**WSCC 3 Machine 9 Bus System**

***Network***

This Western System Coordinating Council (WSCC) 3-machine, 9-bus system is used widely in the literature. All parameters shown below are come from the book titled “Power system control and stability” [1].



**Basic Data and Characteristics**

***Generators***

Parameters for the two-axis model of the synchronous machines are shown in Tables as follows. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mac# | Bus# |  |  |  |  |  |  |  |  |  |
| 1 | 1 | 0.1460 | 0.0608 | 0.0969 | 0.0969 | 0.0000 | 0 | 8.9600 | 0.3100 | 23.6000 |
| 2 | 2 | 0.8958 | 0.1198 | 0.8645 | 0.1969 | 0.0000 | 0 | 6.0000 | 0.5350 | 6.4000 |
| 3 | 3 | 1.3125 | 0.1813 | 1.2578 | 0.2500 | 0.0000 | 0 | 5.8900 | 0.6000 | 3.0100 |

***Line/transformers***

The network data for this system is shown in the Table below. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Line Data | | | | | Transformer Tap | |
| From Bus | To Bus |  |  |  | Magnitude | Angle |
| 4 | 5 | 0.0100 | 0.0850 | 0.1760 | 0 | 0 |
| 4 | 6 | 0.0170 | 0.0920 | 0.1580 | 0 | 0 |
| 5 | 7 | 0.0320 | 0.1610 | 0.3060 | 0 | 0 |
| 6 | 9 | 0.0390 | 0.1700 | 0.3580 | 0 | 0 |
| 7 | 8 | 0.0085 | 0.0720 | 0.1490 | 0 | 0 |
| 8 | 9 | 0.0119 | 0.1008 | 0.2090 | 0 | 0 |
| 1 | 4 | 0 | 0.0576 | 0 | 1.0000 | 0 |
| 2 | 7 | 0 | 0.0625 | 0 | 1.0000 | 0 |
| 3 | 9 | 0 | 0.0586 | 0 | 1.0000 | 0 |

***Power and Voltage Set Points***

All values are given on the same system base MVA. Note that generator 1 is the swing node.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bus | Type | Voltage[pu] | Load | | Generator | | | Grounding Parameter | |
|  |  |  |  |  |  |  | Machine-Type |  |  |
| 1 | PV | 1.04 | 0 | 0 | 0.0000 | 0 | 1 | 0 | 0 |
| 2 | PV | 1.025 | 0 | 0 | 163.0000 | 0 | 1 | 0 | 0 |
| 3 | PV | 1.025 | 0 | 0 | 85.0000 | 0 | 1 | 0 | 0 |
| 4 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 5 | PQ | - | 125.0000 | 50.0000 | 0 | 0 | - | 0 | 0 |
| 6 | PQ | - | 90.0000 | 30.0000 | 0 | 0 | - | 0 | 0 |
| 7 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 8 | PQ | - | 100.0000 | 35.0000 | 0 | 0 | - | 0 | 0 |
| 9 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |

\* Where Machine-Type =1 denotes generator, Machine-Type =0 denotes phase modifier.

***Exciter Model***



Fig. 1: IEEE-Type I exciter model

Where **is the field saturation function with coefficientsand.

***Excitation data***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mac# | Bus# |  |  |  |  |  |  |  |  |
| 1 | 1 | 20.0000 | 0.2000 | 1.0000 | 0.3140 | 0.0630 | 0.3500 | 0.0039 | 1.5550 |
| 2 | 2 | 20.0000 | 0.2000 | 1.0000 | 0.3140 | 0.0630 | 0.3500 | 0.0039 | 1.5550 |
| 3 | 3 | 20.0000 | 0.2000 | 1.0000 | 0.3140 | 0.0630 | 0.3500 | 0.0039 | 1.5550 |

**IEEE 10 Machines 39 Bus System**

This IEEE 39 bus system is well known as 10-machine New-England Power System. All parameters shown below are come from [2].

***Network***



**Basic Data and Characteristics**

***Generators***

Parameters for the two-axis model of the synchronous machines are shown in Tables as follows. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mac# | Bus# |  |  |  |  |  |  |  |  |  |
| 1 | 39 | 0.0200 | 0.0060 | 0.0190 | 0.0080 | 0 | 0 | 7.0000 | 0.7000 | 500.0000 |
| 2 | 31 | 0.2950 | 0.0697 | 0.2820 | 0.1700 | 0 | 0 | 6.5600 | 1.5000 | 30.3000 |
| 3 | 32 | 0.2495 | 0.0531 | 0.2370 | 0.0876 | 0 | 0 | 5.7000 | 1.5000 | 35.8000 |
| 4 | 33 | 0.2620 | 0.0436 | 0.2580 | 0.1660 | 0 | 0 | 5.6900 | 1.5000 | 28.6000 |
| 5 | 34 | 0.6700 | 0.1320 | 0.6200 | 0.1660 | 0 | 0 | 5.4000 | 0.4400 | 26.0000 |
| 6 | 35 | 0.2540 | 0.0500 | 0.2410 | 0.0814 | 0 | 0 | 7.3000 | 0.4000 | 34.8000 |
| 7 | 36 | 0.2950 | 0.0490 | 0.2920 | 0.1860 | 0 | 0 | 5.6600 | 1.5000 | 26.4000 |
| 8 | 37 | 0.2900 | 0.0570 | 0.2800 | 0.0911 | 0 | 0 | 6.7000 | 0.4100 | 24.3000 |
| 9 | 38 | 0.2106 | 0.0570 | 0.2050 | 0.0587 | 0 | 0 | 4.7900 | 1.9600 | 34.5000 |
| 10 | 30 | 0.1000 | 0.0310 | 0.0690 | 0.0080 | 0 | 0 | 10.2000 | 0.5000 | 42.0000 |

***Line/transformers***

The network data for this system is shown in the Table below. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Line Data | | | | | Transformer Tap | |
| From Bus | To Bus |  |  |  | Magnitude | Angle |
| 1 | 2 | 0.0035 | 0.0411 | 0.6986 | 0 | 0 |
| 1 | 39 | 0.0010 | 0.0250 | 0.7500 | 0 | 0 |
| 2 | 3 | 0.0013 | 0.0151 | 0.2572 | 0 | 0 |
| 2 | 25 | 0.0070 | 0.0086 | 0.1460 | 0 | 0 |
| 3 | 4 | 0.0013 | 0.0213 | 0.2214 | 0 | 0 |
| 3 | 18 | 0.0011 | 0.0133 | 0.2138 | 0 | 0 |
| 4 | 5 | 0.0008 | 0.0128 | 0.1342 | 0 | 0 |
| 4 | 14 | 0.0008 | 0.0129 | 0.1382 | 0 | 0 |
| 5 | 6 | 0.0002 | 0.0026 | 0.0434 | 0 | 0 |
| 5 | 8 | 0.0008 | 0.0112 | 0.1476 | 0 | 0 |
| 6 | 7 | 0.0006 | 0.0092 | 0.1130 | 0 | 0 |
| 6 | 11 | 0.0007 | 0.0082 | 0.1389 | 0 | 0 |
| 7 | 8 | 0.0004 | 0.0046 | 0.0780 | 0 | 0 |
| 8 | 9 | 0.0023 | 0.0363 | 0.3804 | 0 | 0 |
| 9 | 39 | 0.0010 | 0.0250 | 1.2000 | 0 | 0 |
| 10 | 11 | 0.0004 | 0.0043 | 0.0729 | 0 | 0 |
| 10 | 13 | 0.0004 | 0.0043 | 0.0729 | 0 | 0 |
| 13 | 14 | 0.0009 | 0.0101 | 0.1723 | 0 | 0 |
| 14 | 15 | 0.0018 | 0.0217 | 0.3660 | 0 | 0 |
| 15 | 16 | 0.0009 | 0.0094 | 0.1710 | 0 | 0 |
| 16 | 17 | 0.0007 | 0.0089 | 0.1342 | 0 | 0 |
| 16 | 19 | 0.0016 | 0.0195 | 0.3040 | 0 | 0 |
| 16 | 21 | 0.0008 | 0.0135 | 0.2548 | 0 | 0 |
| 16 | 24 | 0.0003 | 0.0059 | 0.0680 | 0 | 0 |
| 17 | 18 | 0.0007 | 0.0082 | 0.1319 | 0 | 0 |
| 17 | 27 | 0.0013 | 0.0173 | 0.3216 | 0 | 0 |
| 21 | 22 | 0.0008 | 0.0140 | 0.2565 | 0 | 0 |
| 22 | 23 | 0.0006 | 0.0096 | 0.1846 | 0 | 0 |
| 23 | 24 | 0.0022 | 0.0350 | 0.3610 | 0 | 0 |
| 25 | 26 | 0.0032 | 0.0323 | 0.5130 | 0 | 0 |
| 26 | 27 | 0.0014 | 0.0147 | 0.2396 | 0 | 0 |
| 26 | 28 | 0.0043 | 0.0474 | 0.7802 | 0 | 0 |
| 26 | 29 | 0.0057 | 0.0625 | 1.0290 | 0 | 0 |
| 28 | 29 | 0.0014 | 0.0151 | 0.2490 | 0 | 0 |
| 12 | 11 | 0.0016 | 0.0435 | 0 | 1.0060 | 0 |
| 12 | 13 | 0.0016 | 0.0435 | 0 | 1.0060 | 0 |
| 6 | 31 | 0.0000 | 0.0250 | 0 | 1.0700 | 0 |
| 10 | 32 | 0.0000 | 0.0200 | 0 | 1.0700 | 0 |
| 19 | 33 | 0.0007 | 0.0142 | 0 | 1.0700 | 0 |
| 20 | 34 | 0.0009 | 0.0180 | 0 | 1.0090 | 0 |
| 22 | 35 | 0.0000 | 0.0143 | 0 | 1.0250 | 0 |
| 23 | 36 | 0.0005 | 0.0272 | 0 | 1.0000 | 0 |
| 25 | 37 | 0.0006 | 0.0232 | 0 | 1.0250 | 0 |
| 2 | 30 | 0.0000 | 0.0181 | 0 | 1.0250 | 0 |
| 29 | 38 | 0.0008 | 0.0156 | 0 | 1.0250 | 0 |
| 19 | 20 | 0.0007 | 0.0138 | 0 | 1.0600 | 0 |

***Power and Voltage Set Points***

All values are given on the same system base MVA. Note that generator 2 is the swing node.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bus | Type | Voltage[pu] | Load | | Generator | | | Grounding Parameter | |
|  |  |  |  | Machine-type |  |  |
| 1 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 2 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 3 | PQ | - | 322.0000 | 2.4000 | 0 | 0 | - | 0 | 0 |
| 4 | PQ | - | 500.0000 | 184.0000 | 0 | 0 | - | 0 | 0 |
| 5 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 6 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 7 | PQ | - | 233.8000 | 84.0000 | 0 | 0 | - | 0 | 0 |
| 8 | PQ | - | 522.0000 | 176.0000 | 0 | 0 | - | 0 | 0 |
| 9 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 10 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 11 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 12 | PQ | - | 7.5000 | 88.0000 | 0 | 0 | - | 0 | 0 |
| 13 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 14 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 15 | PQ | - | 320.0000 | 153.0000 | 0 | 0 | - | 0 | 0 |
| 16 | PQ | - | 329.0000 | 32.3000 | 0 | 0 | - | 0 | 0 |
| 17 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 18 | PQ | - | 158.0000 | 30.0000 | 0 | 0 | - | 0 | 0 |
| 19 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 20 | PQ | - | 628.0000 | 103.0000 | 0 | 0 | - | 0 | 0 |
| 21 | PQ | - | 274.0000 | 115.0000 | 0 | 0 | - | 0 | 0 |
| 22 | PQ | - | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 23 | PQ | - | 247.5000 | 84.6000 | 0 | 0 | - | 0 | 0 |
| 24 | PQ | - | 308.6000 | -92.0000 | 0 | 0 | - | 0 | 0 |
| 25 | PQ | - | 224.0000 | 47.2000 | 0 | 0 | - | 0 | 0 |
| 26 | PQ | - | 139.0000 | 17.0000 | 0 | 0 | - | 0 | 0 |
| 27 | PQ | - | 281.0000 | 75.5000 | 0 | 0 | - | 0 | 0 |
| 28 | PQ | - | 206.0000 | 27.6000 | 0 | 0 | - | 0 | 0 |
| 29 | PQ | - | 283.5000 | 26.9000 | 0 | 0 | - | 0 | 0 |
| 30 | PV | 1.0475 | 0 | 0 | 250.0000 | 0 | 1 | 0 | 0 |
| 31 | PV | 0.9820 | 9.2000 | 4.6000 | 0 | 0 | 1 | 0 | 0 |
| 32 | PV | 0.9831 | 0 | 0 | 650.0000 | 0 | 1 | 0 | 0 |
| 33 | PV | 0.9972 | 0 | 0 | 632.0000 | 0 | 1 | 0 | 0 |
| 34 | PV | 1.0123 | 0 | 0 | 508.0000 | 0 | 1 | 0 | 0 |
| 35 | PV | 1.0493 | 0 | 0 | 650.0000 | 0 | 1 | 0 | 0 |
| 36 | PV | 1.0635 | 0 | 0 | 560.0000 | 0 | 1 | 0 | 0 |
| 37 | PV | 1.0278 | 0 | 0 | 540.0000 | 0 | 1 | 0 | 0 |
| 38 | PV | 1.0265 | 0 | 0 | 830.0000 | 0 | 1 | 0 | 0 |
| 39 | PV | 1.0300 | 1104.0000 | 250.0000 | 1000.0000 | 0 | 1 | 0 | 0 |

\* Where Machine-Type =1 denotes generator, Machine-Type =0 denotes phase modifier. All values shown are in per unit at 60Hz on a 100MVA base.

***Excitation data***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mac# | Bus# |  |  |  |  |  |  |  |  |
| 1 | **39** | 5.0000 | 0.0600 | -0.0485 | 0.2500 | 0.0400 | 1.0000 | 0.0063 | 0.0171 |
| 2 | **31** | 6.2000 | 0.0500 | -0.6330 | 0.4050 | 0.0570 | 0.5000 | 0.3700 | 0.4916 |
| 3 | **32** | 5.0000 | 0.0600 | -0.0198 | 0.5000 | 0.0800 | 1.0000 | 0.0249 | 0.0853 |
| 4 | **33** | 5.0000 | 0.0600 | -0.0525 | 0.5000 | 0.0800 | 1.0000 | 0.0055 | 0.0231 |
| 5 | **34** | 40.0000 | 0.0200 | 1.0000 | 0.7850 | 0.0300 | 1.0000 | 0.0002 | 0.0016 |
| 6 | **35** | 5.0000 | 0.0200 | -0.0419 | 0.4710 | 0.0754 | 1.2460 | 0.0033 | 0.0104 |
| 7 | **36** | 40.0000 | 0.0200 | 1.0000 | 0.7300 | 0.0300 | 1.0000 | 0.2784 | 0.3980 |
| 8 | **37** | 5.0000 | 0.0200 | -0.0470 | 0.5280 | 0.0854 | 1.2600 | 0.0043 | 0.0156 |
| 9 | **38** | 40.0000 | 0.0200 | 1.0000 | 1.4000 | 0.0300 | 1.0000 | 0.3005 | 0.3754 |
| 10 | **30** | 5.0000 | 0.0600 | -0.0485 | 0.2500 | 0.0400 | 1.0000 | 0.0063 | 0.0171 |

**IEEE 54 Machines 118 Bus System**

The IEEE 118-bus modified test system consists of 54 synchronous machines with IEEE type-1 exciters, 20 of which are synchronous compensators used only for reactive power support and 15 of which are motors.

***Network***



**Basic Data and Characteristics**

***Generators***

Parameters for the two-axis model of the synchronous machines are shown in Tables as follows. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bus |  |  |  |  |  |  |  |  |  |
| 10 | 0.357627 | 0.047458 | 0.342373 | 0.083051 | 0 | 11.8 | 0.5573 | 0.1371 | 13.6821 |
| 69 | 0.357627 | 0.047458 | 0.342373 | 0.083051 | 0 | 11.8 | 0.5573 | 0.1371 | 13.6821 |
| 80 | 0.357627 | 0.047458 | 0.342373 | 0.083051 | 0 | 11.8 | 0.5573 | 0.1371 | 13.6821 |
| 12 | 0.976 | 0.1392 | 0.928 | 0.2 | 0 | 2.5 | 8.97 | 0.5 | 5.96 |
| 25 | 0.590909 | 0.096061 | 0.581818 | 0.339394 | 0 | 6.6 | 0.9754 | 0.875 | 9.9198 |
| 49 | 0.590909 | 0.096061 | 0.581818 | 0.339394 | 0 | 6.6 | 0.9754 | 0.875 | 9.9198 |
| 100 | 0.590909 | 0.096061 | 0.581818 | 0.339394 | 0 | 6.6 | 0.9754 | 0.875 | 9.9198 |
| 26 | 0.430927 | 0.06678 | 0.426073 | 0.246439 | 0 | 8.2 | 0.8418 | 0.8676 | 15.1864 |
| 31 | 1.4 | 0.246667 | 1.306667 | 0.48 | 0 | 1.5 | 1.0748 | 0.1102 | 4.64025 |
| 46 | 1.4 | 0.246667 | 1.306667 | 0.48 | 0 | 1.5 | 1.0748 | 0.1102 | 4.64025 |
| 87 | 1.4 | 0.246667 | 1.306667 | 0.48 | 0 | 1.5 | 1.0748 | 0.1102 | 4.64025 |
| 54 | 1.18 | 0.22 | 1.05 | 0.38 | 0 | 2 | 1.1 | 0.1086 | 4.985 |
| 103 | 1.18 | 0.22 | 1.05 | 0.38 | 0 | 2 | 1.1 | 0.1086 | 4.985 |
| 111 | 1.18 | 0.22 | 1.05 | 0.38 | 0 | 2 | 1.1 | 0.1086 | 4.985 |
| 59 | 0.673391 | 0.139056 | 0.664378 | 0.393991 | 0 | 4.66 | 1.0614 | 0.8895 | 9.60426 |
| 61 | 0.673391 | 0.139056 | 0.664378 | 0.393991 | 0 | 4.66 | 1.0614 | 0.8895 | 9.60426 |
| 65 | 0.332031 | 0.052734 | 0.322266 | 0.091797 | 0 | 10.24 | 0.6035 | 0.1367 | 13.47072 |
| 66 | 0.332031 | 0.052734 | 0.322266 | 0.091797 | 0 | 10.24 | 0.6035 | 0.1367 | 13.47072 |
| 89 | 0.261437 | 0.049461 | 0.258323 | 0.153892 | 0 | 16.7 | 5.69 | 1.5 | 22.059865 |
| 1 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 6 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 15 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 19 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 32 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 34 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 36 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 55 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 56 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 62 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 74 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 76 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 77 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 85 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 92 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 104 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 105 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 110 | 7.076 | 1.216 | 3.42 | 2.318 | 0 | 0 | 8 | 0.008 | 0.3 |
| 18 | 5.9325 | 0.8575 | 2.93 | 0.43 | 0 | 0 | 11.6 | 0.159 | 0.608 |
| 70 | 5.9325 | 0.8575 | 2.93 | 0.43 | 0 | 0 | 11.6 | 0.159 | 0.608 |
| 4 | 5 | 0.928 | 4.88 | 2.86 | 0 | 0.5 | 4.75 | 1.5 | 1.254 |
| 24 | 5 | 0.928 | 4.88 | 2.86 | 0 | 0.5 | 4.75 | 1.5 | 1.254 |
| 27 | 5 | 0.928 | 4.88 | 2.86 | 0 | 0.5 | 4.75 | 1.5 | 1.254 |
| 72 | 5 | 0.928 | 4.88 | 2.86 | 0 | 0.5 | 4.75 | 1.5 | 1.254 |
| 73 | 5 | 0.928 | 4.88 | 2.86 | 0 | 0.5 | 4.75 | 1.5 | 1.254 |
| 8 | 3.967129 | 0.654576 | 3.887787 | 0.17002 | 0 | 0.7058 | 5.5 | 0.008 | 1.584274 |
| 91 | 3.967129 | 0.654576 | 3.887787 | 0.17002 | 0 | 0.7058 | 5.5 | 0.008 | 1.584274 |
| 107 | 3.967129 | 0.654576 | 3.887787 | 0.17002 | 0 | 0.7058 | 5.5 | 0.008 | 1.584274 |
| 40 | 2.480469 | 0.408203 | 2.421875 | 1.660156 | 0 | 1.024 | 6.6 | 0.008 | 2.599936 |
| 113 | 2.480469 | 0.408203 | 2.421875 | 1.660156 | 0 | 1.024 | 6.6 | 0.008 | 2.599936 |
| 42 | 1.4 | 0.246667 | 1.306667 | 0.48 | 0 | 1.5 | 6.1 | 0.3 | 4.6395 |
| 99 | 1.4 | 0.246667 | 1.306667 | 0.48 | 0 | 1.5 | 6.1 | 0.3 | 4.6395 |
| 90 | 1.18 | 0.22 | 1.05 | 0.38 | 0 | 2 | 5.9 | 0.3 | 4.985 |
| 112 | 1.18 | 0.22 | 1.05 | 0.38 | 0 | 2 | 5.9 | 0.3 | 4.985 |
| 116 | 0.468229 | 0.084375 | 0.463021 | 0.273698 | 0 | 7.68 | 5.21 | 1.5 | 10.06464 |

***Line/transformers***

The network data for this system is shown in the Table below. All values are given on the same system base MVA.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Line Data | | | | | Transformer Tap | |
| From Bus | To Bus |  |  |  | Magnitude | Angle |
| 1 | 2 | 0.0303 | 0.0999 | 0.0254 | 0 | 0 |
| 1 | 3 | 0.0129 | 0.0424 | 0.01082 | 0 | 0 |
| 4 | 5 | 0.00176 | 0.00798 | 0.0021 | 0 | 0 |
| 3 | 5 | 0.0241 | 0.108 | 0.0284 | 0 | 0 |
| 5 | 6 | 0.0119 | 0.054 | 0.01426 | 0 | 0 |
| 6 | 7 | 0.00459 | 0.0208 | 0.0055 | 0 | 0 |
| 8 | 9 | 0.00244 | 0.0305 | 1.162 | 0 | 0 |
| 9 | 10 | 0.00258 | 0.0322 | 1.23 | 0 | 0 |
| 4 | 11 | 0.0209 | 0.0688 | 0.01748 | 0 | 0 |
| 5 | 11 | 0.0203 | 0.0682 | 0.01738 | 0 | 0 |
| 11 | 12 | 0.00595 | 0.0196 | 0.00502 | 0 | 0 |
| 2 | 12 | 0.0187 | 0.0616 | 0.01572 | 0 | 0 |
| 3 | 12 | 0.0484 | 0.16 | 0.0406 | 0 | 0 |
| 7 | 12 | 0.00862 | 0.034 | 0.00874 | 0 | 0 |
| 11 | 13 | 0.02225 | 0.0731 | 0.01876 | 0 | 0 |
| 12 | 14 | 0.0215 | 0.0707 | 0.01816 | 0 | 0 |
| 13 | 15 | 0.0744 | 0.2444 | 0.06268 | 0 | 0 |
| 14 | 15 | 0.0595 | 0.195 | 0.0502 | 0 | 0 |
| 12 | 16 | 0.0212 | 0.0834 | 0.0214 | 0 | 0 |
| 15 | 17 | 0.0132 | 0.0437 | 0.0444 | 0 | 0 |
| 16 | 17 | 0.0454 | 0.1801 | 0.0466 | 0 | 0 |
| 17 | 18 | 0.0123 | 0.0505 | 0.01298 | 0 | 0 |
| 18 | 19 | 0.01119 | 0.0493 | 0.01142 | 0 | 0 |
| 19 | 20 | 0.0252 | 0.117 | 0.0298 | 0 | 0 |
| 15 | 19 | 0.012 | 0.0394 | 0.0101 | 0 | 0 |
| 20 | 21 | 0.0183 | 0.0849 | 0.0216 | 0 | 0 |
| 21 | 22 | 0.0209 | 0.097 | 0.0246 | 0 | 0 |
| 22 | 23 | 0.0342 | 0.159 | 0.0404 | 0 | 0 |
| 23 | 24 | 0.0135 | 0.0492 | 0.0498 | 0 | 0 |
| 23 | 25 | 0.0156 | 0.08 | 0.0864 | 0 | 0 |
| 25 | 27 | 0.0318 | 0.163 | 0.1764 | 0 | 0 |
| 27 | 28 | 0.01913 | 0.0855 | 0.0216 | 0 | 0 |
| 28 | 29 | 0.0237 | 0.0943 | 0.0238 | 0 | 0 |
| 8 | 30 | 0.00431 | 0.0504 | 0.514 | 0 | 0 |
| 26 | 30 | 0.00799 | 0.086 | 0.908 | 0 | 0 |
| 17 | 31 | 0.0474 | 0.1563 | 0.0399 | 0 | 0 |
| 29 | 31 | 0.0108 | 0.0331 | 0.0083 | 0 | 0 |
| 23 | 32 | 0.0317 | 0.1153 | 0.1173 | 0 | 0 |
| 31 | 32 | 0.0298 | 0.0985 | 0.0251 | 0 | 0 |
| 27 | 32 | 0.0229 | 0.0755 | 0.01926 | 0 | 0 |
| 15 | 33 | 0.038 | 0.1244 | 0.03194 | 0 | 0 |
| 19 | 34 | 0.0752 | 0.247 | 0.0632 | 0 | 0 |
| 35 | 36 | 0.00224 | 0.0102 | 0.00268 | 0 | 0 |
| 35 | 37 | 0.011 | 0.0497 | 0.01318 | 0 | 0 |
| 33 | 37 | 0.0415 | 0.142 | 0.0366 | 0 | 0 |
| 34 | 36 | 0.00871 | 0.0268 | 0.00568 | 0 | 0 |
| 34 | 37 | 0.00256 | 0.0094 | 0.00984 | 0 | 0 |
| 37 | 39 | 0.0321 | 0.106 | 0.027 | 0 | 0 |
| 37 | 40 | 0.0593 | 0.168 | 0.042 | 0 | 0 |
| 30 | 38 | 0.00464 | 0.054 | 0.422 | 0 | 0 |
| 39 | 40 | 0.0184 | 0.0605 | 0.01552 | 0 | 0 |
| 40 | 41 | 0.0145 | 0.0487 | 0.01222 | 0 | 0 |
| 40 | 42 | 0.0555 | 0.183 | 0.0466 | 0 | 0 |
| 41 | 42 | 0.041 | 0.135 | 0.0344 | 0 | 0 |
| 43 | 44 | 0.0608 | 0.2454 | 0.06068 | 0 | 0 |
| 34 | 43 | 0.0413 | 0.1681 | 0.04226 | 0 | 0 |
| 44 | 45 | 0.0224 | 0.0901 | 0.0224 | 0 | 0 |
| 45 | 46 | 0.04 | 0.1356 | 0.0332 | 0 | 0 |
| 46 | 47 | 0.038 | 0.127 | 0.0316 | 0 | 0 |
| 46 | 48 | 0.0601 | 0.189 | 0.0472 | 0 | 0 |
| 47 | 49 | 0.0191 | 0.0625 | 0.01604 | 0 | 0 |
| 42 | 49 | 0.0715 | 0.323 | 0.086 | 0 | 0 |
| 42 | 49 | 0.0715 | 0.323 | 0.086 | 0 | 0 |
| 45 | 49 | 0.0684 | 0.186 | 0.0444 | 0 | 0 |
| 48 | 49 | 0.0179 | 0.0505 | 0.01258 | 0 | 0 |
| 49 | 50 | 0.0267 | 0.0752 | 0.01874 | 0 | 0 |
| 49 | 51 | 0.0486 | 0.137 | 0.0342 | 0 | 0 |
| 51 | 52 | 0.0203 | 0.0588 | 0.01396 | 0 | 0 |
| 52 | 53 | 0.0405 | 0.1635 | 0.04058 | 0 | 0 |
| 53 | 54 | 0.0263 | 0.122 | 0.031 | 0 | 0 |
| 49 | 54 | 0.073 | 0.289 | 0.0738 | 0 | 0 |
| 49 | 54 | 0.0869 | 0.291 | 0.073 | 0 | 0 |
| 54 | 55 | 0.0169 | 0.0707 | 0.0202 | 0 | 0 |
| 54 | 56 | 0.00275 | 0.00955 | 0.00732 | 0 | 0 |
| 55 | 56 | 0.00488 | 0.0151 | 0.00374 | 0 | 0 |
| 56 | 57 | 0.0343 | 0.0966 | 0.0242 | 0 | 0 |
| 50 | 57 | 0.0474 | 0.134 | 0.0332 | 0 | 0 |
| 56 | 58 | 0.0343 | 0.0966 | 0.0242 | 0 | 0 |
| 51 | 58 | 0.0255 | 0.0719 | 0.01788 | 0 | 0 |
| 54 | 59 | 0.0503 | 0.2293 | 0.0598 | 0 | 0 |
| 56 | 59 | 0.0825 | 0.251 | 0.0569 | 0 | 0 |
| 56 | 59 | 0.0803 | 0.239 | 0.0536 | 0 | 0 |
| 55 | 59 | 0.04739 | 0.2158 | 0.05646 | 0 | 0 |
| 59 | 60 | 0.0317 | 0.145 | 0.0376 | 0 | 0 |
| 59 | 61 | 0.0328 | 0.15 | 0.0388 | 0 | 0 |
| 60 | 61 | 0.00264 | 0.0135 | 0.01456 | 0 | 0 |
| 60 | 62 | 0.0123 | 0.0561 | 0.01468 | 0 | 0 |
| 61 | 62 | 0.00824 | 0.0376 | 0.0098 | 0 | 0 |
| 63 | 64 | 0.00172 | 0.02 | 0.216 | 0 | 0 |
| 38 | 65 | 0.00901 | 0.0986 | 1.046 | 0 | 0 |
| 64 | 65 | 0.00269 | 0.0302 | 0.38 | 0 | 0 |
| 49 | 66 | 0.018 | 0.0919 | 0.0248 | 0 | 0 |
| 49 | 66 | 0.018 | 0.0919 | 0.0248 | 0 | 0 |
| 62 | 66 | 0.0482 | 0.218 | 0.0578 | 0 | 0 |
| 62 | 67 | 0.0258 | 0.117 | 0.031 | 0 | 0 |
| 66 | 67 | 0.0224 | 0.1015 | 0.02682 | 0 | 0 |
| 65 | 68 | 0.00138 | 0.016 | 0.638 | 0 | 0 |
| 47 | 69 | 0.0844 | 0.2778 | 0.07092 | 0 | 0 |
| 49 | 69 | 0.0985 | 0.324 | 0.0828 | 0 | 0 |
| 69 | 70 | 0.03 | 0.127 | 0.122 | 0 | 0 |
| 24 | 70 | 0.00221 | 0.4115 | 0.10198 | 0 | 0 |
| 70 | 71 | 0.00882 | 0.0355 | 0.00878 | 0 | 0 |
| 24 | 72 | 0.0488 | 0.196 | 0.0488 | 0 | 0 |
| 71 | 72 | 0.0446 | 0.18 | 0.04444 | 0 | 0 |
| 71 | 73 | 0.00866 | 0.0454 | 0.01178 | 0 | 0 |
| 70 | 74 | 0.0401 | 0.1323 | 0.03368 | 0 | 0 |
| 70 | 75 | 0.0428 | 0.141 | 0.036 | 0 | 0 |
| 69 | 75 | 0.0405 | 0.122 | 0.124 | 0 | 0 |
| 74 | 75 | 0.0123 | 0.0406 | 0.01034 | 0 | 0 |
| 76 | 77 | 0.0444 | 0.148 | 0.0368 | 0 | 0 |
| 69 | 77 | 0.0309 | 0.101 | 0.1038 | 0 | 0 |
| 75 | 77 | 0.0601 | 0.1999 | 0.04978 | 0 | 0 |
| 77 | 78 | 0.00376 | 0.0124 | 0.01264 | 0 | 0 |
| 78 | 79 | 0.00546 | 0.0244 | 0.00648 | 0 | 0 |
| 77 | 80 | 0.017 | 0.0485 | 0.0472 | 0 | 0 |
| 77 | 80 | 0.0294 | 0.105 | 0.0228 | 0 | 0 |
| 79 | 80 | 0.0156 | 0.0704 | 0.0187 | 0 | 0 |
| 68 | 81 | 0.00175 | 0.0202 | 0.808 | 0 | 0 |
| 77 | 82 | 0.0298 | 0.0853 | 0.08174 | 0 | 0 |
| 82 | 83 | 0.0112 | 0.03665 | 0.03796 | 0 | 0 |
| 83 | 84 | 0.0625 | 0.132 | 0.0258 | 0 | 0 |
| 83 | 85 | 0.043 | 0.148 | 0.0348 | 0 | 0 |
| 84 | 85 | 0.0302 | 0.0641 | 0.01234 | 0 | 0 |
| 85 | 86 | 0.035 | 0.123 | 0.0276 | 0 | 0 |
| 86 | 87 | 0.02828 | 0.2074 | 0.0445 | 0 | 0 |
| 85 | 88 | 0.02 | 0.102 | 0.0276 | 0 | 0 |
| 85 | 89 | 0.0239 | 0.173 | 0.047 | 0 | 0 |
| 88 | 89 | 0.0139 | 0.0712 | 0.01934 | 0 | 0 |
| 89 | 90 | 0.0518 | 0.188 | 0.0528 | 0 | 0 |
| 89 | 90 | 0.0238 | 0.0997 | 0.106 | 0 | 0 |
| 90 | 91 | 0.0254 | 0.0836 | 0.0214 | 0 | 0 |
| 89 | 92 | 0.0099 | 0.0505 | 0.0548 | 0 | 0 |
| 89 | 92 | 0.0393 | 0.1581 | 0.0414 | 0 | 0 |
| 91 | 92 | 0.0387 | 0.1272 | 0.03268 | 0 | 0 |
| 92 | 93 | 0.0258 | 0.0848 | 0.0218 | 0 | 0 |
| 92 | 94 | 0.0481 | 0.158 | 0.0406 | 0 | 0 |
| 93 | 94 | 0.0223 | 0.0732 | 0.01876 | 0 | 0 |
| 94 | 95 | 0.0132 | 0.0434 | 0.0111 | 0 | 0 |
| 80 | 96 | 0.0356 | 0.182 | 0.0494 | 0 | 0 |
| 82 | 96 | 0.0162 | 0.053 | 0.0544 | 0 | 0 |
| 94 | 96 | 0.0269 | 0.0869 | 0.023 | 0 | 0 |
| 80 | 97 | 0.0183 | 0.0934 | 0.0254 | 0 | 0 |
| 80 | 98 | 0.0238 | 0.108 | 0.0286 | 0 | 0 |
| 80 | 99 | 0.0454 | 0.206 | 0.0546 | 0 | 0 |
| 92 | 100 | 0.0648 | 0.295 | 0.0472 | 0 | 0 |
| 94 | 100 | 0.0178 | 0.058 | 0.0604 | 0 | 0 |
| 95 | 96 | 0.0171 | 0.0547 | 0.01474 | 0 | 0 |
| 96 | 97 | 0.0173 | 0.0885 | 0.024 | 0 | 0 |
| 98 | 100 | 0.0397 | 0.179 | 0.0476 | 0 | 0 |
| 99 | 100 | 0.018 | 0.0813 | 0.0216 | 0 | 0 |
| 100 | 101 | 0.0277 | 0.1262 | 0.0328 | 0 | 0 |
| 92 | 102 | 0.0123 | 0.0559 | 0.01464 | 0 | 0 |
| 101 | 102 | 0.0246 | 0.112 | 0.0294 | 0 | 0 |
| 100 | 103 | 0.016 | 0.0525 | 0.0536 | 0 | 0 |
| 100 | 104 | 0.0451 | 0.204 | 0.0541 | 0 | 0 |
| 103 | 104 | 0.0466 | 0.1584 | 0.0407 | 0 | 0 |
| 103 | 105 | 0.0535 | 0.1625 | 0.0408 | 0 | 0 |
| 100 | 106 | 0.0605 | 0.229 | 0.062 | 0 | 0 |
| 104 | 105 | 0.00994 | 0.0378 | 0.00986 | 0 | 0 |
| 105 | 106 | 0.014 | 0.0547 | 0.01434 | 0 | 0 |
| 105 | 107 | 0.053 | 0.183 | 0.0472 | 0 | 0 |
| 105 | 108 | 0.0261 | 0.0703 | 0.01844 | 0 | 0 |
| 106 | 107 | 0.053 | 0.183 | 0.0472 | 0 | 0 |
| 108 | 109 | 0.0105 | 0.0288 | 0.0076 | 0 | 0 |
| 103 | 110 | 0.03906 | 0.1813 | 0.0461 | 0 | 0 |
| 109 | 110 | 0.0278 | 0.0762 | 0.0202 | 0 | 0 |
| 110 | 111 | 0.022 | 0.0755 | 0.02 | 0 | 0 |
| 110 | 112 | 0.0247 | 0.064 | 0.062 | 0 | 0 |
| 17 | 113 | 0.00913 | 0.0301 | 0.00768 | 0 | 0 |
| 32 | 113 | 0.0615 | 0.203 | 0.0518 | 0 | 0 |
| 32 | 114 | 0.0135 | 0.0612 | 0.01628 | 0 | 0 |
| 27 | 115 | 0.0164 | 0.0741 | 0.01972 | 0 | 0 |
| 114 | 115 | 0.0023 | 0.0104 | 0.00276 | 0 | 0 |
| 68 | 116 | 0.00034 | 0.00405 | 0.164 | 0 | 0 |
| 12 | 117 | 0.0329 | 0.14 | 0.0358 | 0 | 0 |
| 75 | 118 | 0.0145 | 0.0481 | 0.01198 | 0 | 0 |
| 76 | 118 | 0.0164 | 0.0544 | 0.01356 | 0 | 0 |
| 8 | 5 | 0 | 0.0267 | 0 | 0.985 | 0 |
| 26 | 25 | 0 | 0.0382 | 0 | 0.96 | 0 |
| 30 | 17 | 0 | 0.0388 | 0 | 0.96 | 0 |
| 38 | 37 | 0 | 0.0375 | 0 | 0.935 | 0 |
| 63 | 59 | 0 | 0.0386 | 0 | 0.96 | 0 |
| 64 | 61 | 0 | 0.0268 | 0 | 0.985 | 0 |
| 65 | 66 | 0 | 0.037 | 0 | 0.935 | 0 |
| 68 | 69 | 0 | 0.037 | 0 | 0.935 | 0 |
| 81 | 80 | 0 | 0.037 | 0 | 0.935 | 0 |
| 92 | 100 | 0.0648 | 0.295 | 0 | 1 | 0 |
| 106 | 107 | 0.053 | 0.183 | 0 | 1 | 0 |

***Power and Voltage Set Points***

All values are given on the same system base MVA. Note that generator 69 is the swing node.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bus | Type | Voltage[pu] | Load | | Generator | | | Grounding Parameter | |
|  |  |  |  | Machine-type |  |  |
| 1 | PV | 0.955 | 51 | 27 | 0 | 0 | 0 | 0 | 0 |
| 2 | PQ | -- | 20 | 9 | 0 | 0 | -- | 0 | 0 |
| 3 | PQ | -- | 39 | 10 | 0 | 0 | -- | 0 | 0 |
| 4 | PV | 0.998 | 30 | 12 | -9 | 0 | 0 | 0 | 0 |
| 5 | PQ | -- | 0 | 0 | 0 | 0 | -- | 0 | -0.4 |
| 6 | PV | 0.99 | 52 | 22 | 0 | 0 | 0 | 0 | 0 |
| 7 | PQ | -- | 19 | 2 | 0 | 0 | -- | 0 | 0 |
| 8 | PV | 1.015 | 0 | 0 | -28 | 0 | 0 | 0 | 0 |
| 10 | PV | 1.05 | 0 | 0 | 450 | 0 | 1 | 0 | 0 |
| 11 | PQ | -- | 70 | 23 | 0 | 0 | -- | 0 | 0 |
| 12 | PV | 0.99 | 47 | 10 | 85 | 0 | 1 | 0 | 0 |
| 13 | PQ | -- | 34 | 16 | 0 | 0 | -- | 0 | 0 |
| 14 | PQ | -- | 14 | 1 | 0 | 0 | -- | 0 | 0 |
| 15 | PV | 0.97 | 90 | 30 | 0 | 0 | 0 | 0 | 0 |
| 16 | PQ | -- | 25 | 10 | 0 | 0 | -- | 0 | 0 |
| 17 | PQ | -- | 11 | 3 | 0 | 0 | -- | 0 | 0 |
| 18 | PV | 0.973 | 60 | 34 | 0 | 0 | 0 | 0 | 0 |
| 19 | PV | 0.962 | 45 | 25 | 0 | 0 | 0 | 0 | 0 |
| 20 | PQ | -- | 18 | 3 | 0 | 0 | -- | 0 | 0 |
| 21 | PQ | -- | 14 | 8 | 0 | 0 | -- | 0 | 0 |
| 22 | PQ | -- | 10 | 5 | 0 | 0 | -- | 0 | 0 |
| 23 | PQ | -- | 7 | 3 | 0 | 0 | -- | 0 | 0 |
| 24 | PV | 0.992 | 0 | 0 | -13 | 0 | 0 | 0 | 0 |
| 25 | PV | 1.05 | 0 | 0 | 220 | 0 | 1 | 0 | 0 |
| 26 | PV | 1.015 | 0 | 0 | 314 | 0 | 1 | 0 | 0 |
| 27 | PV | 0.968 | 62 | 13 | -9 | 0 | 0 | 0 | 0 |
| 28 | PQ | -- | 17 | 7 | 0 | 0 | -- | 0 | 0 |
| 29 | PQ | -- | 24 | 4 | 0 | 0 | -- | 0 | 0 |
| 31 | PV | 0.967 | 43 | 27 | 7 | 0 | 0 | 0 | 0 |
| 32 | PV | 0.963 | 59 | 23 | 0 | 0 | 0 | 0 | 0 |
| 33 | PQ | -- | 23 | 9 | 0 | 0 | -- | 0 | 0 |
| 34 | PV | 0.984 | 59 | 26 | 0 | 0 | 0 | 0 | 0.14 |
| 35 | PQ | -- | 33 | 9 | 0 | 0 | -- | 0 | 0 |
| 36 | PV | 0.98 | 31 | 17 | 0 | 0 | 0 | 0 | 0 |
| 37 | PQ | -- | 0 | 0 | 0 | 0 | -- | 0 | -0.25 |
| 39 | PQ | -- | 27 | 11 | 0 | 0 | -- | 0 | 0 |
| 40 | PV | 0.97 | 20 | 23 | -46 | 0 | 0 | 0 | 0 |
| 41 | PQ | -- | 37 | 10 | 0 | 0 | -- | 0 | 0 |
| 42 | PV | 0.985 | 37 | 23 | -59 | 0 | 0 | 0 | 0 |
| 43 | PQ | -- | 18 | 7 | 0 | 0 | -- | 0 | 0 |
| 44 | PQ | -- | 16 | 8 | 0 | 0 | -- | 0 | 0.1 |
| 45 | PQ | -- | 53 | 22 | 0 | 0 | -- | 0 | 0.1 |
| 46 | PV | 1.005 | 28 | 10 | 19 | 0 | 0 | 0 | 0.1 |
| 47 | PQ | -- | 34 | 0 | 0 | 0 | -- | 0 | 0 |
| 48 | PQ | -- | 20 | 11 | 0 | 0 | -- | 0 | 0.15 |
| 49 | PV | 1.025 | 87 | 30 | 204 | 0 | 1 | 0 | 0 |
| 50 | PQ | -- | 17 | 4 | 0 | 0 | -- | 0 | 0 |
| 51 | PQ | -- | 17 | 8 | 0 | 0 | -- | 0 | 0 |
| 52 | PQ | -- | 18 | 5 | 0 | 0 | -- | 0 | 0 |
| 53 | PQ | -- | 23 | 11 | 0 | 0 | -- | 0 | 0 |
| 54 | PV | 0.955 | 113 | 32 | 48 | 0 | 1 | 0 | 0 |
| 55 | PV | 0.952 | 63 | 22 | 0 | 0 | 0 | 0 | 0 |
| 56 | PV | 0.954 | 84 | 18 | 0 | 0 | 0 | 0 | 0 |
| 57 | PQ | -- | 12 | 3 | 0 | 0 | -- | 0 | 0 |
| 58 | PQ | -- | 12 | 3 | 0 | 0 | -- | 0 | 0 |
| 59 | PV | 0.985 | 277 | 113 | 155 | 0 | 1 | 0 | 0 |
| 60 | PQ | -- | 78 | 3 | 0 | 0 | -- | 0 | 0 |
| 61 | PV | 0.995 | 0 | 0 | 160 | 0 | 1 | 0 | 0 |
| 62 | PV | 0.998 | 77 | 14 | 0 | 0 | 0 | 0 | 0 |
| 65 | PV | 1.005 | 0 | 0 | 391 | 0 | 1 | 0 | 0 |
| 66 | PV | 1.05 | 39 | 18 | 392 | 0 | 1 | 0 | 0 |
| 67 | PQ | -- | 28 | 7 | 0 | 0 | -- | 0 | 0 |
| 69 | PV | 1.035 | 0 | 0 | 516.4 | 0 | 1 | 0 | 0 |
| 70 | PV | 0.984 | 66 | 20 | 0 | 0 | 0 | 0 | 0 |
| 72 | PV | 0.98 | 0 | 0 | -12 | 0 | 0 | 0 | 0 |
| 73 | PV | 0.991 | 0 | 0 | -6 | 0 | 0 | 0 | 0 |
| 74 | PV | 0.958 | 68 | 27 | 0 | 0 | 0 | 0 | 0.12 |
| 75 | PQ | -- | 47 | 11 | 0 | 0 | -- | 0 | 0 |
| 76 | PV | 0.943 | 68 | 36 | 0 | 0 | 0 | 0 | 0 |
| 77 | PV | 1.006 | 61 | 28 | 0 | 0 | -- | 0 | 0 |
| 78 | PQ | -- | 71 | 26 | 0 | 0 | -- | 0 | 0 |
| 79 | PQ | -- | 39 | 32 | 0 | 0 | -- | 0 | 0.2 |
| 80 | PV | 1.04 | 130 | 26 | 477 | 0 | 1 | 0 | 0 |
| 82 | PQ | -- | 54 | 27 | 0 | 0 | -- | 0 | 0.2 |
| 83 | PQ | -- | 20 | 10 | 0 | 0 | -- | 0 | 0.1 |
| 84 | PQ | -- | 11 | 7 | 0 | 0 | -- | 0 | 0 |
| 85 | PV | 0.985 | 24 | 15 | 0 | 0 | 0 | 0 | 0 |
| 86 | PQ | -- | 21 | 10 | 0 | 0 | -- | 0 | 0 |
| 87 | PV | 1.015 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 88 | PQ | -- | 48 | 10 | 0 | 0 | -- | 0 | 0 |
| 89 | PV | 1.005 | 0 | 0 | 607 | 0 | 1 | 0 | 0 |
| 90 | PV | 0.985 | 78 | 42 | -85 | 0 | 0 | 0 | 0 |
| 91 | PV | 0.98 | 0 | 0 | -10 | 0 | 0 | 0 | 0 |
| 92 | PV | 0.99 | 65 | 10 | 0 | 0 | 0 | 0 | 0 |
| 93 | PQ | -- | 12 | 7 | 0 | 0 | -- | 0 | 0 |
| 94 | PQ | -- | 30 | 16 | 0 | 0 | -- | 0 | 0 |
| 95 | PQ | -- | 42 | 31 | 0 | 0 | -- | 0 | 0 |
| 96 | PQ | -- | 38 | 15 | 0 | 0 | -- | 0 | 0 |
| 97 | PQ | -- | 15 | 9 | 0 | 0 | -- | 0 | 0 |
| 98 | PQ | -- | 34 | 8 | 0 | 0 | -- | 0 | 0 |
| 99 | PV | 1.01 | 0 | 0 | -42 | 0 | 0 | 0 | 0 |
| 100 | PV | 1.017 | 37 | 18 | 252 | 0 | 1 | 0 | 0 |
| 101 | PQ | -- | 22 | 15 | 0 | 0 | -- | 0 | 0 |
| 102 | PQ | -- | 5 | 3 | 0 | 0 | -- | 0 | 0 |
| 103 | PV | 1.01 | 23 | 16 | 40 | 0 | 1 | 0 | 0 |
| 104 | PV | 0.971 | 38 | 25 | 0 | 0 | 0 | 0 | 0 |
| 105 | PV | 0.965 | 31 | 26 | 0 | 0 | 0 | 0 | 0.2 |
| 106 | PQ | -- | 43 | 16 | 0 | 0 | -- | 0 | 0 |
| 107 | PV | 0.952 | 28 | 12 | -22 | 0 | 0 | 0 | 0.06 |
| 108 | PQ | -- | 2 | 1 | 0 | 0 | -- | 0 | 0 |
| 109 | PQ | -- | 8 | 3 | 0 | 0 | -- | 0 | 0 |
| 110 | PV | 0.973 | 39 | 30 | 0 | 0 | 0 | 0 | 0.06 |
| 111 | PV | 0.98 | 0 | 0 | 36 | 0 | 1 | 0 | 0 |
| 112 | PV | 0.975 | 25 | 13 | -43 | 0 | 0 | 0 | 0 |
| 113 | PV | 0.993 | 0 | 0 | -6 | 0 | 0 | 0 | 0 |
| 114 | PQ | -- | 8 | 3 | 0 | 0 | -- | 0 | 0 |
| 115 | PQ | -- | 22 | 7 | 0 | 0 | -- | 0 | 0 |
| 116 | PV | 1.005 | 0 | 0 | -184 | 0 | 0 | 0 | 0 |
| 117 | PQ | -- | 20 | 8 | 0 | 0 | -- | 0 | 0 |
| 118 | PQ | -- | 33 | 15 | 0 | 0 | -- | 0 | 0 |

\* Where Machine-Type =1 denotes generator, Machine-Type =0 denotes phase modifier.

***Excitation data***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mac# | Bus# |  |  |  |  |  |  |  |  |
| 10 | 10 | 200 | 0.3575 | 1 | 0.011 | 0.0529 | 1 | 0 | 0 |
| 69 | 69 | 200 | 0.3575 | 1 | 0.011 | 0.0529 | 1 | 0 | 0 |
| 80 | 80 | 200 | 0.3575 | 1 | 0.011 | 0.0529 | 1 | 0 | 0 |
| 12 | 12 | 25 | 0.2 | -0.061 | 0.6758 | 0.108 | 0.35 | 0.0016 | 1.6353 |
| 25 | 25 | 400 | 0.05 | -0.17 | 0.95 | 0.04 | 1 | 0.0027 | 0.3863 |
| 49 | 49 | 400 | 0.05 | -0.17 | 0.95 | 0.04 | 1 | 0.0027 | 0.3863 |
| 100 | 100 | 400 | 0.05 | -0.17 | 0.95 | 0.04 | 1 | 0.0027 | 0.3863 |
| 26 | 26 | 400 | 0.02 | 1 | 0.92 | 0.03 | 1 | 0.1658 | 0.3909 |
| 31 | 31 | 20 | 0.05 | 1 | 1.98 | 0 | 0.1 | 0.0016 | 1.713 |
| 46 | 46 | 20 | 0.05 | 1 | 1.98 | 0 | 0.1 | 0.0016 | 1.713 |
| 87 | 87 | 20 | 0.05 | 1 | 1.98 | 0 | 0.1 | 0.0016 | 1.713 |
| 54 | 54 | 25 | 0.2 | -0.0582 | 0.6544 | 0.105 | 0.35 | 0.0015 | 1.5838 |
| 103 | 103 | 25 | 0.2 | -0.0582 | 0.6544 | 0.105 | 0.35 | 0.0015 | 1.5838 |
| 111 | 111 | 25 | 0.2 | -0.0582 | 0.6544 | 0.105 | 0.35 | 0.0015 | 1.5838 |
| 59 | 59 | 250 | 0.06 | 1 | 0.613 | 0.053 | 0.33 | 0 | 0 |
| 61 | 61 | 250 | 0.06 | 1 | 0.613 | 0.053 | 0.33 | 0 | 0 |
| 65 | 65 | 200 | 0.395 | 1 | 0.008 | 0.0635 | 1 | 0 | 0 |
| 66 | 66 | 200 | 0.395 | 1 | 0.008 | 0.0635 | 1 | 0 | 0 |
| 89 | 89 | 200 | 0.02 | 1 | 0.942 | 0.03 | 1 | 0.023 | 0.9475 |
| 1 | 1 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 6 | 6 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 15 | 15 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 19 | 19 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 32 | 32 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 34 | 34 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 36 | 36 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 55 | 55 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 56 | 56 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 62 | 62 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 74 | 74 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 76 | 76 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 77 | 77 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 85 | 85 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 92 | 92 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 104 | 104 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 105 | 105 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 110 | 110 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 1.0355 |
| 18 | 18 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 0.6884 |
| 70 | 70 | 200 | 0.05 | 1 | 0.95 | 0.04 | 1 | 0.0027 | 0.6884 |
| 4 | 4 | 20 | 0.05 | 1 | 0.7 | 0 | 0.008 | 0.0392 | 0.8809 |
| 24 | 24 | 20 | 0.05 | 1 | 0.7 | 0 | 0.008 | 0.0392 | 0.8809 |
| 27 | 27 | 20 | 0.05 | 1 | 0.7 | 0 | 0.008 | 0.0392 | 0.8809 |
| 72 | 72 | 20 | 0.05 | 1 | 0.7 | 0 | 0.008 | 0.0392 | 0.8809 |
| 73 | 73 | 20 | 0.05 | 1 | 0.7 | 0 | 0.008 | 0.0392 | 0.8809 |
| 8 | 8 | 57.14 | 0.05 | -0.0445 | 0.5 | 0.08 | 1 | 0.0012 | 1.2101 |
| 91 | 91 | 57.14 | 0.05 | -0.0445 | 0.5 | 0.08 | 1 | 0.0012 | 1.2101 |
| 107 | 107 | 57.14 | 0.05 | -0.0445 | 0.5 | 0.08 | 1 | 0.0012 | 1.2101 |
| 40 | 40 | 400 | 0.05 | -0.0769 | 1.37 | 0.04 | 1 | 0.0137 | 0.6774 |
| 113 | 113 | 400 | 0.05 | -0.0769 | 1.37 | 0.04 | 1 | 0.0137 | 0.6774 |
| 42 | 42 | 20 | 0.05 | 1 | 1.98 | 0 | 0.008 | 0.0016 | 1.713 |
| 99 | 99 | 20 | 0.05 | 1 | 1.98 | 0 | 0.008 | 0.0016 | 1.713 |
| 90 | 90 | 25 | 0.02 | -0.0582 | 0.6544 | 0.105 | 0.35 | 0.0015 | 1.5838 |
| 112 | 112 | 25 | 0.02 | -0.0582 | 0.6544 | 0.105 | 0.35 | 0.0015 | 1.5838 |
| 116 | 116 | 400 | 0.02 | 1 | 0.812 | 0.06 | 1 | 0.1572 | 0.2909 |

TABLE Ⅰ spectral abscissa

|  |  |
| --- | --- |
| Test systems |  |
| WSCC 3-machine 9-bus system | -0.1907+8.3677i |
| New England 10-machine 39-bus system | -0.1055 + 0.4373i |
| IEEE 54-machine 118-bus system | -0.0768 |

\*Wheredenotes the spectral abscissa of the state matrix at the equilibrium point.

TABLE Ⅱ

Spectral Abscissa sensitivities for 3-machine-9-bus system

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bus | Active power | | | Reactive power | |
| NSAS | CFSAS | MSAD | CFSAS | MSAD |
| 1 | —— | -0.0014 | -0.2365 | -0.0042 | -0.0673 |
| 2 | **0.1210** | **0.0794** | 0.0549 | -0.0840 | 0.0721 |
| 3 | 0.0369 | -0.0114 | -0.0364 | -0.0187 | 0.0671 |

\*NSAS: Numerical spectral abscissa sensitivity \*CFSAS: Closed-form spectral abscissa sensitivity \*MSAD: Mathematical spectral abscissa derivatives

TABLE Ⅲ

Spectral Abscissa sensitivities for 10-machine-39-bus system

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bus | Active power | | | Reactive power | |
| NSAS | CFSAS | MSAD | CFSAS | MSAD |
| 30 | -5.75E-04 | -1.38E-04 | -1.80E-03 | -2.09E-05 | -2.22E-03 |
| 31 | —— | -9.31E-06 | -7.91E-06 | -5.85E-06 | -1.58E-05 |
| 32 | 1.03E-05 | 1.53E-04 | -1.89E-04 | -5.81E-05 | -3.22E-05 |
| 33 | 5.28E-05 | 8.11E-05 | -1.02E-04 | -1.68E-04 | -5.18E-05 |
| 34 | -1.75E-05 | 5.46E-05 | 7.16E-05 | 1.61E-05 | 7.29E-06 |
| 35 | 7.31E-05 | 1.88E-04 | -2.07E-04 | -9.60E-05 | -3.14E-05 |
| 36 | -1.10E-04 | 1.20E-05 | 4.54E-05 | 4.31E-06 | 2.49E-05 |
| 37 | **8.19E-03** | **6.26E-03** | -6.93E-03 | -3.14E-02 | -3.57E-02 |
| 38 | -6.29E-06 | 1.42E-04 | -1.08E-04 | -1.06E-06 | -8.63E-05 |
| 39 | -7.30E-05 | 3.21E-04 | 1.84E-04 | -9.14E-08 | 7.46E-05 |

TABLE Ⅳ

Eigenvalue sensitivities for 54-machine-118-bus system

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bus | Active power | | | Reactive power | |
| NSAS | CFSAS | MSAD | CFSAS | MSAD |
| 10 | 3.06E-06 | 2.11E-10 | 1.45E-10 | -4.00E-11 | -1.04E-09 |
| 12 | 3.47E-06 | 1.08E-10 | 1.30E-10 | -1.05E-11 | 1.15E-10 |
| 25 | 2.57E-06 | -4.99E-09 | -1.09E-08 | -3.90E-11 | -1.92E-09 |
| 26 | 2.66E-06 | -6.91E-10 | 8.77E-09 | -1.26E-11 | 1.76E-09 |
| 49 | 1.34E-05 | 2.49E-03 | -6.34E-02 | 1.58E-05 | -2.34E-02 |
| 54 | **-3.49E-02** | **-3.34E-02** | -2.04E-02 | 5.91E-03 | 1.22E-02 |
| 59 | -8.26E-05 | 1.94E-03 | -8.18E-02 | 1.48E-06 | -2.62E-02 |
| 61 | -4.07E-05 | -8.29E-05 | 3.73E-03 | -3.48E-11 | 1.12E-03 |
| 65 | -1.08E-05 | -3.23E-07 | -7.46E-05 | -1.84E-11 | -3.76E-07 |
| 66 | 4.49E-06 | -4.77E-05 | 2.32E-03 | 3.80E-09 | 7.88E-04 |
| 69 | —— | 4.73E-11 | 9.65E-03 | -1.61E-10 | 3.92E-03 |
| 80 | -4.24E-06 | 2.47E-08 | 2.02E-08 | -1.66E-10 | 6.93E-08 |
| 89 | -3.57E-06 | 2.35E-09 | 3.91E-08 | -1.78E-11 | -1.80E-07 |
| 100 | -4.01E-06 | 1.99E-09 | 7.49E-10 | -4.42E-11 | -5.04E-09 |
| 103 | -4.16E-06 | 7.58E-10 | 5.26E-10 | -2.12E-11 | -1.77E-10 |
| 111 | -4.32E-06 | -5.69E-10 | -3.00E-10 | 5.99E-12 | 2.17E-09 |

TABLE Ⅴ

The eigenvalue sensitivity with respect to,,,,andfor 3-machine-9-bus system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Bus |  |  |  |  |  |  |
| 1 | –0.0286 + 0.0797i | –0.0037 + 0.0138i | 0.0017 – 0.0007i | 0.0366 – 0.0478i | –0.0123 + 1.0502i | –3.4482e-6– 1.2449e-5i |
| 2 | 0.0870 – 0.8550i | 0.0500 – 0.0697i | –0.0226 + 0.4151i | 0.0948 + 2.7669i | –0.1574 + 0.7793i | 1.3967e-5 + 1.8324e-3i |
| 3 | 0.0363 – 0.1783i | 0.0095 – 0.0282i | –0.0160 + 0.0896i | –0.0378 + 0.4633i | –0.0266 + 0.1362i | 1.3012e-5 + 2.4155e-4i |

TABLE Ⅵ

The eigenvalue sensitivity with respect to,,,,andfor 10-machine-39-bus system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Bus |  |  |  |  |  |  |
| 30 | -3.16e-4 - 0.00232i | 1.39e-5 + 1.0e-4i | 5.27e-5 + 1.06e-4i | 0.00242 - 9.89e-4i | - 3.54e-4 + 1.43e-4i | - 1.59e-5 + 2.86e-6i |
| 31 | -3.92e-5 - 2.85e-5i | - 2.3e-6 - 1.03e-6i | 5.24e-6 + 2.17e-6i | 2.68e-5 + 1.02e-5i | - 6.74e-6 - 2.5e-6i | - 2.61e-5 + 3.6e-5i |
| 32 | 2.25e-4 - 0.00108i | 4.91e-5 + 6.85e-5i | 1.24e-4 + 2.47e-5i | 3.12e-4 + 1.54e-4i | - 2.36e-4 - 1.04e-4i | - 1.50e-5 + 9.60e-6i |
| 33 | 0.00101 - 0.00131i | 5.86e-6 + 1.41e-4i | 1.72e-4 + 7.88e-5i | 1.84e-4 + 1.28e-4i | - 2.96e-4 - 1.52e-4i | - 1.05e-6 + 2.86e-7i |
| 34 | - 4.27e-5 + 1.8e-5i | - 1.15e-6 - 6.82e-6i | - 2.35e-5 - 1.83e-5i | - 6.84e-5 - 3.91e-5i | 2.46e-5 + 1.37e-5i | 4.0e-11 + 3.32e-11i |
| 35 | 4.64e-4 - 0.00198i | 4.04e-5 + 1.44e-4i | 1.69e-4 + 5.7e-5i | 4.35e-4 + 1.44e-4i | - 3.31e-4 - 9.07e-5i | - 3.78e-7 + 1.81e-7i |
| 36 | 9.6e-5 + 8.31e-5i | -5.38e-6 - 3.51e-6i | - 2.09e-5 + 2.0e-6i | - 7.93e-5 + 1.77e-6i | 5.28e-5 - 7.6e-6i | 2.40e-5 + 1.11e-6i |
| 37 | 0.181 - 0.155i | - 0.00837 + 0.028i | 0.018 + 0.0145i | - 0.0089 - 0.00111i | - 0.0269 - 0.00806i | - 7.91e-5 - 1.30e-5i |
| 38 | -8.81e-4 - 0.00132i | 8.51e-5 + 1.65e-6i | 8.7e-5 - 7.61e-5i | 2.79e-4 + 1.84e-4i | - 3.33e-4 - 7.76e-5i | - 3.24e-4 + 2.28e-4i |
| 39 | -1.79e-4 - 8.04e-5i | 1.55e-7 + 1.68e-7i | 1.62e-6 + 6.07e-7i | 1.99e-4 + 5.42e-5i | - 2.86e-5 - 9.54e-6i | - 8.65e-8 + 1.01e-8i |

TABLE Ⅶ

The eigenvalue sensitivity with respect to,,,,andfor 54-machine-118-bus system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Bus |  |  |  |  |  |  |
| 10 | 5.1355e-09 | 5.2416e-11 | -9.4100e-10 | -1.1331e-08 | -1.1104e-09 | 0 |
| 12 | -1.1219e-09 | 1.4844e-10 | 1.4861e-10 | 7.6561e-10 | -1.0634e-09 | -1.2443e-11 |
| 25 | 3.6262e-09 | 2.5786e-10 | -2.4252e-09 | -7.1555e-09 | -2.6930e-09 | -2.8417e-14 |
| 26 | 4.5515e-09 | 1.2276e-10 | -2.3310e-09 | -9.4631e-09 | -1.8446e-09 | 4.5222e-12 |
| 49 | -4.3117e-05 | -2.7353e-07 | -3.3200e-05 | -1.7483e-05 | 6.1140e-06 | -5.5457e-07 |
| 54 | -1.6234e-10 | 2.0614e-10 | 6.5119e-11 | 1.1625e-10 | -8.3695e-10 | -2.0612e-13 |
| 59 | -3.4595e-03 | -3.6862e-05 | -2.7438e-02 | -9.2154e-03 | 4.6920e-03 | -9.0607e-03 |
| 61 | -6.1512e-09 | 1.1018e-09 | 1.9096e-09 | 5.0725e-09 | -5.0107e-09 | -2.8909e-11 |
| 65 | 1.3498e-09 | 1.6066e-09 | -1.6750e-09 | -4.4204e-09 | -7.3138e-09 | -1.7325e-13 |
| 66 | 5.1286e-05 | -2.8096e-06 | -2.3138e-05 | -5.3497e-05 | 2.0581e-05 | 0 |
| 69 | -1.3274e-08 | 2.1136e-09 | -5.2400e-09 | -6.6154e-08 | -4.5031e-08 | 0 |
| 80 | 3.6265e-08 | 4.1593e-10 | -5.2035e-09 | -6.2663e-08 | -8.7947e-09 | 0 |
| 89 | -1.9281e-08 | 8.7254e-09 | -2.2950e-08 | -5.8174e-08 | -6.2924e-08 | 0 |
| 100 | 1.5075e-08 | 7.6177e-10 | -9.1609e-09 | -2.6989e-08 | -7.9480e-09 | 1.5982e-14 |
| 103 | 4.2425e-07 | -6.9775e-08 | 5.2766e-08 | -3.5608e-07 | 1.0277e-07 | -3.7526e-08 |
| 111 | -5.2941e-10 | 9.8249e-10 | 1.7374e-10 | 3.4629e-10 | -3.9872e-09 | -6.4511e-14 |

TABLE Ⅷ

The eigenvalue sensitivity with respect toandfor three benchmark systems

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Bus | 3-machine-9-bus system | | 10-machine-39-bus system | | 54-machine-118-bus system | |
|  |  |  |  |  |  |
| 1 | - 0.104 + 1.06i | - 0.0409 + 0.253i | - 7.12e-4 + 0.00274i | 2.08e-4 - 5.98e-4i | 7.80e-11 | 2.12e-10 |
| 2 | 0.304 - 0.478i | 0.0989 - 0.162i | - 4.79e-4 + 0.0362i | 0.00531 - 0.0467i | -1.62e-12 | 1.74e-12 |
| 3 | 0.0671 - 0.226i | 0.00887 - 0.0332i | 2.17e-4 + 0.00310i | 5.50e-4 - 0.00180i | -6.63e-11 | -1.82e-11 |
| 4 | - 0.0488 + 0.920i | - 0.0267 + 0.222i | 1.61e-4 + 0.00140i | 2.34e-4 - 1.41e-4i | 4.42e-9 | -1.24e-9 |
| 5 | - 0.0524 + 0.893i | - 0.0247 + 0.111i | - 1.86e-5 + 2.35e-4i | - 2.84e-5 + 2.87e-5i | 7.58e-10 | -9.27e-10 |
| 6 | - 0.0344 + 0.470i | - 0.00577 + 0.0171i | 3.71e-5 + 1.08e-4i | - 5.00e-5 + 3.01e-5i | 2.45e-10 | 6.15e-10 |
| 7 | - 0.0642 + 1.05i | - 0.0659 + 0.353i | 2.46e-5 + 6.12e-6i | 5.05e-5 + 1.75e-5i | -2.12e-11 | -1.63e-11 |
| 8 | - 0.00343 + 0.0843i | - 0.0113 + 0.0421i | - 2.17e-5 + 1.68e-5i | 1.11e-4 + 2.97e-5i | 3.18e-10 | 3.37e-10 |
| 9 | - 0.0308 + 0.382i | - 0.0273 + 0.150i | - 1.03e-4 + 8.28e-7i | - 9.33e-6 + 5.01e-6i | 4.05e-10 | 7.10e-11 |
| 10 | -- | -- | 2.68e-4 + 9.94e-4i | - 2.34e-4 - 8.55e-5i | 1.01e-8 | -6.80e-9 |
| 11 | -- | -- | 4.16e-5 + 1.06e-4i | - 3.84e-5 + 1.35e-5i | -7.33e-11 | 8.21e-12 |
| 12 | -- | -- | 1.08e-5 + 1.59e-5i | 5.40e-7 + 7.34e-7i | 1.48e-9 | -4.77e-11 |
| 13 | -- | -- | 3.02e-5 + 1.72e-4i | - 4.16e-5 - 5.72e-7i | -2.55e-10 | 1.08e-10 |
| 14 | -- | -- | 2.49e-5 + 3.04e-4i | - 7.1e-5 + 5.03e-5i | -3.09e-10 | 1.21e-10 |
| 15 | -- | -- | 3.85e-5 + 1.99e-5i | 6.57e-5 + 6.59e-6i | -2.92e-9 | 1.26e-9 |
| 16 | -- | -- | - 4.91e-4 + 0.00255i | - 1.03e-4 - 9.67e-5i | -1.21e-11 | 7.02e-11 |
| 17 | -- | -- | - 5.30e-4 + 0.00316i | - 6.33e-5 - 8.02e-5i | -6.63e-10 | 1.21e-9 |
| 18 | -- | -- | 4.12e-5 + 4.55e-4i | 1.28e-4 - 1.88e-4i | -3.61e-10 | -1.76e-11 |
| 19 | -- | -- | - 1.29e-4 + 0.00137i | - 1.61e-4 - 4.17e-4i | -5.07e-9 | 1.91e-9 |
| 20 | -- | -- | 1.42e-4 - 7.41e-5i | - 2.89e-6 - 4.04e-5i | -2.62e-10 | 7.38e-11 |
| 21 | -- | -- | - 3.46e-5 + 6.39e-4i | - 1.37e-4 - 4.86e-5i | -2.19e-10 | 8.56e-11 |
| 22 | -- | -- | 2.97e-4 + 0.00121i | - 2.33e-4 - 3.43e-4i | -2.56e-10 | 1.61e-10 |
| 23 | -- | -- | 3.90e-5 + 2.06e-4i | - 4.99e-5 - 9.38e-5i | 4.87e-9 | -1.06e-9 |
| 24 | -- | -- | - 8.04e-5 + 2.46e-4i | - 2.12e-5 + 1.95e-6i | 1.57e-8 | 5.95e-10 |
| 25 | -- | -- | - 0.0147 + 0.171i | 0.00234 - 0.0192i | 8.50e-9 | -7.33e-9 |
| 26 | -- | -- | 7.43e-4 + 0.0109i | 4.25e-4 - 0.00234i | 6.86e-9 | -4.77e-9 |
| 27 | -- | -- | - 2.79e-4 + 0.0021i | 7.07e-4 - 0.00167i | 2.54e-10 | -4.86e-10 |
| 28 | -- | -- | 3.79e-4 + 0.00106i | 2.10e-4 + 1.39e-4i | -3.68e-11 | -1.42e-11 |
| 29 | -- | -- | 6.73e-4 + 0.00287i | - 3.80e-4 + 7.80e-4i | -4.23e-11 | -4.94e-11 |
| 30 | -- | -- | -0.00335+ 0.00448i | 2.68e-4 + 0.00235i | -4.23e-10 | 6.71e-9 |
| 31 | -- | -- | - 8.78e-5 - 3.98e-6i | - 5.32e-5 - 1.35e-5i | 3.09e-10 | -3.01e-10 |
| 32 | -- | -- | - 0.00173 - 0.00118i | 3.45e-5 + 0.00102i | 1.98e-10 | 8.59e-10 |
| 33 | -- | -- | - 9.69e-4 - 0.00266i | -7.65e-4 + 0.00173i | -4.45e-9 | 2.10e-9 |
| 34 | -- | -- | 1.55e-4 + 2.08e-4i | 2.06e-5 + 1.05e-6i | -9.05e-8 | -1.25e-8 |
| 35 | -- | -- | - 0.00179 - 0.00289i | -3.89e-5 + 0.00237i | -8.14e-11 | 1.11e-10 |
| 36 | -- | -- | 2.32e-4 + 1.99e-5i | - 6.58e-5 - 4.85e-5i | -1.62e-9 | -1.34e-9 |
| 37 | -- | -- | 0.0318 - 0.406i | - 0.190 + 0.227i | 2.79e-9 | 9.31e-9 |
| 38 | -- | -- | -0.00305+ 0.00195i | 3.50e-4 + 9.44e-4i | 1.26e-7 | 3.66e-9 |
| 39 | -- | -- | - 3.12e-4 + 9.52e-4i | 2.04e-4 + 3.55e-5i | -1.32e-9 | 3.99e-9 |
| 40 | -- | -- | -- | -- | -1.59e-7 | -6.89e-8 |
| 41 | -- | -- | -- | -- | -7.30e-8 | -1.06e-8 |
| 42 | -- | -- | -- | -- | -1.67e-6 | 3.00e-7 |
| 43 | -- | -- | -- | -- | -1.82e-7 | 4.03e-9 |
| 44 | -- | -- | -- | -- | -1.03e-7 | 6.74e-8 |
| 45 | -- | -- | -- | -- | -1.25e-7 | 4.30e-7 |
| 46 | -- | -- | -- | -- | -2.09e-6 | 3.07e-7 |
| 47 | -- | -- | -- | -- | -1.07e-6 | 4.12e-7 |
| 48 | -- | -- | -- | -- | -2.08e-7 | 3.86e-7 |
| 49 | -- | -- | -- | -- | -0.00422 | 0.00109 |
| 50 | -- | -- | -- | -- | -2.18e-4 | 2.21e-5 |
| 51 | -- | -- | -- | -- | -6.49e-4 | 5.24e-5 |
| 52 | -- | -- | -- | -- | -4.91e-4 | 2.46e-5 |
| 53 | -- | -- | -- | -- | -3.51e-4 | 3.51e-4 |
| 54 | -- | -- | -- | -- | 0.0758 | -0.0135 |
| 55 | -- | -- | -- | -- | -0.0118 | 0.00161 |
| 56 | -- | -- | -- | -- | -0.0435 | 0.0076 |
| 57 | -- | -- | -- | -- | -2.41e-4 | 1.73e-5 |
| 58 | -- | -- | -- | -- | 5.09e-6 | 2.79e-5 |
| 59 | -- | -- | -- | -- | -0.0033 | 5.14e-4 |
| 60 | -- | -- | -- | -- | 1.27e-7 | 3.24e-8 |
| 61 | -- | -- | -- | -- | 2.61e-7 | -4.56e-8 |
| 62 | -- | -- | -- | -- | 7.12e-8 | -7.26e-9 |
| 63 | -- | -- | -- | -- | 3.58e-7 | 2.83e-7 |
| 64 | -- | -- | -- | -- | 5.00e-7 | 7.06e-8 |
| 65 | -- | -- | -- | -- | 4.29e-7 | -8.38e-8 |
| 66 | -- | -- | -- | -- | -6.09e-6 | 5.38e-8 |
| 67 | -- | -- | -- | -- | 3.51e-8 | -6.78e-9 |
| 68 | -- | -- | -- | -- | 5.77e-8 | -1.58e-8 |
| 69 | -- | -- | -- | -- | -1.27e-6 | 4.49e-7 |
| 70 | -- | -- | -- | -- | 9.23e-9 | 1.47e-9 |
| 71 | -- | -- | -- | -- | 2.70e-9 | -1.29e-9 |
| 72 | -- | -- | -- | -- | 6.29e-9 | -1.43e-9 |
| 73 | -- | -- | -- | -- | 9.67e-10 | -1.36e-10 |
| 74 | -- | -- | -- | -- | 8.62e-10 | 1.39e-9 |
| 75 | -- | -- | -- | -- | -2.05e-9 | -7.07e-10 |
| 76 | -- | -- | -- | -- | -5.8e-10 | 8.10e-11 |
| 77 | -- | -- | -- | -- | -8.08e-9 | 4.55e-9 |
| 78 | -- | -- | -- | -- | -2.47e-10 | -6.38e-10 |
| 79 | -- | -- | -- | -- | -4.61e-11 | -1.44e-11 |
| 80 | -- | -- | -- | -- | 6.02e-8 | -3.32e-9 |
| 81 | -- | -- | -- | -- | 1.28e-8 | -2.76e-8 |
| 82 | -- | -- | -- | -- | -1.10e-9 | -3.31e-9 |
| 83 | -- | -- | -- | -- | 3.15e-9 | 3.28e-9 |
| 84 | -- | -- | -- | -- | 6.36e-10 | -4.23e-10 |
| 85 | -- | -- | -- | -- | -3.26e-9 | -1.52e-8 |
| 86 | -- | -- | -- | -- | -3.87e-10 | -1.28e-9 |
| 87 | -- | -- | -- | -- | 4.00e-9 | -7.26e-10 |
| 88 | -- | -- | -- | -- | 6.29e-10 | -1.17e-10 |
| 89 | -- | -- | -- | -- | 7.43e-8 | -6.15e-8 |
| 90 | -- | -- | -- | -- | 4.60e-9 | -2.13e-10 |
| 91 | -- | -- | -- | -- | 3.96e-9 | 6.62e-10 |
| 92 | -- | -- | -- | -- | -2.63e-9 | -1.28e-8 |
| 93 | -- | -- | -- | -- | 7.92e-10 | -3.44e-10 |
| 94 | -- | -- | -- | -- | 1.58e-9 | -8.50e-10 |
| 95 | -- | -- | -- | -- | 2.53e-10 | -3.16e-10 |
| 96 | -- | -- | -- | -- | 2.66e-9 | 1.07e-8 |
| 97 | -- | -- | -- | -- | -2.75e-11 | 1.17e-10 |
| 98 | -- | -- | -- | -- | 2.15e-10 | 3.28e-11 |
| 99 | -- | -- | -- | -- | 5.28e-9 | -2.72e-10 |
| 100 | -- | -- | -- | -- | 2.07e-8 | -2.79e-8 |
| 101 | -- | -- | -- | -- | 2.17e-10 | 7.34e-12 |
| 102 | -- | -- | -- | -- | 2.06e-10 | -5.92e-11 |
| 103 | -- | -- | -- | -- | 5.21e-9 | -6.53e-10 |
| 104 | -- | -- | -- | -- | -5.31e-10 | 6.33e-10 |
| 105 | -- | -- | -- | -- | -9.82e-10 | 7.47e-10 |
| 106 | -- | -- | -- | -- | -4.12e-10 | 1.31e-10 |
| 107 | -- | -- | -- | -- | 4.13e-9 | 1.05e-9 |
| 108 | -- | -- | -- | -- | -1.6e-10 | -3.31e-11 |
| 109 | -- | -- | -- | -- | -8.94e-11 | 2.93e-11 |
| 110 | -- | -- | -- | -- | -1.02e-9 | 1.73e-9 |
| 111 | -- | -- | -- | -- | 8.20e-9 | -6.03e-9 |
| 112 | -- | -- | -- | -- | 7.69e-9 | 2.46e-10 |
| 113 | -- | -- | -- | -- | 1.69e-10 | -5.99e-12 |
| 114 | -- | -- | -- | -- | -1.30e-12 | 1.02e-12 |
| 115 | -- | -- | -- | -- | 4.30e-12 | -3.61e-12 |
| 116 | -- | -- | -- | -- | 3.81e-8 | 2.10e-8 |
| 117 | -- | -- | -- | -- | 5.17e-13 | 6.79e-13 |
| 118 | -- | -- | -- | -- | -4.57e-10 | 6.47e-11 |

TABLE Ⅷ

The comparison of efficiency between two methods

|  |  |  |
| --- | --- | --- |
| Test systems | Vector-based Formulation(s) | Numerical differentiation method (s) |
| WSCC 3-machine 9-bus system | 0.0083 | 0.0098 |
| New England 10-machine 39-bus system | 0.0161 | 0.0668 |
| IEEE 54-machine 118-bus system | 0.1894 | 2.3553 |

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