PSSE Contingency Analysis

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Chapter 1

Introduction

1.1 Study Description

The Year 1 Topology 1 contingency analysis of the hypothetical SAVNW system is carried out to report the branches reporting loading greater than 100% and buses reporting upper and lower voltage limit violations.

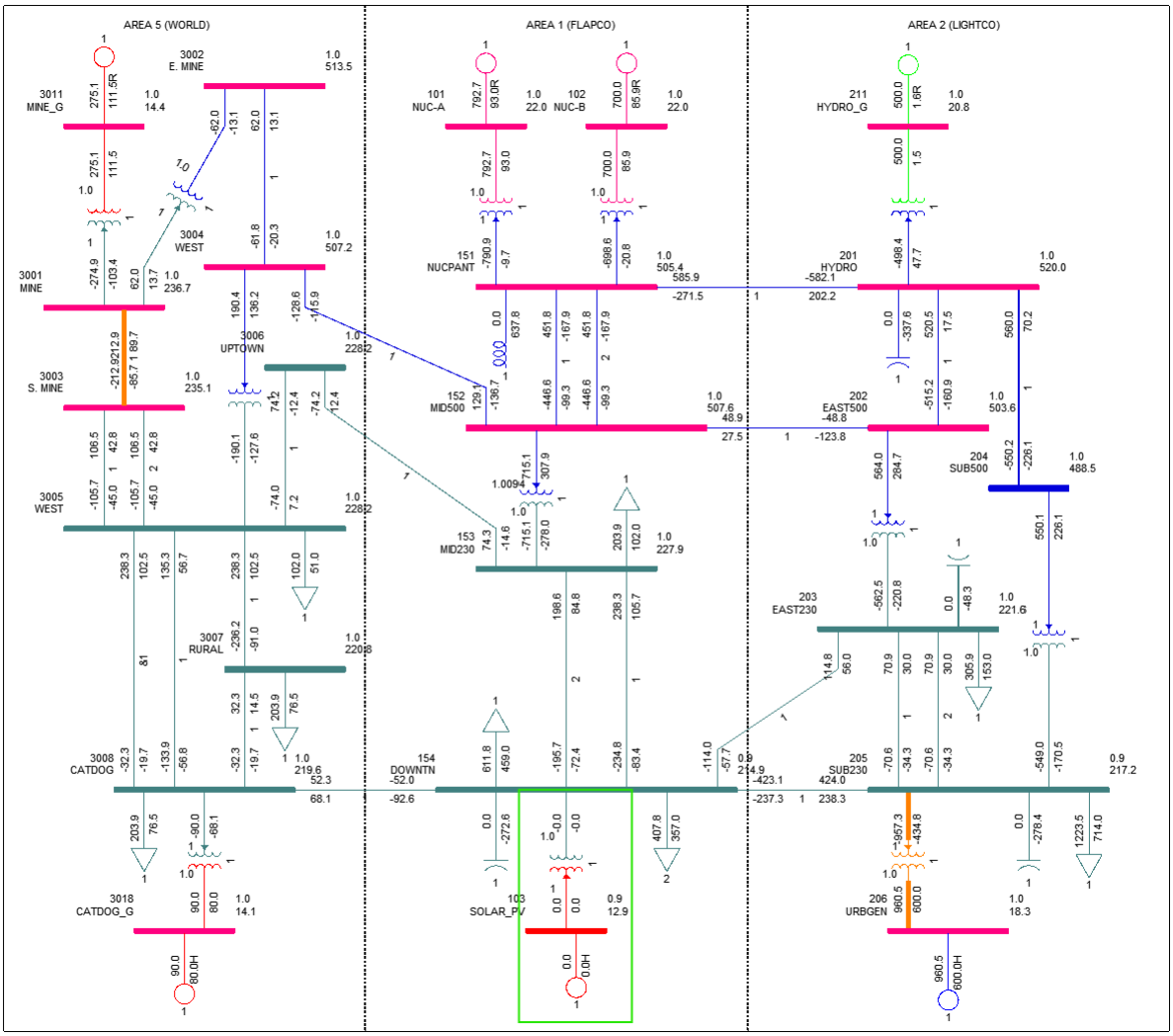

Figure 1.1: Single Line Diagram Year 1, Topology 1

For the hypothetical SAVNW system, in year 1, the solar farm in area 2 is operational. The solar farm has an

installed capacity of 117 MW. For the Year 1 - Topology 1, there are 7 generators in 3 areas. Total installed capacity of the system is a combination of firm capacity provided by already existing 6 generating units of 4153.25 MW and the non-firm capacity 117 MW added to the system by the solar farm at Bus 103. Solar being an intermittent resource, the output is varying with no output expected from it at night. In this study the intermittent behaviour of solar farm in taken into account by considering 3 output cases. A 0 MW output case is considered when there is no output from solar farm along with an average expected output of 50 MW and a maximum expected output of 100 MW. For Year 1 topology in addition to the three generation scenarios, three forecasted load scenarios are also studied.

Detailed analysis of Year 1 Topology 1 Base Case was carried out. Analysis of system totals by area, generator contributions to each scenario and the considered load scenarios can be found here. The overload and voltage violations can be found here.

1.2 Contingency Analysis

AC contingency calculation was conducted on the hypothetical SAVNW system for 9 different scenarios and hence on 9 different case files corresponding to Topology 1. The same configuration files are used for the 9 scenarios and are:

- Subsystem file savnw.sub - Studied subsystems of the studied scenario/ case are defined via the Subsystem Definition data file (Figure 1.2)
- Monitor file savnw.mon - Monitored Element Data File identifies the branches that are to be monitored for flow violations and the buses that are to be monitored for voltage violations (Figure 1.3)
- Contingency file savnw.con - Contingency cases that are to be tested are defined in the Contingency Definition data file (Figure 1.4)

```
SUBSYSTEM CON
 AREA 1
 AREA 2
 AREA 5
END

SUBSYSTEM MON
 AREA 1
 AREA 2
 AREA 5
END

END
```

Figure 1.2: The subsystem file corresponding to Year 1 Topology 1

```
MONITOR VOLTAGE RANGE ALL BUSES 0.9 1.1
MONITOR ALL BRANCHES
MONITOR TIES FROM AREA 1 TO AREAS 2 5
MONITOR TIES FROM AREA 2 TO AREA 5
END
END
```

Figure 1.3: The monitored file corresponding to Year 1 Topology 1

```
SINGLE BRANCH IN AREA 1
SINGLE BRANCH IN AREA 2
SINGLE BRANCH IN AREA 5
SINGLE BUS IN AREA 1
SINGLE BUS IN AREA 2
SINGLE BUS IN AREA 5
SINGLE MACHINE IN AREA 1
SINGLE MACHINE IN AREA 2
SINGLE MACHINE IN AREA 5
END
```

Figure 1.4: The contingency file corresponding to Year 1 Topology 1

For each of the 9 studied scenarios, the API DFAX_2 is used to construct 9 different distribution factor data files corresponding to each .sav file, and the above defined .sub, .mon, .con configuration files. For each of the 9 scenarios, by running the AC contingency calculation function ACCC_WITH_DSP_3, the contingency solution output .acc files are obtained.

Python code to conduct AC contingency calculation is:

```
import psspy
list_gens = [0,50,100]
list_lsc = ['lls','rls','hls']
for gen in list_gens:
    for lsc in list_lsc:
        file_in = 'sav\savnw_sol_' + str(gen) +'_'+ lsc +'.sav'
        file_dist = 'savnw_sol_' + str(gen) +'_'+ lsc + '.dfx'
        file_out = 'savnw_sol_' + str(gen) +'_'+ lsc + '.acc'
        file_sav = r"{}".format(file_in)
        file_dfx = r"{}".format(file_dist)
        file_acc = r"{}".format(file_out)
        psspy.case(file_in)
        psspy.fdns([0,1,0,0,0,0,0,0])
        psspy.dfax_2([1,1,0],r"""savnw.sub""",r"""savnw.mon""",r"""savnw.con""",file_dfx)
        psspy.accc_with_dsp_3(0.1,[0,1,0,0,0,0,0,0,0,0,0],"",file_dfx,file_acc,"","","")
```

For each of the 9 scenarios, using the contingency solution output files, the results are exported as excel files for further analysis. The results exported are ACCC Analysis Summary, Monitored Branch Flows (MVA), Monitored Bus Voltages.

Python code to export AC contingency solution output file as excel is:

```
import psspy
import pssexcel
list_gens = [0,50,100]
list_lsc = ['lls','rls','hls']
for gen in list_gens:
    for lsc in list_lsc:
        file_in = 'acc\savnw_sol_' + str(gen) +'_'+ lsc + '.acc'
        file_out = 'savnw_sol_' + str(gen) +'_'+ lsc + '.xlsx'
        file_acc = r"{}".format(file_in)
        file_xlsx = r"{}".format(file_out)
        pssexcel.accc(file_acc, ['s','v','g','l','b','i','n','w'], colabel='',stype='contingency',
                                                    busmsm=0.5, sysmsm=5.0,
                      rating='a', namesplit=False,xlsfile=file_out, sheet='', overwritesheet=True
                                                    , show=False, ratecon='b',
                      baseflowvio=True,basevoltvio=True, flowlimit=100.0, flowchange=0.0,
                                                    voltchange=0.0,swdrating='
                                                    a',
                      swdratecon='b',baseswdflowvio=False,basenodevoltvio=False,overloadreport=
                                                    False)
```

Contingency analysis was carried out in PSSE for each of the studied scenario for Year 1 Topology 1. It was seen that the power flow solution did not converge for some of the tested contingencies for the studied scenario. For each of the studied scenario, the contingencies for which power flow solution did not converge are:

- Solar = 0 MW, LLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, SING OPN LIN 15 205-206(1)
- Solar = 0 MW, RLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, BUS 151, SING OPN LIN 15 205-206(1)
- Solar = 0 MW, HLS
  - BUS 202, BUS 154, BUS 201, UNIT 206(1), BUS 152, BUS 151, SING OPN LIN 15 205-206(1)
- Solar = 50 MW, LLS
  - BUS 201, BUS 154, BUS 152
- Solar = 50 MW, RLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, SING OPN LIN 15 205-206(1)

- Solar = 50 MW, HLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, BUS 151, SING OPN LIN 15 205-206(1)
- Solar = 100 MW, LLS
  - BUS 201, BUS 154, BUS 152
- Solar = 100 MW, RLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, SING OPN LIN 15 205-206(1)
- Solar = 100 MW, HLS
  - BUS 154, BUS 201, UNIT 206(1), BUS 152, BUS 151, SING OPN LIN 15 205-206(1)

For the converged contingencies for each of the studied scenario, the results of the contingency analysis were analysed to check for branch overload ($> 100\%$) and out of range bus voltage violations (lower emergency limit $< 0.9PU$ and upper emergency limit $> 1.1PU$). It was seen that for some of the contingencies there were no branch overload or bus voltage violations reported. Rest of the contingencies violating branch overload and bus voltage emergency ranges are reported in the subsequent chapters. Chapter 2 of this document gives the observed branch flow violations for each of the studied scenario. Chapter 4 gives the lower voltage violations reported for each of the studied scenarios. Chapter 3 gives the upper voltage violations reported for each of the studied scenarios. To conclude, Chapter 5 summarises the result of the contingency analysis carried out on Year 1, Topology 1 of the hypothetical SAVNW system.

Chapter 2

Branch Overload Violation

2.1 Introduction

In this chapter, for each of the studied scenario, the branches that are loaded more than 100% of their rating is tabulated. Branches that are loaded more than 130% of the rating are said to be severely/ critically loaded and are noted down for reporting as operating these branches for prolonged duration is not recommended for a safe and reliable power system.

2.2 Solar = 0 MW, LLS

For the studied scenario Solar = 0 MW, LLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingency UNIT 101(1), for the branches 3001-3003(1), 3003-3005(1), 3003-3005(2) for the bus fault contingency BUS 151, and for the branch 3001-3003(1) for single line open contingencies SING OPN LIN 1 101-151(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	513.17	496.15	300.00	165.38

Table 2.1: Unit faults reporting branch flow greater than 100% for scenario Solar = 0 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	BUS 151	1026.47	1030.17	300.00	343.39
3001 MINE 230.00 3011 MINE_G 13.800 1	BUS 151	-1606.05	1606.05	1560.00	102.95
3003 S. MINE 230.00 3005 WEST 230.00 1	BUS 151	505.93	515.08	350.00	147.17
3003 S. MINE 230.00 3005 WEST 230.00 2	BUS 151	505.93	515.08	350.00	147.17
3005 WEST 230.00 3007 RURAL 230.00 1	BUS 151	-346.44	369.36	350.00	105.53
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-345.16	353.67	350.00	101.05
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	284.68	318.15	250.00	127.26

Table 2.2: Bus faults reporting branch flow greater than 100% for scenario Solar = 0 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	513.17	496.15	300.00	165.38
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-346.58	355.41	350.00	101.55

Table 2.3: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 0 MW, LLS

2.3 Solar = 0 MW, RLS

For the studied scenario Solar = 0 MW, RLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingency UNIT 101(1) and single line open contingency SING OPN LIN 1 101-151(1), and for the branch 154-203(1) for the bus fault contingency BUS 205.

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	568.29	550.89	300.00	183.63
205 SUB230 230.00 206 URBGEN 18.000 1	UNIT 211(1)	-1253.09	1253.09	1250.00	100.25

Table 2.4: Unit faults reporting branch flow greater than 100% for scenario Solar = 0 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-354.71	364.24	350.00	104.07
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 205	-321.62	375.49	350.00	107.28
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	297.88	347.78	250.00	139.11

Table 2.5: Bus faults reporting branch flow greater than 100% for scenario Solar = 0 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	568.29	550.89	300.00	183.63
154 DOWNTN 230.00 205 SUB230 230.00 1	SING OPN LIN 6 152-153(1)	672.26	694.04	660.00	105.16
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 10 201-205(&1)	-324.03	351.40	350.00	100.40
205 SUB230 230.00 206 URBGEN 18.000 1	SING OPN LIN 11 201-211(1)	-1253.06	1253.06	1250.00	100.25
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-356.57	366.46	350.00	104.70

Table 2.6: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 0 MW, RLS

2.4 Solar = 0 MW, HLS

For the studied scenario Solar = 0 MW, HLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingencies UNIT 101(1) and single line open contingency SING OPN LIN 1 101-151(1), and for the branch 154-203(1) for the bus fault contingency BUS 205.

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	612.37	595.00	300.00	198.33
101 NUC-A 21.600 151 NUCPANT 500.00 1	UNIT 102(1)	1377.00	1377.00	1350.00	102.00
205 SUB230 230.00 206 URBGEN 18.000 1	UNIT 211(1)	-1327.88	1327.88	1250.00	106.23

Table 2.7: Unit faults reporting branch flow greater than 100% for scenario Solar = 0 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
154 DOWNTN 230.00 205 SUB230 230.00 1	BUS 153	649.27	670.42	660.00	101.58
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-362.58	372.97	350.00	106.56
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 205	-335.66	409.71	350.00	117.06
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	308.70	376.80	250.00	150.72

Table 2.8: Bus faults reporting branch flow greater than 100% for scenario Solar = 0 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	612.37	595.00	300.00	198.33
101 NUC-A 21.600 151 NUCPANT 500.00 1	SING OPN LIN 2 102-151(1)	1377.00	1377.00	1350.00	102.00
154 DOWNTN 230.00 205 SUB230 230.00 1	SING OPN LIN 6 152-153(1)	717.09	750.02	660.00	113.64
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 10 201-205(&1)	-338.42	399.53	350.00	114.15
205 SUB230 230.00 206 URBGEN 18.000 1	SING OPN LIN 11 201-211(1)	-1327.86	1327.86	1250.00	106.23
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-372.18	406.86	350.00	116.25

Table 2.9: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 0 MW, HLS

2.5 Solar = 50 MW, LLS

For the studied scenario Solar = 50 MW, LLS, loading greater than 130% were reported for the branch 3001-3003(1) for unit fault contingencies UNIT 101(1), UNIT 206(1), for single line open contingencies SING OPN LIN 1 101-151(1), SING OPN LIN 15 205-206(1), and for the branches 3001-3003(1), 3003-3005(1), 3003-3005(2) for the bus fault contingency BUS 151.

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	479.02	462.62	300.00	154.21
153 MID230 230.00 154 DOWNTN 230.00 1	UNIT 206(1)	-319.68	370.72	350.00	105.92
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 206(1)	647.55	641.38	300.00	213.79
3005 WEST 230.00 3007 RURAL 230.00 1	UNIT 206(1)	-325.74	359.78	350.00	102.79

Table 2.10: Unit faults reporting branch flow greater than 100% for scenario Solar = 50 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	BUS 151	985.23	984.52	300.00	328.17
3003 S. MINE 230.00 3005 WEST 230.00 1	BUS 151	486.35	492.26	350.00	140.65
3003 S. MINE 230.00 3005 WEST 230.00 2	BUS 151	486.35	492.26	350.00	140.65
3005 WEST 230.00 3007 RURAL 230.00 1	BUS 151	-336.71	356.53	350.00	101.86
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	271.60	300.48	250.00	120.19

Table 2.11: Bus faults reporting branch flow greater than 100% for scenario Solar = 50 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	479.02	462.62	300.00	154.21
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 15 205-206(1)	-319.68	370.72	350.00	105.92
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 15 205-206(1)	647.55	641.38	300.00	213.79
3005 WEST 230.00 3007 RURAL 230.00 1	SING OPN LIN 15 205-206(1)	-325.74	359.78	350.00	102.79

Table 2.12: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 50 MW, LLS

2.6 Solar = 50 MW, RLS

For the studied scenario Solar = 50 MW, RLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingency UNIT 101(1), for the branches 3001-3003(1), 3003-3005(1), 3003-3005(2) for the bus fault contingency BUS 151, for the branch 154-203(1) for the bus fault contingency BUS 205, and for the branch 3001-3003(1) for single line open contingency SING OPN LIN 1 101-151(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	533.75	516.73	300.00	172.24

Table 2.13: Unit faults reporting branch flow greater than 100% for scenario Solar = 50 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
153 MID230 230.00 3006 UPTOWN 230.00 1	BUS 151	-329.34	377.95	350.00	107.99
3001 MINE 230.00 3003 S. MINE 230.00 1	BUS 151	1117.38	1159.84	300.00	386.61
3001 MINE 230.00 3011 MINE_G 13.800 1	BUS 151	-1805.06	1805.06	1560.00	115.71
3003 S. MINE 230.00 3005 WEST 230.00 1	BUS 151	-499.62	580.89	350.00	165.97
3003 S. MINE 230.00 3005 WEST 230.00 2	BUS 151	-499.62	580.89	350.00	165.97
3005 WEST 230.00 3006 UPTOWN 230.00 1	BUS 151	326.17	379.22	350.00	108.35
3005 WEST 230.00 3007 RURAL 230.00 1	BUS 151	-354.86	424.54	350.00	121.30
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-344.74	353.82	350.00	101.09
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 205	-309.30	356.38	350.00	101.82
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	285.04	328.43	250.00	131.37

Table 2.14: Bus faults reporting branch flow greater than 100% for scenario Solar = 50 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	533.75	516.73	300.00	172.24
154 DOWNTN 230.00 205 SUB230 230.00 1	SING OPN LIN 6 152-153(1)	642.92	663.52	660.00	100.53
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-346.37	355.80	350.00	101.66

Table 2.15: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 50 MW, RLS

2.7 Solar = 50 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	577.57	560.36	300.00	186.79
205 SUB230 230.00 206 URBGEN 18.000 1	UNIT 211(1)	-1323.48	1323.48	1250.00	105.88

Table 2.16: Unit faults reporting branch flow greater than 100% for scenario Solar = 50 MW, HLS

For the studied scenario Solar = 50 MW, HLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingency UNIT 101(1), for the branch 154-203(1) for the bus fault contingency BUS 205, and for the branch 3001-3003(1) for single line open contingency SING OPN LIN 1 101-151(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 202	-320.34	376.82	350.00	107.66
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-352.26	362.17	350.00	103.48
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 205	-323.57	388.14	350.00	110.90
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	296.06	355.14	250.00	142.06

Table 2.17: Bus faults reporting branch flow greater than 100% for scenario Solar = 50 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	577.57	560.36	300.00	186.79
154 DOWNTN 230.00 205 SUB230 230.00 1	SING OPN LIN 6 152-153(1)	690.45	713.82	660.00	108.15
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 10 201-205(&1)	-326.81	376.29	350.00	107.51
205 SUB230 230.00 206 URBGEN 18.000 1	SING OPN LIN 11 201-211(1)	-1323.45	1323.45	1250.00	105.88
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-356.29	372.29	350.00	106.37

Table 2.18: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 50 MW, HLS

2.8 Solar = 100 MW, LLS

For the studied scenario Solar = 100 MW, LLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingencies UNIT 101(1), UNIT 206(1), for the branches 3001-3003(1), 3003-3005(1), 3003-3005(2) for the bus fault contingency BUS 151, and for single line open contingencies SING OPN LIN 1 101-151(1) and SING OPN LIN 15 205-206(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	445.39	429.71	300.00	143.24
153 MID230 230.00 154 DOWNTN 230.00 1	UNIT 206(1)	-312.25	360.29	350.00	102.94
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 206(1)	642.96	636.21	300.00	212.07
3005 WEST 230.00 3007 RURAL 230.00 1	UNIT 206(1)	-322.06	354.27	350.00	101.22

Table 2.19: Unit faults reporting branch flow greater than 100% for scenario Solar = 100 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	BUS 151	937.87	932.95	300.00	310.98
3003 S. MINE 230.00 3005 WEST 230.00 1	BUS 151	463.70	466.47	350.00	133.28
3003 S. MINE 230.00 3005 WEST 230.00 2	BUS 151	463.70	466.47	350.00	133.28
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	259.17	284.87	250.00	113.95

Table 2.20: Bus faults reporting branch flow greater than 100% for scenario Solar = 100 MW, LLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	445.39	429.71	300.00	143.24
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 15 205-206(1)	-312.25	360.29	350.00	102.94
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 15 205-206(1)	642.96	636.21	300.00	212.07
3005 WEST 230.00 3007 RURAL 230.00 1	SING OPN LIN 15 205-206(1)	-322.06	354.27	350.00	101.22

Table 2.21: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 100 MW, LLS

2.9 Solar = 100 MW, RLS

For the studied scenario Solar = 100 MW, RLS, loading greater than 130% were reported for the branches 3001-3003(1) for the unit fault contingency UNIT 101(1), for the branches 3001-3003(1), 3003-3005(1), 3003-3005(2) for the bus fault contingency BUS 151, and for the branch 3001-3003(1) for single line open contingency SING OPN LIN 1 101-151(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	499.44	482.94	300.00	160.98

Table 2.22: Unit faults reporting branch flow greater than 100% for scenario Solar = 100 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	BUS 151	1009.59	1012.10	300.00	337.37
3001 MINE 230.00 3011 MINE_G 13.800 1	BUS 151	-1576.73	1576.73	1560.00	101.07
3003 S. MINE 230.00 3005 WEST 230.00 1	BUS 151	-482.23	506.06	350.00	144.59
3003 S. MINE 230.00 3005 WEST 230.00 2	BUS 151	-482.23	506.06	350.00	144.59
3005 WEST 230.00 3007 RURAL 230.00 1	BUS 151	-345.24	368.28	350.00	105.22
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	272.88	311.80	250.00	124.72

Table 2.23: Bus faults reporting branch flow greater than 100% for scenario Solar = 100 MW, RLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	499.44	482.94	300.00	160.98

Table 2.24: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 100 MW, RLS

2.10 Solar = 100 MW, HLS

For the studied scenario Solar = 100 MW, HLS, loading greater than 130% were reported for the branch 3001-3003(1) for the unit fault contingency UNIT 101(1), for the branch 154-203(1) for the bus fault contingency BUS 205, and for the branch 3001-3003(1) for single line open contingencies SING OPN LIN 1 101-151(1).

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	UNIT 101(1)	543.04	526.14	300.00	175.38
205 SUB230 230.00 206 URBGEN 18.000 1	UNIT 211(1)	-1320.38	1320.38	1250.00	105.63

Table 2.25: Unit faults reporting branch flow greater than 100% for scenario Solar = 100 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 202	-310.34	359.43	350.00	102.69
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 203	-342.40	351.91	350.00	100.55
153 MID230 230.00 154 DOWNTN 230.00 1	BUS 205	-312.22	370.53	350.00	105.87
154 DOWNTN 230.00 203 EAST230 230.00 1	BUS 205	284.22	337.30	250.00	134.92

Table 2.26: Bus faults reporting branch flow greater than 100% for scenario Solar = 100 MW, HLS

Branch	Contingency	MVA Flow	AMP Flow	Rate	Loading
3001 MINE 230.00 3003 S. MINE 230.00 1	SING OPN LIN 1 101-151(1)	543.04	526.14	300.00	175.38
154 DOWNTN 230.00 205 SUB230 230.00 1	SING OPN LIN 6 152-153(1)	663.58	685.92	660.00	103.93
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 10 201-205(&1)	-316.02	358.47	350.00	102.42
205 SUB230 230.00 206 URBGEN 18.000 1	SING OPN LIN 11 201-211(1)	-1320.36	1320.36	1250.00	105.63
153 MID230 230.00 154 DOWNTN 230.00 1	SING OPN LIN 12 202-203(1)	-344.05	353.93	350.00	101.12

Table 2.27: Single line open contingencies reporting branch flow greater than 100% for scenario Solar = 100 MW, HLS

2.11 Results Summary

The Table 2.28 summarises the results of the AC contingency calculation carried out on the hypothetical SAVNW system for Topology 1 for branch overload violations, by tabulating the summary of branch load violation grouped by scenario and contingency to give the branches overloaded and count of the branches overloaded. It can be seen that the scenario and contingency for which system is most overloaded is the scenario Solar = 50 MW, RLS and bus fault BUS 151, resulting in 7 branch load violations. The system scenario for the bus fault needs to be studied for long term planning for system reinforcements, and operational planning for alternate dispatch arrangements, demand side measures to ensure system operates within the specified tolerance levels such a contingency occurs. The table gives the branch overload violation count in descending order, and as can be seen the scenarios with the greatest number of violations grouped by Scenario and contingency followed by Solar = 50 MW, RLS & BUS 151 are the Solar = 0 MW, LLS & BUS 151, Solar = 100 MW, RLS & BUS 151 with 5 violations and Solar = 50 MW, LLS & BUS 151 with 4 violations. As can be seen from the Appendix, Table 5.2, the contingency reporting the most number of load violation is the bus fault BUS 151 with 24, followed by the bus fault BUS 205. The single open line contingency reporting the most number of overload violation is the SING OPN LIN 1 101-151(1) with 9 violations. The unit fault contingency with most number of overload violation is the UNIT 101(1) with 9 violations. The branches reporting the most number of violations are 3001-3003(1) and 153-154(1) which reported a loading violation for 27 times each followed by 154-203(1) with 9, 3005-3007(1) with 8, and 205-206(1) with 8 violations respectively. The Table 5.3 in the Appendix gives count of branches exceeding the overload > 100%.

Scenario	Contingency	Branches	Branch Count
Solar = 50 MW, RLS	BUS 151	153-3006(1),3001-3003(1),3001-3011(1),3003-3005(1),3003-3005(2),3005-3006(1),3005-3007(1)	7
Solar = 0 MW, LLS	BUS 151	3001-3003(1),3001-3011(1),3003-3005(1),3003-3005(2),3005-3007(1)	5
Solar = 100 MW, RLS	BUS 151	3001-3003(1),3001-3011(1),3003-3005(1),3003-3005(2),3005-3007(1)	5
Solar = 50 MW, LLS	BUS 151	3001-3003(1),3003-3005(1),3003-3005(2),3005-3007(1)	4
Solar = 50 MW, LLS	SING OPN LIN 15 205-206(1)	153-154(1),3001-3003(1),3005-3007(1)	3
Solar = 100 MW, LLS	BUS 151	3001-3003(1),3003-3005(1),3003-3005(2)	3
Solar = 100 MW, LLS	SING OPN LIN 15 205-206(1)	153-154(1),3001-3003(1),3005-3007(1)	3
Solar = 100 MW, LLS	UNIT 206(1)	153-154(1),3001-3003(1),3005-3007(1)	3
Solar = 50 MW, LLS	UNIT 206(1)	153-154(1),3001-3003(1),3005-3007(1)	3
Solar = 0 MW, RLS	BUS 205	153-154(1),154-203(1)	2
Solar = 100 MW, HLS	BUS 205	153-154(1),154-203(1)	2
Solar = 50 MW, HLS	BUS 205	153-154(1),154-203(1)	2
Solar = 50 MW, RLS	BUS 205	153-154(1),154-203(1)	2
Solar = 0 MW, HLS	BUS 205	153-154(1),154-203(1)	2
Solar = 50 MW, HLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 100 MW, RLS	BUS 205	154-203(1)	1
Solar = 100 MW, LLS	UNIT 101(1)	3001-3003(1)	1
Solar = 100 MW, RLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 100 MW, RLS	UNIT 101(1)	3001-3003(1)	1
Solar = 100 MW, LLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 50 MW, HLS	BUS 202	153-154(1)	1
Solar = 50 MW, HLS	BUS 203	153-154(1)	1
Solar = 0 MW, HLS	BUS 153	154-205(1)	1
Solar = 50 MW, HLS	SING OPN LIN 6 152-153(1)	154-205(1)	1
Solar = 50 MW, HLS	SING OPN LIN 10 201-205(&1)	153-154(1)	1
Solar = 50 MW, HLS	SING OPN LIN 11 201-211(1)	205-206(1)	1
Solar = 50 MW, HLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 50 MW, HLS	UNIT 101(1)	3001-3003(1)	1
Solar = 50 MW, HLS	UNIT 211(1)	205-206(1)	1
Solar = 50 MW, LLS	BUS 205	154-203(1)	1
Solar = 50 MW, LLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 50 MW, LLS	UNIT 101(1)	3001-3003(1)	1
Solar = 50 MW, RLS	BUS 203	153-154(1)	1
Solar = 50 MW, RLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 50 MW, RLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 50 MW, RLS	SING OPN LIN 6 152-153(1)	154-205(1)	1
Solar = 100 MW, LLS	BUS 205	154-203(1)	1
Solar = 100 MW, HLS	UNIT 101(1)	3001-3003(1)	1
Solar = 100 MW, HLS	UNIT 211(1)	205-206(1)	1
Solar = 0 MW, HLS	BUS 203	153-154(1)	1
Solar = 0 MW, HLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 0 MW, HLS	SING OPN LIN 10 201-205(&1)	153-154(1)	1
Solar = 0 MW, HLS	SING OPN LIN 11 201-211(1)	205-206(1)	1
Solar = 0 MW, HLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 0 MW, HLS	SING OPN LIN 2 102-151(1)	101-151(1)	1
Solar = 0 MW, HLS	SING OPN LIN 6 152-153(1)	154-205(1)	1
Solar = 0 MW, HLS	UNIT 101(1)	3001-3003(1)	1
Solar = 0 MW, HLS	UNIT 102(1)	101-151(1)	1
Solar = 0 MW, HLS	UNIT 211(1)	205-206(1)	1
Solar = 0 MW, LLS	BUS 203	153-154(1)	1
Solar = 0 MW, LLS	BUS 205	154-203(1)	1
Solar = 0 MW, LLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 0 MW, LLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 0 MW, LLS	UNIT 101(1)	3001-3003(1)	1
Solar = 0 MW, RLS	BUS 203	153-154(1)	1
Solar = 0 MW, RLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 0 MW, RLS	SING OPN LIN 10 201-205(&1)	153-154(1)	1
Solar = 0 MW, RLS	SING OPN LIN 11 201-211(1)	205-206(1)	1
Solar = 0 MW, RLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 0 MW, RLS	SING OPN LIN 6 152-153(1)	154-205(1)	1
Solar = 0 MW, RLS	UNIT 101(1)	3001-3003(1)	1
Solar = 0 MW, RLS	UNIT 211(1)	205-206(1)	1
Solar = 100 MW, HLS	BUS 202	153-154(1)	1
Solar = 100 MW, HLS	BUS 203	153-154(1)	1
Solar = 100 MW, HLS	SING OPN LIN 1 101-151(1)	3001-3003(1)	1
Solar = 100 MW, HLS	SING OPN LIN 10 201-205(&1)	153-154(1)	1
Solar = 100 MW, HLS	SING OPN LIN 11 201-211(1)	205-206(1)	1
Solar = 100 MW, HLS	SING OPN LIN 12 202-203(1)	153-154(1)	1
Solar = 100 MW, HLS	SING OPN LIN 6 152-153(1)	154-205(1)	1
Solar = 50 MW, RLS	UNIT 101(1)	3001-3003(1)	1

Table 2.28: Summary of branch load violation grouped by Scenario and Contingency

Chapter 3

Upper Emergency Bus Voltage Violation

3.1 Introduction

In this chapter the upper voltage limit violations are reported by bus faults, unit faults and single line faults for each of the studied scenario. The violations are reported in tabular format and in the reported table, Base Voltage is PU base case voltage, Contingency Voltage is PU contingency case voltage, Deviation is difference between contingency case and base case voltage, Range Violation is range violations calculated as Contingency Voltage - maximum range limit (1.1 PU for the upper emergency range). It was seen that for Topology 1, only the scenarios, Solar = 50 MW, LLS, Solar = 100 MW, LLS reported upper voltage limit violations.

3.2 Solar = 50 MW, LLS

For the studied scenario, Solar = 50 MW, LLS, the bus reporting the upper emergency range violation is the bus 211 for the unit fault UNIT 206(1) and the single line open fault SING OPN LIN 15 205-206(1).

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
211	UNIT 206(1)	1.04	1.11	0.07	0.06

Table 3.1: Unit faults reporting bus voltages greater than emergency voltage of 1.1 PU for scenario Solar = 50 MW, LLS

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
211	SING OPN LIN 15 205-206(1)	1.04	1.11	0.07	0.06

Table 3.2: Single line open contingencies reporting bus voltages greater than emergency voltage of 1.1 PU for scenario Solar = 50 MW, LLS

3.3 Solar = 100 MW, LLS

For the studied scenario Solar = 100 MW, LLS, the bus violating the upper voltage limit is the bus 211 for the unit fault UNIT 206(1) and the single line open fault SING OPN LIN 15 205-206(1).

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
211	UNIT 206(1)	1.04	1.11	0.07	0.06

Table 3.3: Unit faults reporting bus voltages greater than emergency voltage of 1.1 PU for scenario Solar = 100 MW, LLS

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
211	SING OPN LIN 15 205-206(1)	1.04	1.11	0.07	0.06

Table 3.4: Single line open contingencies reporting bus voltages greater than emergency voltage of 1.1 PU for scenario Solar = 100 MW, LLS

3.4 Results Summary

It can be seen that there is only the Bus 211 reporting the upper voltage range violation. The bus 211 reports upper voltage range violation for the single open line contingency of SING OPN LIN 15 205-206(1) and for the unit fault UNIT 206(1) for two scenarios Solar = 100 MW, LLS and Solar = 50 MW, LLS.

Scenario	Contingency	Buses	Bus Count
Solar = 100 MW, LLS	SING OPN LIN 15 205-206(1)	211	1
Solar = 100 MW, LLS	UNIT 206(1)	211	1
Solar = 50 MW, LLS	SING OPN LIN 15 205-206(1)	211	1
Solar = 50 MW, LLS	UNIT 206(1)	211	1

Table 3.5: Summary of upper limit voltage violation grouped by Scenario and Contingency

Chapter 4

Lower Emergency Bus Voltage Violation

4.1 Introduction

In this chapter the lower voltage limit violations are reported by bus faults, unit faults and single line faults for each of the studied scenario. The violations are reported in tabular format and in the reported table, Base Voltage is PU base case voltage, Contingency Voltage is PU contingency case voltage, Deviation is difference between contingency case and base case voltage, Range Violation is range violations calculated as Contingency Voltage - minimum range limit (0.9 PU for lower emergency range).

4.2 Solar = 0 MW, LLS

For the studied scenario Solar = 0 MW, LLS, the buses violating the lower voltage limits are buses 103, 154 for the bus fault BUS 205.

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 205	0.977	0.895	-0.082	-0.055
154	BUS 205	0.977	0.895	-0.082	-0.055

Table 4.1: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 0 MW, LLS

4.3 Solar = 0 MW, RLS

For the studied scenario Solar = 0 MW, RLS, the buses violating the lower voltage limits are Buses 203, 103, 154, 3008. Bus 203 reported lower emergency range violation for the bus fault BUS 202 and the buses 103, 154, 3008 reported lower emergency range violations for BUS 205.

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
203	BUS 202	1.000	0.893	-0.107	-0.057
103	BUS 205	0.975	0.857	-0.118	-0.093
154	BUS 205	0.975	0.857	-0.118	-0.093
3008	BUS 205	0.993	0.897	-0.096	-0.053

Table 4.2: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 0 MW, RLS

4.4 Solar = 0 MW, HLS

For the studied scenario Solar = 0 MW, HLS, the buses violating the lower voltage limits are Buses 103, 154, 203, 205, 3008, 3007 For the bus fault BUS 205, the buses reporting lower emergency range violations are 103, 154, 203, 3007, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 205	0.973	0.819	-0.154	-0.131
154	BUS 205	0.973	0.819	-0.154	-0.131
203	BUS 205	0.998	0.898	-0.100	-0.052
3007	BUS 205	0.993	0.885	-0.108	-0.065
3008	BUS 205	0.990	0.865	-0.125	-0.085

Table 4.3: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 0 MW, HLS

For the single line fault SING OPN LIN 10 201-205(&1), the buses reporting lower emergency range violations are 103, 154, 203, 205, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	SING OPN LIN 10 201-205(&1)	0.973	0.847	-0.126	-0.103
154	SING OPN LIN 10 201-205(&1)	0.973	0.847	-0.126	-0.103
203	SING OPN LIN 10 201-205(&1)	0.998	0.887	-0.111	-0.063
205	SING OPN LIN 10 201-205(&1)	0.980	0.852	-0.128	-0.098
3008	SING OPN LIN 10 201-205(&1)	0.990	0.885	-0.105	-0.065

Table 4.4: Single line open contingencies reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 0 MW, HLS

4.5 Solar = 50 MW, LLS

For the studied scenario Solar = 50 MW, LLS, the buses violating the lower voltage limits are Buses 103, 154, 205, 3008, 206 For the unit fault UNIT 206(1), the buses reporting lower emergency range violations are 103, 154, 205, 206, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	UNIT 206(1)	0.976	0.861	-0.115	-0.089
154	UNIT 206(1)	0.977	0.862	-0.115	-0.088
205	UNIT 206(1)	0.980	0.864	-0.116	-0.086
206	UNIT 206(1)	0.996	0.864	-0.132	-0.086
3008	UNIT 206(1)	0.997	0.893	-0.104	-0.057

Table 4.5: Unit faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 50 MW, LLS

For the single line fault SING OPN LIN 15 205-206(1), the buses reporting lower emergency range violations are 103, 154, 205, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	SING OPN LIN 15 205-206(1)	0.976	0.861	-0.115	-0.089
154	SING OPN LIN 15 205-206(1)	0.977	0.862	-0.115	-0.088
205	SING OPN LIN 15 205-206(1)	0.980	0.864	-0.116	-0.086
3008	SING OPN LIN 15 205-206(1)	0.997	0.893	-0.104	-0.057

Table 4.6: Single line open contingencies reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 50 MW, LLS

4.6 Solar = 50 MW, RLS

For the studied scenario Solar = 50 MW, RLS, the buses violating the lower voltage limits are Buses 103, 153, 154, 203, 205, 3004, 3005, 3006, 3007, 3008 For the bus fault BUS 151, the buses reporting lower emergency range violations are 103, 153, 154, 203, 205, 3004, 3005, 3006, 3007, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 151	0.974	0.856	-0.118	-0.094
153	BUS 151	1.024	0.881	-0.143	-0.069
154	BUS 151	0.975	0.858	-0.117	-0.092
203	BUS 151	1.001	0.891	-0.110	-0.059
205	BUS 151	0.980	0.877	-0.103	-0.073
3004	BUS 151	1.043	0.882	-0.161	-0.068
3005	BUS 151	1.022	0.860	-0.162	-0.090
3006	BUS 151	1.024	0.871	-0.153	-0.079
3007	BUS 151	0.997	0.836	-0.161	-0.114
3008	BUS 151	0.994	0.845	-0.149	-0.105

Table 4.7: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 50 MW, RLS

4.7 Solar = 50 MW, HLS

For the studied scenario Solar = 50 MW, HLS, the buses violating the lower voltage limits are Buses 103, 154, 205, 203, 3008, 3007 For the bus fault BUS 202, the buses reporting lower emergency range violations are 103, 154, 203, 205, 3008 For the bus fault BUS 205, the buses reporting lower emergency range violations are 3007

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 202	0.973	0.849	-0.124	-0.101
154	BUS 202	0.974	0.850	-0.123	-0.100
203	BUS 202	0.999	0.833	-0.166	-0.117
205	BUS 202	0.980	0.858	-0.122	-0.092
3008	BUS 202	0.991	0.890	-0.100	-0.060
3007	BUS 205	0.994	0.896	-0.098	-0.054

Table 4.8: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 50 MW, HLS

For the single line fault SING OPN LIN 10 201-205(&1), the buses reporting lower emergency range violations are 103, 154, 205

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	SING OPN LIN 10 201-205(&1)	0.973	0.867	-0.105	-0.083
154	SING OPN LIN 10 201-205(&1)	0.974	0.868	-0.105	-0.082
205	SING OPN LIN 10 201-205(&1)	0.980	0.874	-0.106	-0.076

Table 4.9: Single line open contingencies reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 50 MW, HLS

4.8 Solar = 100 MW, LLS

For the studied scenario Solar = 100 MW, LLS, the buses violating the lower voltage limits are Buses 103, 154, 205, 3008, 206 For the unit fault UNIT 206(1), the buses reporting lower emergency range violations are 103, 154, 205, 206, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	UNIT 206(1)	0.974	0.861	-0.112	-0.089
154	UNIT 206(1)	0.977	0.867	-0.111	-0.083
205	UNIT 206(1)	0.980	0.869	-0.111	-0.081
206	UNIT 206(1)	0.994	0.869	-0.126	-0.081
3008	UNIT 206(1)	0.997	0.897	-0.101	-0.053

Table 4.10: Unit faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 100 MW, LLS

For the single line fault SING OPN LIN 15 205-206(1), the buses reporting lower emergency range violations are 103, 154, 205, 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	SING OPN LIN 15 205-206(1)	0.974	0.861	-0.112	-0.089
154	SING OPN LIN 15 205-206(1)	0.977	0.867	-0.111	-0.083
205	SING OPN LIN 15 205-206(1)	0.980	0.869	-0.111	-0.081
3008	SING OPN LIN 15 205-206(1)	0.997	0.897	-0.101	-0.053

Table 4.11: Single line open contingencies reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 100 MW, LLS

4.9 Solar = 100 MW, RLS

For the studied scenario Solar = 100 MW, RLS, the buses violating the lower voltage limits are Buses 103, 154 For the bus fault BUS 205, the buses reporting lower emergency range violations are 103, 154

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 205	0.972	0.870	-0.102	-0.080
154	BUS 205	0.975	0.875	-0.100	-0.075

Table 4.12: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 100 MW, RLS

4.10 Solar = 100 MW, HLS

For the studied scenario Solar = 100 MW, HLS, the buses violating the lower voltage limits are Buses 103, 154, 205, 203, 3008 For the bus fault BUS 202, the buses reporting lower emergency range violations are 103, 154, 203, 205 For the bus fault BUS 205, the buses reporting lower emergency range violations are 3008

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	BUS 202	0.970	0.858	-0.112	-0.092
154	BUS 202	0.974	0.863	-0.110	-0.087
203	BUS 202	1.000	0.847	-0.153	-0.103
205	BUS 202	0.980	0.871	-0.109	-0.079
3008	BUS 205	0.991	0.885	-0.106	-0.065

Table 4.13: Bus faults reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 100 MW, HLS

For the single line fault SING OPN LIN 10 201-205(&1), the buses reporting lower emergency range violations are 103, 154, 205

Bus Number	Contingency	Base Voltage	Contingency Voltage	Deviation	Range Violation
103	SING OPN LIN 10 201-205(&1)	0.970	0.876	-0.094	-0.074
154	SING OPN LIN 10 201-205(&1)	0.974	0.882	-0.092	-0.068
205	SING OPN LIN 10 201-205(&1)	0.980	0.887	-0.093	-0.063

Table 4.14: Single line open contingencies reporting bus voltages lower than emergency voltage of 0.9 PU for scenario Solar = 100 MW, HLS

4.11 Results Summary

The Table 4.15 summarises the results of the AC contingency calculation carried out on the hypothetical SAVNW system for Topology 1 for lower emergency bus voltage violations by tabulating the summary of lower voltage

violations grouped by scenario and contingency to give the buses reporting lower voltage range violation and count of the lower voltage range violations.

It can be seen that the scenario Solar = 50 MW, RLS and bus fault BUS 151 reports the most number of buses violating the lower emergency limit of 0.9 PU with 10 buses. For scenarios and faults Solar = 0 MW, HLS & BUS 205, Solar = 0 MW, HLS & SING OPN LIN 10 201-205(&1), Solar = 50 MW, LLS & UNIT 206(1), Solar = 50 MW, HLS & BUS 202, Solar = 100 MW, LLS & UNIT 206(1) there were 5 lower limit violations reported.

The buses reporting most number of lower voltage limit violations are the buses 103 & 154 with 34 violations, followed by buses 3008, 205 with 22 and 20 violations respectively. Further transmission planning studies needed to be carried out for system reinforcements to ensure reliable and stable operation of the system should a contingency causes system to violate the lower voltage limit. The Table 5.6 in the Appendix gives the count of times the buses violate the lower voltage limit $< 0.9PU$.

The contingency causing the most number of lower voltage limit violation is the bus fault BUS 205 resulting in 42 lower limit violation across all the studied scenarios followed by SING OPN LIN 10 201-205(&1) with 22 violations, BUS 202, UNIT 206(1), and BUS 151 with 20 limit violations. The Table 5.7 in the Appendix gives the contingencies and no of times these contingencies cause a lower voltage limit violation $< 0.9PU$.

Scenario	Contingency	Buses	Bus Count
Solar = 50 MW, RLS	BUS 151	103,153,154,203,205,3004,3005,3006,3007,3008	10
Solar = 0 MW, HLS	BUS 205	103,154,203,3007,3008	5
Solar = 0 MW, HLS	SING OPN LIN 10 201-205(&1)	103,154,203,205,3008	5
Solar = 50 MW, LLS	UNIT 206(1)	103,154,205,206,3008	5
Solar = 50 MW, HLS	BUS 202	103,154,203,205,3008	5
Solar = 100 MW, LLS	UNIT 206(1)	103,154,205,206,3008	5
Solar = 100 MW, LLS	SING OPN LIN 15 205-206(1)	103,154,205,3008	4
Solar = 100 MW, HLS	BUS 202	103,154,203,205	4
Solar = 50 MW, HLS	BUS 205	103,154,3007,3008	4
Solar = 50 MW, LLS	SING OPN LIN 15 205-206(1)	103,154,205,3008	4
Solar = 100 MW, HLS	BUS 205	103,154,3008	3
Solar = 100 MW, HLS	SING OPN LIN 10 201-205(&1)	103,154,205	3
Solar = 0 MW, RLS	BUS 205	103,154,3008	3
Solar = 50 MW, HLS	SING OPN LIN 10 201-205(&1)	103,154,205	3
Solar = 100 MW, RLS	BUS 205	103,154	2
Solar = 0 MW, LLS	BUS 205	103,154	2
Solar = 50 MW, RLS	BUS 205	103,154	2
Solar = 0 MW, RLS	BUS 202	203	1

Table 4.15: Summary of lower limit voltage violation grouped by Scenario and Contingency

Chapter 5

Conculsion

The contingency analysis was carried out on the hypothetical SAVNW study system for the Year 1, Topology 1 for 9 study scenarios for (N-1) bus, single line open, unit contingencies. Out of all the studied (N-1) contingencies, the contingencies for which the system did not converge are tabulated in Table 5.1 with the corresponding number of scenarios.

Contingency	Count of Scenarios
BUS 152	9
BUS 154	9
BUS 201	9
UNIT 206(1)	7
SING OPN LIN 15 205-206(1)	7
BUS 151	4
BUS 202	1

Table 5.1: Count of scenarios for which the tested contingency failed to converge

It can be seen from the Table 5.1, for the (N-1) contingencies BUS 152, BUS 154, BUS 201 did not converge for any of the 9 studied scenarios. The (N-1) contingencies UNIT 206(1), SING OPN LIN 15 205-206(1) did not converge for 7 of the studied scenarios, followed by BUS 151 for 4 and BUS 202 for 1 of the studied scenarios.

For the converged contingency scenarios, Chapter 2 studied the branch overload violations, Chapter 3 studied the upper limit voltage violation, and Chapter 4 studied the lower limit voltage violations.

In the Chapter 2 branches reporting loading greater than 100% were tabulated for each scenario and from the table, branches reporting loading greater than 130% were also noted down. It was seen that the branch with most number of overload violation were reported for branches 3001-3003(1) and 153-154(1) with 27 violations each.

In the Chapter 3 buses reporting voltage greater than 1.1 PU (violation of upper limit) were studied and it was seen that only the generator bus 211reported the upper limit violation. In the Chapter 4 buses reporting voltage less than 0.9 PU (violation of lower limit) were tabulated, there were multiple buses reporting lower limit violation and the buses 103 and 154 in area 1 reported the most number of violations.

Appendix

5.1 Branch Overload Violation $> 100\%$ Counts

Contingency Overloaded	Overload Count
BUS 151	24
BUS 205	14
SING OPN LIN 1 101-151(1)	9
UNIT 101(1)	9
SING OPN LIN 12 202-203(1)	6
BUS 203	6
SING OPN LIN 15 205-206(1)	6
UNIT 206(1)	6
SING OPN LIN 6 152-153(1)	5
SING OPN LIN 10 201-205(&1)	4
SING OPN LIN 11 201-211(1)	4
UNIT 211(1)	4
BUS 202	2
SING OPN LIN 2 102-151(1)	1
BUS 153	1
UNIT 102(1)	1

Table 5.2: Count of reported branch overload violations due to contingency

Branch Overloaded	Overload Count
3001-3003(1)	27
153-154(1)	27
3001-3011(1)	3
3003-3005(1)	5
3003-3005(2)	5
3005-3007(1)	8
154-203(1)	9
154-205(1)	6
205-206(1)	8
101-151(1)	2
153-3006(1)	1
3005-3006(1)	1

Table 5.3: Count of branches reporting overload violations

Scenario	Overload Counts
Solar = 50 MW, RLS	14
Solar = 0 MW, HLS	13
Solar = 50 MW, LLS	13
Solar = 100 MW, LLS	12
Solar = 50 MW, HLS	11
Solar = 100 MW, HLS	11
Solar = 0 MW, LLS	10
Solar = 0 MW, RLS	10
Solar = 100 MW, RLS	8

Table 5.4: Scenario Overload Summary

5.2 Upper Voltage Range Violation ($> 1.1PU$) Counts

Scenario	Overload Counts
Solar = 50 MW, LLS	4
Solar = 100 MW, LLS	4

Table 5.5: Scenario upper voltage limit violation summary

5.3 Lower Voltage Range Violation ($< 0.9PU$) Counts

Bus	Lower violation counts
103	34
154	34
3008	22
205	20
203	12
3007	6
206	4
153	2
3004	2
3005	2
3006	2

Table 5.6: Summary of lower voltage range violation - Bus count

Contingency	Lower violation count
BUS 205	42
SING OPN LIN 10 201-205(&1)	22
BUS 202	20
UNIT 206(1)	20
BUS 151	20
SING OPN LIN 15 205-206(1)	16

Table 5.7: Summary of lower voltage range violation - Contingency count

Scenario	Overload Counts
Solar = 50 MW, RLS	24
Solar = 50 MW, HLS	24
Solar = 0 MW, HLS	20
Solar = 100 MW, HLS	20
Solar = 50 MW, LLS	18
Solar = 100 MW, LLS	18
Solar = 0 MW, RLS	8
Solar = 0 MW, LLS	4
Solar = 100 MW, RLS	4

Table 5.8: Scenario lower voltage limit violation summary