration of cascade and sympathetic tripping effects.

The analysis was carried out in two steps: determination of the best scenario using correlated sampling and computation of value of security for this scenario.

The selection of the best scenario step by correlated sampling (Table 2.17) determines that the No-Fawley scenario is the best. In this case, none of the samples satisfies the convergence criterion needed to determine the value of security.

The second step relies on the adaptive stratified sampling method because this method has been shown to require the smallest number of trials for computing the value of security in the South-Western system. Table 2.18 shows the results for this step. The value of security interval is [4510, 4731] in k£.

Comparison with the total cost obtained in study case 2 (adaptive sampling from Table 2.11 and total cost interval from Table 2.14) concludes that consideration of sympathetic tripping has an important effect on the computation of value of security.

Table 2.17 Case 4 SW System -Correlated Sampling-Selection of the Best Scenario

CASE 4- SCENARIO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	507	4388	1295	3093	326	7.44	13.1
2	694	4828	1742	3086	1094	22.66	12.7
3	3611	4702	1613	3088	288	6.13	78.9
4	423	4108	1017	3091	319	7.76	8.6
5	300	4282	1190	3092	441	10.31	7.5
6	1097	4353	1262	3092	211	4.84	28.8
7	300	4409	1315	3094	409	9.28	5.2
8	300	3729	642	3087	219	5.88	4.1
Total	7232	4534	1445	3089	185	4.08	

CASE 4- SCENARIO NO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	507	4318	1299	3019	343	7.95	13.1
2	694	4777	1765	3013	1096	22.95	12.7
3	3611	4633	1618	3015	295	6.38	78.9
4	423	4058	1040	3018	331	8.16	8.6
5	300	4210	1191	3019	441	10.47	7.5
6	1097	4297	1279	3018	221	5.14	28.8
7	300	4324	1303	3021	413	9.55	5.2
8	300	3465	449	3016	152	4.40	4.1
Total	7232	4461	1445	3016	189	4.23	

1- The maximum number of trials was 100000

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Fawley Scenario - No Fawley Scenario

Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	69.5	-4.5	74.0	35.3	50.8	No Fawley
2	50.3	-22.6	72.9	25.6	50.9	No Fawley
3	68.8	-4.3	73.1	35.1	51.0	No Fawley
4	49.8	-23.1	72.9	25.3	50.8	No Fawley
5	72.0	-1.3	73.3	1.5	2.1	No Fawley
6	56.3	-17.0	73.3	26.9	47.8	No Fawley
7	84.8	11.8	73.0	16.1	19.0	No Fawley
8	264.1	192.5	71.6	121.8	46.1	No Fawley
Total	73.0	-0.1	73.1			No Fawley

Table 2.18 Case 4 SW System – Computation of Value of Security -

CASE 4- SCENARIO NO FAWLEY - Variance Reduction Methods Application

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Adaptive Strat.	13001	4813	1798	3015	107	2.22	162.7
Adaptive Strat.	13493	4808	1793	3016	105	2.18	161.5
Adaptive Strat.	3022	4065	1047	3018	99	2.44	36.1
Adaptive Strat.	11875	4442	1426	3016	116	2.61	132.8
Adaptive Strat.	1775	3928	911	3017	97	2.47	17.1
Total	43166	4621	1605	3016	56	1.22	

1- The maximum number of trials was 100000

2- Convergence criterion 95% degree of confidence and 5% confidence interval

2.5 Case 5

This case considers the following conditions:

- VOLL is a function of the duration of interruptions as defined in Case 2.
- Average weather condition hold during the full 24 hours period.
- Cascade and sympathetic tripping are not simulated.
- The simulation extends over 24 hours
- The failure rate of DIDC3A, which is equal to the Fawley's failure rate in previous cases, is equal to DIDC2A's failure rate.

As in case 4, the analysis consists of two steps: the determination of the best scenario using correlated sampling and the computation of the value of security for this scenario.

The selection of the best scenario step by correlated sampling (Table 2.19) determines that the No-Fawley scenario is the best. In this case, none of the samples satisfies the convergence criterion needed to determine the value of security.

The second step relies on the adaptive stratified sampling method because this method requires smallest number of trials for computing the value of security in the South-Western system. Table 2.20 shows the results of simulations for this case. The value of security interval is [4486, 4704] in k£.

Comparison with the total cost obtained in study case 2 (adaptive sampling from Table 2.11 and total cost interval from Table 2.14) shows that an increase in the failure rate of Didcot3A provokes an increase in the interruption and total costs. This is a logical and expected result.

Table 2.19 Case 5 SW System – Correlation Sampling – Selection of Best Scenario

CASE 5- SCENARIO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1132	4107	1017	3090	311	7.56	22.6
2	300	4099	1009	3090	394	9.61	7.8
3	574	3860	770	3090	202	5.22	14.0
4	342	4203	1112	3091	330	7.85	10.0
5	300	3929	840	3090	394	10.03	5.5
6	300	4010	919	3091	342	8.52	4.8
7	300	4629	1543	3086	1160	25.06	6.8
8	685	4210	1117	3093	253	6.00	13.0
Total	3933	4115	1025	3090	148	3.60	

CASE 5- SCENARIO NO FAWLEY

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1132	4061	1044	3017	317	7.79	22.6
2	300	4008	991	3017	384	9.57	7.8
3	574	3684	666	3018	157	4.26	14.0
4	342	4060	1041	3018	314	7.72	10.0
5	300	3864	847	3017	399	10.33	5.5
6	300	3940	922	3018	343	8.69	4.8
7	300	4547	1533	3014	1158	25.48	6.8
8	685	4158	1139	3020	263	6.32	13.0
Total	3933	4031	1014	3017	148	3.67	

[1] The maximum number of trials was 100000

[2] CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Fawley Scenario - No Fawley Scenario

Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	46.1	-26.6	72.7	23.5	51.0	No Fawley
2	91.1	18.6	72.5	18.6	20.4	No Fawley
3	176.0	103.6	72.4	89.6	50.9	No Fawley
4	143.3	70.3	73.0	72.9	50.9	No Fawley
5	65.4	-6.9	72.3	5.5	8.4	No Fawley
6	69.6	-3.4	73.0	2.4	3.4	No Fawley
7	82.9	10.7	72.2	9.2	11.1	No Fawley
8	51.5	-21.9	73.4	26.3	51.1	No Fawley
Total	84.0	11.2	72.7			No Fawley

Table 2.20 Case 5 SW System – Computation of Value of Security -

CASE 5- SCENARIO NO FAWLEY - Variance Reduction Methods Application

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
Adaptive Strat.	18358	4580	1564	3016	116	2.53	219.9
Adaptive Strat.	2808	4232	1214	3018	105	2.49	34.3
Adaptive Strat.	5001	4514	1496	3018	106	2.34	59.5
Adaptive Strat.	13001	4514	1497	3017	114	2.52	145.8
Adaptive Strat.	15111	4777	1760	3017	94	1.96	165.4
Total	54279	4595	1578	3017	55	1.21	

[1] The maximum number of trials was 100000

[2] Convergence criterion 95% degree of confidence and 5% confidence interval

3 SETTING SIMULATION PARAMETERS – USING A LARGE POWER SYSTEM

As the Value of Security Assessor uses a Monte Carlo probabilistic method for the computation of the cost of outages, it needs the definition of some parameters in order to give confidence to the results. These parameters are:

- The convergence criterion
- The minimum number of trials

Decisions about these parameters affect not only the confidence in the results but also the computation time.

3.1 Defining the Convergence Criterion

The Assessor uses the following equation as convergence criterion

$$\frac{\alpha\,\sigma}{\mu} \leq x\% \tag{3.1}$$

Where the value of α depends of the degree of confidence required and it is 2.567 and 1.956 for a 99% and 95% confidence degree respectively. **x** is the convergence parameter.

In the tables that follow, the confidence that can be associated with the results is given in terms of the ratio of the standard deviation to the mean value of the total cost of value of security (σ/μ). Table 2.2 gives the value of this ratio associated with some combinations of degrees of confidence and confidence interval.

The confidence interval is defined as a function of the mean (μ) and standard deviation (σ) values and the degree of confidence as in equation (2.1). α in equation (2.1) is equal to 1.96 for a 95% degree of confidence and 2.57 for a 99% degree of confidence.

The Assessor has the facility to use as mean value (μ) either the outage cost or the total cost of operation of the system. The outage cost is defined as the load interruption cost plus the generation rescheduling cost. The total cost is defined as the outage cost plus the cost associated with the original generation schedule.

Therefore, the Assessor requires the definition of:

- Confidence degree
- Convergence parameter or confidence interval degree (equation 2.1)
- Partial blackout reference cost (see equations 3.7 to 3.10)

The following discussion will be based on a sample test of the NGC system 1996/97 under normal weather conditions. A total of 30000 trials were simulated. Partial results were recorded each 100 trials in order to see the evolution of both the mean value of the outage and total costs and of the standard deviation (σ).

3.1.1 Outage and Total Cost

Figure 3.1 shows the evolution of the mean value of the outage cost. It also shows some mean values. These values are before and after a large variation in the outage cost mean value occurs.

This strong variation indicates that a big outage (total or partial blackout) caused by some contingency (or contingencies) was present in this interval of trials. Obviously, other outage cases were presented in other trials of this sample, but with a small impact on the mean value.

The interesting point about these three severe outages is that their costs are very close. Table 3.1 shows a comparison of the outage cost for the 100 trials interval where the severe contingency occurs.

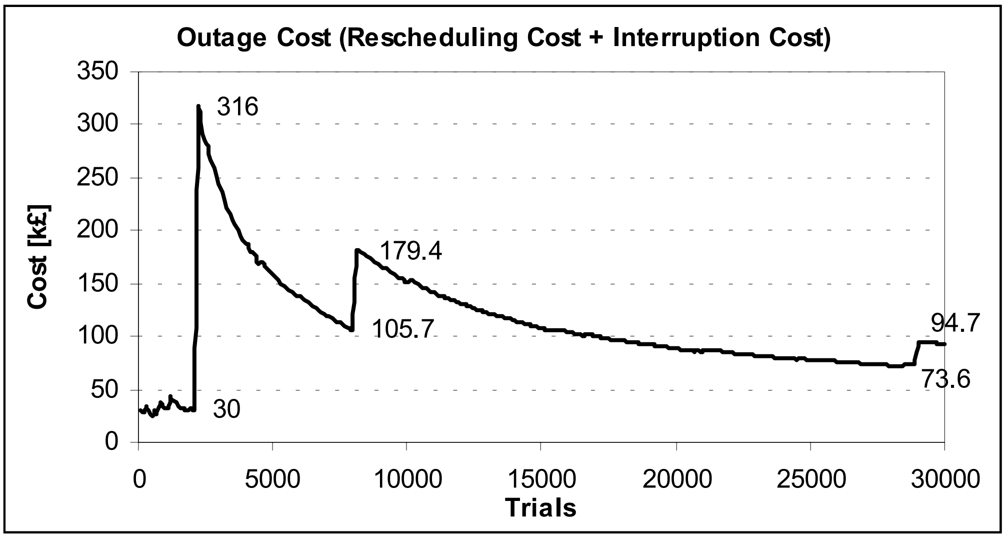

Figure 3.1 Outage Cost Evolution of Mean Value

Table 3.1 Outage Cost Severe Outages intervals

Severe contingency's interval	Outage Cost (k£) of the 100 Trails interval
2100 – 2200	632200
8000 – 8100	631840
28900 – 29000	630860

The effect of a new severe outage on the mean value of the outage cost will be smaller outwards of the 30000 trials. This means that there are enough trials to "ensure" that, if one of the new trials results in a major incident, the effect of the interruption cost of this incident will not affect "too much" the values of the mean and the standard deviation.

As the total cost is equal to the outage cost plus a constant value (6876.8 k£), the evolution of this variable is similar to the evolution of the outage cost.

3.1.2 Standard Deviation Evolution and Convergence Criterion

The standard deviation evolves in a very similar manner as the mean value (Figure 3.2) with large variations due to the severe outages.

Since, α is a constant value, equation (3.1) can be written as:

$$\frac{\sigma}{\mu} \leq y\% \qquad (3.2)$$

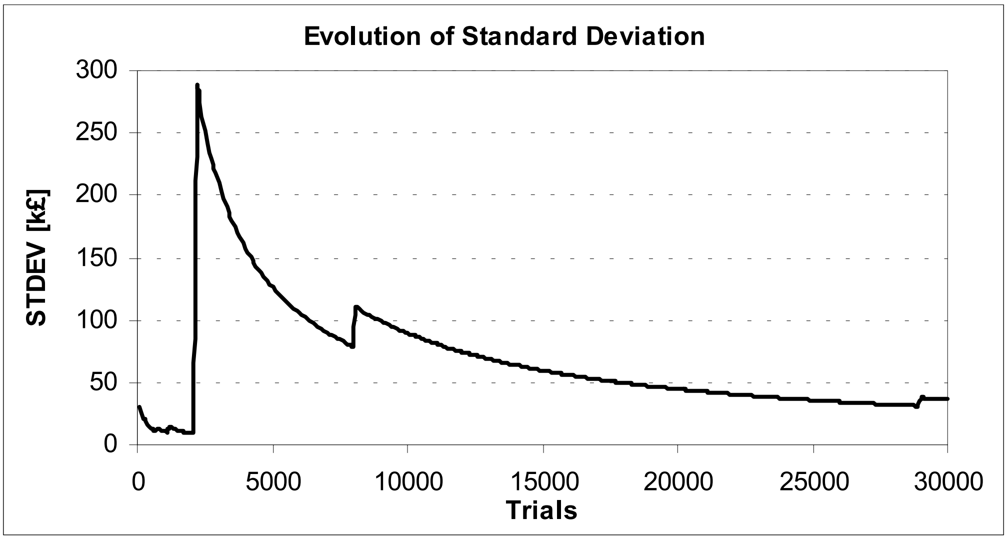

Figure 3.2 Evolution of the Standard Deviation

As μ can be either the total cost or the outage cost, two different patterns are possible for the σ/μ ratio. Figure 3.3 shows the evolution of this ratio when the total cost is used. A convergence criterion of 99% confidence degree and 1% confidence interval means that **y** in (3.2) is **0.39%**. Based on Figure 3.3, it is clear that the simulation will be stopped before the first severe contingency. The ratio **σ/Total Cost** is smaller than 0.39% from interval 200-300 trials until interval 2000-2100 trials. So, if the minimum number of trials is lower than 2000 (in this sample) the simulation stops at the minimum number with results that do not include severe shocks to the system.

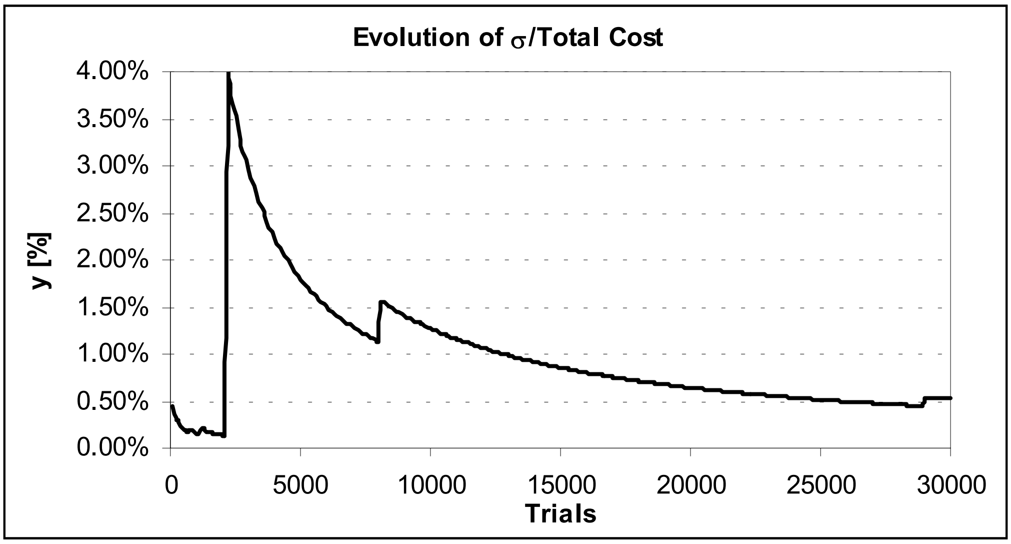

Figure 3.3 Evolution σ / Total Cost

On the other hand, if the minimum number of trials is set larger than 2100 the simulation will require more than 30000 trials.

Table 3.2 shows an estimate of the number of trials to satisfy different convergence criteria based on the σ/μ ratio (**μ of the Total Cost)**. As it is shown, the confidence interval is more significant than the confidence degree for determining the number of trials. On the other hand, the convergence is not reached before 26000 or 27000 trials (from Figure 3.3).

Therefore, an appropriate convergence criterion on **σ/Total Cost** ratio is 95%-1% using a larger minimum number of trials.

Table 3.2 Estimation of number of trials

Confidence Degree	Confidence Interval	**y [%]** Value	Estimated Number of Trials
99 %	1 %	0.39 %	> 30000
95 %	1 %	0.51 %	Around 30000
99 %	5 %	1.95 %	4600
95 %	5 %	2.56 %	3500

As was mentioned above, the σ/μ ratio could be computed using the mean value of the outage cost rather than the total cost. Figure 3.4 shows the evolution of this ratio for the μ of the Outage Cost.

As the cost associated with the original scheduled generation (constant value) is not included here, the interruption cost is not masked by the total cost of operation. However, setting of the convergence criterion is a problem.

If μ and σ are respectively the mean value and the standard deviation of the outage cost and α is the parameter associated with the confidence degree, the interval of confidence of the value of security is given by:

$$[\mu - \alpha\,\sigma, \mu + \alpha\,\sigma] \quad (3.3)$$

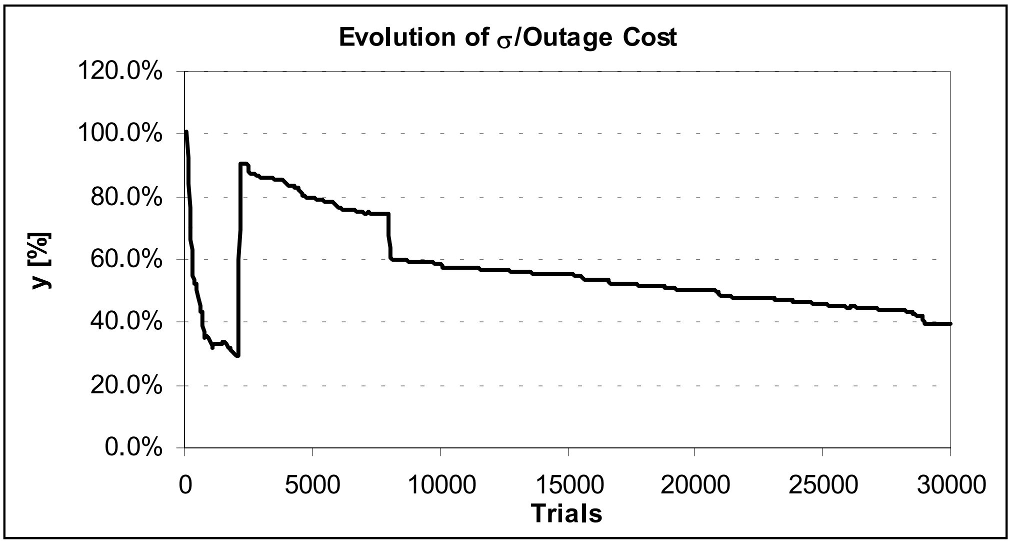

Figure 3.4 Evolution σ / μ (Outage Cost)

If **y** is defined as:

$$y = \frac{\sigma}{\mu} \tag{3.4}$$

Then, the interval of (3.3) is re-defined as:

$$[\mu(1-\alpha y), \mu(1+\alpha y)] \tag{3.5}$$

Since the simulation contains at least one trial with load interruption, the outage cost value is non-zero. Hence, **y** must satisfy:

$$y < \frac{1}{\alpha} \tag{3.6}$$

So, **y** is **38.9%** and **51.1%** for a confidence degree of **99%** and **95%** respectively. Based on this constraint and Figure 3.4, the test simulation requires more than 30000 trials for a 99% degree of confidence and 19000 trials for a 95% degree of confidence. A confidence degree of 99% is recommended when an **σ/Outage cost** ratio is used.

3.1.3 A new constraint

The cost of a blackout (**$C_{blackout}$**) can be computed a-priori based on the load restoration model, the load demand and the VOLL function. Assume that the simulation stops at trial **i.**

The impact of a major outage on the mean value at the next trial (i.e. **i+1**) is lower than the impact produced by a blackout and is given by:

$$\mu_{i+1} = \frac{i\,\mu_i + C_{blackout}}{i+1} \tag{3.7}$$

Dividing by μ_i, when **i** is large, equation (3.7) is approximated by

$$\frac{\mu_{i+1}}{\mu_i} \approx 1 + \frac{C_{blackout}}{i\,\mu_i} \tag{3.8}$$

On the other hand, the confidence interval gives the interval with certain probability where the true value of the outage cost is. If it is assumed that the confidence interval for trial **i** includes all major incidents, the following equation must be satisfied

$$\mu_i + \alpha\,\sigma_i \geq \mu_i + \frac{C_{major\ incident}}{i} \tag{3.9}$$

where **$C_{major\ incident}$** is the cost associated with a major incident (for example a blackout). So, a minimum value of standard deviation as function of the number of trials that gives a confidence interval including major incidents is defined as:

$$\sigma_{\min}(i) = \frac{C_{major\ incident}}{\alpha}\frac{1}{i} \tag{3.10}$$

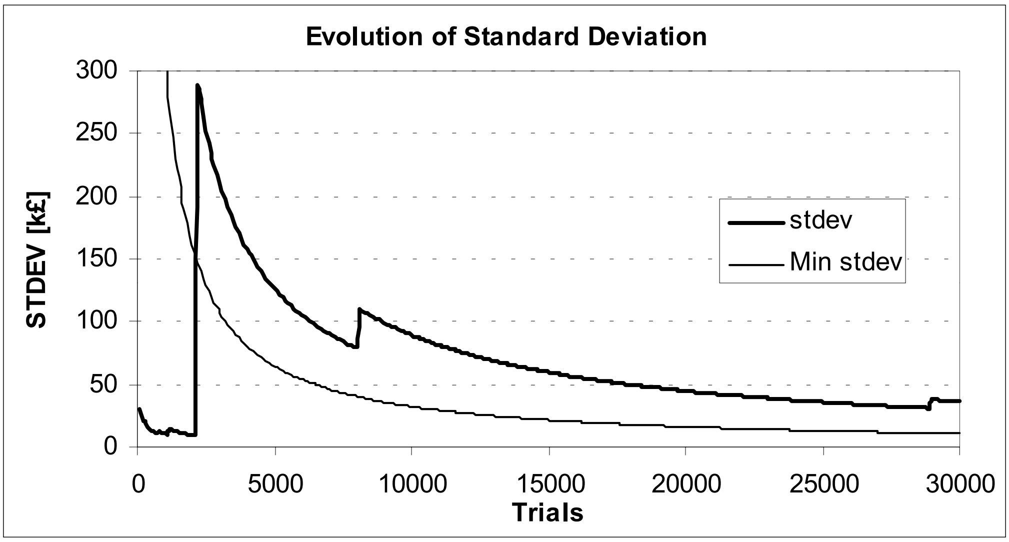

Figure 3.5 Minimal Standard Deviation

Figure 3.5 shows a comparison of σ and $\sigma_{\min}$ for the test used. The blackout cost has been used as the cost of the major incident. As the figure shows the first 2100 trials do not satisfy this constraint. This constraint could be moved depending on the value of the cost of the major incident that is took to define it.

3.2 Setting the Minimum Number of Trials

One of the most important parameters to set for the simulation is the minimum number of trials. The last section suggests that a large number must be used for this parameter.

In the sample test used in section 3.1, it is clear that the minimum value for trials must be larger than 2100. But, how can it be defined before the simulation?

Assume that a new sample will be simulated and a convergence criterion on σ/μ ratio (μ Total Cost) of 95%-1% will be used. Let **x** represent the minimum number of trials.

Simulation of these **x** trials can give one of the following results:

1. A least one severe contingency was present and the convergence criterion is not satisfied at trial **x**. The simulation continues until the convergence criterion is satisfied. The calculated value of security will be reliable.

2. As in the previous case, severe outages are present but the convergence criterion is satisfied at trial **x**. The simulation stops and the results are reliable. This case is unlikely.

3. No severe outages occur before trial **x** and the convergence criterion is not satisfied. The simulation continues until the convergence criterion is satisfied. This case is improbable.

4. No severe outages occurred before trial **x** and the convergence criterion is satisfied. Simulation stops. The results are unreliable.

Figure 3.6 shows the evolution of the σ/μ ratio (Total Cost) for a new sample of the test system. The convergence criterion is satisfied if the ratio is less than 0.51%. At trial 4000 (**x**), the simulation stops. None severe contingency was present. Note that the **σ/Total Cost** ratio is much smaller than ratio for satisfying the converge criterion (0.51%).

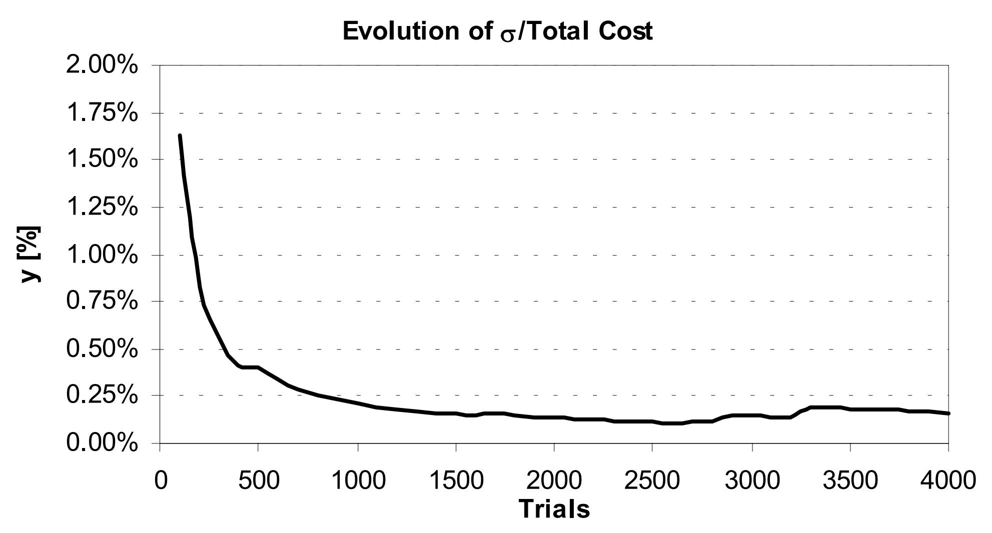

Figure 3.6 Simulation Sample – Minimum number of trials = 4000 -

Table 3.3 compares the outage cost and the standard deviation for the original test sample (sample 1) and the new sample (sample 2). The difference is clear.

Table 3.3 Results Comparison - Samples 1 & 2

Sample	Outage Cost (k£)	σ (k£)
1	92.8	36.6
2	37.8	11.3

Sample 2 was run another time with the minimum number of trials set at 10000. A severe contingency occurs between trials 4500 and 4600. This suggests that a larger minimum value must be used.

The minimum number of trials can be set based on the initial test sample (sample 1) as the number of trials divided by the number of severe outages (30000/3). The problem of setting this parameter in this way is that it requires a large number of trials. On the other hand, in spite of setting a large number as the minimum number of trials (**x**), it is still possible that the simulation will stop at the minimum **x** with a small **σ/Total Cost** ratio.

It is therefore not enough a large value for setting the minimum number of trials. There is always a risk of getting non-reliable results.

One important characteristic: the σ/μ (μ is the total cost average) ratio is smaller than the convergence criterion ratio during almost all the simulation. As Figure 3.6 shows, the σ/μ ratio decreases quickly in the first trials (<1000). After that, it remains very small.

So, a method for automatically adjusting the minimum number of trials has been developed. It is based on the concept of minimum standard deviation presented before and works as follow:

1. Choose values for the initial minimum number of trials **x** and its increment **Δx**. Assume that the required $\boldsymbol{\sigma_{\min}}$ is a low percentage (**z%**) of the scheduled generation cost. As the cost of the reference major incident ($\mathbf{C_{major\ incident}}$) is known a priori and the confidence degree defines the α value, the **x** value is computed from equation (2.11) as:

   $$x = \frac{C_{major\,incident}}{\alpha\,\sigma_{\min}} \tag{3.11}$$

   Define **Δx** as a percentage of **x** (e.g. 10%).

2. Simulate until the minimum number of trials **x** is reached.

3. Compare $\boldsymbol{\sigma}$ to $\boldsymbol{\sigma_{\min}}$**(x)**. If σ is smaller than $\boldsymbol{\sigma_{\min}}$**(x)**, increase **x** to **x** + **Δx** and go to step 2.

4. Continue the simulation without a new adjustment of the minimum number of trials.

At the last point, the σ/μ ratio is compared to the ratio given by the convergence criteria. If the σ/μ ratio is smaller than the convergence criteria (0.51%) the simulation stops. In the other case (i.e. it is higher than 0.51%), the simulation continues until it satisfies the convergence criteria.

4 TESTING THE ASSESSOR OF VALUE OF SECURITY ON A LARGE POWER SYSTEM - THE NGC SYSTEM

A model of the NGC transmission system for 1996/97 has been used for testing the Value of Security Assessor program on a large power system. This model has 700 nodes, 1464 branches (lines, transformers and shunt compensation equipment) and 82 available generators. The load demand is at the minimum: 34484 MW.

The data on reliability of transmission equipment provided by [1] has been used as typical data for this system. Failure rates of transmission lines have been computed using their length (See appendix B of [2]). Failure rates of generators have been computed from forced outage rates (FOR) provided in [3] and assuming mean time to repair (MTTR) values given by [4]. The generation prices associated with each generator are given in appendix D of [2].

The same load restoration process has been assumed in all cases. Each step was given a duration of 20 minutes. The simulation therefore involves 3 subintervals for each hour.

The system has been divided into 8 areas for the weather modelling. These areas are:

1- Scotland
2- Northwest
3- Northeast
4- Yorkshire
5- West Midlands
6- East Anglia
7- London including the Thames Estuary, Inner and Outer London, and the Southeast coast
8- Southwest and South of Wales

4.1 Scenarios

Three scenarios have been defined for testing the Assessor:

- Scenario 1 is the base scenario. The reserve margin is 2342 MW. Units 1 and 2 of DIDCOT are running. Units 1 to 4 at West Burton are running.

- Scenario 2. Units 1, 3 and 4 of DIDCOT are running. Units 1 to 4 of West Burton are running but reduced total generated power. The difference with scenario 1 is the replacement of generation from West Burton by generation from Didcot and the commitment of one more unit replacement at Didcot. The reserve margin is 2843 MW.

- Scenario 3. Units 1, 3 and 4 of DIDCOT are running. Units 1, 3 and 4 of West Burton are running. The difference with scenario 1 is the replacement of generation from West Burton by generation from Didcot without changing the reserve margin of the system. The reserve margin is 2349 MW, almost equal to the scenario 1's reserve margin.

4.2 Computation of Value of Security by Naïve Monte Carlo

As an initial step for testing the Value of Security Assessor program with a large power system, naïve Monte Carlo simulations were run for each scenario. Three different cases are used. Their main characteristics are:

- **Case 1**: No weather effect is considered, i.e. the failure rates for average weather conditions are used. Cascade and sympathetic tripping are not simulated.
- **Case 2**: No weather effect is considered. Cascade and sympathetic tripping are simulated.
- **Case 3**: Adverse weather conditions are applied to the south of the system (areas 6, 7, 8), i.e. the area around Didcot. Cascade and sympathetic tripping are simulated.

Simulations of each case use the following:

- VOLL is a function of the duration of interruption (Data from [5]). A consumer distribution of 35% residential consumers, 27% commercial consumers, 34% industrial consumers and 4% large users is assumed. The load factor is assumed to be 0.65 at each node.
- The simulation extends over 1 hour using 3 intervals of 20 minutes.
- A convergence criterion of 95% confidence degree and 1% confidence interval, as it is recommended in section 3.1. The total cost is used for computation of the convergence criterion, i.e. the expected value of **y** (equation 3.2) is 0.51.
- The minimum number of trials is computed by the auto-adjustable method. The initial minimum number of trials is 4860. The incremental value is 10%.

4.2.1 Case 1

Table 4.1 presents the results obtained for case 1 for the three scenarios. Two samples were run for each scenario.

These samples are stopped by the specified criterion. Some simulations have required the adjustment of the minimum number of trials in order to satisfy equation 3.10. In this way, the confidence in the results is guaranteed. Note that each sample includes at least one severe outage in the system.

Fulfilment of the minimum standard deviation criterion (equation 3.10) makes the results reliable but requires a lot of time due to the increase in the number of trials required.

Table 4.1 Case 1 NGC System – Naïve Monte Carlo Simulation -

CASE 1- SCENARIO 1 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time
1	12502	5346	6938.4	62.5	-0.9	35.4	0.51	339' 23"
2	25234	4860	6955.1	79.3	-1.0	35.5	0.51	596' 12"
Total	37736		6949.6	73.7	-1.0	26.5	0.38	

CASE 1- SCENARIO 2 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	25216	5346	6947.4	71.0	-0.4	35.4	0.51	665' 37"
2	30824	11664	6955.6	79.4	-0.6	35.5	0.51	799' 1"
Total	56040		6951.9	75.6	-0.5	25.2	0.36	

CASE 1- SCENARIO 3 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	7578	4860	6930.1	54.0	-0.7	35.5	0.51	184' 34"
2	30918	4860	6976.0	100.4	-1.2	35.6	0.51	795' 23"
Total	38496		6967.0	91.3	-1.1	29.4	0.42	

1- Maximum number of trials = 100000.
Minimum number of trials = 4860 (auto-adjustable).
Convergence criterion of 95% of degree of confidence and 1% of confidence interval

4.2.2 Case 2

Table 4.2 Case 2 NGC System – Naïve Monte Carlo Simulation -

CASE 2- SCENARIO 1 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time
1	18468	18468	6948.2	72.4	-1.0	34.5	0.50	429' 11"
2	18373	5346	6958.6	82.8	-1.0	35.5	0.51	490' 32"
Total	36841		6953.4	77.6	-1.0	24.7	0.36	

CASE 2- SCENARIO 2 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	47628	47628	6903.7	26.9	0.0	3.4	0.05	1470' 01"
2	18025	17982	6939.0	62.6	-0.4	35.4	0.51	489' 31"
Total	65653		6913.4	36.7	-0.1	10.0	0.15	

CASE 2- SCENARIO 3 - System NGC 1996/97								
Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	7020	7020	6942.4	66.4	-0.8	33.8	0.49	156' 55"
2	17900	4680	6942.9	67.0	-0.9	35.4	0.51	426' 54"
Total	24920		6942.8	66.8	-0.9	27.2	0.39	

1- Maximum number of trials = 100000.
Minimum number of trials = 4860 (auto-adjustable).
Convergence criterion of 95% of degree of confidence and 1% of confidence interval

Table 4.2 presents the results obtained for case 2 for the three scenarios. Two samples were run for each scenario. These samples are stopped by the specified criterion.

Only 1 sample has not required the adjustment of the minimum value of trials in order to satisfy equation 3.10. 4 samples have required many adjustments to the minimum such as the final minimum number of trials is very close to the required number of trials. In some cases, these values are the same (sample 1 of each scenario). Sample 1 in scenario 2 has required a lot of simulations to satisfy equation 3.10 criterion. Severe outages are not present in this sample, that is the reason of the small value of the standard deviation.

On the other hand, the outage costs are similar to those obtained in case 1. Note that the system is operating at a low load level, so the effect of cascade or sympathetic tripping could be diminished.

4.2.3 Case 3

Table 4.3 presents the results obtained for case 3 for the three scenarios. The adverse weather increases the number of contingencies and, hence, the number of trials to be analysed. Results show that the interruption cost increases as expected.

Table 4.3 Case 3 NGC System – Naïve Monte Carlo Simulation -

CASE 3- SCENARIO 1 - System NGC 1996/97

Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time
1	5346	5346	7100.8	226.3	-2.3	34.5	0.49	505' 59"
2	25127	18468	7045.1	170.2	-1.9	35.5	0.50	2155' 22"
Total	30473		7054.9	180.0	-2.0	29.9	0.42	

CASE 3- SCENARIO 2 - System NGC 1996/97

Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	21951	4860	7098.6	223.6	-1.8	36.2	0.51	2448' 30"
2	22356	22356	7007.2	131.3	-0.9	28.7	0.41	2494' 32"
Total	44307		7052.5	177.0	-1.3	23.1	0.33	

CASE 3- SCENARIO 3 - System NGC 1996/97

Sample	Trials [1]	Final Adjusted Minimum	Total Cost (k£)	Interruption Cost (k£)	Reschedule Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min]
1	65728	7488	7212.0	338.6	-3.4	36.8	0.51	6570' 1"

1- Maximum number of trials = 100000.
Minimum number of trials = 4860 (auto-adjustable).
Convergence criterion of 95% of degree of confidence and 1% of confidence interval

On the other hand, the simulation time increases dramatically. Almost all the samples have required the adjustment of the minimum number of trials. In some cases, the required number of trials is equal to the adjusted minimum.

4.3 Correlated Sampling

Reference [12] has shown that correlated sampling is a good method for selecting the best scenario. Section 4.2 shows the results of the computation of the value of security for three scenarios under and three cases. However, the computation of the value of security intervals does not allow the selection of the best scenario in a direct way. The correlated sampling is used here to select the best scenario in each case (the cases are defined in section 4.2).

4.3.1 Case 1

The comparison of the three scenarios is realised in two steps: first two scenarios are compared (scenario 1 vs. scenario 2) and then the best of them is compared with the third scenario (scenario 3).

Table 4.4 Case 1 NGC System – Scenario 1 vs. Scenario 2 - Correlated Sampling

CASE 1- SCENARIO 1 - System NGC 1996/97							
Sample	Trials[1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min][2]
1	1995	6908.2	31.9	6876.3	12.1	0.18	191' 33"
2	1000	6881.6	5.0	6876.6	3.2	0.05	61' 53"
3	5783	6914.2	38.0	6876.2	13.4	0.19	226' 54"
4	1941	6897.2	20.8	6876.4	7.5	0.11	84' 17"
5	4113	7053.3	177.5	6875.8	147.1	2.09	185' 45"
Total	14832	6947.5	71.4	6876.2	41.2	0.59	

CASE 1- SCENARIO 2 - System NGC 1996/97							
Sample	Trials[1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min][2]
1	1995	6894.5	17.6	6876.9	7.3	0.11	191' 33"
2	1000	6882.0	5.0	6877.0	3.2	0.05	61' 53"
3	5783	6909.8	33.1	6876.7	0.4	0.01	226' 54"
4	1941	6884.6	7.6	6877.0	2.9	0.04	84' 17"
5	4113	7045.1	168.7	6876.4	147.2	2.09	185' 45"
Total	14832	6940.1	63.4	6876.7	40.8	0.59	

1- Maximum number of trials = 100000. Minimum number of trials = 1000.
Convergence criterion of 95% of degree of confidence

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 1 - Scenario 2						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	13.7	14.3	-0.6	6.3	46.0	Scenario 2
2	-0.4	0.0	-0.4	0.0	0.08	Scenario 1
3	4.4	4.9	-0.5	2.2	50.0	Scenario 2
4	12.6	13.2	-0.6	6.4	50.8	Scenario 2
5	8.2	8.8	-0.6	3.9	47.6	Scenario 2
Total	7.5	8.0	-0.5			Scenario 2

Table 4.5 Case 1 NGC System – Scenario 2 vs. Scenario 3 – Correlated Sampling

CASE 1- SCENARIO 2 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1000	6877.7	0.6	6877.1	0.5	0.01	102' 33"
2	1527	6896.2	19.3	6876.9	7.3	0.11	84' 55"
3	2921	6899.3	22.4	6876.9	11.6	0.17	188' 24"
4	3366	6910.1	33.3	6876.8	15.2	0.22	140' 28"
5	5281	7011.0	134.5	6876.5	114.7	1.64	320' 54"
Total	14095	6941.9	65.1	6876.7	43.2	0.62	

CASE 1- SCENARIO 3 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1000	6877.7	0.6	6877.1	0.5	0.01	102' 33"
2	1527	6903.5	27.1	6876.4	3.2	0.05	84' 55"
3	2921	6909.6	33.3	6876.3	0.4	0.01	188' 24"
4	3366	6918.1	41.8	6876.3	2.9	0.04	140' 28"
5	5281	7018.7	142.8	6875.9	114.6	1.63	320' 54"
Total	14095	6949.6	73.4	6876.2	42.9	0.62	

1- Maximum number of trials = 100000. Minimum number of trials = 1000.
Convergence criterion of 95% of degree of confidence

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 2 - Scenario 3						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	0.0	0.0	0.0			Scenario 2
2	-7.3	-7.8	0.5	3.7	50.68	Scenario 2
3	-10.3	-10.9	0.6	4.8	46.6	Scenario 2
4	-8.0	-8.5	0.5	4.0	50.0	Scenario 2
5	-7.7	-8.3	0.6	4.0	51.9	Scenario 2
Total	-7.7	-8.2	0.5			Scenario 2

Table 4.4 compares scenarios 1 and 2 using correlated sampling. Four of the 5 samples choose scenario 2 as the best. The second sample converges at the minimum number of trials and gives almost identical cost for both scenarios. Conclusions from this sample are not reliable.

Table 4.5 compares scenario 2 (the best from the previous stage) and scenario 3. As in the previous case, four of five samples indicate scenario 2 as the best one. Sample 1 gives costs so close that the difference between them is almost zero.

Both tables show that a relatively small number of trials is required to get a reliable answer about the best scenario. Presence of major incidents (partial or total blackouts) is not necessary to draw conclusions from the correlated sampling comparison. Sample 5 in Table 4.4 is the only one that includes the simulation of a major incident in the system.

4.3.2 Case 2

Two samples are obtained for each step of scenarios comparison (scenario 1 vs. scenario 2 and the best vs. scenario 3).

Table 4.6 Case 2 NGC System – Scenario 1 vs. Scenario 2 – Correlated Sampling

CASE 1- SCENARIO 1 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	5436	6903.4	27.1	6876.3	9.9	0.14	252' 50"
2	1498	6905.8	29.5	6876.3	11.9	0.17	78' 33"
Total	6934	6903.9	27.6	6876.3	8.2	0.12	

CASE 1- SCENARIO 2 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	5436	6897.8	20.9	6876.9	9.6	0.14	252' 50"
2	1498	6889.1	12.1	6877.0	6.6	0.10	78' 33"
Total	6934	6895.9	19.0	6876.9	7.7	0.11	

1- Minimum number of trials = 1000. Convergence criterion of 95% of degree of confidence

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 1 - Scenario 2						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	5.6	6.2	-0.6	2.7	48.2	Scenario 2
2	16.7	17.4	-0.7	8.1	48.5	Scenario 2
Total	8.0	8.6	-0.6			Scenario 2

Table 4.7 Case 2 NGC System – Scenario 2 vs. Scenario 3 – Correlated Sampling

CASE 1- SCENARIO 2 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1349	6892.4	15.5	6876.9	5.8	0.08	69' 37"
2	1282	6891.0	14.1	6876.9	7.7	0.11	78' 38"
Total	2631	6891.7	14.8	6876.9	4.8	0.07	

CASE 1- SCENARIO 3 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1349	6912.6	36.3	6876.3	14.1	0.20	69' 37"
2	1282	6913.0	36.7	6876.3	14.6	0.21	78' 38"
Total	2631	6912.8	36.5	6876.3	10.1	0.15	

1- Minimum number of trials = 1000. Convergence criterion of 95% of degree of confidence

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 2 - Scenario 3						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	-20.2	-20.8	0.6	9.7	48.0	Scenario 2
2	-22.0	-22.6	0.6	10.1	45.9	Scenario 2
Total	-21.1	-21.7	0.6			Scenario 2

Table 4.6 compares scenario 1 and scenario 2, while Table 4.7 compares scenario 2, the best in the previous step and scenario 3. The general conclusion is that scenario 2 is the best. As the difference between scenarios, in each comparison, is remarkable the sample simulation requires a relative small number of trials. Of preference, the required number of trials must be higher than the minimum value fixed. When the convergence criterion stops simulation at the minimum number of trials, the results are not very confident, requiring an increase of the minimum.

4.3.3 Case 3

Three samples are obtained for each step of the comparison of scenarios (scenario 1 vs. scenario 2 and the best vs. scenario 3).

Table 4.8 compares scenario 1 and scenario 2, while Table 4.9 compares scenario 2 (the best in the previous comparison) and scenario 3. Scenario 2 is again selected as the best one. Since adverse weather is modelled in 3 areas of the system, the failure rates of lines in these areas increase. The number of analysed trials also increases; hence the CPU time increases dramatically. For this reason, the maximum number of trials was set at 5000.

Table 4.8 Case 3 NGC System – Scenario 1 vs. Scenario 2 – Correlated Sampling

CASE 3- SCENARIO 1 - System NGC 1996/97

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1136	7083.3	208.7	6874.6	46.8	0.66	235' 57"
2	5000	7186.7	313.3	6873.4	135.8	1.89	977' 32"
3	2155	7071.4	196.7	6874.7	36.9	0.52	408' 10"
Total	8291	7142.6	268.7	6873.9	82.7	1.16	

CASE 3- SCENARIO 2 - System NGC 1996/97

Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	1136	7015.2	139.4	6875.8	30.7	0.44	235' 57"
2	5000	7039.5	163.9	6875.6	19.8	0.28	977' 32"
3	2155	7043.2	167.6	6875.6	32.8	0.47	408' 10"
Total	8291	7037.1	161.5	6875.6	15.3	0.22	

1- Maximum number of trials = 5000. Minimum number of trials = 1000.
Convergence criterion of 95% of degree of confidence

2- CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 1 - Scenario 2

Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	68.1	69.3	-1.2	34.5	50.7	Scenario 2
2	147.2	149.4	-2.2	130.3	88.5	Scenario 2
3	28.2	29.1	-0.9	14.2	50.4	Scenario 2
Total	105.4	107.2	-1.7			Scenario 2

Sample 2 in Table 4.8 reached the maximum number of trials without satisfying the convergence criterion (see σ/μ ratio in the difference section is higher than 51%). However, the difference between scenarios is enough to conclude that scenario 2 is the best. An even larger number of trials would be required to confirm this selection.

The last comment also applies to all the samples in Table 4.9. Note that for sample 2 the conclusion is that the best scenario is the third.

Table 4.9 Case 3 NGC System – Scenario 2 vs. Scenario 3 – Correlated Sampling

CASE 3- SCENARIO 2 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	5000	7151.7	277.3	6874.4	127.1	1.78	16 hr 30'
2	5000	7101.5	226.5	6875.0	48.8	0.69	16 hr 30'
3	5000	7089.5	214.4	6875.1	33.3	0.47	16 hr 30'
Total	15000	7114.2	239.4	6874.8	46.7	0.66	

CASE 3- SCENARIO 3 - System NGC 1996/97							
Sample	Trials [1]	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	CPU Time [min] [2]
1	5000	7184.8	311.4	6873.4	136.0	1.89	16 hr 30'
2	5000	7061.3	186.5	6874.8	23.1	0.33	16 hr 30'
3	5000	7169.2	294.7	6874.5	123.0	1.72	16 hr 30'
Total	15000	7138.4	264.2	6874.2	61.6	0.86	

1- Maximum number of trials = 5000. Minimum number of trials = 1000.
Convergence criterion of 95% of degree of confidence

2- Estimated CPU Time in this case is the total time used to simulate the two scenarios

DIFFERENCE : Scenario 2 - Scenario 3						
Sample	Total Cost (k£)	Interruption Cost (k£)	Generation Cost (k£)	Standard Dev. σ (k£)	σ / μ [%]	Best Scenario
1	-33.1	-34.1	1.0	44.1	133.2	Scenario 2
2	40.2	40.0	0.2	40.2	100.0	Scenario 3
3	-79.7	-80.3	0.6	121.6	152.6	Scenario 2
Total	-24.2	-24.8	0.6			Scenario 2

5 CONSIDERATION OF SEVERE OUTAGES

The computation of the value of security must take into consideration the consequences of severe contingencies. As test of the Value of Security Assessor program ("Assessor") on the NGC systems shows, severe outages have a great impact on the final statistics of Value of Security.

On the other hand, the computation of this impact imposes additional constraints on the Assessor (minimal standard deviation, equation 3.10) that ensure that this impact is included in the simulation.

The following has been observed from the Assessor's test on the NGC system:

- Load outages can be grouped in two distinct categories: small outages and large outages.
- Major load outages are associated with partial or total blackouts. A sample simulation requires a huge number of trials to include a major outage and to satisfy the convergence criteria. A sample simulation will normally include at least one major incident.
- If a major incident is not included in a sample simulation, the minimal standard deviation constraint results in a number of trials so large that a major incident will not affect the statistics obtained from this simulation.
- Statistics for small outages can be obtained using a small number of trials. However, the Assessor has to analyse a lot of small outages for every large outage that is simulated. The simulation time required therefore increases dramatically if large outages are to be included in the simulation.

This document examines some ideas on how to compute the Value of Security taking into account the effect of major and minor incidents separately.

5.1 Some Facts

The following facts must be noted before the analysis of large and small outages:

- The outage cost associated with a total or partial blackout can be computed analytically ("a priori"). Indeed, the duration of the interruption is calculated from the total lost load and based on a model of the restoration process. As the VOLL depends on the duration of the interruption, the outage cost can be easily computed.
- Major outages (total or partial blackouts) have a very small probability. For example, 1 major incident occurs for every 17000 trials in the NGC system tests.

5.2 Assumptions

The following assumptions are formulated from the analyses of previous simulations on the NGC system:

- A major incident will be defined as an incident whose outage cost is higher than a predefined value. Let $\mathbf{C_{blackout}}$ be the outage cost for a total blackout. Outages whose cost is less than the predefined value $\mathbf{C_{bound}}$ (see section 5.6) will be consider minor.

- The outage costs of major incidents will be modelled by a probabilistic distribution function (pdf), for example a uniform distribution between $\mathbf{C_{bound}}$ and $\mathbf{C_{blackout}}$. Hence, the mean value (μ_1) and variance of the population ($\mathbf{var_1}$) are given by:

$$\mu_1 = \frac{C_{blackout} + C_{bound}}{2} \tag{5.1}$$

$$\mathrm{var}_1 = \frac{\left(C_{blackout} - C_{bound}\right)^2}{12} \tag{5.2}$$

- The assessor will be used to compute the mean value (μ_2) and the standard deviation of the estimator (σ_2) for incidents below the boundary cost, i.e. it does not take into account trials whose outage costs are higher than $\mathbf{C_{bound}}$. The variance of the population of these incidents is given by:

$$\mathrm{var}_2 = n_2\, \sigma_2^2 \tag{5.3}$$

  where $\mathbf{n_2}$ is the number of trials (of small incidents).

- The probability of major incident ($\mathbf{p_1}$) is uncertain and very low.

5.3 A Theorical Analysis

The impact of large and small outages on the VS can be analysed using the basic theory of stratified sampling. Let us define two strata based on the outage costs: small outages and large outages. In this way, a simple estimator of the mean (μ) of the value of the security is given by [13]:

$$\mu = p_1\, \mu_1 + p_2\, \mu_2 \tag{5.4}$$

Subscripts 1 and 2 refer to the large and small incident strata respectively. The variance of the stratified estimator is given by [13]:

$$\sigma^2 = \sum_{k=1}^{2} p_k^2 \frac{\mathrm{var}_k}{n_k} \tag{5.5}$$

where $\mathbf{n_k}$ is the number of trials in strata $\mathbf{k}$, and $\mathbf{var_k}$ is the population variance in the strata (it is not the variance of the estimator).

As

$$p_2 = \frac{n_2}{n_2 + n_1} \quad and \quad p_1 = \frac{n_1}{n_2 + n_1} \tag{5.6}$$

Equation (5.5) becomes

$$\sigma^2 = \frac{n_1}{(n_1 + n_2)^2} \mathrm{var}_1 + \frac{n_2}{(n_1 + n_2)^2} \mathrm{var}_2 \tag{5.7}$$

As **n₁** « **n₂**. Equation (5.5) can be approximated by:

$$\sigma^2 = \frac{n_1 \mathrm{var}_1}{n_2^2} + \frac{\mathrm{var}_2}{n_2} = \frac{n_1 \mathrm{var}_1}{n_2^2} + \sigma_2^2 \tag{5.8}$$

The variance of the estimator can be computed from the variance of the estimator for small incidents obtained by the Assessor (assumption 3) and the population variance for large impacts (assumption 2). The variance of the estimator is a function of the number of trials. But this number is approximately equal to the inverse of the probability of large outages, i.e.

$$\sigma^2(p_1) = \sigma_2^2 + p_1^2 \frac{(C_{blackout} - C_{bound})^2}{12} \tag{5.9}$$

Consequently, the Assessor is used to compute the statistics for the small impact outages, the final statistics of the Value of Security can be obtained from equations (5.4) and (5.9). The last one is expressed as a function of the probability of major incidents.

5.4 Example

A previous simulation of scenario 1 for the system NGC 1996/97 system is used in this example. Table 5.1 shows the value of the parameters associated with the assumptions on the impact of large incidents. This table also gives the statistics results produced by the Assessor for small incidents.

Table 5.1 Example Data

Parameter	Value
Blackout Cost (k£)	637000
Boundary Cost (k£)	318500
Mean Value Large Impacts (k£)	477750
Population Variance Large Impacts	8453520833
Mean Value Small Incidents (k£) –Assessor-	38
Standard Deviation Estimator – Assessor -	11

Figure 5.1 shows the effect of the major impacts on the mean value and the confidence intervals (inferior border and superior border). The mean value of the Value of Security computed by Assessor for small (and frequent) incidents and the bounds of the confidence interval are independent of the probability of major incidents. Major incidents increase the mean value as well as the bounds of the confidence interval, the impact is higher if the probability of occurrence of major incidents is higher (left side in the figure).

In the NGC test (scenario 1), one major incident has been observed for almost 17000 trials. This value will be assumed to be equal to the inverse of the probability of major incidents. Figure 5.1 presents the mean value and the limits of the confidence interval for this case.

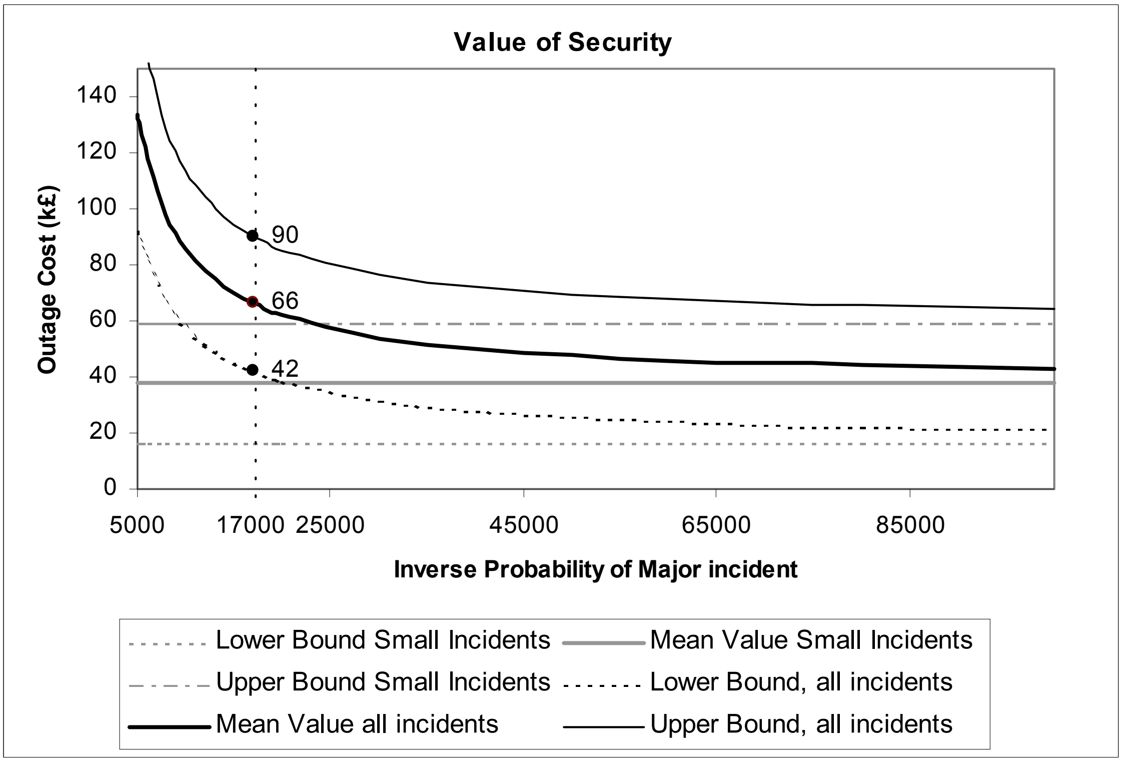

Figure 5.1 Value of Security Confidence Intervals

If the Assessor is used to analyse simultaneously both small and major incidents (i.e. taking into account the constraint on minimum standard deviation), the mean value of the outage cost is 79.3 k£ and the confidence interval is [9.9, 148.7]. The proposed technique therefore very significantly reduces the size of the confidence interval.

If the probability of major incidents is very small, the impact will be very small (right hand side of the figure).

5.5 Sensitivity Analysis

5.5.1 Boundary Cost

The sensitivity analysis shown in Table 5.2 illustrates the effect of moving the boundary cost (equations 5.1 and 5.2). A lower boundary value (**C_{bound}**) implies a smaller mean value for the cost of large incidents. This table shows that the variation in the statistics of the outage cost is small. The third row corresponds to the example case.

Table 5.2 Sensitivity on the Boundary Cost ($p_1^{-1} = 17000$)

Boundary Cost (k£)	Estimator Mean Value (k£)	Inferior Border (k£)	Superior Border (k£)
95550	60	32	80
159250	61	35	88
318500	66	42	90
477750	71	49	93
541450	73	51	94

5.5.2 Probability distribution function of major incidents

The sensitivity analysis shown Table 5.3 illustrates the effect of the choice of the pdf used to represent the major outages. This analysis uses a normal distribution function, whose mean value is equal to the average value used in Table 5.1 but whose standard deviation changes. The fourth line corresponds to a normal distribution whose standard deviation is equal to the standard deviation of the uniform distribution of the example (Table 5.1). The second column is the probability that the cost of a major incident is between the boundary cost and the blackout cost.

With a normal distribution with variance σ_N^2, equation (5.9) becomes

$$\sigma^2(p_1) = \sigma_2^2 + p_1^2\,\sigma_N^2 \tag{5.10}$$

Table 5.3 Sensitivity on the standard deviation of major impacts ($p_1^{-1} = 17000$) – Normal Distribution

Standard Dev. (σ_N) Major Impacts (k£)	Prob. %	Estimator Mean Value (k£)	Inferior Border (k£)	Superior Border (k£)
36777	99.99	66	44	88
55166	99.61	66	44	89
73554	96.97	66	43	89
91943	91.67	66	42	90

As Table 5.3 shows, varying the standard deviation of the normal distribution while keeping constant the mean value does not affect the estimate of the outage cost and has a small impact on the confidence interval.

These two sensitivity analyses suggest that the most important parameter to fix is the boundary cost $\mathbf{C_{bound}}$. On the other hand, a more detailed knowledge of the major incidents' pdf is not necessary.

5.6 Boundary Cost

The computation of the outage cost for many severe outages allows the determination of a boundary cost. Some simulations have been carried out using artificially high failure rates in order to provoke severe outages. The failure rate of lines has been increased 100 times and the sympathetic tripping probability has been set at 20% (a very high value). Obviously, the contingencies model many elements out of service at the same time.

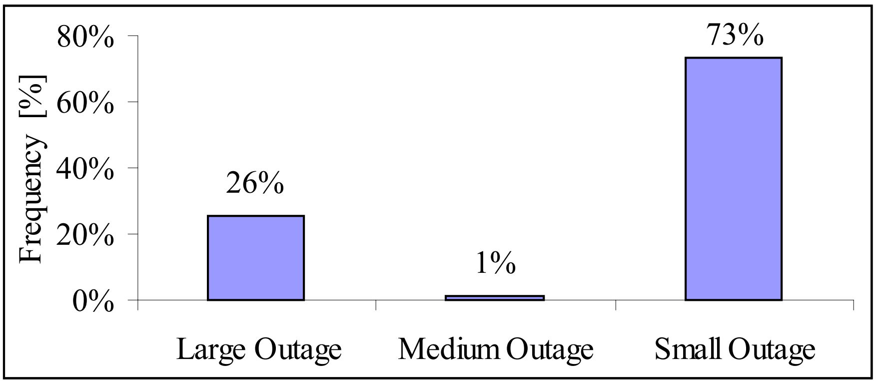

Figure 5.2 Frequency of outages – Artificial failure rates –

Figure 5.2 shows the distribution of failure rates from trials obtained using these artificial failure rates. A large outage includes blackouts whose lost of load is between 92% and 100% of the total load of the system. Small outages correspond to a loss of less than 25% of the total load of the system.

The boundary cost could be fixed at the lower limit of large outages. So, the boundary cost is set a 95% of the blackout cost for this case. The Table 5.1 and Figure 5.1 are updated using the uniform pdf between this new boundary cost and the total blackout cost (see Table 5.4 and Figure 5.3).

Table 5.5 summarises the differences between calculating the value of security using this approach and a Monte Carlo simulation that includes small and large outages.

Table 5.4 Updating Example

Parameter	**Value**
Blackout Cost (k£)	637000
Boundary Cost (k£)	605150
Mean Value Large Impacts (k£)	621075
Population Variance Large Impacts	84535208
Mean Value Small Incidents (k£) –Assessor-	38
Standard Deviation Estimator – Assessor -	11

Table 5.5 Comparison of two approaches to compute Value of Security

Statistic	Naïve Monte Carlo including small and large outages [k£]	Computing impact of large and small outages separetely [k£]
Mean Value	79.3	74.5
Confidence Interval	[9.9, 148.7]	[53.0, 96.1]

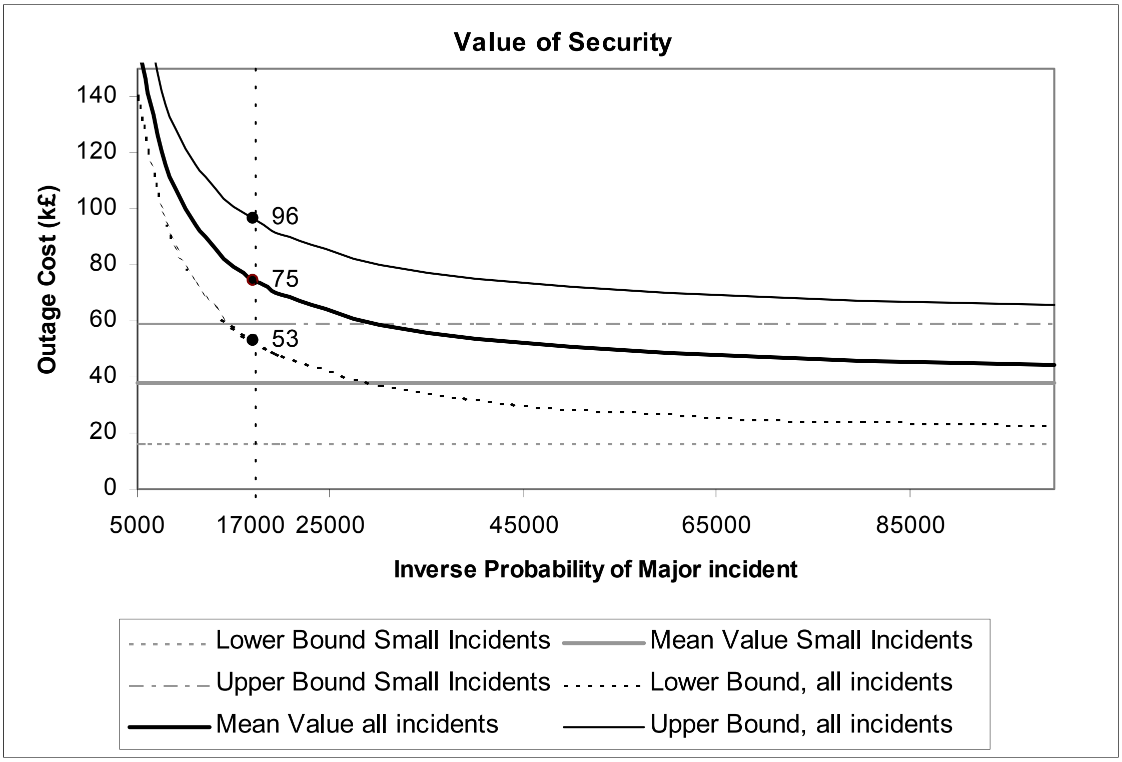

Figure 5.3 Update Value of Security Curves

5.7 Comparing Scenarios

Comparison of scenarios based on the Value of Security computed using equations (5.4) and (5.9) (or the most general equation (5.10)) requires the knowledge of $\mathbf{p_1}$ for these scenarios.

If we assume that we are comparing two scenarios, two cases are possible:

1. The probability of severe outages, i.e. total or partial blackouts, is equal for both scenarios. In this case the impact of major outages on the Value of Security will be equal for both scenarios. The difference will be equal to the difference of the Value of Security associated only with the small outages. So, knowledge of $\mathbf{p_1}$ is not necessary.

2. The probability of severe outages is different for both scenarios. Figure 5.4 shows an example. Scenario 2 has a mean value of small outages 15% higher than the same value for scenario 1. $\mathbf{p_1}$ is 1/17000 for scenario 1 and 1/50000 for scenario 2. The final outage cost indicates that scenario 2 is the best. So, the knowledge of $\mathbf{p_1}$ is necessary in this case.

It should be noted that a comparison using correlated sampling determines the best scenario from a “small” number of trials, which may or may not include severe outages. In other words, a comparison by correlated sampling avoids the comparison based on the final values of the Value of Security and, hence, does not require the knowledge of $\mathbf{p_1}$.

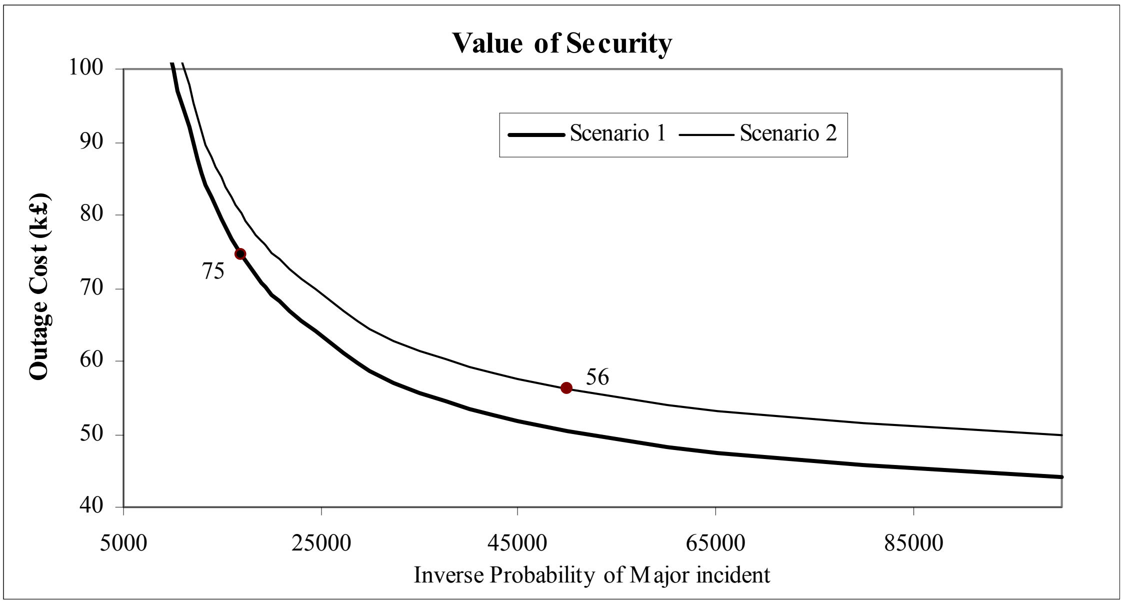

Figure 5.4 Comparing Scenarios

5.8 Observations

- The Assessor can be employed to compute the Value of Security statistics of small outages (i.e. below $\mathbf{C}_{\mathbf{bound}}$).
- The impact of severe outages on the Value of Security can be shown as a function of the probability that a severe outage occurs (i.e. as a curve like Figure 5.3).
- Separation of “small” and “large” outages for comparing scenarios is not relevant when correlated sampling is used.

6 CONCLUSIONS

Volumes I of this final report has presented a probabilistic approach to the computation of the Value of Security of power systems in an operational timeframe based on Monte Carlo sequential simulations. The Monte Carlo simulations represent the operation of the system subject to random events, modelling of corrective actions taken by the system operators and the load restoration process.

The modelling of the operation of power systems incorporates also time-dependent phenomena, such as cascade and sympathetic tripping, using simple and fast models. The modelling includes also the weather effect on the computation of the Value of Security.

Based on this model, the Value of Security Assessor Program has been developed under the research project supported by the EPSRC/ERCOS, grant reference no. GR/K 80310.

The Value of Security Assessor program can be used in two ways:

- To compare different operating scenarios.
- To compute the value of security of the system.

Comparison of different scenarios can be realised using their computed total costs or using the correlated sampling method. The first approach consumes much more CPU time and depending on the system and scenarios, it may be inconclusive.

Correlated sampling is thus a better way of selecting the best operating scenario.

Computing an accurate value of the total cost or the cost of outages is justifiable only for the best scenario. The naïve Monte Carlo gives a reliable estimate of the value of security but requires a lot of CPU time.

Volume II has presented testing applications of the Assessor program on a small (South-West portion of England and Wales system) and on a large power system (NGC system). The modelling capabilities of the Value of Security Assessor program have been tested and have shown the expected behaviour. In particular:

- The effect of adverse weather is reflected in an increase in interruption costs and, hence, in total cost. The best scenario can change depending on the weather conditions.

- An increase in the failure rate of one or more components increases the interruption costs.

- Consideration of sympathetic tripping also increases the interruption and total costs.

- The variance reduction methods, different of correlated sampling, have shown a well performance for reducing the required number of trials in small power systems; however, their performance in large power systems is not good.

As Chapter 5 shows, applications of the concept of stratified sampling variance reduction method based on small and large outage strata could provide an effective way to reduce the computational effort involved in the naïve Monte Carlo simulations. The separation analysis between small and large outages must be researched in more detail; developing and strategy to compute the probability associated with the occurrence of large load outages in the system (i.e. probability of blackouts).

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8 APPENDIX A – SOUTH WEST ENGLAND-WALES SYSTEM DATA

This appendix presents in more detail the data of the south-west portion of the England and Wales system that is used for testing the Value of Security Assessor program. It comprises the 400 kV system extending from Dungeness in Kent, and Melksham in Wiltshire, to Indian Queens in Cornwall.

8.1 Transmission Network

The network topology must be the same for all considered scenarios.

- **Summary data and area names**

It is assumed that there is only one area for this system. Therefore, any used weather condition applies to all the system in the same way. Table 2.1 gives the general data of the system: 1 area, 53 nodes, 115 branches, 25 generation units.

- **Bus data**

Table 8.1 gives the bus data for No-Fawley scenario: load and generation for the maximum load condition, limits on reactive power generation and base voltage in kV.

For the Fawley Scenario the generation is changed according to the schedule presented below (section 8.2).

- **Branch data**

Table 8.2 gives the list of lines, transformers and compensation equipment installed in the south-west portion of the England-Wales system. This table provides the electric characteristics (in p.u.) using a base of 100 MVA. The MVA limit of each branch is also supplied. An equal number of transformers and generating units is installed in the generating stations, however only a HV and a LV busbar is used in each one. For example, there are 4 generators in Didcot and 4 transformers DIDC0-DIDC4 (20/400 kV).

- **Generation data**

Table 8.3 shows generation data used in the load flow data file of the Value of Security Assessor for the scenario No-Fawley. For the Fawley scenario the changes correspond to the appropriate schedule. In this part, the supplied generation schedule corresponds to the peak load condition.

Table 8.1 Bus Data – No Fawley Scenario -

	Name	Pl	Ql	Pg	Qg	Vbase	Qmax	Qmin
		[MW]	[MVAr]	[MW]	[MVAr]	[kV]	[MVAr]	[MVAr]
1	DUNG4	0.00	0.00	2642.00	514.00	400.00	1946.00	-830.00
2	BRLE4	100.00	0.00	0.00	0.00	400.00	0.00	0.00
3	DIDC4	-500.00	100.00	0.00	0.00	400.00	0.00	0.00
4	MELK4	-500.00	100.00	0.00	0.00	400.00	0.00	0.00
5	HINP4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
6	FAWL4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
7	EXET4	0.00	0.00	0.00	-47.26	400.00	95.00	-105.00
8	LOVE4	0.00	0.00	0.00	-38.63	400.00	95.00	-105.00
9	MANN4	0.00	0.00	0.00	-37.21	400.00	95.00	-105.00
10	NINF4	0.00	0.00	0.00	-38.74	400.00	95.00	-105.00
11	INDQ4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
12	LAND4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
13	ABHA4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
14	ALVE4Q	0.00	0.00	0.00	0.00	400.00	0.00	0.00
15	ALVE4R	0.00	0.00	0.00	0.00	400.00	0.00	0.00
16	TAUN4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
17	TAUN4R	0.00	0.00	0.00	0.00	400.00	0.00	0.00
18	AXMI4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
19	CHIC4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
20	NURS4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
21	BOTW4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
22	BOLN4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
23	FLEE4	0.00	0.00	0.00	0.00	400.00	0.00	0.00
24	BRWA2	0.00	0.00	0.00	0.00	275.00	0.00	0.00
25	HINP2J	0.00	0.00	0.00	0.00	275.00	0.00	0.00
26	HINP2K	0.00	0.00	0.00	0.00	275.00	0.00	0.00
27	ABHA1	279.00	93.00	0.00	0.00	132.00	0.00	0.00
28	BOLN1K	410.00	137.00	0.00	0.00	132.00	0.00	0.00
29	BOLN1J	410.00	137.00	0.00	0.00	132.00	0.00	0.00
30	CHIC1	97.00	32.00	0.00	0.00	132.00	0.00	0.00
31	FLEE1K	380.00	127.00	0.00	0.00	132.00	0.00	0.00
32	FLEE1J	380.00	127.00	0.00	4.04	132.00	95.00	-105.00
33	LOVE1K	296.00	99.00	0.00	0.00	132.00	0.00	0.00
34	LOVE1J	235.00	78.00	0.00	0.00	132.00	0.00	0.00
35	NURS1	340.00	113.00	0.00	0.00	132.00	0.00	0.00
36	ALVE1	163.00	54.00	0.00	0.00	132.00	0.00	0.00
37	BOTW1	137.00	46.00	0.00	0.00	132.00	0.00	0.00
38	EXET1	304.00	101.00	0.00	0.00	132.00	0.00	0.00
39	INDQ1	373.00	124.00	0.00	0.00	132.00	0.00	0.00
40	MANN1	650.00	217.00	0.00	0.00	132.00	0.00	0.00
41	TAUN1	114.00	38.00	0.00	0.00	132.00	0.00	0.00
42	AXMI1	188.00	63.00	0.00	0.00	132.00	0.00	0.00
43	BRLE1	548.00	183.00	0.00	0.00	132.00	0.00	0.00
44	FAWL1	270.00	90.00	0.00	0.00	132.00	0.00	0.00
45	LAND1	276.00	92.00	0.00	0.00	132.00	0.00	0.00
46	NINF1J	307.00	102.00	0.00	0.00	132.00	0.00	0.00
47	NINF1K	52.00	17.00	0.00	0.00	132.00	0.00	0.00
48	BRWA1	257.00	86.00	0.00	0.00	132.00	0.00	0.00
49	HINP0	0.00	0.00	1270.00	424.67	20.00	784.00	-258.00
50	HINP0K	0.00	0.00	240.00	78.24	20.00	195.00	-87.00
51	HINP0J	0.00	0.00	240.00	78.19	20.00	195.00	-87.00
52	DIDC0	0.00	0.00	1267.00	542.00	20.00	1128.00	-232.00
53	FAWL0	0.00	0.00	0.00	0.00	20.00	0.00	0.00

Table 8.2 Line, transformer and compensation Data

Bus 1	Bus 2	Circuit	r [p.u.]	x [p.u.]	B [p.u.]	MVA limit
11	12	1	0.0010	0.0094	0.2874	1380
13	11	1	0.0020	0.0185	0.5535	967
13	7	1	0.0010	0.0099	0.2760	967
13	12	1	0.0010	0.0091	0.2649	1072
13	7	2	0.0010	0.0098	0.2760	1072
14	11	1	0.0020	0.0196	0.5478	1390
15	11	1	0.0020	0.0196	0.5478	1390
14	17	1	0.0015	0.0146	0.4092	1390
15	16	1	0.0015	0.0146	0.4092	1390
7	17	1	0.0007	0.0071	0.2341	2010
7	16	1	0.0007	0.0071	0.2341	2010
5	17	1	0.0005	0.0050	0.1634	2010
5	16	1	0.0005	0.0050	0.1634	2010
18	7	1	0.0004	0.0060	0.2461	2780
19	7	1	0.0008	0.0126	0.5156	2780
18	9	1	0.0010	0.0155	0.6335	2780
19	9	1	0.0006	0.0089	0.3645	2780
8	9	1	0.0009	0.0133	0.5436	2780
6	9	1	0.0007	0.0101	0.4110	2780
8	20	1	0.0004	0.0067	0.2726	2780
6	20	1	0.0002	0.0034	0.1389	2780
21	6	1	0.0001	0.0015	0.5984	1100
6	8	1	0.0003	0.0040	0.7507	1100
21	8	1	0.0002	0.0025	0.1003	2780
22	8	1	0.0007	0.0108	0.4400	2780
22	8	2	0.0007	0.0108	0.4400	2780
22	10	1	0.0006	0.0085	0.3484	2720
22	10	2	0.0006	0.0085	0.3484	2720
1	10	1	0.0005	0.0072	0.2937	2780
1	10	2	0.0005	0.0072	0.2952	2780
23	8	1	0.0007	0.0073	0.2388	2010
23	8	2	0.0007	0.0073	0.2388	2010
2	23	1	0.0002	0.0029	0.1192	2780
2	23	2	0.0002	0.0029	0.1192	2780
2	4	1	0.0017	0.0157	0.4811	1390
2	4	2	0.0017	0.0157	0.4811	1390
24	25	1	0.0008	0.0076	0.1247	240
24	26	1	0.0008	0.0076	0.1171	240
5	4	1	0.0015	0.0161	0.5299	2010
5	4	2	0.0015	0.0161	0.5300	2010
2	3	1	0.0005	0.0073	0.8557	2200
2	3	2	0.0005	0.0073	0.8557	2200
25	5	1	0.0003	0.0242	0.0590	500
26	5	1	0.0003	0.0242	0.0590	500
27	13	1	0.0015	0.0833	-0.0032	240
27	13	2	0.0015	0.0833	-0.0032	240
36	14	1	0.0015	0.0833	-0.0032	240
36	15	1	0.0015	0.0833	-0.0032	240
42	18	1	0.0008	0.0417	-0.0063	480
29	22	1	0.0007	0.0362	-0.0073	552
28	22	1	0.0007	0.0362	-0.0073	552
37	21	1	0.0008	0.0417	-0.0063	480
43	2	1	0.0005	0.0278	-0.0095	720
48	24	1	0.0015	0.0833	-0.0032	240
48	24	2	0.0015	0.0833	-0.0032	240
30	19	1	0.0008	0.0417	-0.0063	480
38	7	1	0.0008	0.0417	-0.0063	480
44	6	1	0.0008	0.0417	-0.0063	480

Table 8.2 Line, transformer and compensation Data (Continuation)

32	23	1	0.0008	0.0417	-0.0063	480
31	23	1	0.0008	0.0417	-0.0063	480
39	11	1	0.0005	0.0278	-0.0095	720
45	12	1	0.0008	0.0417	-0.0063	480
34	8	1	0.0008	0.0417	-0.0063	480
33	8	1	0.0008	0.0417	-0.0063	480
40	9	1	0.0004	0.0208	-0.0127	960
46	10	1	0.0008	0.0417	-0.0063	480
47	10	1	0.0015	0.0833	-0.0032	240
35	20	1	0.0008	0.0417	-0.0063	480
41	16	1	0.0015	0.0833	-0.0032	240
27	38	1	0.0000	0.0343	0.0000	500
27	45	1	0.0000	0.0675	0.0000	500
36	39	1	0.0000	0.1143	0.0000	500
43	32	1	0.0000	0.0548	0.0000	500
43	31	1	0.0000	0.0506	0.0000	500
48	41	1	0.0000	0.0225	0.0000	500
32	31	1	0.0000	0.1274	0.0000	500
51	25	1	0.0016	0.1618	0.0000	110
51	25	2	0.0016	0.1618	0.0000	110
51	25	3	0.0016	0.1618	0.0000	110
50	26	1	0.0016	0.1618	0.0000	110
50	26	2	0.0016	0.1618	0.0000	110
50	26	3	0.0016	0.1618	0.0000	110
49	5	1	0.0002	0.0206	0.0000	783
49	5	2	0.0002	0.0206	0.0000	783
53	6	1	0.0003	0.0255	0.0000	570
52	3	1	0.0003	0.0272	0.0000	600
52	3	2	0.0003	0.0272	0.0000	600
52	3	3	0.0003	0.0272	0.0000	600
52	3	4	0.0003	0.0272	0.0000	600
27	0	1	0.0000	0.0000	0.2730	500
36	0	1	0.0000	0.0000	0.1267	500
42	0	1	0.0000	0.0000	0.0853	500
29	0	1	0.0000	0.0000	0.6930	500
28	0	1	0.0000	0.0000	0.6700	500
43	0	1	0.0000	0.0000	0.5420	500
48	0	1	0.0000	0.0000	0.0940	500
30	0	1	0.0000	0.0000	0.0176	500
38	0	1	0.0000	0.0000	0.2500	500
44	0	1	0.0000	0.0000	1.0900	500
32	0	1	0.0000	0.0000	0.5900	500
31	0	1	0.0000	0.0000	0.5800	500
39	0	1	0.0000	0.0000	0.1330	500
45	0	1	0.0000	0.0000	0.1950	500
34	0	1	0.0000	0.0000	0.7200	500
33	0	1	0.0000	0.0000	0.9300	500
40	0	1	0.0000	0.0000	0.5570	500
46	0	1	0.0000	0.0000	0.1430	500
47	0	1	0.0000	0.0000	0.0230	500
35	0	1	0.0000	0.0000	0.1730	500
41	0	1	0.0000	0.0000	0.0486	500
39	0	2	0.0000	0.0000	1.8000	500
40	0	2	0.0000	0.0000	1.8000	500
31	0	2	0.0000	0.0000	1.8000	500
38	0	2	0.0000	0.0000	-0.5100	500
45	0	2	0.0000	0.0000	-0.6000	500

Table 8.3 Generation Data – No Fawley Scenario -

* Set	Busbar	Type	Pg (MW)	Pmax (MW)	Pmin (MW)	Qmax (MVAr)	Qmin (MVAr)	Price (£/MWh)
DIDCA1	DIDC0	2	287	490	245	282	-64	22.72
DIDCA2	DIDC0	2	245	490	245	282	-52	22.74
DIDCA3	DIDC0	3	245	490	245	282	-52	31.51
DIDCA4	DIDC0	3	490	490	245	282	-64	22.66
DIDCA3G	DIDC0	10	0	25	0	19	-7	101.85
DIDCA4G	DIDC0	10	0	25	0	19	-7	101.9
DUNGA1	DUNG4	12	112	112	56	105	-34	0
DUNGA2	DUNG4	12	112	112	56	105	-34	0
DUNGA3	DUNG4	12	112	112	56	105	-34	0
DUNGA4	DUNG4	12	112	112	56	105	-34	0
DUNGB21	DUNG4	12	600	600	300	413	-172	0
DUNGB22	DUNG4	12	600	600	300	413	-172	0
FAWL3	FAWL0	3	0	484	242	300	-74	53.09
FAWL1G	FAWL0	10	0	17	0	11	-6	999
FAWL3G	FAWL0	10	0	17	0	11	-6	101.59
FRANCE1	DUNG4	1	497	497	0	350	-175	7
FRANCE2	DUNG4	1	497	497	0	350	-175	7
HINPA1	HINP0J	12	80	80	40	65	-29	0
HINPA2	HINP0J	12	80	80	40	65	-29	0
HINPA3	HINP0J	12	80	80	40	65	-29	0
HINPA4	HINP0K	12	80	80	40	65	-29	0
HINPA5	HINP0K	12	80	80	40	65	-29	0
HINPA6	HINP0K	12	80	80	40	65	-29	0
HINPB1	HINP0	12	635	635	318	392	-129	0.19
HINPB2	HINP0	12	635	635	318	392	-129	0.19

8.2 Generation Schedules

The Value of Security Assessor program requires a generation schedule for each scenario. These schedules must include:

- The schedule for each generator for each period that will be included in the value of security evaluation (for example 24 hours).
- The set of all generators used by all the scenarios.
- Maximum Bid Price or SMP for each hour. The Assessor program uses these values for computing the generation cost.

Table 8.4 shows the schedule for the No-Fawley scenario, while Table 8.5 shows the schedule for the Fawley scenario. The last line of both tables gives the SMP value. Both scenarios use the same SMP. In the Fawley scenario, the generation cost associated with the Fawley generator is costed at its bid price (53.09 £/MWh – see Table 8.3).

The schedule construction has taken into account:

- A spinning reserve larger than the largest generator (635 MW).
- A merit order based on generators' bid prices.

Table 8.4 Generation Schedule – No Fawley Scenario –

* Name	1	2	3	4	5	6	7	8	9	10	11	12
DIDCA1	0	0	0	0	0	0	0	245	245	245	287	245
DIDCA2	0	0	0	0	0	0	0	245	245	245	245	245
DIDCA3	0	0	0	0	0	0	0	0	245	245	245	245
DIDCA4	0	0	0	0	0	245	245	264	253.2	380	490	358
DIDCA3G	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4G	0	0	0	0	0	0	0	0	0	0	0	0
DUNGA1	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA2	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA3	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA4	112	112	112	112	112	112	112	112	112	112	112	112
DUNGB21	600	600	600	600	600	600	600	600	600	600	600	600
DUNGB22	600	600	600	600	600	600	600	600	600	600	600	600
FAWL3	0	0	0	0	0	0	0	0	0	0	0	0
FAWL1G	0	0	0	0	0	0	0	0	0	0	0	0
FAWL3G	0	0	0	0	0	0	0	0	0	0	0	0
FRANCE1	94	126	83	93.5	147	132.5	295	497	497	497	497	497
FRANCE2	94	126	83	93.5	147	132.5	295	497	497	497	497	497
HINPA1	80	80	80	80	80	80	80	80	80	80	80	80
HINPA2	80	80	80	80	80	80	80	80	80	80	80	80
HINPA3	80	80	80	80	80	80	80	80	80	80	80	80
HINPA4	80	80	80	80	80	80	80	80	80	80	80	80
HINPA5	80	80	80	80	80	80	80	80	80	80	80	80
HINPA6	80	80	80	80	80	80	80	80	80	80	80	80
HINPB1	635	635	635	635	635	635	635	635	635	635	635	635
HINPB2	635	635	635	635	635	635	635	635	635	635	635	635
COST	7.00	7.00	7.00	7.00	7.00	22.66	22.66	22.74	31.51	31.51	31.51	31.51

* Name	13	14	15	16	17	18	19	20	21	22	23	24
DIDCA1	245	245	245	245	245	245	245	245	245	245	245	0
DIDCA2	245	245	245	245	245	245	245	245.4	245	245	0	0
DIDCA3	245	245	245	245	245	245	245	245	245	245	0	0
DIDCA4	358	271	423	489	271	245	245	245	380	245	245	245
DIDCA3G	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4G	0	0	0	0	0	0	0	0	0	0	0	0
DUNGA1	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA2	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA3	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA4	112	112	112	112	112	112	112	112	112	112	112	112
DUNGB21	600	600	600	600	600	600	600	600	600	600	600	600
DUNGB22	600	600	600	600	600	600	600	600	600	600	600	600
FAWL3	0	0	0	0	0	0	0	0	0	0	0	0
FAWL1G	0	0	0	0	0	0	0	0	0	0	0	0
FAWL3G	0	0	0	0	0	0	0	0	0	0	0	0
FRANCE1	497	497	497	497	497	488.5	457.5	488.5	497	435	380.5	121.5
FRANCE2	497	497	497	497	497	488.5	457.5	488.5	497	435	380.5	121.5
HINPA1	80	80	80	80	80	80	80	80	80	80	80	80
HINPA2	80	80	80	80	80	80	80	80	80	80	80	80
HINPA3	80	80	80	80	80	80	80	80	80	80	80	80
HINPA4	80	80	80	80	80	80	80	80	80	80	80	80
HINPA5	80	80	80	80	80	80	80	80	80	80	80	80
HINPA6	80	80	80	80	80	80	80	80	80	80	80	80
HINPB1	635	635	635	635	635	635	635	635	635	635	635	635
HINPB2	635	635	635	635	635	635	635	635	635	635	635	635
COST	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	22.72	22.66

Table 8.5 Generation Schedule – Fawley Scenario -

* Name	1	2	3	4	5	6	7	8	9	10	11	12
DIDCA1	0	0	0	0	0	0	0	245	245	245	290	245
DIDCA2	0	0	0	0	0	0	0	245	245	245	245	245
DIDCA3	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4	0	0	0	0	0	245	245	245	256	383	490	361
DIDCA3G	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4G	0	0	0	0	0	0	0	0	0	0	0	0
DUNGA1	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA2	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA3	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA4	112	112	112	112	112	112	112	112	112	112	112	112
DUNGB21	600	600	600	600	600	600	600	600	600	600	600	600
DUNGB22	600	600	600	600	600	600	600	600	600	600	600	600
FAWL3	0	0	0	0	0	0	0	0	242	242	242	242
FAWL1G	0	0	0	0	0	0	0	0	0	0	0	0
FAWL3G	0	0	0	0	0	0	0	0	0	0	0	0
FRANCE1	94	126	83	93.5	147	132.5	295	497	497	497	497	497
FRANCE2	94	126	83	93.5	147	132.5	295	497	497	497	497	497
HINPA1	80	80	80	80	80	80	80	80	80	80	80	80
HINPA2	80	80	80	80	80	80	80	80	80	80	80	80
HINPA3	80	80	80	80	80	80	80	80	80	80	80	80
HINPA4	80	80	80	80	80	80	80	80	80	80	80	80
HINPA5	80	80	80	80	80	80	80	80	80	80	80	80
HINPA6	80	80	80	80	80	80	80	80	80	80	80	80
HINPB1	635	635	635	635	635	635	635	635	635	635	635	635
HINPB2	635	635	635	635	635	635	635	635	635	635	635	635
COST	7.00	7.00	7.00	7.00	7.00	22.66	22.66	22.74	31.51	31.51	31.51	31.51

* Name	13	14	15	16	17	18	19	20	21	22	23	24
DIDCA1	245	245	245	247	245	245	245	245	245	245	245	0
DIDCA2	245	245	245	245	245	245	245	245	245	245	0	0
DIDCA3	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4	361	274	426	490	274	245	245	245	383	245	245	245
DIDCA3G	0	0	0	0	0	0	0	0	0	0	0	0
DIDCA4G	0	0	0	0	0	0	0	0	0	0	0	0
DUNGA1	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA2	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA3	112	112	112	112	112	112	112	112	112	112	112	112
DUNGA4	112	112	112	112	112	112	112	112	112	112	112	112
DUNGB21	600	600	600	600	600	600	600	600	600	600	600	600
DUNGB22	600	600	600	600	600	600	600	600	600	600	600	600
FAWL3	242	242	242	242	242	242	242	242	242	242	0	0
FAWL1G	0	0	0	0	0	0	0	0	0	0	0	0
FAWL3G	0	0	0	0	0	0	0	0	0	0	0	0
FRANCE1	497	497	497	497	497	490	459	490	497	436.5	380.5	121.5
FRANCE2	497	497	497	497	497	490	459	490	497	436.5	380.5	121.5
HINPA1	80	80	80	80	80	80	80	80	80	80	80	80
HINPA2	80	80	80	80	80	80	80	80	80	80	80	80
HINPA3	80	80	80	80	80	80	80	80	80	80	80	80
HINPA4	80	80	80	80	80	80	80	80	80	80	80	80
HINPA5	80	80	80	80	80	80	80	80	80	80	80	80
HINPA6	80	80	80	80	80	80	80	80	80	80	80	80
HINPB1	635	635	635	635	635	635	635	635	635	635	635	635
HINPB2	635	635	635	635	635	635	635	635	635	635	635	635
COST	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	31.51	22.72	22.66

8.3 Probabilistic Data

The failures rates (λ) for the generators have been computed from the forced outage rates (FOR) of each generator provided in reference [3] and mean time to repair (MTTR) provided in reference [4]. The MTTR values were selected based on the generator type and generator size. For nuclear generators the available data is only for units with capacities greater than 400 MW, however the MTTR for these units was used for all nuclear units in this study.

The failure rate of unit DIDCA3 (Didcot) was assumed to be equal to the failure rate of FAWL3 (Fawley) for study purposes. In case 5, the DIDCA3's λ was set equal to the value of DIDCA2's λ. Note that in the No-Fawley scenario the DIDCA3 generator replaces the generation at Fawley. The assumption above makes possible an evaluation of the impact of different locations of generation. The second case (different failure rates) evaluates the complex impact of location and reliability.

The failure rate of OCGT at Fawley is based on the average value of λ for OCGT units in the NGC system. The original data was a FOR of 0.0 %. Table 8.6 shows the failure rates used in the SW test and the data used to compute them.

Table 8.6 Failure Rate of Generators SW System

Generator	Node	Pmax [MW]	Type	Year	FOR	MTTR [hr]	λ [fail/yr]
DIDCA1	DIDC0	490	Large Coal	1972-1975	0.159	48.9	33.923
DIDCA2	DIDC0	490	Large Coal	1972-1975	0.159	48.9	33.902
DIDCA3	DIDC0	490	Large Coal	1972-1975			5.610
DIDCA4	DIDC0	490	Large Coal	1972-1975	0.159	48.9	33.904
DIDCA3G	DIDC0	25	OCGT	1968-1970	0.120	53.2	22.441
DIDCA4G	DIDC0	25	OCGT	1968-1970	0.120	53.2	22.441
DUNGA1	DUNG4	112	Magnox	1965	0.132	93.8	14.209
DUNGA2	DUNG4	112	Magnox	1965	0.132	93.8	14.209
DUNGA3	DUNG4	112	Magnox	1965	0.132	93.8	14.203
DUNGA4	DUNG4	112	Magnox	1965	0.132	93.8	14.203
DUNGB21	DUNG4	600	Nuclear	1985-1989	0.091	93.8	9.366
DUNGB22	DUNG4	600	Nuclear	1985-1989	0.093	93.8	9.565
FAWL3	FAWL0	484	Oil	1969-1970	0.041	67.5	5.610
FAWL1G	FAWL0	17	OCGT	1969-1970	0.048	53.2	8.352
FAWL3G	FAWL0	17	OCGT	1969-1970	0.048	53.2	8.352
FRANCE1	DUNG4	497	Interconnection				0.074
FRANCE2	DUNG4	497	Interconnection				0.074
HINPA1	HINP0J	80	Magnox	1965	0.082	93.8	8.360
HINPA2	HINP0J	80	Magnox	1965	0.082	93.8	8.360
HINPA3	HINP0J	80	Magnox	1965	0.082	93.8	8.360
HINPA4	HINP0K	80	Magnox	1965	0.078	93.8	7.898
HINPA5	HINP0K	80	Magnox	1965	0.078	93.8	7.898
HINPA6	HINP0K	80	Magnox	1965	0.078	93.8	7.898
HINPB1	HINP0	635	Nuclear	1976-1978	0.073	93.8	7.319
HINPB2	HINP0	635	Nuclear	1976-1978	0.074	93.8	7.482

Data for Coal, Oil and OCGT is believed to be very accurate. NGC 93
Fawley OCGT Units using average rates from NGC 93
MTTR from CEA

Failure rates for lines were computed based on the length of the lines and the average values of λ, provided for the Canadian system [1], taking into account the line's voltage level. Reference [1] also provides failure rate data for transformers and compensation equipment.

8.4 Weather Modelling

The Value of Security Assessor program has the capability to include weather effects on the failure rates of transmission equipment. Reference [7] explains the modelling characteristics used in the program. The number of weather states defined depends on the study. A detailed modelling is not always necessary. The effect of adverse weather conditions is evaluated for testing purposes. In this way only two weather conditions are used: adverse weather and normal weather conditions. Table 8.7 gives the data used in these tests.

Table 8.7 Weather Model for Preliminary Test - SW System

Weather State	Duration Factor [%]		Proportion Factor of Failures [%]
	Season (Winter)	Year	
Adverse	2	1	70
Other Condition	98	99	30

These factors have been computed as follow:

- The proportion of failures factor in adverse weather was computed from data collected in the Canadian system for the period 1991-1995 [10]. 67% of permanent failures take place in adverse weather conditions at 300 kV to 400 kV for any type of supporting structures. The proportion factor is 68% for supporting structures in steel. 72% of 110-149 kV line failures occur in adverse weather.

- It is assumed that adverse weather conditions have an average duration of 5 hours and take place every 750 hours based on a yearly average and every 300 hours on a (winter) seasonal average.

8.5 VOLL Modelling

VOLL is a function of the duration of interruption computed from the sector customer damage functions (SCDF) provided in [11]. A consumer distribution of 35% residential consumers, 27% commercial consumers, 34% industrial consumers and 4% large users is assumed in order to compute the VOLL. The assumed busbar's load factor is 0.65. Table 8.8 gives the VOLL function used in this study computed by the Value of Security Assessor program.

Table 8.8 VOLL function for Assessor's Tests

Duration of interruption	VOLL [£/kWh]
1 min	258.21
20 min	28.75
1 hr	18.37
4 hr	14.14
8 hr	12.55
24 hr	5.60

8.6 Load Restoration Modelling

The restoration model and data presented in reference [6] was used in this study. Table 8.9 gives the corresponding data.

Table 8.9 Load Restoration Rates - SW System

Time Period [min]	Restoration Rate [MW/min]
0 – 30	10.0
30 – 60	33.3
60 – 90	66.6
90 and more	83.3

9 APPENDIX B – NGC SYSTEM DATA

This appendix presents some characteristics of the data employed with the NGC system 1996/97 system for testing the Value of Security Assessor program.

9.1 Probabilistic Data

The failures rates (λ) for the generators have been computed from the forced outage rates (FOR) of each generator provided in reference [3] and mean time to repair (MTTR) provided in reference [4]. The MTTR values were selected based on the generator type and generator size. For nuclear generators the available data is only for units with capacities greater than 400 MW, however the MTTR for these units was used for all nuclear units in this study. Table 9.1 shows the failure rates used in this study and the data used to compute them. Failure rates for lines were computed based on the length of the lines and the average values of λ, provided for the Canadian system [1], taking into account the line's voltage level. Reference [1] also provides failure rate data for transformers and compensation equipment.

Table 9.1 Failure Rate of Generators - NGC System

Generator	Node	Pmax [MW]	Type	Year	FOR	MTTR [hr]	λ [fail/yr]
COCK	GEN1						0.000
HUER	GEN2						0.000
KINC	GEN3						0.000
LOAN	GEN4						0.000
PEHE	GEN5						0.000
TORN	GEN6						0.000
ABTH-7	GEN7	485	Large Coal	1976	0.126	48.9	25.765
ABTH-8	GEN8	485	Large Coal	1971	0.126	48.9	25.765
BLYT-8	GEN9	313	Medium Co	1966	0.121	60.2	20.119
COTT-1	GEN10	497	Large Coal	1969	0.074	48.9	14.420
COTT-2	GEN11	497	Large Coal	1969	0.074	48.9	14.420
COTT-3	GEN12	517	Large Coal	1970	0.074	48.9	14.410
COTT-4	GEN13	497	Large Coal	1970	0.074	48.9	14.406
DIDC-1	GEN14	490	Large Coal	1972-1975	0.159	48.9	33.923
DIDC-2	GEN15	490	Large Coal	1972-1975	0.159	48.9	33.902
DIDC-3	GEN16	490	Large Coal	1972-1975	0.159	53.2	31.164
DIDC-4	GEN17	490	Large Coal	1972-1975	0.159	48.9	33.904
DINO-5	GEN18	288	Pumped Sto	1984	0.039	24.0	14.877
DRAX-1	GEN19	645	Large Coal	1974	0.071	48.9	13.763
DRAX-2	GEN20	645	Large Coal	1974	0.071	48.9	13.758
DRAX-3	GEN21	645	Large Coal	1976	0.071	48.9	13.764
DRAX-4	GEN22	645	Large Coal	1984	0.071	48.9	13.743
DRAX-5	GEN23	645	Large Coal	1985	0.092	48.9	18.210
DRAX-6	GEN24	645	Large Coal	1986	0.071	48.9	13.760
DUNG-1	GEN25	111	Magnox	1965	0.132	93.8	14.209
DUNG-2	GEN26	111	Magnox	1965	0.132	93.8	14.209
DUNG-3	GEN27	111	Magnox	1965	0.132	93.8	14.203
DUNG-4	GEN28	112	Magnox	1965	0.132	93.8	14.203
DUNG91	GEN29	545	Nuclear	1985-1989	0.091	93.8	9.366
DUNG92	GEN30	558	Nuclear	1985-1989	0.093	93.8	9.565

Table 9.1 Failure Rate of Generators - NGC System (Continuation)

Generator	Node	Pmax [MW]	Type	Year	FOR	MTTR [hr]	λ [fail/yr]
EGGB-1	GEN31	505	Large Coal	1968	0.066	48.9	12.661
EGGB-2	GEN32	490	Large Coal	1968	0.066	48.9	12.648
EGGB-3	GEN33	505	Large Coal	1968	0.066	48.9	12.656
EGGB-4	GEN34	505	Large Coal	1969	0.066	48.9	12.656
FERR-1	GEN35	490	Large Coal	1966	0.096	48.9	18.993
FERR-2	GEN36	490	Large Coal	1967	0.096	48.9	19.004
HATL-1	GEN37	613	Nuclear	1989	0.057	93.8	5.692
HATL-2	GEN38	624	Nuclear	1989			5.514
HEYS-1	GEN39	575	Nuclear	1989			4.246
HEYS-2	GEN40	573	Nuclear	1989			4.241
HEYS-7	GEN41	657	Nuclear	1989			8.275
HEYS-8	GEN42	663	Nuclear	1989	0.083	93.8	8.421
HINP-7	GEN43	645	Nuclear	1976-1978	0.073	93.8	7.319
HINP-8	GEN44	655	Nuclear	1976-1978	0.074	93.8	7.482
INCE-5	GEN45	450	Orimulsion	1982	0.167	36.1	48.520
IRON-1	GEN46	485	Large Coal	1970	0.105	48.9	21.040
IRON-2	GEN47	485	Large Coal	1970	0.105	48.9	21.049
KILLI0	GEN48	150	CCGT	1992	0.040	42.7	8.549
KILLI1	GEN49	150	CCGT	1992	0.040	42.7	8.549
KILLI2	GEN50	150	CCGT	1992	0.050	42.7	10.800
KILLZ0	GEN51	141	CCGT	1993	0.103	42.7	23.622
KILLZ1	GEN52	141	CCGT	1993	0.103	42.7	23.622
KILLZ2	GEN53	141	CCGT	1993	0.103	42.7	23.622
KINO-1	GEN54	485	Large Coal	1970	0.093	48.9	18.324
KINO-2	GEN55	485	Large Coal	1971	0.093	48.9	18.339
KINO-3	GEN56	485	Large Coal	1972	0.093	48.9	18.314
KINO-4	GEN57	485	Large Coal	1973			18.317
RATS-1	GEN58	500	Large Coal	1968			13.633
RATS-2	GEN59	500	Large Coal	1969			13.628
RATS-3	GEN60	500	Large Coal	1969			13.621
RATS-4	GEN61	500	Large Coal	1970			17.521
RUGE-5	GEN62	498	Large Coal	1972	0.072	48.9	13.841
RUGE-6	GEN63	498	Large Coal	1972	0.072	48.9	13.841
RUGE-7	GEN64	498	Large Coal	1972	0.072	48.9	13.844
RYEH-1	GEN65	263	CCGT	1993	0.176	24.7	75.814
RYEHG1	GEN66	159	CCGT	1993	0.176	42.7	43.883
RYEHG2	GEN67	159	CCGT	1993	0.176	42.7	43.883
RYEHG3	GEN68	159	CCGT	1993	0.176	42.7	43.883
SELLA1	GEN69	1988	France Exp	0	0.000	0.0	0.074
SIZE-1	GEN70	215	Magnox	1966	0.136	93.8	14.749
SIZE-2	GEN71	215	Magnox	1966	0.104	93.8	10.823
TILB-7	GEN72	340	Medium Co	1968	0.123	60.2	20.504
WBUR-1	GEN73	493	Large Coal	1967	0.089	48.9	17.498
WBUR-2	GEN74	493	Large Coal	1967	0.089	48.9	17.502
WBUR-3	GEN75	493	Large Coal	1967	0.089	48.9	17.514
WBUR-4	GEN76	493	Large Coal	1968	0.089	48.9	17.502
WILL-5	GEN77	188	Medium Co	1962	0.062	29.6	19.538
WILL-6	GEN78	188	Medium Co	1963	0.062	29.6	19.516
WYLF-1	GEN79	262	Magnox	1971	0.007	93.8	0.633
WYLF-2	GEN80	262	Magnox	1971	0.007	93.8	0.633
WYLF-3	GEN81	262	Magnox	1971	0.005	93.8	0.425
WYLF-4	GEN82	262.47	Magnox	1971	0.005	93.8	0.425

9.2 Weather Modelling

The Value of Security Assessor program has the capability to include weather effects on the failure rates of transmission equipment. Reference [7] explains the modelling characteristics used in the program. The number of weather states defined depends on the study. A detailed modelling is not always necessary. The effect of adverse weather conditions is evaluated for testing purposes. In this way only two weather conditions are used for testing the NGC system 1996/97: adverse weather and normal weather conditions. The same modelling has been used in the SW system (section 8.4).

9.3 VOLL Modelling

VOLL is a function of the duration of interruption computed from the sector customer damage functions (SCDF) provided in [11]. A consumer distribution of 35% residential consumers, 27% commercial consumers, 34% industrial consumers and 4% large users is assumed in order to compute the VOLL. The assumed busbar's load factor is 0.65. Table 8.8 gives the VOLL function used in this study computed by the Value of Security Assessor program.

9.4 Load Restoration Modelling

The restoration model and data presented in reference [6] was used in this study. Table 9.2 gives the corresponding data.

Table 9.2 Load Restoration Rates – NGC System

Time Period [min]	Restoration Rate [MW/min]
0 – 20	10.0
20 – 40	21.6
40 – 60	33.3
60 – 80	50.0
80 – 100	66.6
100 and more	83.3