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**ECE 558**

**Final Project Report**

**Introduction**

This project report calculates the reliability indices of 4 different load points in a 5 bus system with a total installed capacity of 210 MW and annualized peak load of 155 MW. The system has 12 generating units of various capacities and 8 transmission lines.

The objective of this project is to evaluate load point reliability indices (such as expected load curtailed, number of load curtailments, expected energy not served and expected duration of load curtailments) using frequency and duration techniques. At the end of the project report, there is a recommendation to improve the reliability of the system.

**List of Procedural Steps:**

The section describes the steps of the whole projects, any algorithms implemented along with the details of the MATLAB code given in the appendix.

1. The first step of project involves evaluating the generator capacity availability tables. The tables calculate the probability, positive and negative departure rates and the frequency for various capacity outages. There are three tables: one for just the generators present in bus 1, one for just the generators present in bus 2. The third table combines the first two tables to get the same data for the generator subsystem. For the first 2 tables, the rows are limited to states which have a probability of occurrence of at least 10-6 while for the third table, the rows are limited to states which have a probability of occurrence of at least 5x10-7.

This section of the code uses several user-defined functions: **prob, prob\_v2, lambap, lambap\_v2, lambda, lambda\_v2**. All of these functions implement the recursive functions taught in class.

Both **prob** and **prob\_v2** functions implement the recursive algorithm for calculating individual probability given in page 89 (Section 3.2.2) of the textbook. The difference between them is that **prob** can only work for a number of generating units having **identical values of FOR and capacity** while **prob\_v2** can also work with units having **different values of FOR and capacity**. So, in case of **prob**, **FOR and capacity** are just numbers while in case of **prob\_v2**, both FOR and capacity are lists of values.

**lambap** and **lambdap\_v2** functions implement the recursive algorithms for calculating the positive departure rates given in page 89 (Section 3.2.2) of the textbook. Similarly, **lamban** and **lambdan\_v2** functions implement the negative departure rates. The differences between **lambap** and **lambdap\_v2** and between **lamban** and **lambdan\_v2** are the same as those between **prob** and **prob\_v2.**

**prob, lambap, lambda** have been used for generators at bus 1 since they are identical with respect to FORs and capacities. **prob\_v2, lambap\_v2, lambda\_v2** have been used for generators at bus 2 since they are not identical with respect to FORs and capacities.

Using the repair and failure rates given in t5\_data.txt, the FORs for each generator has been calculated. Using these FOR values, the capacities of each generator, the above-mentioned functions and a for-loop to go through all possible states, the tables for Generator 1 and 2 have been generated. Any states having probabilities < 10-6 have been eliminated using a for-loop (to scan through the probability values), and an if statement (to check and delete the row if probability < 10-6).

1. To calculate the generator subsystem table, a probability array is formed first. The rows of this array represent Bus 1 Capacity Outage states while the columns represent Bus 2 Capacity Outage states. The cells of this array represent the probability of the corresponding states occurring simultaneously.

Nested for loops are used to generate the various columns of the generation subsystem capacity availability table. The inner loop goes through the relevant states of Bus 2 generators while the outer loop goes through the relevant states of Bus 1 generators. If the probability of the composite state is > 5x10-7, then only append the columns of the table with the required data (such as the generation capacities at each bus, individual probability of the state, positive and negative departure rates and frequency). The positive departure rate (PosDep) of any state in this table is the sum of the positive departure rates of the corresponding states in the previous two tables. Same goes for the negative departure rates (NegDep). And from these values, we calculate frequency using the formula learned in class:

Frequency(state) = Indivual Prob(state)x{PosDep(state) + NegDep(state)}

1. The next step is to get the transmission capacity availability table. The calculations in these tables are relatively simple due to the assumption that only one transmission line can be out at any given time. The individual probabilities are determined by multiplying the probability of availability/unavailability (depending on the state) of the different lines. Except for the first row (all lines in service), the positive departure rates are the repair rates for the transmission line which is out. Negative departure rates are zero except for the first row, due to the assumption stated earlier.
2. The composite generation and transmission availability table involves combining the generation subsystem capacity availability table and transmission capacity availability table. Nested loops have been used to combine the values in the two tables. The outermost loop involves the transmission line states, the middle loop involves the states in generator bus 1 and the innermost loop involves the states in generator bus 2. Within the loops, the calculation of probability, departure rates and frequencies involve methods which have been already discussed in step (b). In the table, Duration(state) = Prob(state)/Freq(state)\*8760 hours.
3. The final part of the project involved calculating the load point reliability indices tables for each of the load bus. A major part of the calculations involved determining what fraction (frac) of the peak load needs to be curtailed for each state in the composite generation and transmission table. Since bus loads have been inflated to include network losses, if the generation = load, it is assumed that the system capacity is adequate. Another important assumption is that ‘frac’ is same for each load bus, i.e., if load at some bus is not served and we have to curtail by a certain fraction, then the loads at all buses are curtailed by the same fraction.

There is a for loop to generate the reliability indices for each of the composite states in the previous table. Inside the loop, Pinj1 and Pinj2 are power injection vectors which assume that the total load is being supplied by Bus 1 generators and Bus 2 generators respectively. pre\_flow1 and pre\_flow2 calculate branch flows using Pinj1 and Pinj2 and the PTDF matrix. After that, if there is any transmission line outage, we calculate the post\_flow1 and post\_flow2 from pre\_flow1 and pre\_flow2 and the LODF matrices. If there is no branch outaged, then post\_flow1 = pre\_flow1 and post\_flow2 = pre\_flow2.

Then the function ‘**Pkj\_function\_v3**’ is used to calculate ‘frac’, where frac = 1 – CF. Initially, frac = frac\_init = 1. **Pkj\_function\_v3** is a recursive function. It gets the post flows, the MWmax and the capacity available. Then it calls the function **gen\_dispatch** to determine if the peak loads can be met by the available generation without overloading any branch. If yes, then it returns the current value of frac. If not, then **Pkj\_function\_v3** sets frac = frac – 1, recalculates all the bus loads, pre flows and post flows and calls itself again. In this way, **Pkj\_function\_v3** calls itself again and again, until there is success in generation dispatch or until frac = 0 (in which case it displays that the load dispatch totally fails). Using frac, the probability and frequency values in the composite table, and the formulae in the textbook, all the data in the load point reliability indices table (Capacity available, Pkj, Lkj, ELC, NLC, EDLC, EENS) have been computed.

**Results:**

**Frequency and Duration Based Generator Capacity Availability Tables**

**Bus 1**

For each generator, FOR: = = 0.0148

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| State  No. | List of Units  out | Capacity  available | Prob. | Positive  Departure  Rate | Negative  Departure  rate | Frequency  (occ/yr) |
| 1 | 0 | 80 | 0.941929 | 0 | 4.4 | 4.144491 |
| 2 | 1 | 60 | 0.056773 | 73 | 3.3 | 4.331845 |
| 3 | 2 | 40 | 0.001283 | 146 | 2.2 | 0.190176 |
| 4 | 3 | 20 | 1.289104e-05 | 219 | 1.1 | 0.0028373 |

**Bus 2**

For each generator, FOR: = = 0.0050

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| State  No. | List of Units  out | Capacity  available | Prob. | Positive  Departure  Rate | Negative  Departure  rate | Frequency  (occ/yr) |
| 1 | 0,0,0 | 130 | 0.9419 | 0 | 6 | 5.6514 |
| 2 | 1,0,0 | 125 | 0.0330 | 100 | 5.5 | 3.4779 |
| 3 | 2,0,0 | 120 | 4.9450e-4 | 200 | 5 | 0.1013 |
| 4 | 3,0,0 || 0,1,0 | 115 | 0.0047 | 100.1748 | 5.4991 | 0.4981 |
| 5 | 4,0,0 || 1,1,0 || 0,0,1 | 110 | 0.0190 | 100.8677 | 5.4957 | 2.0212 |
| 6 | 5,0,0 || 2,1,0 || 1,0,1 | 105 | 6.6181e-04 | 200.3736 | 4.9981 | 0.1359 |
| 7 | 6,0,0 || 3,1,0 || 2,0,1 | 100 | 9.9106e-06 | 300.2079 | 4.4990 | 0.0030 |
| 8 | 7,0,0 || 4,1,0 || 3,0,1 ||  0,1,1 | 95 | 9.4273e-05 | 200.1752 | 4.9991 | 0.0193 |
| 9 | 5,1,0 || 4,0,1 || 0,0,2 ||  1,1,1 | 90 | 1.4458e-04 | 202.2810 | 4.9886 | 0.0300 |
| 10 | 6,1,0 || 5,0,1 || 1,0,2 ||  2,1,1 | 85 | 4.9945e-06 | 300.9902 | 4.4950 | 0.0015 |

**Generator Subsystem Capacity Availability Table**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| State No. | Capa. at Gen. Bus 1 | Capa. at Gen Bus 2 | Prob. of this state | Positive departure rate | Negative departure rate | Frequency(occ/yr) |
| 1 | 80 | 130 | 0.887209 | 0 | 10.4 | 9.226972 |
| 2 | 80 | 125 | 0.031052 | 100 | 9.9 | 3.412649 |
| 3 | 80 | 120 | 0.000466 | 200 | 9.4 | 0.097535 |
| 4 | 80 | 115 | 0.00444 | 100.1748 | 9.899126 | 0.48872 |
| 5 | 80 | 110 | 0.017899 | 100.8677 | 9.895661 | 1.982605 |
| 6 | 80 | 105 | 0.000623 | 200.3736 | 9.398132 | 0.130767 |
| 7 | 80 | 100 | 9.34E-06 | 300.2079 | 8.89896 | 0.002886 |
| 8 | 80 | 95 | 8.88E-05 | 200.1752 | 9.399124 | 0.01861 |
| 9 | 80 | 90 | 0.000136 | 202.281 | 9.388595 | 0.028827 |
| 10 | 80 | 85 | 4.70E-06 | 300.9902 | 8.895049 | 0.001458 |
| 11 | 60 | 130 | 0.053476 | 73 | 9.3 | 4.401042 |
| 12 | 60 | 125 | 0.001872 | 173 | 8.8 | 0.340265 |
| 13 | 60 | 120 | 2.81E-05 | 273 | 8.3 | 0.007897 |
| 14 | 60 | 115 | 0.000268 | 173.1748 | 8.799126 | 0.048698 |
| 15 | 60 | 110 | 0.001079 | 173.8677 | 8.795661 | 0.19707 |
| 16 | 60 | 105 | 3.76E-05 | 273.3736 | 8.298132 | 0.010583 |
| 17 | 60 | 100 | 5.63E-07 | 373.2079 | 7.79896 | 0.000214 |
| 18 | 60 | 95 | 5.35E-06 | 273.1752 | 8.299124 | 0.001507 |
| 19 | 60 | 90 | 8.21E-06 | 275.281 | 8.288595 | 0.002328 |
| 20 | 40 | 130 | 0.001209 | 146 | 8.2 | 0.186381 |
| 21 | 40 | 125 | 4.23E-05 | 246 | 7.7 | 0.010733 |
| 22 | 40 | 120 | 6.35E-07 | 346 | 7.2 | 0.000224 |
| 23 | 40 | 115 | 6.05E-06 | 246.1748 | 7.699126 | 0.001536 |
| 24 | 40 | 110 | 2.44E-05 | 246.8677 | 7.695661 | 0.006208 |
| 25 | 40 | 105 | 8.49E-07 | 346.3736 | 7.198132 | 0.0003 |
| 26 | 20 | 130 | 1.21E-05 | 219 | 7.1 | 0.002745 |

**Frequency and Duration Based Transmission Capacity Availability Table**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| State No. | Name of branch out | Probability | Positive departure rate (repairs/yr) | Negative departure rate  (failures/yr) | Frequency (occ/yr) |
| 1 | 0 (all in service) | 0.977474 | 0 | 20 | 19.54949 |
| 2 | L1 | 0.001674 | 876 | 0 | 1.466211 |
| 3 | L2 | 0.005579 | 876 | 0 | 4.887371 |
| 4 | L3 | 0.004463 | 876 | 0 | 3.909897 |
| 5 | L4 | 0.001116 | 876 | 0 | 0.977474 |
| 6 | L5 | 0.001116 | 876 | 0 | 0.977474 |
| 7 | L6 | 0.001674 | 876 | 0 | 1.466211 |
| 8 | L7 | 0.005579 | 876 | 0 | 4.887371 |
| 9 | L8 | 0.001116 | 876 | 0 | 0.977474 |

**Frequency and Duration Based Composite Generation and Transmission Availability Table**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 1 | 0 | 80 | 130 | 0.867224 | 0 | 30.4 | 26.3636 | 288.1579 |
| 2 | 0 | 80 | 125 | 0.030353 | 100 | 29.9 | 3.942833 | 67.43649 |
| 3 | 0 | 80 | 120 | 0.000455 | 200 | 29.4 | 0.104444 | 38.18657 |
| 4 | 0 | 80 | 115 | 0.00434 | 100.1748 | 29.89913 | 0.56451 | 67.34629 |
| 5 | 0 | 80 | 110 | 0.017496 | 100.8677 | 29.89566 | 2.28787 | 66.99122 |
| 6 | 0 | 80 | 105 | 0.000609 | 200.3736 | 29.39813 | 0.140008 | 38.12479 |
| 7 | 0 | 80 | 100 | 9.12E-06 | 300.2079 | 28.89896 | 0.003003 | 26.61749 |
| 8 | 0 | 80 | 95 | 8.68E-05 | 200.1752 | 29.39912 | 0.019927 | 38.15758 |
| 9 | 0 | 80 | 90 | 0.000133 | 202.281 | 29.3886 | 0.03084 | 37.81247 |
| 10 | 0 | 80 | 85 | 4.60E-06 | 300.9902 | 28.89505 | 0.001517 | 26.55469 |
| 11 | 0 | 60 | 130 | 0.052271 | 73 | 29.3 | 5.347326 | 85.6305 |
| 12 | 0 | 60 | 125 | 0.001829 | 173 | 28.8 | 0.36919 | 43.40932 |
| 13 | 0 | 60 | 120 | 2.74E-05 | 273 | 28.3 | 0.008268 | 29.07401 |
| 14 | 0 | 60 | 115 | 0.000262 | 173.1748 | 28.79913 | 0.052833 | 43.37193 |
| 15 | 0 | 60 | 110 | 0.001055 | 173.8677 | 28.79566 | 0.213723 | 43.22438 |
| 16 | 0 | 60 | 105 | 3.67E-05 | 273.3736 | 28.29813 | 0.011079 | 29.03818 |
| 17 | 0 | 60 | 100 | 5.50E-07 | 373.2079 | 27.79896 | 0.000221 | 21.84501 |
| 18 | 0 | 60 | 95 | 5.23E-06 | 273.1752 | 28.29912 | 0.001577 | 29.0572 |
| 19 | 0 | 60 | 90 | 8.02E-06 | 275.281 | 28.2886 | 0.002436 | 28.85665 |
| 20 | 0 | 40 | 130 | 0.001181 | 146 | 28.2 | 0.205812 | 50.28703 |
| 21 | 0 | 40 | 125 | 4.14E-05 | 246 | 27.7 | 0.011318 | 32.00585 |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 22 | 0 | 40 | 120 | 6.20E-07 | 346 | 27.2 | 0.000231 | 23.47267 |
| 23 | 0 | 40 | 115 | 5.91E-06 | 246.1748 | 27.69913 | 0.001619 | 31.98551 |
| 24 | 0 | 40 | 110 | 2.38E-05 | 246.8677 | 27.69566 | 0.006545 | 31.9052 |
| 25 | 0 | 40 | 105 | 8.30E-07 | 346.3736 | 27.19813 | 0.00031 | 23.44931 |
| 26 | 0 | 20 | 130 | 1.19E-05 | 219 | 27.1 | 0.002921 | 35.59529 |
| 27 | 1 | 80 | 130 | 0.001485 | 876 | 10.4 | 1.316279 | 9.882671 |
| 28 | 1 | 80 | 125 | 5.20E-05 | 976 | 9.9 | 0.051241 | 8.885282 |
| 29 | 1 | 80 | 120 | 7.80E-07 | 1076 | 9.4 | 0.000846 | 8.070757 |
| 30 | 1 | 80 | 115 | 7.43E-06 | 976.1748 | 9.899126 | 0.007328 | 8.883715 |
| 31 | 1 | 80 | 110 | 3.00E-05 | 976.8677 | 9.895661 | 0.029563 | 8.877508 |
| 32 | 1 | 80 | 105 | 1.04E-06 | 1076.374 | 9.398132 | 0.001133 | 8.067994 |
| 33 | 1 | 80 | 100 | 1.56E-08 | 1176.208 | 8.89896 | 1.85E-05 | 7.391738 |
| 34 | 1 | 80 | 95 | 1.49E-07 | 1076.175 | 9.399124 | 0.000161 | 8.069461 |
| 35 | 1 | 80 | 90 | 2.28E-07 | 1078.281 | 9.388595 | 0.000248 | 8.053917 |
| 36 | 1 | 80 | 85 | 7.87E-09 | 1176.99 | 8.895049 | 9.34E-06 | 7.386887 |
| 37 | 1 | 60 | 130 | 8.95E-05 | 949 | 9.3 | 0.085773 | 9.141188 |
| 38 | 1 | 60 | 125 | 3.13E-06 | 1049 | 8.8 | 0.003314 | 8.281339 |
| 39 | 1 | 60 | 120 | 4.70E-08 | 1149 | 8.3 | 5.44E-05 | 7.569342 |
| 40 | 1 | 60 | 115 | 4.48E-07 | 1049.175 | 8.799126 | 0.000474 | 8.279977 |
| 41 | 1 | 60 | 110 | 1.81E-06 | 1049.868 | 8.795661 | 0.001912 | 8.274585 |
| 42 | 1 | 60 | 105 | 6.29E-08 | 1149.374 | 8.298132 | 7.28E-05 | 7.566912 |
| 43 | 1 | 60 | 100 | 9.42E-10 | 1249.208 | 7.79896 | 1.18E-06 | 6.968936 |
| 44 | 1 | 60 | 95 | 8.96E-09 | 1149.175 | 8.299124 | 1.04E-05 | 7.568203 |
| 45 | 1 | 60 | 90 | 1.37E-08 | 1151.281 | 8.288595 | 1.59E-05 | 7.554527 |
| 46 | 1 | 40 | 130 | 2.02E-06 | 1022 | 8.2 | 0.002084 | 8.503203 |
| 47 | 1 | 40 | 125 | 7.08E-08 | 1122 | 7.7 | 8.00E-05 | 7.754271 |
| 48 | 1 | 40 | 120 | 1.06E-09 | 1222 | 7.2 | 1.31E-06 | 7.126586 |
| 49 | 1 | 40 | 115 | 1.01E-08 | 1122.175 | 7.699126 | 1.14E-05 | 7.753077 |
| 50 | 1 | 40 | 110 | 4.08E-08 | 1122.868 | 7.695661 | 4.61E-05 | 7.748349 |
| 51 | 1 | 40 | 105 | 1.42E-09 | 1222.374 | 7.198132 | 1.75E-06 | 7.124432 |
| 52 | 1 | 20 | 130 | 2.03E-08 | 1095 | 7.1 | 2.24E-05 | 7.948462 |
| 53 | 2 | 80 | 130 | 0.00495 | 876 | 10.4 | 4.387598 | 9.882671 |
| 54 | 2 | 80 | 125 | 0.000173 | 976 | 9.9 | 0.170804 | 8.885282 |
| 55 | 2 | 80 | 120 | 2.60E-06 | 1076 | 9.4 | 0.002821 | 8.070757 |
| 56 | 2 | 80 | 115 | 2.48E-05 | 976.1748 | 9.899126 | 0.024426 | 8.883715 |
| 57 | 2 | 80 | 110 | 9.99E-05 | 976.8677 | 9.895661 | 0.098543 | 8.877508 |
| 58 | 2 | 80 | 105 | 3.48E-06 | 1076.374 | 9.398132 | 0.003776 | 8.067994 |
| 59 | 2 | 80 | 100 | 5.21E-08 | 1176.208 | 8.89896 | 6.17E-05 | 7.391738 |
| 60 | 2 | 80 | 95 | 4.95E-07 | 1076.175 | 9.399124 | 0.000538 | 8.069461 |
| 61 | 2 | 80 | 90 | 7.60E-07 | 1078.281 | 9.388595 | 0.000826 | 8.053917 |
| 62 | 2 | 80 | 85 | 2.62E-08 | 1176.99 | 8.895049 | 3.11E-05 | 7.386887 |
| 63 | 2 | 60 | 130 | 0.000298 | 949 | 9.3 | 0.285909 | 9.141188 |
| 64 | 2 | 60 | 125 | 1.04E-05 | 1049 | 8.8 | 0.011046 | 8.281339 |
| 65 | 2 | 60 | 120 | 1.57E-07 | 1149 | 8.3 | 0.000181 | 7.569342 |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 66 | 2 | 60 | 115 | 1.49E-06 | 1049.175 | 8.799126 | 0.00158 | 8.279977 |
| 67 | 2 | 60 | 110 | 6.02E-06 | 1049.868 | 8.795661 | 0.006372 | 8.274585 |
| 68 | 2 | 60 | 105 | 2.10E-07 | 1149.374 | 8.298132 | 0.000243 | 7.566912 |
| 69 | 2 | 60 | 100 | 3.14E-09 | 1249.208 | 7.79896 | 3.95E-06 | 6.968936 |
| 70 | 2 | 60 | 95 | 2.99E-08 | 1149.175 | 8.299124 | 3.46E-05 | 7.568203 |
| 71 | 2 | 60 | 90 | 4.58E-08 | 1151.281 | 8.288595 | 5.31E-05 | 7.554527 |
| 72 | 2 | 40 | 130 | 6.74E-06 | 1022 | 8.2 | 0.006947 | 8.503203 |
| 73 | 2 | 40 | 125 | 2.36E-07 | 1122 | 7.7 | 0.000267 | 7.754271 |
| 74 | 2 | 40 | 120 | 3.54E-09 | 1222 | 7.2 | 4.35E-06 | 7.126586 |
| 75 | 2 | 40 | 115 | 3.37E-08 | 1122.175 | 7.699126 | 3.81E-05 | 7.753077 |
| 76 | 2 | 40 | 110 | 1.36E-07 | 1122.868 | 7.695661 | 0.000154 | 7.748349 |
| 77 | 2 | 40 | 105 | 4.74E-09 | 1222.374 | 7.198132 | 5.83E-06 | 7.124432 |
| 78 | 2 | 20 | 130 | 6.77E-08 | 1095 | 7.1 | 7.47E-05 | 7.948462 |
| 79 | 3 | 80 | 130 | 0.00396 | 876 | 10.4 | 3.510079 | 9.882671 |
| 80 | 3 | 80 | 125 | 0.000139 | 976 | 9.9 | 0.136643 | 8.885282 |
| 81 | 3 | 80 | 120 | 2.08E-06 | 1076 | 9.4 | 0.002257 | 8.070757 |
| 82 | 3 | 80 | 115 | 1.98E-05 | 976.1748 | 9.899126 | 0.019541 | 8.883715 |
| 83 | 3 | 80 | 110 | 7.99E-05 | 976.8677 | 9.895661 | 0.078834 | 8.877508 |
| 84 | 3 | 80 | 105 | 2.78E-06 | 1076.374 | 9.398132 | 0.003021 | 8.067994 |
| 85 | 3 | 80 | 100 | 4.17E-08 | 1176.208 | 8.89896 | 4.94E-05 | 7.391738 |
| 86 | 3 | 80 | 95 | 3.96E-07 | 1076.175 | 9.399124 | 0.00043 | 8.069461 |
| 87 | 3 | 80 | 90 | 6.08E-07 | 1078.281 | 9.388595 | 0.000661 | 8.053917 |
| 88 | 3 | 80 | 85 | 2.10E-08 | 1176.99 | 8.895049 | 2.49E-05 | 7.386887 |
| 89 | 3 | 60 | 130 | 0.000239 | 949 | 9.3 | 0.228728 | 9.141188 |
| 90 | 3 | 60 | 125 | 8.35E-06 | 1049 | 8.8 | 0.008837 | 8.281339 |
| 91 | 3 | 60 | 120 | 1.25E-07 | 1149 | 8.3 | 0.000145 | 7.569342 |
| 92 | 3 | 60 | 115 | 1.19E-06 | 1049.175 | 8.799126 | 0.001264 | 8.279977 |
| 93 | 3 | 60 | 110 | 4.82E-06 | 1049.868 | 8.795661 | 0.005098 | 8.274585 |
| 94 | 3 | 60 | 105 | 1.68E-07 | 1149.374 | 8.298132 | 0.000194 | 7.566912 |
| 95 | 3 | 60 | 100 | 2.51E-09 | 1249.208 | 7.79896 | 3.16E-06 | 6.968936 |
| 96 | 3 | 60 | 95 | 2.39E-08 | 1149.175 | 8.299124 | 2.77E-05 | 7.568203 |
| 97 | 3 | 60 | 90 | 3.66E-08 | 1151.281 | 8.288595 | 4.25E-05 | 7.554527 |
| 98 | 3 | 40 | 130 | 5.39E-06 | 1022 | 8.2 | 0.005558 | 8.503203 |
| 99 | 3 | 40 | 125 | 1.89E-07 | 1122 | 7.7 | 0.000213 | 7.754271 |
| 100 | 3 | 40 | 120 | 2.83E-09 | 1222 | 7.2 | 3.48E-06 | 7.126586 |
| 101 | 3 | 40 | 115 | 2.70E-08 | 1122.175 | 7.699126 | 3.05E-05 | 7.753077 |
| 102 | 3 | 40 | 110 | 1.09E-07 | 1122.868 | 7.695661 | 0.000123 | 7.748349 |
| 103 | 3 | 40 | 105 | 3.79E-09 | 1222.374 | 7.198132 | 4.66E-06 | 7.124432 |
| 104 | 3 | 20 | 130 | 5.42E-08 | 1095 | 7.1 | 5.97E-05 | 7.948462 |
| 105 | 4 | 80 | 130 | 0.00099 | 876 | 10.4 | 0.87752 | 9.882671 |
| 106 | 4 | 80 | 125 | 3.46E-05 | 976 | 9.9 | 0.034161 | 8.885282 |
| 107 | 4 | 80 | 120 | 5.20E-07 | 1076 | 9.4 | 0.000564 | 8.070757 |
| 108 | 4 | 80 | 115 | 4.95E-06 | 976.1748 | 9.899126 | 0.004885 | 8.883715 |
| 109 | 4 | 80 | 110 | 2.00E-05 | 976.8677 | 9.895661 | 0.019709 | 8.877508 |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 110 | 4 | 80 | 105 | 6.96E-07 | 1076.374 | 9.398132 | 0.000755 | 8.067994 |
| 111 | 4 | 80 | 100 | 1.04E-08 | 1176.208 | 8.89896 | 1.23E-05 | 7.391738 |
| 112 | 4 | 80 | 95 | 9.91E-08 | 1076.175 | 9.399124 | 0.000108 | 8.069461 |
| 113 | 4 | 80 | 90 | 1.52E-07 | 1078.281 | 9.388595 | 0.000165 | 8.053917 |
| 114 | 4 | 80 | 85 | 5.25E-09 | 1176.99 | 8.895049 | 6.23E-06 | 7.386887 |
| 115 | 4 | 60 | 130 | 5.97E-05 | 949 | 9.3 | 0.057182 | 9.141188 |
| 116 | 4 | 60 | 125 | 2.09E-06 | 1049 | 8.8 | 0.002209 | 8.281339 |
| 117 | 4 | 60 | 120 | 3.13E-08 | 1149 | 8.3 | 3.63E-05 | 7.569342 |
| 118 | 4 | 60 | 115 | 2.99E-07 | 1049.175 | 8.799126 | 0.000316 | 8.279977 |
| 119 | 4 | 60 | 110 | 1.20E-06 | 1049.868 | 8.795661 | 0.001274 | 8.274585 |
| 120 | 4 | 60 | 105 | 4.19E-08 | 1149.374 | 8.298132 | 4.85E-05 | 7.566912 |
| 121 | 4 | 60 | 100 | 6.28E-10 | 1249.208 | 7.79896 | 7.89E-07 | 6.968936 |
| 122 | 4 | 60 | 95 | 5.97E-09 | 1149.175 | 8.299124 | 6.91E-06 | 7.568203 |
| 123 | 4 | 60 | 90 | 9.16E-09 | 1151.281 | 8.288595 | 1.06E-05 | 7.554527 |
| 124 | 4 | 40 | 130 | 1.35E-06 | 1022 | 8.2 | 0.001389 | 8.503203 |
| 125 | 4 | 40 | 125 | 4.72E-08 | 1122 | 7.7 | 5.33E-05 | 7.754271 |
| 126 | 4 | 40 | 120 | 7.08E-10 | 1222 | 7.2 | 8.70E-07 | 7.126586 |
| 127 | 4 | 40 | 115 | 6.75E-09 | 1122.175 | 7.699126 | 7.63E-06 | 7.753077 |
| 128 | 4 | 40 | 110 | 2.72E-08 | 1122.868 | 7.695661 | 3.08E-05 | 7.748349 |
| 129 | 4 | 40 | 105 | 9.48E-10 | 1222.374 | 7.198132 | 1.17E-06 | 7.124432 |
| 130 | 4 | 20 | 130 | 1.35E-08 | 1095 | 7.1 | 1.49E-05 | 7.948462 |
| 131 | 5 | 80 | 130 | 0.00099 | 876 | 10.4 | 0.87752 | 9.882671 |
| 132 | 5 | 80 | 125 | 3.46E-05 | 976 | 9.9 | 0.034161 | 8.885282 |
| 133 | 5 | 80 | 120 | 5.20E-07 | 1076 | 9.4 | 0.000564 | 8.070757 |
| 134 | 5 | 80 | 115 | 4.95E-06 | 976.1748 | 9.899126 | 0.004885 | 8.883715 |
| 135 | 5 | 80 | 110 | 2.00E-05 | 976.8677 | 9.895661 | 0.019709 | 8.877508 |
| 136 | 5 | 80 | 105 | 6.96E-07 | 1076.374 | 9.398132 | 0.000755 | 8.067994 |
| 137 | 5 | 80 | 100 | 1.04E-08 | 1176.208 | 8.89896 | 1.23E-05 | 7.391738 |
| 138 | 5 | 80 | 95 | 9.91E-08 | 1076.175 | 9.399124 | 0.000108 | 8.069461 |
| 139 | 5 | 80 | 90 | 1.52E-07 | 1078.281 | 9.388595 | 0.000165 | 8.053917 |
| 140 | 5 | 80 | 85 | 5.25E-09 | 1176.99 | 8.895049 | 6.23E-06 | 7.386887 |
| 141 | 5 | 60 | 130 | 5.97E-05 | 949 | 9.3 | 0.057182 | 9.141188 |
| 142 | 5 | 60 | 125 | 2.09E-06 | 1049 | 8.8 | 0.002209 | 8.281339 |
| 143 | 5 | 60 | 120 | 3.13E-08 | 1149 | 8.3 | 3.63E-05 | 7.569342 |
| 144 | 5 | 60 | 115 | 2.99E-07 | 1049.175 | 8.799126 | 0.000316 | 8.279977 |
| 145 | 5 | 60 | 110 | 1.20E-06 | 1049.868 | 8.795661 | 0.001274 | 8.274585 |
| 146 | 5 | 60 | 105 | 4.19E-08 | 1149.374 | 8.298132 | 4.85E-05 | 7.566912 |
| 147 | 5 | 60 | 100 | 6.28E-10 | 1249.208 | 7.79896 | 7.89E-07 | 6.968936 |
| 148 | 5 | 60 | 95 | 5.97E-09 | 1149.175 | 8.299124 | 6.91E-06 | 7.568203 |
| 149 | 5 | 60 | 90 | 9.16E-09 | 1151.281 | 8.288595 | 1.06E-05 | 7.554527 |
| 150 | 5 | 40 | 130 | 1.35E-06 | 1022 | 8.2 | 0.001389 | 8.503203 |
| 151 | 5 | 40 | 125 | 4.72E-08 | 1122 | 7.7 | 5.33E-05 | 7.754271 |
| 152 | 5 | 40 | 120 | 7.08E-10 | 1222 | 7.2 | 8.70E-07 | 7.126586 |
| 153 | 5 | 40 | 115 | 6.75E-09 | 1122.175 | 7.699126 | 7.63E-06 | 7.753077 |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 154 | 5 | 40 | 110 | 2.72E-08 | 1122.868 | 7.695661 | 3.08E-05 | 7.748349 |
| 155 | 5 | 40 | 105 | 9.48E-10 | 1222.374 | 7.198132 | 1.17E-06 | 7.124432 |
| 156 | 5 | 20 | 130 | 1.35E-08 | 1095 | 7.1 | 1.49E-05 | 7.948462 |
| 157 | 6 | 80 | 130 | 0.001485 | 876 | 10.4 | 1.316279 | 9.882671 |
| 158 | 6 | 80 | 125 | 5.20E-05 | 976 | 9.9 | 0.051241 | 8.885282 |
| 159 | 6 | 80 | 120 | 7.80E-07 | 1076 | 9.4 | 0.000846 | 8.070757 |
| 160 | 6 | 80 | 115 | 7.43E-06 | 976.1748 | 9.899126 | 0.007328 | 8.883715 |
| 161 | 6 | 80 | 110 | 3.00E-05 | 976.8677 | 9.895661 | 0.029563 | 8.877508 |
| 162 | 6 | 80 | 105 | 1.04E-06 | 1076.374 | 9.398132 | 0.001133 | 8.067994 |
| 163 | 6 | 80 | 100 | 1.56E-08 | 1176.208 | 8.89896 | 1.85E-05 | 7.391738 |
| 164 | 6 | 80 | 95 | 1.49E-07 | 1076.175 | 9.399124 | 0.000161 | 8.069461 |
| 165 | 6 | 80 | 90 | 2.28E-07 | 1078.281 | 9.388595 | 0.000248 | 8.053917 |
| 166 | 6 | 80 | 85 | 7.87E-09 | 1176.99 | 8.895049 | 9.34E-06 | 7.386887 |
| 167 | 6 | 60 | 130 | 8.95E-05 | 949 | 9.3 | 0.085773 | 9.141188 |
| 168 | 6 | 60 | 125 | 3.13E-06 | 1049 | 8.8 | 0.003314 | 8.281339 |
| 169 | 6 | 60 | 120 | 4.70E-08 | 1149 | 8.3 | 5.44E-05 | 7.569342 |
| 170 | 6 | 60 | 115 | 4.48E-07 | 1049.175 | 8.799126 | 0.000474 | 8.279977 |
| 171 | 6 | 60 | 110 | 1.81E-06 | 1049.868 | 8.795661 | 0.001912 | 8.274585 |
| 172 | 6 | 60 | 105 | 6.29E-08 | 1149.374 | 8.298132 | 7.28E-05 | 7.566912 |
| 173 | 6 | 60 | 100 | 9.42E-10 | 1249.208 | 7.79896 | 1.18E-06 | 6.968936 |
| 174 | 6 | 60 | 95 | 8.96E-09 | 1149.175 | 8.299124 | 1.04E-05 | 7.568203 |
| 175 | 6 | 60 | 90 | 1.37E-08 | 1151.281 | 8.288595 | 1.59E-05 | 7.554527 |
| 176 | 6 | 40 | 130 | 2.02E-06 | 1022 | 8.2 | 0.002084 | 8.503203 |
| 177 | 6 | 40 | 125 | 7.08E-08 | 1122 | 7.7 | 8.00E-05 | 7.754271 |
| 178 | 6 | 40 | 120 | 1.06E-09 | 1222 | 7.2 | 1.31E-06 | 7.126586 |
| 179 | 6 | 40 | 115 | 1.01E-08 | 1122.175 | 7.699126 | 1.14E-05 | 7.753077 |
| 180 | 6 | 40 | 110 | 4.08E-08 | 1122.868 | 7.695661 | 4.61E-05 | 7.748349 |
| 181 | 6 | 40 | 105 | 1.42E-09 | 1222.374 | 7.198132 | 1.75E-06 | 7.124432 |
| 182 | 6 | 20 | 130 | 2.03E-08 | 1095 | 7.1 | 2.24E-05 | 7.948462 |
| 183 | 7 | 80 | 130 | 0.00495 | 876 | 10.4 | 4.387598 | 9.882671 |
| 184 | 7 | 80 | 125 | 0.000173 | 976 | 9.9 | 0.170804 | 8.885282 |
| 185 | 7 | 80 | 120 | 2.60E-06 | 1076 | 9.4 | 0.002821 | 8.070757 |
| 186 | 7 | 80 | 115 | 2.48E-05 | 976.1748 | 9.899126 | 0.024426 | 8.883715 |
| 187 | 7 | 80 | 110 | 9.99E-05 | 976.8677 | 9.895661 | 0.098543 | 8.877508 |
| 188 | 7 | 80 | 105 | 3.48E-06 | 1076.374 | 9.398132 | 0.003776 | 8.067994 |
| 189 | 7 | 80 | 100 | 5.21E-08 | 1176.208 | 8.89896 | 6.17E-05 | 7.391738 |
| 190 | 7 | 80 | 95 | 4.95E-07 | 1076.175 | 9.399124 | 0.000538 | 8.069461 |
| 191 | 7 | 80 | 90 | 7.60E-07 | 1078.281 | 9.388595 | 0.000826 | 8.053917 |
| 192 | 7 | 80 | 85 | 2.62E-08 | 1176.99 | 8.895049 | 3.11E-05 | 7.386887 |
| 193 | 7 | 60 | 130 | 0.000298 | 949 | 9.3 | 0.285909 | 9.141188 |
| 194 | 7 | 60 | 125 | 1.04E-05 | 1049 | 8.8 | 0.011046 | 8.281339 |
| 195 | 7 | 60 | 120 | 1.57E-07 | 1149 | 8.3 | 0.000181 | 7.569342 |
| 196 | 7 | 60 | 115 | 1.49E-06 | 1049.175 | 8.799126 | 0.00158 | 8.279977 |
| 197 | 7 | 60 | 110 | 6.02E-06 | 1049.868 | 8.795661 | 0.006372 | 8.274585 |
| State | TrOut | G1CA (MW) | G2CA (MW) | Prob. | PosDep (rep./yr) | NegDep  (fail/yr) | Freq.  (occ/yr) | Dur  (hrs) |
| 198 | 7 | 60 | 105 | 2.10E-07 | 1149.374 | 8.298132 | 0.000243 | 7.566912 |
| 199 | 7 | 60 | 100 | 3.14E-09 | 1249.208 | 7.79896 | 3.95E-06 | 6.968936 |
| 200 | 7 | 60 | 95 | 2.99E-08 | 1149.175 | 8.299124 | 3.46E-05 | 7.568203 |
| 201 | 7 | 60 | 90 | 4.58E-08 | 1151.281 | 8.288595 | 5.31E-05 | 7.554527 |
| 202 | 7 | 40 | 130 | 6.74E-06 | 1022 | 8.2 | 0.006947 | 8.503203 |
| 203 | 7 | 40 | 125 | 2.36E-07 | 1122 | 7.7 | 0.000267 | 7.754271 |
| 204 | 7 | 40 | 120 | 3.54E-09 | 1222 | 7.2 | 4.35E-06 | 7.126586 |
| 205 | 7 | 40 | 115 | 3.37E-08 | 1122.175 | 7.699126 | 3.81E-05 | 7.753077 |
| 206 | 7 | 40 | 110 | 1.36E-07 | 1122.868 | 7.695661 | 0.000154 | 7.748349 |
| 207 | 7 | 40 | 105 | 4.74E-09 | 1222.374 | 7.198132 | 5.83E-06 | 7.124432 |
| 208 | 7 | 20 | 130 | 6.77E-08 | 1095 | 7.1 | 7.47E-05 | 7.948462 |
| 209 | 8 | 80 | 130 | 0.00099 | 876 | 10.4 | 0.87752 | 9.882671 |
| 210 | 8 | 80 | 125 | 3.46E-05 | 976 | 9.9 | 0.034161 | 8.885282 |
| 211 | 8 | 80 | 120 | 5.20E-07 | 1076 | 9.4 | 0.000564 | 8.070757 |
| 212 | 8 | 80 | 115 | 4.95E-06 | 976.1748 | 9.899126 | 0.004885 | 8.883715 |
| 213 | 8 | 80 | 110 | 2.00E-05 | 976.8677 | 9.895661 | 0.019709 | 8.877508 |
| 214 | 8 | 80 | 105 | 6.96E-07 | 1076.374 | 9.398132 | 0.000755 | 8.067994 |
| 215 | 8 | 80 | 100 | 1.04E-08 | 1176.208 | 8.89896 | 1.23E-05 | 7.391738 |
| 216 | 8 | 80 | 95 | 9.91E-08 | 1076.175 | 9.399124 | 0.000108 | 8.069461 |
| 217 | 8 | 80 | 90 | 1.52E-07 | 1078.281 | 9.388595 | 0.000165 | 8.053917 |
| 218 | 8 | 80 | 85 | 5.25E-09 | 1176.99 | 8.895049 | 6.23E-06 | 7.386887 |
| 219 | 8 | 60 | 130 | 5.97E-05 | 949 | 9.3 | 0.057182 | 9.141188 |
| 220 | 8 | 60 | 125 | 2.09E-06 | 1049 | 8.8 | 0.002209 | 8.281339 |
| 221 | 8 | 60 | 120 | 3.13E-08 | 1149 | 8.3 | 3.63E-05 | 7.569342 |
| 222 | 8 | 60 | 115 | 2.99E-07 | 1049.175 | 8.799126 | 0.000316 | 8.279977 |
| 223 | 8 | 60 | 110 | 1.20E-06 | 1049.868 | 8.795661 | 0.001274 | 8.274585 |
| 224 | 8 | 60 | 105 | 4.19E-08 | 1149.374 | 8.298132 | 4.85E-05 | 7.566912 |
| 225 | 8 | 60 | 100 | 6.28E-10 | 1249.208 | 7.79896 | 7.89E-07 | 6.968936 |
| 226 | 8 | 60 | 95 | 5.97E-09 | 1149.175 | 8.299124 | 6.91E-06 | 7.568203 |
| 227 | 8 | 60 | 90 | 9.16E-09 | 1151.281 | 8.288595 | 1.06E-05 | 7.554527 |
| 228 | 8 | 40 | 130 | 1.35E-06 | 1022 | 8.2 | 0.001389 | 8.503203 |
| 229 | 8 | 40 | 125 | 4.72E-08 | 1122 | 7.7 | 5.33E-05 | 7.754271 |
| 230 | 8 | 40 | 120 | 7.08E-10 | 1222 | 7.2 | 8.70E-07 | 7.126586 |
| 231 | 8 | 40 | 115 | 6.75E-09 | 1122.175 | 7.699126 | 7.63E-06 | 7.753077 |
| 232 | 8 | 40 | 110 | 2.72E-08 | 1122.868 | 7.695661 | 3.08E-05 | 7.748349 |
| 233 | 8 | 40 | 105 | 9.48E-10 | 1222.374 | 7.198132 | 1.17E-06 | 7.124432 |
| 234 | 8 | 20 | 130 | 1.35E-08 | 1095 | 7.1 | 1.49E-05 | 7.948462 |

**Load Point Reliability Indices Table for Bus 2**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 19 | 18 | 1 | 2 | 0.004871 | 0.002436 | 0.140574 | 0.070287 |
| 24 | 18 | 1 | 2 | 0.013089 | 0.006545 | 0.417609 | 0.208805 |
| 25 | 18 | 1 | 2 | 0.00062 | 0.00031 | 0.014544 | 0.007272 |
| 26 | 18 | 1 | 2 | 0.005842 | 0.002921 | 0.207938 | 0.103969 |
| 33 | 18 | 1 | 2 | 3.70E-05 | 1.85E-05 | 0.000274 | 0.000137 |
| 34 | 18 | 1 | 2 | 0.000323 | 0.000161 | 0.002604 | 0.001302 |
| 35 | 18 | 1 | 2 | 0.000496 | 0.000248 | 0.003994 | 0.001997 |
| 36 | 18 | 1 | 2 | 1.87E-05 | 9.34E-06 | 0.000138 | 6.90E-05 |
| 43 | 18 | 1 | 2 | 2.37E-06 | 1.18E-06 | 1.65E-05 | 8.25E-06 |
| 44 | 18 | 1 | 2 | 2.07E-05 | 1.04E-05 | 0.000157 | 7.85E-05 |
| 45 | 18 | 1 | 2 | 3.19E-05 | 1.59E-05 | 0.000241 | 0.00012 |
| 50 | 18 | 1 | 2 | 9.23E-05 | 4.61E-05 | 0.000715 | 0.000358 |
| 51 | 18 | 1 | 2 | 3.50E-06 | 1.75E-06 | 2.49E-05 | 1.25E-05 |
| 52 | 18 | 1 | 2 | 4.48E-05 | 2.24E-05 | 0.000356 | 0.000178 |
| 71 | 18 | 1 | 2 | 0.000106 | 5.31E-05 | 0.000802 | 0.000401 |
| 76 | 18 | 1 | 2 | 0.000308 | 0.000154 | 0.002384 | 0.001192 |
| 77 | 18 | 1 | 2 | 1.17E-05 | 5.83E-06 | 8.30E-05 | 4.15E-05 |
| 78 | 18 | 1 | 2 | 0.000149 | 7.47E-05 | 0.001187 | 0.000593 |
| 97 | 18 | 1 | 2 | 8.50E-05 | 4.25E-05 | 0.000642 | 0.000321 |
| 102 | 18 | 1 | 2 | 0.000246 | 0.000123 | 0.001907 | 0.000953 |
| 103 | 18 | 1 | 2 | 9.32E-06 | 4.66E-06 | 6.64E-05 | 3.32E-05 |
| 104 | 18 | 1 | 2 | 0.000119 | 5.97E-05 | 0.000949 | 0.000475 |
| 123 | 18 | 1 | 2 | 2.12E-05 | 1.06E-05 | 0.00016 | 8.02E-05 |
| 128 | 18 | 1 | 2 | 6.15E-05 | 3.08E-05 | 0.000477 | 0.000238 |
| 129 | 18 | 1 | 2 | 2.33E-06 | 1.17E-06 | 1.66E-05 | 8.30E-06 |
| 130 | 18 | 1 | 2 | 2.99E-05 | 1.49E-05 | 0.000237 | 0.000119 |
| 149 | 18 | 1 | 2 | 2.12E-05 | 1.06E-05 | 0.00016 | 8.02E-05 |
| 154 | 18 | 1 | 2 | 6.15E-05 | 3.08E-05 | 0.000477 | 0.000238 |
| 155 | 18 | 1 | 2 | 2.33E-06 | 1.17E-06 | 1.66E-05 | 8.30E-06 |
| 156 | 18 | 1 | 2 | 2.99E-05 | 1.49E-05 | 0.000237 | 0.000119 |
| 163 | 18 | 1 | 2 | 3.70E-05 | 1.85E-05 | 0.000274 | 0.000137 |
| 164 | 18 | 1 | 2 | 0.000323 | 0.000161 | 0.002604 | 0.001302 |
| 165 | 18 | 1 | 2 | 0.000496 | 0.000248 | 0.003994 | 0.001997 |
| 166 | 18 | 1 | 2 | 1.87E-05 | 9.34E-06 | 0.000138 | 6.90E-05 |
| 173 | 18 | 1 | 2 | 2.37E-06 | 1.18E-06 | 1.65E-05 | 8.25E-06 |
| 174 | 18 | 1 | 2 | 2.07E-05 | 1.04E-05 | 0.000157 | 7.85E-05 |
| 175 | 18 | 1 | 2 | 3.19E-05 | 1.59E-05 | 0.000241 | 0.00012 |
| 180 | 18 | 1 | 2 | 9.23E-05 | 4.61E-05 | 0.000715 | 0.000358 |
| 181 | 18 | 1 | 2 | 3.50E-06 | 1.75E-06 | 2.49E-05 | 1.25E-05 |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 182 | 18 | 1 | 2 | 4.48E-05 | 2.24E-05 | 0.000356 | 0.000178 |
| 201 | 18 | 1 | 2 | 0.000106 | 5.31E-05 | 0.000802 | 0.000401 |
| 206 | 18 | 1 | 2 | 0.000308 | 0.000154 | 0.002384 | 0.001192 |
| 207 | 18 | 1 | 2 | 1.17E-05 | 5.83E-06 | 8.30E-05 | 4.15E-05 |
| 208 | 18 | 1 | 2 | 0.000149 | 7.47E-05 | 0.001187 | 0.000593 |
| 227 | 18 | 1 | 2 | 2.12E-05 | 1.06E-05 | 0.00016 | 8.02E-05 |
| 232 | 18 | 1 | 2 | 6.15E-05 | 3.08E-05 | 0.000477 | 0.000238 |
| 233 | 18 | 1 | 2 | 2.33E-06 | 1.17E-06 | 1.66E-05 | 8.30E-06 |
| 234 | 18 | 1 | 2 | 2.99E-05 | 1.49E-05 | 0.000237 | 0.000119 |

**Load Point Reliability Indices Table for Bus 3**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 19 | 76.5 | 1 | 8.5 | 0.020704 | 0.002436 | 0.597439 | 0.070287 |
| 24 | 76.5 | 1 | 8.5 | 0.055629 | 0.006545 | 1.77484 | 0.208805 |
| 25 | 76.5 | 1 | 8.5 | 0.002636 | 0.00031 | 0.061811 | 0.007272 |
| 26 | 76.5 | 1 | 8.5 | 0.024827 | 0.002921 | 0.883738 | 0.103969 |
| 33 | 76.5 | 1 | 8.5 | 0.000157 | 1.85E-05 | 0.001163 | 0.000137 |
| 34 | 76.5 | 1 | 8.5 | 0.001371 | 0.000161 | 0.011067 | 0.001302 |
| 35 | 76.5 | 1 | 8.5 | 0.002107 | 0.000248 | 0.016973 | 0.001997 |
| 36 | 76.5 | 1 | 8.5 | 7.94E-05 | 9.34E-06 | 0.000586 | 6.90E-05 |
| 43 | 76.5 | 1 | 8.5 | 1.01E-05 | 1.18E-06 | 7.01E-05 | 8.25E-06 |
| 44 | 76.5 | 1 | 8.5 | 8.81E-05 | 1.04E-05 | 0.000667 | 7.85E-05 |
| 45 | 76.5 | 1 | 8.5 | 0.000135 | 1.59E-05 | 0.001023 | 0.00012 |
| 50 | 76.5 | 1 | 8.5 | 0.000392 | 4.61E-05 | 0.003039 | 0.000358 |
| 51 | 76.5 | 1 | 8.5 | 1.49E-05 | 1.75E-06 | 0.000106 | 1.25E-05 |
| 52 | 76.5 | 1 | 8.5 | 0.00019 | 2.24E-05 | 0.001513 | 0.000178 |
| 71 | 76.5 | 1 | 8.5 | 0.000451 | 5.31E-05 | 0.00341 | 0.000401 |
| 76 | 76.5 | 1 | 8.5 | 0.001307 | 0.000154 | 0.01013 | 0.001192 |
| 77 | 76.5 | 1 | 8.5 | 4.95E-05 | 5.83E-06 | 0.000353 | 4.15E-05 |
| 78 | 76.5 | 1 | 8.5 | 0.000635 | 7.47E-05 | 0.005044 | 0.000593 |
| 97 | 76.5 | 1 | 8.5 | 0.000361 | 4.25E-05 | 0.002728 | 0.000321 |
| 102 | 76.5 | 1 | 8.5 | 0.001046 | 0.000123 | 0.008104 | 0.000953 |
| 103 | 76.5 | 1 | 8.5 | 3.96E-05 | 4.66E-06 | 0.000282 | 3.32E-05 |
| 104 | 76.5 | 1 | 8.5 | 0.000508 | 5.97E-05 | 0.004035 | 0.000475 |
| 123 | 76.5 | 1 | 8.5 | 9.03E-05 | 1.06E-05 | 0.000682 | 8.02E-05 |
| 128 | 76.5 | 1 | 8.5 | 0.000261 | 3.08E-05 | 0.002026 | 0.000238 |
| 129 | 76.5 | 1 | 8.5 | 9.90E-06 | 1.17E-06 | 7.06E-05 | 8.30E-06 |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 130 | 76.5 | 1 | 8.5 | 0.000127 | 1.49E-05 | 0.001009 | 0.000119 |
| 149 | 76.5 | 1 | 8.5 | 9.03E-05 | 1.06E-05 | 0.000682 | 8.02E-05 |
| 154 | 76.5 | 1 | 8.5 | 0.000261 | 3.08E-05 | 0.002026 | 0.000238 |
| 155 | 76.5 | 1 | 8.5 | 9.90E-06 | 1.17E-06 | 7.06E-05 | 8.30E-06 |
| 156 | 76.5 | 1 | 8.5 | 0.000127 | 1.49E-05 | 0.001009 | 0.000119 |
| 163 | 76.5 | 1 | 8.5 | 0.000157 | 1.85E-05 | 0.001163 | 0.000137 |
| 164 | 76.5 | 1 | 8.5 | 0.001371 | 0.000161 | 0.011067 | 0.001302 |
| 165 | 76.5 | 1 | 8.5 | 0.002107 | 0.000248 | 0.016973 | 0.001997 |
| 166 | 76.5 | 1 | 8.5 | 7.94E-05 | 9.34E-06 | 0.000586 | 6.90E-05 |
| 173 | 76.5 | 1 | 8.5 | 1.01E-05 | 1.18E-06 | 7.01E-05 | 8.25E-06 |
| 174 | 76.5 | 1 | 8.5 | 8.81E-05 | 1.04E-05 | 0.000667 | 7.85E-05 |
| 175 | 76.5 | 1 | 8.5 | 0.000135 | 1.59E-05 | 0.001023 | 0.00012 |
| 180 | 76.5 | 1 | 8.5 | 0.000392 | 4.61E-05 | 0.003039 | 0.000358 |
| 181 | 76.5 | 1 | 8.5 | 1.49E-05 | 1.75E-06 | 0.000106 | 1.25E-05 |
| 182 | 76.5 | 1 | 8.5 | 0.00019 | 2.24E-05 | 0.001513 | 0.000178 |
| 201 | 76.5 | 1 | 8.5 | 0.000451 | 5.31E-05 | 0.00341 | 0.000401 |
| 206 | 76.5 | 1 | 8.5 | 0.001307 | 0.000154 | 0.01013 | 0.001192 |
| 207 | 76.5 | 1 | 8.5 | 4.95E-05 | 5.83E-06 | 0.000353 | 4.15E-05 |
| 208 | 76.5 | 1 | 8.5 | 0.000635 | 7.47E-05 | 0.005044 | 0.000593 |
| 227 | 76.5 | 1 | 8.5 | 9.03E-05 | 1.06E-05 | 0.000682 | 8.02E-05 |
| 232 | 76.5 | 1 | 8.5 | 0.000261 | 3.08E-05 | 0.002026 | 0.000238 |
| 233 | 76.5 | 1 | 8.5 | 9.90E-06 | 1.17E-06 | 7.06E-05 | 8.30E-06 |
| 234 | 76.5 | 1 | 8.5 | 0.000127 | 1.49E-05 | 0.001009 | 0.000119 |

**Load Point Reliability Indices Table for Bus 4**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 19 | 36 | 1 | 4 | 0.009743 | 0.002436 | 0.281148 | 0.070287 |
| 24 | 36 | 1 | 4 | 0.026178 | 0.006545 | 0.835219 | 0.208805 |
| 25 | 36 | 1 | 4 | 0.00124 | 0.00031 | 0.029088 | 0.007272 |
| 26 | 36 | 1 | 4 | 0.011683 | 0.002921 | 0.415877 | 0.103969 |
| 33 | 36 | 1 | 4 | 7.41E-05 | 1.85E-05 | 0.000547 | 0.000137 |
| 34 | 36 | 1 | 4 | 0.000645 | 0.000161 | 0.005208 | 0.001302 |
| 35 | 36 | 1 | 4 | 0.000992 | 0.000248 | 0.007987 | 0.001997 |
| 36 | 36 | 1 | 4 | 3.74E-05 | 9.34E-06 | 0.000276 | 6.90E-05 |
| 43 | 36 | 1 | 4 | 4.74E-06 | 1.18E-06 | 3.30E-05 | 8.25E-06 |
| 44 | 36 | 1 | 4 | 4.15E-05 | 1.04E-05 | 0.000314 | 7.85E-05 |
| 45 | 36 | 1 | 4 | 6.37E-05 | 1.59E-05 | 0.000481 | 0.00012 |
| 50 | 36 | 1 | 4 | 0.000185 | 4.61E-05 | 0.00143 | 0.000358 |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 51 | 36 | 1 | 4 | 6.99E-06 | 1.75E-06 | 4.98E-05 | 1.25E-05 |
| 52 | 36 | 1 | 4 | 8.96E-05 | 2.24E-05 | 0.000712 | 0.000178 |
| 71 | 36 | 1 | 4 | 0.000212 | 5.31E-05 | 0.001605 | 0.000401 |
| 76 | 36 | 1 | 4 | 0.000615 | 0.000154 | 0.004767 | 0.001192 |
| 77 | 36 | 1 | 4 | 2.33E-05 | 5.83E-06 | 0.000166 | 4.15E-05 |
| 78 | 36 | 1 | 4 | 0.000299 | 7.47E-05 | 0.002374 | 0.000593 |
| 97 | 36 | 1 | 4 | 0.00017 | 4.25E-05 | 0.001284 | 0.000321 |
| 102 | 36 | 1 | 4 | 0.000492 | 0.000123 | 0.003814 | 0.000953 |
| 103 | 36 | 1 | 4 | 1.86E-05 | 4.66E-06 | 0.000133 | 3.32E-05 |
| 104 | 36 | 1 | 4 | 0.000239 | 5.97E-05 | 0.001899 | 0.000475 |
| 123 | 36 | 1 | 4 | 4.25E-05 | 1.06E-05 | 0.000321 | 8.02E-05 |
| 128 | 36 | 1 | 4 | 0.000123 | 3.08E-05 | 0.000953 | 0.000238 |
| 129 | 36 | 1 | 4 | 4.66E-06 | 1.17E-06 | 3.32E-05 | 8.30E-06 |
| 130 | 36 | 1 | 4 | 5.97E-05 | 1.49E-05 | 0.000475 | 0.000119 |
| 149 | 36 | 1 | 4 | 4.25E-05 | 1.06E-05 | 0.000321 | 8.02E-05 |
| 154 | 36 | 1 | 4 | 0.000123 | 3.08E-05 | 0.000953 | 0.000238 |
| 155 | 36 | 1 | 4 | 4.66E-06 | 1.17E-06 | 3.32E-05 | 8.30E-06 |
| 156 | 36 | 1 | 4 | 5.97E-05 | 1.49E-05 | 0.000475 | 0.000119 |
| 163 | 36 | 1 | 4 | 7.41E-05 | 1.85E-05 | 0.000547 | 0.000137 |
| 164 | 36 | 1 | 4 | 0.000645 | 0.000161 | 0.005208 | 0.001302 |
| 165 | 36 | 1 | 4 | 0.000992 | 0.000248 | 0.007987 | 0.001997 |
| 166 | 36 | 1 | 4 | 3.74E-05 | 9.34E-06 | 0.000276 | 6.90E-05 |
| 173 | 36 | 1 | 4 | 4.74E-06 | 1.18E-06 | 3.30E-05 | 8.25E-06 |
| 174 | 36 | 1 | 4 | 4.15E-05 | 1.04E-05 | 0.000314 | 7.85E-05 |
| 175 | 36 | 1 | 4 | 6.37E-05 | 1.59E-05 | 0.000481 | 0.00012 |
| 180 | 36 | 1 | 4 | 0.000185 | 4.61E-05 | 0.00143 | 0.000358 |
| 181 | 36 | 1 | 4 | 6.99E-06 | 1.75E-06 | 4.98E-05 | 1.25E-05 |
| 182 | 36 | 1 | 4 | 8.96E-05 | 2.24E-05 | 0.000712 | 0.000178 |
| 201 | 36 | 1 | 4 | 0.000212 | 5.31E-05 | 0.001605 | 0.000401 |
| 206 | 36 | 1 | 4 | 0.000615 | 0.000154 | 0.004767 | 0.001192 |
| 207 | 36 | 1 | 4 | 2.33E-05 | 5.83E-06 | 0.000166 | 4.15E-05 |
| 208 | 36 | 1 | 4 | 0.000299 | 7.47E-05 | 0.002374 | 0.000593 |
| 227 | 36 | 1 | 4 | 4.25E-05 | 1.06E-05 | 0.000321 | 8.02E-05 |
| 232 | 36 | 1 | 4 | 0.000123 | 3.08E-05 | 0.000953 | 0.000238 |
| 233 | 36 | 1 | 4 | 4.66E-06 | 1.17E-06 | 3.32E-05 | 8.30E-06 |
| 234 | 36 | 1 | 4 | 5.97E-05 | 1.49E-05 | 0.000475 | 0.000119 |

**Load Point Reliability Indices Table for Bus 5**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 19 | 9 | 1 | 1 | 0.002436 | 0.002436 | 0.070287 | 0.070287 |
| 24 | 9 | 1 | 1 | 0.006545 | 0.006545 | 0.208805 | 0.208805 |
| 25 | 9 | 1 | 1 | 0.00031 | 0.00031 | 0.007272 | 0.007272 |
| 26 | 9 | 1 | 1 | 0.002921 | 0.002921 | 0.103969 | 0.103969 |
| 33 | 9 | 1 | 1 | 1.85E-05 | 1.85E-05 | 0.000137 | 0.000137 |
| 34 | 9 | 1 | 1 | 0.000161 | 0.000161 | 0.001302 | 0.001302 |
| 35 | 9 | 1 | 1 | 0.000248 | 0.000248 | 0.001997 | 0.001997 |
| 36 | 9 | 1 | 1 | 9.34E-06 | 9.34E-06 | 6.90E-05 | 6.90E-05 |
| 43 | 9 | 1 | 1 | 1.18E-06 | 1.18E-06 | 8.25E-06 | 8.25E-06 |
| 44 | 9 | 1 | 1 | 1.04E-05 | 1.04E-05 | 7.85E-05 | 7.85E-05 |
| 45 | 9 | 1 | 1 | 1.59E-05 | 1.59E-05 | 0.00012 | 0.00012 |
| 50 | 9 | 1 | 1 | 4.61E-05 | 4.61E-05 | 0.000358 | 0.000358 |
| 51 | 9 | 1 | 1 | 1.75E-06 | 1.75E-06 | 1.25E-05 | 1.25E-05 |
| 52 | 9 | 1 | 1 | 2.24E-05 | 2.24E-05 | 0.000178 | 0.000178 |
| 71 | 9 | 1 | 1 | 5.31E-05 | 5.31E-05 | 0.000401 | 0.000401 |
| 76 | 9 | 1 | 1 | 0.000154 | 0.000154 | 0.001192 | 0.001192 |
| 77 | 9 | 1 | 1 | 5.83E-06 | 5.83E-06 | 4.15E-05 | 4.15E-05 |
| 78 | 9 | 1 | 1 | 7.47E-05 | 7.47E-05 | 0.000593 | 0.000593 |
| 97 | 9 | 1 | 1 | 4.25E-05 | 4.25E-05 | 0.000321 | 0.000321 |
| 102 | 9 | 1 | 1 | 0.000123 | 0.000123 | 0.000953 | 0.000953 |
| 103 | 9 | 1 | 1 | 4.66E-06 | 4.66E-06 | 3.32E-05 | 3.32E-05 |
| 104 | 9 | 1 | 1 | 5.97E-05 | 5.97E-05 | 0.000475 | 0.000475 |
| 123 | 9 | 1 | 1 | 1.06E-05 | 1.06E-05 | 8.02E-05 | 8.02E-05 |
| 128 | 9 | 1 | 1 | 3.08E-05 | 3.08E-05 | 0.000238 | 0.000238 |
| 129 | 9 | 1 | 1 | 1.17E-06 | 1.17E-06 | 8.30E-06 | 8.30E-06 |
| 130 | 9 | 1 | 1 | 1.49E-05 | 1.49E-05 | 0.000119 | 0.000119 |
| 149 | 9 | 1 | 1 | 1.06E-05 | 1.06E-05 | 8.02E-05 | 8.02E-05 |
| 154 | 9 | 1 | 1 | 3.08E-05 | 3.08E-05 | 0.000238 | 0.000238 |
| 155 | 9 | 1 | 1 | 1.17E-06 | 1.17E-06 | 8.30E-06 | 8.30E-06 |
| 156 | 9 | 1 | 1 | 1.49E-05 | 1.49E-05 | 0.000119 | 0.000119 |
| 163 | 9 | 1 | 1 | 1.85E-05 | 1.85E-05 | 0.000137 | 0.000137 |
| 164 | 9 | 1 | 1 | 0.000161 | 0.000161 | 0.001302 | 0.001302 |
| 165 | 9 | 1 | 1 | 0.000248 | 0.000248 | 0.001997 | 0.001997 |
| 166 | 9 | 1 | 1 | 9.34E-06 | 9.34E-06 | 6.90E-05 | 6.90E-05 |
| 173 | 9 | 1 | 1 | 1.18E-06 | 1.18E-06 | 8.25E-06 | 8.25E-06 |
| 174 | 9 | 1 | 1 | 1.04E-05 | 1.04E-05 | 7.85E-05 | 7.85E-05 |
| 175 | 9 | 1 | 1 | 1.59E-05 | 1.59E-05 | 0.00012 | 0.00012 |
| 180 | 9 | 1 | 1 | 4.61E-05 | 4.61E-05 | 0.000358 | 0.000358 |
| 181 | 9 | 1 | 1 | 1.75E-06 | 1.75E-06 | 1.25E-05 | 1.25E-05 |
| 182 | 9 | 1 | 1 | 2.24E-05 | 2.24E-05 | 0.000178 | 0.000178 |
| State | Capacity Available (MW) | Pkj | Lkj | ELC (MW) | NLC (occ) | EENS (MWh) | EDLC (hr) |
| 201 | 9 | 1 | 1 | 5.31E-05 | 5.31E-05 | 0.000401 | 0.000401 |
| 206 | 9 | 1 | 1 | 0.000154 | 0.000154 | 0.001192 | 0.001192 |
| 207 | 9 | 1 | 1 | 5.83E-06 | 5.83E-06 | 4.15E-05 | 4.15E-05 |
| 208 | 9 | 1 | 1 | 7.47E-05 | 7.47E-05 | 0.000593 | 0.000593 |
| 227 | 9 | 1 | 1 | 1.06E-05 | 1.06E-05 | 8.02E-05 | 8.02E-05 |
| 232 | 9 | 1 | 1 | 3.08E-05 | 3.08E-05 | 0.000238 | 0.000238 |
| 233 | 9 | 1 | 1 | 1.17E-06 | 1.17E-06 | 8.30E-06 | 8.30E-06 |
| 234 | 9 | 1 | 1 | 1.49E-05 | 1.49E-05 | 0.000119 | 0.000119 |

**Table summarizing reliability indices with MWmax =71 for all branches:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Load Bus** | **ELC (MW)** | **NLC** | **EENS (MWh)** | **EDLC (hr)** |
| 2 | 2.8516e-02 | 1.4258e-02 | 8.128543e-01 | 4.064272e-01 |
| 3 | 1.2119e-01 | 3.454631e+00 |
| 4 | 5.7032e-02 | 1.625709e+00 |
| 5 | 1.4258e-02 | 4.064272e-01 |

**A recommendation to improve reliability:**

The table below shows details of the state where load needs to be curtailed due to branch overloading. All the other states with inadequacy are due to insufficient generation. Therefore, it is obvious that, of all the branches, branch 1 and branch 6 are playing the most critical role in the overall dispatch. If one of these branches are out, the other branch has a probability of being overloaded since it has to supply the 85 MW peak load at bus 3.

**Table listing states where load curtailment occurs due to branch overload**

|  |  |  |  |
| --- | --- | --- | --- |
| **State** | **TrOut** | **G1CA** | **G2CA** |
| 33 | 1 | 80 | 100 |
| 34 | 1 | 80 | 95 |
| 35 | 1 | 80 | 90 |
| 36 | 1 | 80 | 85 |
| 43 | 1 | 60 | 100 |
| 44 | 1 | 60 | 95 |
| 45 | 1 | 60 | 90 |
| 163 | 6 | 80 | 100 |
| 164 | 6 | 80 | 95 |
| 165 | 6 | 80 | 90 |
| 166 | 6 | 80 | 85 |
| 173 | 6 | 60 | 100 |
| 174 | 6 | 60 | 95 |

The table below shows the effect on the load point reliability indices when the MWmax of branch 1 or branch 6 is increased with steps of 1. Please note that the value of the reliability indices shown represent the total over all load buses. The values in the table have been calculated using a couple of nested for loops. The inner for loop implements the steps in (e). The outer for loop calculates the sum of each reliability index and stores it in a list. And then it increases MWmax by 1.

**Table showing effect of branch MWmax increase on load reliability indices**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **MWmax**  **(branch 1 or 6)** | **ELC (MW)** | **NLC** | **EENS (MWh)** | **EDLC (hr)** |
| 71 | 0.221003 | 0.014258 | 6.299621 | 0.406427 |
| 72 | 0.220697 | 0.014239 | 6.297372 | 0.406282 |
| 73 | 0.220697 | 0.014239 | 6.297372 | 0.406282 |
| 74 | 0.218036 | 0.014067 | 6.275975 | 0.404902 |
| 75 | 0.218036 | 0.014067 | 6.275975 | 0.404902 |
| **76** | **0.214193** | **0.013819** | **6.245024** | **0.402905** |
| 77 | 0.214193 | 0.013819 | 6.245024 | 0.402905 |
| 78 | 0.214193 | 0.013819 | 6.245024 | 0.402905 |
| 79 | 0.214048 | 0.01381 | 6.243955 | 0.402836 |
| 80 | 0.214048 | 0.01381 | 6.243955 | 0.402836 |

It is clear from the table (**reco\_table\_b1** or **reco\_table\_b6** in MATLAB code) above that the reliability increases significantly for all the indices till 76 MWmax, after which the increase is comparatively low. **Therefore, a recommendation to improve reliability would be to increase the capacity of branch 1 or branch 6 to 76 MWmax.**

% Appendix

% Final Project Bikiran Guha (A20378383)

% recursive function to calculate individual probability for a number

% of identical units

function pr = prob(X,u,c,num)

% X = CO, u:FOR, c: Capacity of unit, num: No. of units in system after

% addition of unit

if (num == 1) && (X == 0)

pr= 1-u;

elseif (X<0)

pr = 0;

elseif ( num == 1) && (X==c)

pr = u;

elseif (X>c\*num)

pr = 0;

else

pr= prob(X,u,c,num-1)\*(1-u) + prob(X-c,u,c,num-1)\*u;

end

end

% recursive function to calculate individual probability for a given list of units

function pr = prob\_v2(X,u,c)

% X = CO, u: list of FORs for each unit, c: List of capacity values

if (length(c)==1) && (X == 0)

pr= 1-u(1);

elseif (X<0)

pr = 0;

elseif (length(c)==1) && (X==c(1))

pr = u(1);

elseif (X>sum(c))

pr = 0;

else

up = u(2:length(c));

cp = c(2:length(c));

pr= prob\_v2(X,up,cp)\*(1-u(1)) + prob\_v2(X-c(1),up,cp)\*u(1);

end

end

% recursive function to calculate failure rate for a number

% of identical units

function lmn=lambdan(X,u,c,num,lambda)

% X = CO, u:FOR, c: Capacity of unit, num: No. of units in system

% lambda: failure rate in same units of time

if (num == 1) && (X == 0)

lmn = lambda;

elseif (X<0)

lmn = 0;

elseif (num == 1) && (X==c)

lmn = 0;

elseif (X>c\*num)

lmn = 0;

else

lmn= (prob(X,u,c,num-1)\*(1-u)\*(lambdan(X,u,c,num-1,lambda)+lambda) + prob(X-c,u,c,num-1)\*u\*lambdan(X-c,u,c,num-1,lambda))/prob(X,u,c,num);

end

end

% recursive function to calculate individual negative departure rate for a given list of units

function lmn=lambdan\_v2(X,u,c,lambda)

% X = CO, u: list of FORs for each unit, c: List of capacity values,

% lambda: failure rate in same units of time

if (length(c)==1) && (X == 0)

lmn = lambda;

elseif (X<0)

lmn = 0;

elseif (length(c)==1) && (X==c(1))

lmn = 0;

elseif (X>sum(c))

lmn = 0;

else

if (prob\_v2(X,u,c)~=0)

up = u(2:length(u));

cp = c(2:length(c));

lmn= (prob\_v2(X,up,cp)\*(1-u(1))\*(lambdan\_v2(X,up,cp,lambda)+lambda) + prob\_v2(X-c(1),up,cp)\*u(1)\*lambdan\_v2(X-c(1),up,cp,lambda))/prob\_v2(X,u,c);

else

lmn=0;

end

end

end

% recursive function to calculate repair rate for a number

% of identical units

function lmp=lambdap(X,u,c,num,mu)

% X = CO, u:FOR, c: Capacity of unit, num: No. of units

% mu: repair rate in same units of time

if (num == 1) && (X == 0)

lmp = 0;

elseif (X<0)

lmp = 0;

elseif (num == 1) && (X==c)

lmp = mu;

elseif (X>c\*num)

lmp = 0;

else

lmp= (prob(X,u,c,num-1)\*(1-u)\*lambdap(X,u,c,num-1,mu) + prob(X-c,u,c,num-1)\*u\*(lambdap(X-c,u,c,num-1,mu)+mu))/prob(X,u,c,num);

end

end

% recursive function to calculate individual positive departure rate for a given list of units

function lmp = lambdap\_v2(X,u,c,mu)

% X = CO, u: list of FORs for each unit, c: List of capacity values,

% mu: repair rate in same units of time

if (length(c)==1) && (X == 0)

lmp= 0;

elseif (X<0)

lmp = 0;

elseif (length(c)==1) && (X==c(1))

lmp = mu;

elseif (X>sum(c))

lmp = 0;

else

if (prob\_v2(X,u,c)~=0)

up = u(2:length(u));

cp = c(2:length(c));

lmp= (prob\_v2(X,up,cp)\*(1-u(1))\*lambdap\_v2(X,up,cp,mu) + prob\_v2(X-c(1),up,cp)\*u(1)\*(lambdap\_v2(X-c(1),up,cp,mu)+mu))/(prob\_v2(X,u,c));

else

lmp = 0;

end

end

end

%% Recursive function to calculate the fraction of original load at each bus

function frac = Pkj\_function\_v3(PDk, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax, frac\_init, tr\_out\_no, LODF\_all, PTDF\_all)

% Inputs:

% PDk: vector of loads at each bus

% post\_flow1: % Branch flows (including transmission outages) assuming all load is being supplied by Gen Bus 1

% post\_flow2: % Branch flows (including transmission outages) assuming all load is being supplied by Gen Bus 2

% CapAva1: Capacity available at Gen Bus 1

% CapAva2: Capacity available at Gen Bus 2

% MWmax: vector of branch flow limits (MW)

% frac\_init: Initial value of frac, generally 1

% tr\_out\_no: Transmission line number which is out

% LODF\_all: LODF matrix

% PTDF\_all: PTDF\_all

% Output:

% frac: Ratio of PDk/PD\_pk

Ltotal = sum(PDk);

success = gen\_dispatch(Ltotal, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax);

if (success == 1)

frac = frac\_init;

disp(' Excellent! Generation and Transmission constraints have been met!')

else

frac = frac\_init - 0.1;

PDk = frac\*PDk; % Curtailing the total load by 0.1\*PD\_pk

Ltotal= sum(PDk);

% Getting the new Pinj vectors

Pinj1 = -PDk;

Pinj2 = - PDk;

Pinj1(1,1) = Ltotal;

Pinj2(2,1) = Pinj2(2,1)+ Ltotal;

% Calculating the new flows given that any 1 Gen Bus is supplying

% entire load

pre\_flow1 = PTDF\_all\*Pinj1;

pre\_flow2 = PTDF\_all\*Pinj2;

% Considering any transmission line outage and calculating post flows

if (tr\_out\_no == 0)

post\_flow1 = pre\_flow1;

else

post\_flow1 = pre\_flow1 + LODF\_all(:,tr\_out\_no)\*pre\_flow1(tr\_out\_no);

end

if (tr\_out\_no == 0)

post\_flow2 = pre\_flow2;

else

post\_flow2 = pre\_flow2 + LODF\_all(:,tr\_out\_no)\*pre\_flow2(tr\_out\_no);

end

if(frac > 0)

frac = Pkj\_function\_v3(PDk, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax, frac, tr\_out\_no, LODF\_all, PTDF\_all);

else

frac = 0;

disp(' Dispatch totally failed! No load can be served!')

end

end

end

%% Start of main project: Frequency and Duration Based Generator Capacity Availability Tables

% Bus 1

lam\_b1 = 1.1; % lambda (failures/year) for each generator in Bus 1

mu\_b1 = 73; % mu (repairs/year) for each generator in Bus 1

u\_b1 = (lam\_b1)/(lam\_b1 + mu\_b1); % FOR for generators at Bus 1

c\_b1 = 20; % Capacity of each generator unit in Bus 1

% CO\_b1: Capa. out in Bus 1, CI\_b1: Capa. in. Bus 1

CO\_b1 = c\_b1\*[0:4]; % Since there are 4\*20 MW generators

CI\_b1 = 80 - CO\_b1; % Capacity in service values

% Getting individual prob values for generator outages in Bus 1

for(i=1:length(CO\_b1))

Pr\_b1(i,1) = prob((i-1)\*c\_b1,u\_b1,c\_b1,4);

end

% Eliminate values of Pr\_b1, CO\_b1 and CI\_b1 where Pr\_b1 < 1e-6

todelete = []; % vector to save all the rows where Pr\_b1 < 1e-6

for (i = 1:length(Pr\_b1))

if(Pr\_b1(i,1) < 1e-6)

todelete = [todelete i];

end

end

Pr\_b1(todelete) = [];

CO\_b1(todelete) = [];

CI\_b1(todelete) = [];

% Getting positive departure rates

for (i=1:length(CO\_b1))

% List of positive (repair) departure rate values (per year)

lmp\_b1(i,1) = lambdap(CO\_b1(i),u\_b1,c\_b1,4, mu\_b1);

end

% Getting negative departure rates

for (i=1:length(CO\_b1))

% List of negative (failure) departure rate values (per year)

lmn\_b1(i,1) = lambdan(CO\_b1(i),u\_b1,c\_b1,4,lam\_b1);

end

% Frequency values

for (i=1:length(CO\_b1))

freq\_b1(i,1) = Pr\_b1(i,1)\*(lmp\_b1(i,1)+lmn\_b1(i,1));

end

% Creating the frequency and duration table for Bus 1 Generators

tbl\_b1(:,1) = [1:length(CO\_b1)]';

tbl\_b1(:,2) = [0:length(CO\_b1) - 1]';

tbl\_b1(:,3) = CI\_b1;

tbl\_b1(:,4) = Pr\_b1;

tbl\_b1(:,5) = lmp\_b1;

tbl\_b1(:,6) = lmn\_b1;

tbl\_b1(:,7) = freq\_b1;

disp('Frequency and Duration Table for Bus 1 Generators')

disp(' State Units Capa In Prob. Positive Negative Frequency')

disp(' out dep. rate dep. rate (occ/yr)')

disp(tbl\_b1)

% Bus 2

lam\_b2 = 0.5; % lambda (failures/year) for each generator in Bus 2

mu\_b2 = 100; % mu (repairs/year) for each generator in Bus 2

u\_b2 = (lam\_b2)/(lam\_b2 + mu\_b2); % FOR for generators at Bus 2

% CO\_b2: Capacity in service values

CO\_b2 = 0:5:130; % Bus 2: 7\*5 MW, 15 MW, 4\*20 MW, Total: 130 MW

CI\_b2 = 130 - CO\_b2; % Capacity in service values

% List of FOR values for each generator in Bus 2

u\_b2\_list = u\_b2\*ones(1,12);

c\_b2\_5 = 5\*ones(1,7);

c\_b2\_20 = 20\*ones(1,4);

% List of capa. values for each generator in Bus 2

c\_b2\_list = [c\_b2\_5 15 c\_b2\_20];

% Getting individual prob values for generator outages in Bus 2

for(i=1:length(CO\_b2))

Pr\_b2(i,1) = prob\_v2(CO\_b2(i),u\_b2\_list,c\_b2\_list);

end

% Eliminate values of Pr\_b2, CO\_b2 and CI\_b2 where Pr\_b2 < 1e-6

todelete = []; % vector to save all the rows where Pr\_b2 < 1e-6

for (i = 1:length(Pr\_b2))

if(Pr\_b2(i,1) < 1e-6)

todelete = [todelete i];

end

end

Pr\_b2(todelete) = [];

CO\_b2(todelete) = [];

CI\_b2(todelete) = [];

% Getting positive departure rates

for (i=1:length(CO\_b2))

% List of positive (repair) departure rate values (per year)

lmp\_b2(i,1) = lambdap\_v2(CO\_b2(i),u\_b2\_list,c\_b2\_list, mu\_b2);

end

% Getting negative departure rates

for (i=1:length(CO\_b2))

% List of negative (failure) departure rate values (per year)

lmn\_b2(i,1) = lambdan\_v2(CO\_b2(i),u\_b2\_list,c\_b2\_list,lam\_b2);

end

% Frequency

for (i=1:length(CO\_b2))

freq\_b2(i,1) = Pr\_b2(i,1)\*(lmp\_b2(i,1)+lmn\_b2(i,1));

end

% Creating the frequency and duration table for Bus 2 Generators

tbl\_b2(:,1) = [1:length(CI\_b2)]';

tbl\_b2(:,2) = CI\_b2';

tbl\_b2(:,3) = Pr\_b2;

tbl\_b2(:,4) = lmp\_b2;

tbl\_b2(:,5) = lmn\_b2;

tbl\_b2(:,6) = freq\_b2;

disp('Frequency and Duration Table for Bus 2 Generators')

disp(' State Capa In Prob. Positive Negative Frequency')

disp(' dep. rate dep. rate (occ/yr)')

disp(tbl\_b2)

% Generator subsystem

% Getting a probability array for the generator subsystem

for (i = 1: length(Pr\_b1))

for (j=1:length(Pr\_b2))

Pr\_b1\_b2(i,j) = Pr\_b1(i)\*Pr\_b2(j); % The probability array

end

end

% The following 7 variables will contain all the info in the generator

% subsystem table

Pr\_b1\_b2\_trunc = []; % Individual prob.

CI\_b1\_trunc = []; % Capa. at Bus 1

CI\_b2\_trunc = []; % Capa. at Bus 2

lmp\_b1\_b2\_trunc = []; % Positive departure rate

lmn\_b1\_b2\_trunc = []; % Negative departure rate

freq\_b1\_b2\_trunc = []; % Frequency

% Getting all the values for the generator subsystem table

for (i = 1: length(Pr\_b1))

for (j=1:length(Pr\_b2))

if (Pr\_b1\_b2(i,j) >= 5e-7)

CI\_b1\_trunc = [CI\_b1\_trunc; CI\_b1(i)];

CI\_b2\_trunc = [CI\_b2\_trunc; CI\_b2(j)];

Pr\_b1\_b2\_trunc = [Pr\_b1\_b2\_trunc; Pr\_b1\_b2(i,j)];

lmp\_b1\_b2 = lmp\_b1(i)+lmp\_b2(j);

lmn\_b1\_b2 = lmn\_b1(i)+lmn\_b2(j);

lmp\_b1\_b2\_trunc = [lmp\_b1\_b2\_trunc; lmp\_b1\_b2];

lmn\_b1\_b2\_trunc = [lmn\_b1\_b2\_trunc; lmn\_b1\_b2];

freq\_b1\_b2\_trunc = [freq\_b1\_b2\_trunc; Pr\_b1\_b2(i,j)\*(lmp\_b1\_b2 + lmn\_b1\_b2)];

end

end

end

% Creating the frequency and duration table for the generator subsystem

tbl\_b1\_b2(:,1) = [1:length(Pr\_b1\_b2\_trunc)]';

tbl\_b1\_b2(:,2) = CI\_b1\_trunc;

tbl\_b1\_b2(:,3) = CI\_b2\_trunc;

tbl\_b1\_b2(:,4) = Pr\_b1\_b2\_trunc;

tbl\_b1\_b2(:,5) = lmp\_b1\_b2\_trunc;

tbl\_b1\_b2(:,6) = lmn\_b1\_b2\_trunc;

tbl\_b1\_b2(:,7) = freq\_b1\_b2\_trunc;

disp('Frequency and Duration Table for Generator Subsystem')

disp(' State Gen. Capa. Gen. Capa. Prob. Positive Negative Frequency')

disp(' Bus 1 Bus 2 dep. rate dep. rate (occ/yr)')

disp(tbl\_b1\_b2)

%% Frequency and Duration Based Transmission Capacity Availability Table

% Failure rate for each branch (occ/yr)

lam\_br1 = 1.5;

lam\_br2 = 5.0;

lam\_br3 = 4.0;

lam\_br4 = 1.0;

lam\_br5 = 1.0;

lam\_br6 = 1.5;

lam\_br7 = 5.0;

lam\_br8 = 1.0;

% Repair rates for the branches (occ/yr)

mu\_br = 1/(10/8760);

% FOR for each branch

u\_br1 = lam\_br1/(lam\_br1+mu\_br);

u\_br2 = lam\_br2/(lam\_br2+mu\_br);

u\_br3 = lam\_br3/(lam\_br3+mu\_br);

u\_br4 = lam\_br4/(lam\_br4+mu\_br);

u\_br5 = lam\_br5/(lam\_br5+mu\_br);

u\_br6 = lam\_br6/(lam\_br6+mu\_br);

u\_br7 = lam\_br7/(lam\_br7+mu\_br);

u\_br8 = lam\_br8/(lam\_br8+mu\_br);

% Availability for each branch

a\_br1 = 1-u\_br1;

a\_br2 = 1-u\_br2;

a\_br3 = 1-u\_br3;

a\_br4 = 1-u\_br4;

a\_br5 = 1-u\_br5;

a\_br6 = 1-u\_br6;

a\_br7 = 1-u\_br7;

a\_br8 = 1-u\_br8;

% Individual probability for each outage state

Pr\_br0 = a\_br1\*a\_br2\*a\_br3\*a\_br4\*a\_br5\*a\_br6\*a\_br7\*a\_br8; % All branches in service

Pr\_br1 = u\_br1\*a\_br2\*a\_br3\*a\_br4\*a\_br5\*a\_br6\*a\_br7\*a\_br8; % Branch 1 out

Pr\_br2 = a\_br1\*u\_br2\*a\_br3\*a\_br4\*a\_br5\*a\_br6\*a\_br7\*a\_br8; % Branch 2 out and so on...

Pr\_br3 = a\_br1\*a\_br2\*u\_br3\*a\_br4\*a\_br5\*a\_br6\*a\_br7\*a\_br8;

Pr\_br4 = a\_br1\*a\_br2\*a\_br3\*u\_br4\*a\_br5\*a\_br6\*a\_br7\*a\_br8;

Pr\_br5 = a\_br1\*a\_br2\*a\_br3\*a\_br4\*u\_br5\*a\_br6\*a\_br7\*a\_br8;

Pr\_br6 = a\_br1\*a\_br2\*a\_br3\*a\_br4\*a\_br5\*u\_br6\*a\_br7\*a\_br8;

Pr\_br7 = a\_br1\*a\_br2\*a\_br3\*a\_br4\*a\_br5\*a\_br6\*u\_br7\*a\_br8;

Pr\_br8 = a\_br1\*a\_br2\*a\_br3\*a\_br4\*a\_br5\*a\_br6\*a\_br7\*u\_br8;

Pr\_br = [ Pr\_br0; Pr\_br1; Pr\_br2; Pr\_br3; Pr\_br4; Pr\_br5; Pr\_br6; Pr\_br7 ; Pr\_br8];

% Positive departure rate for each outage state

lmp\_br0 = 0; % Repair rate all branches are in service

lmp\_br1 = mu\_br; % Repair rate when branch 1 is out

lmp\_br2 = mu\_br; % Branch 2 out and so on....

lmp\_br3 = mu\_br;

lmp\_br4 = mu\_br;

lmp\_br5 = mu\_br;

lmp\_br6 = mu\_br;

lmp\_br7 = mu\_br;

lmp\_br8 = mu\_br;

lmp\_br = [ lmp\_br0; lmp\_br1; lmp\_br2; lmp\_br3; lmp\_br4; lmp\_br5; lmp\_br6; lmp\_br7 ; lmp\_br8];

% Negative departure rate for each outage state

% Negative departure rate when all branches in service

lmn\_br0 = (lam\_br1 + lam\_br2 + lam\_br3 + lam\_br4 + lam\_br5 + lam\_br6 + lam\_br7 + lam\_br8);

% Since a max of only one branch can go out at any point of time

lmn\_br = [lmn\_br0; zeros(8,1)];

% Frequency for each state

freq\_br = Pr\_br.\*(lmp\_br+lmn\_br);

% Creating the frequency and duration based transmission availability table

tbl\_br(:,1) = [1:9]';

tbl\_br(:,2) = [0:8]';

tbl\_br(:,3) = Pr\_br;

tbl\_br(:,4) = lmp\_br;

tbl\_br(:,5) = lmn\_br;

tbl\_br(:,6) = freq\_br;

disp('Frequency and Duration Based Transmission Capacity Availability Table')

disp(' State Branch Prob. Positive Negative Frequency')

disp(' No. Name (L#) dep. rate dep. rate (occ/yr)')

disp(tbl\_br)

%% Frequency and Duration Based Composite Generation and Transmission Availability Table

% The following 9 variables will contain all the info in the composite

% generator and transmission availability table

Pr\_b12\_br = []; % Individual Probability

tr\_out = []; % Transmission line out name

g1ca = []; % Capacity available in Bus 1 Generators

g2ca = []; % Capacity available in Bus 1 Generators

lmp\_b12\_br = []; % Positive departure rate

lmn\_b12\_br = []; % Negative departure rate

freq\_b12\_br = []; % Frequency

dur\_b12\_br = []; % Duration

for (i = 1:length(Pr\_br))

for (j=1:length(Pr\_b1\_b2\_trunc))

tr\_out = [tr\_out; tbl\_br(i,2)];

g1ca = [g1ca; CI\_b1\_trunc(j)];

g2ca = [g2ca; CI\_b2\_trunc(j)];

Pr\_temp = Pr\_b1\_b2\_trunc(j)\*Pr\_br(i);

Pr\_b12\_br = [Pr\_b12\_br; Pr\_temp];

lmp\_temp = lmp\_br(i)+lmp\_b1\_b2\_trunc(j);

lmp\_b12\_br = [lmp\_b12\_br; lmp\_temp];

lmn\_temp = lmn\_br(i)+lmn\_b1\_b2\_trunc(j);

lmn\_b12\_br = [lmn\_b12\_br; lmn\_temp];

freq\_temp = Pr\_temp\*(lmp\_temp + lmn\_temp);

freq\_b12\_br = [freq\_b12\_br; freq\_temp];

dur\_temp = Pr\_temp/freq\_temp\*8760; % in hours

dur\_b12\_br = [dur\_b12\_br; dur\_temp];

end

end

% Creating the frequency and duration based composite generation and

% transmission availability table

tbl\_b12\_br(:,1) = [1:length(tr\_out)]';

tbl\_b12\_br(:,2) = tr\_out;

tbl\_b12\_br(:,3) = g1ca;

tbl\_b12\_br(:,4) = g2ca;

tbl\_b12\_br(:,5) = Pr\_b12\_br;

tbl\_b12\_br(:,6) = lmp\_b12\_br;

tbl\_b12\_br(:,7) = lmn\_b12\_br;

tbl\_b12\_br(:,8) = freq\_b12\_br;

tbl\_b12\_br(:,9) = dur\_b12\_br;

disp('Frequency and Duration Based Composite Generation and Transmission Availability Table')

disp(' State TrOut G1CA G2CA Prob. PosDepR NegDepR Freq. Dur.')

disp(' (L#) (r/yr) (f/yr) (occ/yr) (hr)')

disp(tbl\_b12\_br)

%% Generating load point indices

load('PTDF\_LODF.mat')

% Peak load at each bus. Rows correspond to buses

PD\_pk = [0; 20; 85; 40; 10];

Lkj= []; % Matrix of load curtailed (MW) for each load bus for every state

CapaL = []; % Matrix of capacity available at each bus

ELC = []; % Expected Load Curtailed matrix

EENS = []; % EENS values for all the load buses and composite states

% Loop to generate reliability indices for each state

for (i=1:length(tbl\_b12\_br))

frac\_init = 1;

MWmax = 71\*ones(8,1);

Ltotal = sum(PD\_pk);

Pinj1 = [Ltotal; -20; -85; -40; -10]; % Assuming all load is being supplied by Gen 1

Pinj2 = [0; Ltotal-20; -85; -40; -10]; % Assuming all load is being supplied by Gen 2

pre\_flow1 = PTDF\_all\*Pinj1;

pre\_flow2 = PTDF\_all\*Pinj2;

CapAva1 = g1ca(i);

CapAva2 = g2ca(i);

tr\_out\_no = tr\_out(i);

if (tr\_out\_no == 0)

post\_flow1 = pre\_flow1;

else

post\_flow1 = pre\_flow1 + LODF\_all(:,tr\_out\_no)\*pre\_flow1(tr\_out\_no);

end

if (tr\_out\_no == 0)

post\_flow2 = pre\_flow2;

else

post\_flow2 = pre\_flow2 + LODF\_all(:,tr\_out\_no)\*pre\_flow2(tr\_out\_no);

end

frac(i) = Pkj\_function\_v3(PD\_pk, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax, frac\_init, tr\_out\_no, LODF\_all, PTDF\_all);

if (frac(i) == 1)

Pkj(i) = 0; % Note that Pkj will be same for all load buses

else

Pkj(i) = 1;

end

PDk = frac(i)\*PD\_pk;

% Rows of CapaL represent different buses, while the columns represent different composite states

CapaL = [CapaL PDk];

% Rows of Lkj represent different buses, while the columns represent different composite states

Lkj = [Lkj (PD\_pk-PDk)];

% Rows of ELC represent different buses, while the columns represent different composite states

ELC = [ELC Lkj(:,i)\*freq\_b12\_br(i,1)];

if (Pkj(i) == 1)

NLC(i,1) = freq\_b12\_br(i,1); % NLC: No. of load curtailments

else

NLC(i,1) = 0; % Note that NLC will be same for all load buses

end

% Rows of EENS represent different buses, while the columns represent different composite states

EENS = [EENS Lkj(:,i)\*Pr\_b12\_br(i,1)\*8760]; % Units: MWh

if (Pkj(i) == 1)

%EDLC: Expected duration of load curtailments

EDLC(i,1) = Pr\_b12\_br(i,1)\*8760;

else

% Note that EDLC will be same for all load buses

EDLC(i,1) = 0;

end

end

% Building the table for Bus 2

tbl\_lb2(:,1) = tbl\_b12\_br(:,1); % State number

tbl\_lb2(:,2) = CapaL(2,:); % Capacity available or load served at the bus

tbl\_lb2(:,3) = Pkj; % Probability of inadequacy

tbl\_lb2(:,4) = Lkj(2,:); % Load curtailed

tbl\_lb2(:,5) = ELC(2,:); % Expected load curtailed

tbl\_lb2(:,6) = NLC; % No. of load curtailments

tbl\_lb2(:,7) = EENS(2,:); % Expected Energy Not Served

tbl\_lb2(:,8) = EDLC; % Expected duration of load curtailments

% Eliminating all rows where Pkj = 0 from the table

tbl\_lb2\_comp = tbl\_lb2;

todelete = []; % vector to save all the rows where Pkj = 0

for (i = 1:length(tbl\_lb2(:,1)))

if(Pkj(i) == 0)

todelete = [todelete i];

end

end

tbl\_lb2\_comp(todelete,:) = []; % New more compact table

disp('Load Point Reliability Indices Table for Bus 2')

disp(' State CapaAvaL Pkj Lkj ELC NLC EENS EDLC')

disp(' (MW) (MW) (MW) (occ) (MWh) (hr)')

disp(tbl\_lb2\_comp)

% Building the table for Bus 3

tbl\_lb3(:,1) = tbl\_b12\_br(:,1); % State number

tbl\_lb3(:,2) = CapaL(3,:); % Capacity available or load served at the bus

tbl\_lb3(:,3) = Pkj; % Probability of inadequacy

tbl\_lb3(:,4) = Lkj(3,:); % Load curtailed

tbl\_lb3(:,5) = ELC(3,:); % Expected load curtailed

tbl\_lb3(:,6) = NLC; % No. of load curtailments

tbl\_lb3(:,7) = EENS(3,:); % Expected Energy Not Served

tbl\_lb3(:,8) = EDLC; % Expected duration of load curtailments

% Eliminating all rows where Pkj = 0 from the table

tbl\_lb3\_comp = tbl\_lb3;

todelete = []; % vector to save all the rows where Pkj = 0

for (i = 1:length(tbl\_lb3(:,1)))

if(Pkj(i) == 0)

todelete = [todelete i];

end

end

tbl\_lb3\_comp(todelete,:) = []; % New more compact table

disp('Load Point Reliability Indices Table for Bus 3')

disp(' State CapaAvaL Pkj Lkj ELC NLC EENS EDLC')

disp(' (MW) (MW) (MW) (occ) (MWh) (hr)')

disp(tbl\_lb3\_comp)

% Building the table for Bus 4

tbl\_lb4(:,1) = tbl\_b12\_br(:,1); % State number

tbl\_lb4(:,2) = CapaL(4,:); % Capacity available or load served at the bus

tbl\_lb4(:,3) = Pkj; % Probability of inadequacy

tbl\_lb4(:,4) = Lkj(4,:); % Load curtailed

tbl\_lb4(:,5) = ELC(4,:); % Expected load curtailed

tbl\_lb4(:,6) = NLC; % No. of load curtailments

tbl\_lb4(:,7) = EENS(4,:); % Expected Energy Not Served

tbl\_lb4(:,8) = EDLC; % Expected duration of load curtailments

% Eliminating all rows where Pkj = 0 from the table

tbl\_lb4\_comp = tbl\_lb4;

todelete = []; % vector to save all the rows where Pkj = 0

for (i = 1:length(tbl\_lb4(:,1)))

if(Pkj(i) == 0)

todelete = [todelete i];

end

end

tbl\_lb4\_comp(todelete,:) = []; % New more compact table

disp('Load Point Reliability Indices Table for Bus 4')

disp(' State CapaAvaL Pkj Lkj ELC NLC EENS EDLC')

disp(' (MW) (MW) (MW) (occ) (MWh) (hr)')

disp(tbl\_lb4\_comp)

% Building the table for Bus 5

tbl\_lb5(:,1) = tbl\_b12\_br(:,1); % State number

tbl\_lb5(:,2) = CapaL(5,:); % Capacity available or load served at the bus

tbl\_lb5(:,3) = Pkj; % Probability of inadequacy

tbl\_lb5(:,4) = Lkj(5,:); % Load curtailed

tbl\_lb5(:,5) = ELC(5,:); % Expected load curtailed

tbl\_lb5(:,6) = NLC; % No. of load curtailments

tbl\_lb5(:,7) = EENS(5,:); % Expected Energy Not Served

tbl\_lb5(:,8) = EDLC; % Expected duration of load curtailments

% Eliminating all rows where Pkj = 0 from the table

tbl\_lb5\_comp = tbl\_lb5;

todelete = []; % vector to save all the rows where Pkj = 0

for (i = 1:length(tbl\_lb5(:,1)))

if(Pkj(i) == 0)

todelete = [todelete i];

end

end

tbl\_lb5\_comp(todelete,:) = []; % New more compact table

disp('Load Point Reliability Indices Table for Bus 5')

disp(' State CapaAvaL Pkj Lkj ELC NLC EENS EDLC')

disp(' (MW) (MW) (MW) (occ) (MWh) (hr)')

disp(tbl\_lb5\_comp)

% Summary of results

disp('Summary of load point reliability indices:')

ELC\_b2 = sum(tbl\_lb2\_comp(:,5));

X = sprintf('Expected Load Curtailed at Bus 2 = %d MW',ELC\_b2);

disp(X)

ELC\_b3 = sum(tbl\_lb3\_comp(:,5));

X = sprintf('Expected Load Curtailed at Bus 3 = %d MW',ELC\_b3);

disp(X)

ELC\_b4 = sum(tbl\_lb4\_comp(:,5));

X = sprintf('Expected Load Curtailed at Bus 4 = %d MW',ELC\_b4);

disp(X)

ELC\_b5 = sum(tbl\_lb5\_comp(:,5));

X = sprintf('Expected Load Curtailed at Bus 5 = %d MW',ELC\_b5);

disp(X)

NLC\_sum\_b1 = sum(tbl\_lb2\_comp(:,6));

X = sprintf('NLC for any load bus = %d',NLC\_sum\_b1);

disp(X)

EENS\_b2 = sum(tbl\_lb2\_comp(:,7));

X = sprintf('EENS at Bus 2 = %d MWh',EENS\_b2);

disp(X)

EENS\_b3 = sum(tbl\_lb3\_comp(:,7));

X = sprintf('EENS at Bus 3 = %d MWh',EENS\_b3);

disp(X)

EENS\_b4 = sum(tbl\_lb4\_comp(:,7));

X = sprintf('EENS at Bus 4 = %d MWh',EENS\_b4);

disp(X)

EENS\_b5 = sum(tbl\_lb5\_comp(:,7));

X = sprintf('EENS at Bus 5 = %d MWh',EENS\_b5);

disp(X)

EDLC\_sum\_b1 = sum(tbl\_lb2\_comp(:,8));

X = sprintf('EDLC for any load bus = %d hours',EDLC\_sum\_b1);

disp(X)

%% Testing recommendations

% Using a loop to make a table (fstate) which lists the values of TrOut,

%G1CA, G2CA which cause a failure

for (i = 1:length(tbl\_lb2\_comp))

fstate(i,1) = tbl\_lb2\_comp(i);

fstate(i,2) = tr\_out(tbl\_lb2\_comp(i));

fstate(i,3) = g1ca(tbl\_lb2\_comp(i));

fstate(i,4) = g2ca(tbl\_lb2\_comp(i));

end

disp(' Table showing details of composite states which cause load curtailment')

disp('State TrOut G1CA G2CA')

disp(fstate)

% Testing Recommendation about increasing branch 1 capacity

MWmax = 71\*ones(8,1);

% Outer loop gets values for different MWmax for branch 1

for (i = 1:10)

Lkj= [];

CapaL = [];

ELC = [];

EENS = [];

% Inner loop gets the reliability indices for the MWmax value

for (j=1:length(tbl\_b12\_br))

frac\_init = 1;

Ltotal = sum(PD\_pk);

Pinj1 = [Ltotal; -20; -85; -40; -10]; % Assuming all load is being supplied by Gen 1

Pinj2 = [0; Ltotal-20; -85; -40; -10]; % Assuming all load is being supplied by Gen 2

pre\_flow1 = PTDF\_all\*Pinj1;

pre\_flow2 = PTDF\_all\*Pinj2;

CapAva1 = g1ca(j);

CapAva2 = g2ca(j);

tr\_out\_no = tr\_out(j);

if (tr\_out\_no == 0)

post\_flow1 = pre\_flow1;

else

post\_flow1 = pre\_flow1 + LODF\_all(:,tr\_out\_no)\*pre\_flow1(tr\_out\_no);

end

if (tr\_out\_no == 0)

post\_flow2 = pre\_flow2;

else

post\_flow2 = pre\_flow2 + LODF\_all(:,tr\_out\_no)\*pre\_flow2(tr\_out\_no);

end

frac(j) = Pkj\_function\_v3(PD\_pk, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax, frac\_init, tr\_out\_no, LODF\_all, PTDF\_all);

if (frac(j) == 1)

Pkj(j) = 0; % Note that Pkj will be same for all load buses

else

Pkj(j) = 1;

end

PDk = frac(j)\*PD\_pk;

CapaL = [CapaL PDk]; % Rows of CapaL represent different buses, while the columns represent different composite states

Lkj = [Lkj (PD\_pk-PDk)]; % Rows of lkj represent different buses, while the columns represent different composite states

ELC = [ELC Lkj(:,j)\*freq\_b12\_br(j,1)]; % Rows of ELC represent different buses, while the columns represent different composite states

if (Pkj(j) == 1)

NLC(j,1) = freq\_b12\_br(j,1); % NLC: No. of load curtailments

else

NLC(j,1) = 0; % Note that NLC will be same for all load buses

end

% Rows of EENS represent different buses, while the columns represent different composite states

EENS = [EENS Lkj(:,j)\*Pr\_b12\_br(j,1)\*8760]; % Units: MWh

if (Pkj(j) == 1)

EDLC(j,1) = Pr\_b12\_br(j,1)\*8760; %EDLC: Expected duration of load curtailments

else

EDLC(j,1) = 0; % Note that EDLC will be same for all load buses

end

end

MWmax\_b1(i) = MWmax(1,1);

MWmax(1,1) = MWmax(1,1) + 1; % Increasing the MWmax of branch 1 by 1

% Calculating total ELC (for all buses)

ELC\_row\_sum = sum(ELC);

ELC\_sum\_b1(i) = sum(ELC\_row\_sum);

% Calculating total NLC

NLC\_sum\_b1(i) = sum(NLC);

% Calculating total ELC (for all buses)

EENS\_row\_sum = sum(EENS);

EENS\_sum\_b1(i) = sum(EENS\_row\_sum);

% Calculating total EDLC

EDLC\_sum\_b1(i) = sum(EDLC);

end

reco\_table\_b1(:,1) = MWmax\_b1;

reco\_table\_b1(:,2) = ELC\_sum\_b1;

reco\_table\_b1(:,3) = NLC\_sum\_b1;

reco\_table\_b1(:,4) = EENS\_sum\_b1;

reco\_table\_b1(:,5) = EDLC\_sum\_b1;

disp('Table showing effect of Branch 1 MWmax increase on load reliability indices')

disp(' MWmax ELC NLC EENS EDLC')

disp(' (MW) (MWh) (hr)')

disp(reco\_table\_b1)

% Recommendation about increasing branch 6 capacity

MWmax = 71\*ones(8,1);

for (i = 1:10)

Lkj= []; % This matrix will contain the values of load curtailed (MW) for each load bus for every state

CapaL = []; % This matrix will contain the values of capacity available at each bus

ELC = []; % Expected load curtailed Matrix

EENS = []; % This will contain the EENS values for all the load buses and composite states

for (j=1:length(tbl\_b12\_br))

frac\_init = 1;

Ltotal = sum(PD\_pk);

Pinj1 = [Ltotal; -20; -85; -40; -10]; % Assuming all load is being supplied by Gen 1

Pinj2 = [0; Ltotal-20; -85; -40; -10]; % Assuming all load is being supplied by Gen 2

pre\_flow1 = PTDF\_all\*Pinj1;

pre\_flow2 = PTDF\_all\*Pinj2;

CapAva1 = g1ca(j);

CapAva2 = g2ca(j);

tr\_out\_no = tr\_out(j);

if (tr\_out\_no == 0)

post\_flow1 = pre\_flow1;

else

post\_flow1 = pre\_flow1 + LODF\_all(:,tr\_out\_no)\*pre\_flow1(tr\_out\_no);

end

if (tr\_out\_no == 0)

post\_flow2 = pre\_flow2;

else

post\_flow2 = pre\_flow2 + LODF\_all(:,tr\_out\_no)\*pre\_flow2(tr\_out\_no);

end

frac(j) = Pkj\_function\_v3(PD\_pk, post\_flow1, post\_flow2, CapAva1, CapAva2, MWmax, frac\_init, tr\_out\_no, LODF\_all, PTDF\_all);

if (frac(j) == 1)

Pkj(j) = 0; % Note that Pkj will be same for all load buses

else

Pkj(j) = 1;

end

PDk = frac(j)\*PD\_pk;

CapaL = [CapaL PDk]; % Rows of CapaL represent different buses, while the columns represent different composite states

Lkj = [Lkj (PD\_pk-PDk)]; % Rows of lkj represent different buses, while the columns represent different composite states

ELC = [ELC Lkj(:,j)\*freq\_b12\_br(j,1)]; % Rows of ELC represent different buses, while the columns represent different composite states

if (Pkj(j) == 1)

NLC(j,1) = freq\_b12\_br(j,1); % NLC: No. of load curtailments

else

NLC(j,1) = 0; % Note that NLC will be same for all load buses

end

% Rows of EENS represent different buses, while the columns represent different composite states

EENS = [EENS Lkj(:,j)\*Pr\_b12\_br(j,1)\*8760]; % Units: MWh

if (Pkj(j) == 1)

EDLC(j,1) = Pr\_b12\_br(j,1)\*8760; %EDLC: Expected duration of load curtailments

else

EDLC(j,1) = 0; % Note that EDLC will be same for all load buses

end

end

MWmax\_b6(i) = MWmax(6,1);

MWmax(6,1) = MWmax(6,1) + 1; % Increasing the MWmax of branch 6 by 1

% Calculating total ELC (for all buses)

ELC\_row\_sum = sum(ELC);

ELC\_sum\_b6(i) = sum(ELC\_row\_sum);

% Calculating total NLC

NLC\_sum\_b6(i) = sum(NLC);

% Calculating total ELC (for all buses)

EENS\_row\_sum = sum(EENS);

EENS\_sum\_b6(i) = sum(EENS\_row\_sum);

% Calculating total EDLC

EDLC\_sum\_b6(i) = sum(EDLC);

end

reco\_table\_b6(:,1) = MWmax\_b6;

reco\_table\_b6(:,2) = ELC\_sum\_b6;

reco\_table\_b6(:,3) = NLC\_sum\_b6;

reco\_table\_b6(:,4) = EENS\_sum\_b6;

reco\_table\_b6(:,5) = EDLC\_sum\_b6;

disp('Table showing effect of Branch 6 MWmax increase on load reliability indices')

disp(' MWmax ELC NLC EENS EDLC')

disp(' (MW) (MWh) (hr)')

disp(reco\_table\_b6)