# APPENDIX 1

# IEEE 14 BUS SYSTEM

The single line diagram of IEEE 14 bus system is shown in Figure A1.1. Bus data, line data and generator cost coefficients data of IEEE 14 bus system are shown in Tables A1.1-A1.3.

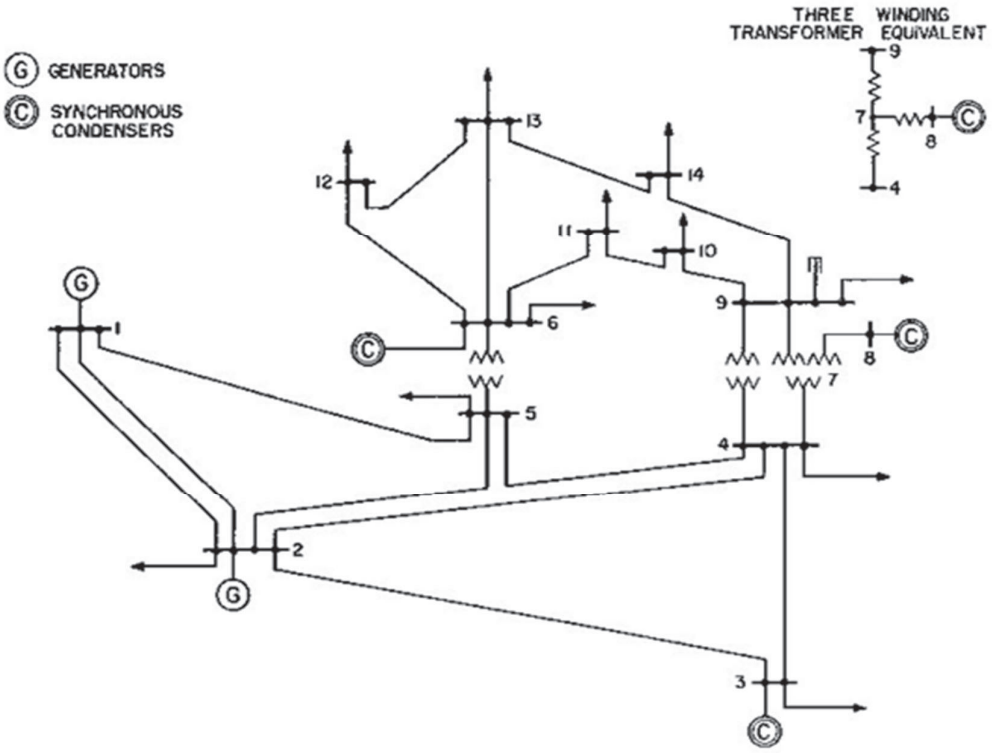


**Figure A1.1 Single line diagram of IEEE 14 bus system**

## Table A1.1 Bus data for IEEE 14 bus system

| Bus No. | Bus Type* | Voltage specified (p.u.) | Voltage angle (p.u.) | P-Generated MW | Q-Generated MVAR | P-Load MW | Q-Load MVAR | Q-Generated max MVAR | Q-Generated min MVAR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.045 | 0 | 0.4 | 0.424 | 0.217 | 0.127 | 0.5 | -0.4 |
| 3 | 2 | 1.01 | 0 | 0 | 0.234 | 0.942 | 0.19 | 0.4 | 0 |
| 4 | 3 | 1 | 0 | 0 | 0 | 0.478 | 0 | 0 | 0 |
| 5 | 3 | 1 | 0 | 0 | 0 | 0.076 | 0.016 | 0 | 0 |
| 6 | 2 | 1.07 | 0 | 0 | 0.122 | 0.112 | 0.075 | 0.24 | -0.06 |
| 7 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 2 | 1.09 | 0 | 0 | 0.174 | 0 | 0 | 0.24 | -0.06 |
| 9 | 3 | 1 | 0 | 0 | 0 | 0.295 | 0.166 | 0 | 0 |
| 10 | 3 | 1 | 0 | 0 | 0 | 0.09 | 0.058 | 0 | 0 |
| 11 | 3 | 1 | 0 | 0 | 0 | 0.035 | 0.018 | 0 | 0 |
| 12 | 3 | 1 | 0 | 0 | 0 | 0.061 | 0.016 | 0 | 0 |
| 13 | 3 | 1 | 0 | 0 | 0 | 0.135 | 0.058 | 0 | 0 |
| 14 | 3 | 1 | 0 | 0 | 0 | 0.149 | 0.05 | 0 | 0 |

* Bus Type: (1) swing bus, (2) generator bus, and (3) load bus

## Table A1.2 Line data for IEEE 14 bus system

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u.) | Half line charging admittance (p.u.) | Tap Ratio |
|---|---|---|---|---|---|
| 1 | 2 | 0.01938 | 0.05917 | 0.0264 | 1 |
| 1 | 5 | 0.05403 | 0.22304 | 0.0246 | 1 |
| 2 | 3 | 0.04699 | 0.19797 | 0.0219 | 1 |
| 2 | 4 | 0.05811 | 0.17632 | 0.017 | 1 |
| 2 | 5 | 0.05695 | 0.17388 | 0.0173 | 1 |
| 3 | 4 | 0.06701 | 0.17103 | 0.0064 | 1 |
| 4 | 5 | 0.01335 | 0.04211 | 0 | 1 |
| 4 | 7 | 0 | 0.20912 | 0 | 0.978 |
| 4 | 9 | 0 | 0.55618 | 0 | 0.969 |
| 5 | 6 | 0 | 0.25202 | 0 | 0.932 |
| 6 | 11 | 0.09498 | 0.1989 | 0 | 1 |
| 6 | 12 | 0.12291 | 0.25581 | 0 | 1 |
| 6 | 13 | 0.06615 | 0.13027 | 0 | 1 |
| 7 | 8 | 0 | 0.17615 | 0 | 1 |
| 7 | 9 | 0 | 0.11001 | 0 | 1 |
| 9 | 10 | 0.03181 | 0.0845 | 0 | 1 |
| 9 | 14 | 0.12711 | 0.27038 | 0 | 1 |
| 10 | 11 | 0.08205 | 0.19207 | 0 | 1 |
| 12 | 13 | 0.22092 | 0.19988 | 0 | 1 |
| 13 | 14 | 0.17093 | 0.34802 | 0 | 1 |

**Table A1.3 Generator cost coefficients data for IEEE 14 bus system**

| Generator Bus No. | a ($/MWh$^2$) | b ($/MWh) | c |
|---|---|---|---|
| 1 | 0.0038 | 2 | 0 |
| 2 | 0.0175 | 1.75 | 0 |
| 3 | 0.0625 | 1 | 0 |
| 6 | 0.0083 | 3.25 | 0 |
| 8 | 0.025 | 3 | 0 |

**Table A1.4 Line flows and losses for IEEE 14 bus system without SVC**

| From Bus | To Bus | Line Flows without FACTS devices | | | | Line losses without FACTS devices | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 157.08 | -20.45 | -152.772 | 27.756 | 4.309 | 7.305 |
| 1 | 5 | 75.513 | 5.217 | -72.74 | 0.922 | 2.773 | 6.139 |
| 2 | 3 | 73.396 | 3.545 | -71.063 | 1.66 | 2.333 | 5.204 |
| 2 | 4 | 55.943 | 1.079 | -54.273 | 0.387 | 1.67 | 1.465 |
| 2 | 5 | 41.733 | 2.848 | -40.813 | -3.717 | 0.92 | -0.868 |
| 3 | 4 | -23.137 | 7.099 | 23.528 | -7.41 | 0.391 | -0.312 |
| 4 | 5 | -59.585 | 11.574 | 60.064 | -10.063 | 0.479 | 1.511 |
| 4 | 7 | 27.066 | -4.104 | -27.066 | 5.565 | 0 | 1.46 |
| 4 | 9 | 15.464 | 3.454 | -15.464 | -2.177 | 0 | 1.277 |
| 5 | 6 | 45.889 | 11.258 | -45.889 | -6.529 | 0 | 4.729 |
| 6 | 11 | 8.287 | 8.898 | -8.165 | -8.641 | 0.123 | 0.257 |
| 6 | 12 | 8.064 | 3.176 | -7.984 | -3.008 | 0.081 | 0.168 |
| 6 | 13 | 18.337 | 9.981 | -18.085 | -9.485 | 0.252 | 0.496 |
| 7 | 8 | 0 | -20.362 | 0 | 21.03 | 0 | 0.668 |
| 7 | 9 | 27.066 | 14.798 | -27.066 | -13.84 | 0 | 0.957 |
| 9 | 10 | 4.393 | -0.904 | -4.387 | 0.92 | 0.006 | 0.016 |
| 9 | 14 | 8.637 | 0.321 | -8.547 | -0.131 | 0.089 | 0.19 |
| 10 | 11 | -4.613 | -6.72 | 4.665 | 6.841 | 0.051 | 0.12 |
| 12 | 13 | 1.884 | 1.408 | -1.873 | -1.398 | 0.011 | 0.01 |
| 13 | 14 | 6.458 | 5.083 | -6.353 | -4.869 | 0.105 | 0.215 |

**Table A1.5 Line flows and losses of IEEE 14 bus system with SVC located at bus 14 identified by conventional method**

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 156.953 | -20.421 | -152.652 | 27.705 | 4.302 | 7.284 |
| 1 | 5 | 75.506 | 4.468 | -72.74 | 1.638 | 2.767 | 6.107 |
| 2 | 3 | 73.303 | 3.554 | -70.976 | 1.626 | 2.327 | 5.18 |
| 2 | 4 | 56.035 | -0.369 | -54.363 | 1.832 | 1.672 | 1.463 |
| 2 | 5 | 41.614 | 1.926 | -40.703 | -2.828 | 0.911 | -0.902 |
| 3 | 4 | -23.224 | 5.653 | 23.605 | -5.995 | 0.38 | -0.342 |
| 4 | 5 | -60.404 | 13.906 | 60.901 | -12.338 | 0.497 | 1.568 |
| 4 | 7 | 27.597 | -7.457 | -27.597 | 9.042 | 0 | 1.585 |
| 4 | 9 | 15.765 | 1.614 | -15.765 | -0.342 | 0 | 1.271 |
| 5 | 6 | 44.942 | 11.927 | -44.942 | -7.362 | 0 | 4.565 |
| 6 | 11 | 7.86 | 6.273 | -7.776 | -6.098 | 0.084 | 0.176 |
| 6 | 12 | 7.75 | 1.773 | -7.682 | -1.632 | 0.068 | 0.141 |
| 6 | 13 | 18.132 | 4.389 | -17.931 | -3.993 | 0.201 | 0.396 |
| 7 | 8 | 0 | -20.967 | 0 | 21.663 | 0 | 0.696 |
| 7 | 9 | 27.597 | 11.926 | -27.597 | -11.032 | 0 | 0.893 |
| 9 | 10 | 4.759 | 1.586 | -4.751 | -1.566 | 0.007 | 0.02 |
| 9 | 14 | 9.103 | -6.811 | -8.952 | 7.132 | 0.151 | 0.321 |
| 10 | 11 | -4.249 | -4.234 | 4.276 | 4.298 | 0.027 | 0.064 |
| 12 | 13 | 1.582 | 0.032 | -1.577 | -0.028 | 0.005 | 0.004 |
| 13 | 14 | 6.008 | -1.779 | -5.948 | 1.902 | 0.06 | 0.123 |

# APPENDIX 2

# IEEE 30 BUS SYSTEM

The single line diagram of IEEE 30 bus system is shown in Figure A2.1. Bus data, line data and generator cost coefficients data of IEEE 30 bus system are shown in Tables A2.1- A2.3 respectively.

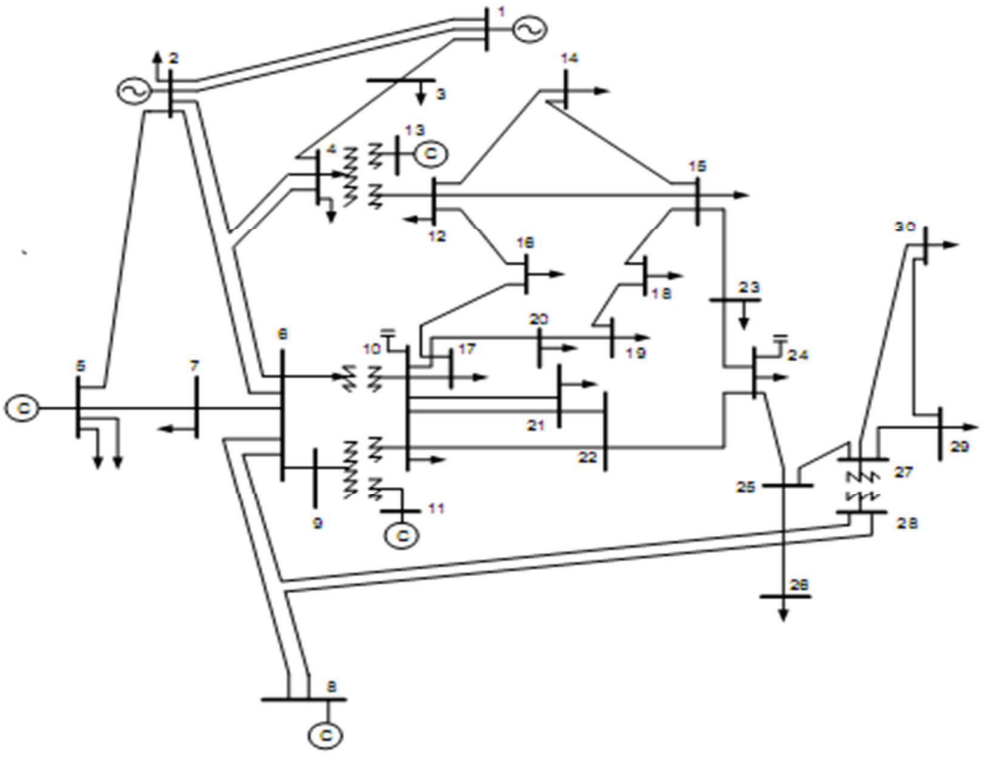


**Figure A2.1 Single line diagram of IEEE 30 bus system**

## Table A2.1 Bus data for IEEE 30 bus system

| Bus No. | Bus Type* | Voltage specified (p.u.) | Voltage angle (p.u.) | P-Generated MW | Q-Generated MVAR | P-Load MW | Q-Load MVAR | Q-Generated max MVAR | Q-Generated min MVAR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.043 | 0 | 0.4 | 0.5 | 0.217 | 0.127 | 0.5 | -0.4 |
| 3 | 3 | 1 | 0 | 0 | 0 | 0.024 | 0.012 | 0 | 0 |
| 4 | 3 | 1.06 | 0 | 0 | 0 | 0.076 | 0.016 | 0 | 0 |
| 5 | 2 | 1.01 | 0 | 0 | 0.37 | 0.942 | 0.19 | 0.4 | -0.4 |
| 6 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 3 | 1 | 0 | 0 | 0 | 0.228 | 0.109 | 0 | 0 |
| 8 | 2 | 1.01 | 0 | 0 | 0.373 | 0.3 | 0.3 | 0.4 | -0.1 |
| 9 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 3 | 1 | 0 | 0 | 0.19 | 0.058 | 0.02 | 0 | 0 |
| 11 | 2 | 1.082 | 0 | 0 | 0.162 | 0 | 0 | 0.24 | -0.06 |
| 12 | 3 | 1 | 0 | 0 | 0 | 0.112 | 0.075 | 0 | 0 |
| 13 | 2 | 1.071 | 0 | 0 | 0.106 | 0 | 0 | 0.24 | -0.06 |
| 14 | 3 | 1 | 0 | 0 | 0 | 0.062 | 0.016 | 0 | 0 |
| 15 | 3 | 1 | 0 | 0 | 0 | 0.082 | 0.025 | 0 | 0 |
| 16 | 3 | 1 | 0 | 0 | 0 | 0.035 | 0.018 | 0 | 0 |
| 17 | 3 | 1 | 0 | 0 | 0 | 0.09 | 0.058 | 0 | 0 |
| 18 | 3 | 1 | 0 | 0 | 0 | 0.032 | 0.009 | 0 | 0 |
| 19 | 3 | 1 | 0 | 0 | 0 | 0.095 | 0.034 | 0 | 0 |
| 20 | 3 | 1 | 0 | 0 | 0 | 0.022 | 0.007 | 0 | 0 |
| 21 | 3 | 1 | 0 | 0 | 0 | 0.175 | 0.112 | 0 | 0 |
| 22 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 3 | 1 | 0 | 0 | 0 | 0.032 | 0.016 | 0 | 0 |
| 24 | 3 | 1 | 0 | 0 | 0.043 | 0.087 | 0.067 | 0 | 0 |
| 25 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 3 | 1 | 0 | 0 | 0 | 0.035 | 0.023 | 0 | 0 |
| 27 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 3 | 1 | 0 | 0 | 0 | 0.024 | 0.009 | 0 | 0 |
| 30 | 3 | 1 | 0 | 0 | 0 | 0.106 | 0.019 | 0 | 0 |

* Bus Type: (1) swing bus, (2) generator bus, and (3) load bus

## Table A2.2 Line data for IEEE 30 bus system

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 1 | 2 | 0.0192 | 0.0575 | 0.0264 | 1 |
| 1 | 3 | 0.0452 | 0.1652 | 0.0204 | 1 |
| 2 | 4 | 0.057 | 0.1737 | 0.0184 | 1 |
| 3 | 4 | 0.0132 | 0.0379 | 0.0042 | 1 |
| 2 | 5 | 0.0472 | 0.1983 | 0.0209 | 1 |
| 2 | 6 | 0.0581 | 0.1763 | 0.0187 | 1 |
| 4 | 6 | 0.0119 | 0.0414 | 0.0045 | 1 |
| 5 | 7 | 0.046 | 0.116 | 0.0102 | 1 |
| 6 | 7 | 0.0267 | 0.082 | 0.0085 | 1 |
| 6 | 8 | 0.012 | 0.042 | 0.0045 | 1 |
| 6 | 9 | 0 | 0.208 | 0 | 0.978 |
| 6 | 10 | 0 | 0.556 | 0 | 0.969 |
| 9 | 11 | 0 | 0.208 | 0 | 1 |
| 9 | 10 | 0 | 0.11 | 0 | 1 |
| 4 | 12 | 0 | 0.256 | 0 | 0.932 |
| 12 | 13 | 0 | 0.14 | 0 | 1 |
| 12 | 14 | 0.1231 | 0.2559 | 0 | 1 |
| 12 | 15 | 0.0662 | 0.1304 | 0 | 1 |
| 12 | 16 | 0.0945 | 0.1987 | 0 | 1 |
| 14 | 15 | 0.221 | 0.1997 | 0 | 1 |
| 16 | 17 | 0.0824 | 0.1923 | 0 | 1 |
| 15 | 18 | 0.1073 | 0.2185 | 0 | 1 |
| 18 | 19 | 0.0639 | 0.1292 | 0 | 1 |
| 19 | 20 | 0.034 | 0.068 | 0 | 1 |
| 10 | 20 | 0.0936 | 0.209 | 0 | 1 |
| 10 | 17 | 0.0324 | 0.0845 | 0 | 1 |
| 10 | 21 | 0.0348 | 0.0749 | 0 | 1 |
| 10 | 22 | 0.0727 | 0.1499 | 0 | 1 |
| 21 | 23 | 0.0116 | 0.0236 | 0 | 1 |
| 15 | 23 | 0.1 | 0.202 | 0 | 1 |
| 22 | 24 | 0.115 | 0.179 | 0 | 1 |
| 23 | 24 | 0.132 | 0.27 | 0 | 1 |
| 24 | 25 | 0.1885 | 0.3292 | 0 | 1 |
| 25 | 26 | 0.2544 | 0.38 | 0 | 1 |
| 25 | 27 | 0.1093 | 0.2087 | 0 | 1 |
| 28 | 27 | 0 | 0.396 | 0 | 0.968 |
| 27 | 29 | 0.2198 | 0.4153 | 0 | 1 |
| 27 | 30 | 0.3202 | 0.6027 | 0 | 1 |
| 29 | 30 | 0.2399 | 0.4533 | 0 | 1 |
| 8 | 28 | 0.0636 | 0.2 | 0.0214 | 1 |
| 6 | 28 | 0.0169 | 0.0599 | 0.0065 | 1 |

## Table A2.3 Generator cost coefficients data for IEEE 30 bus system

| Generator Bus No. | a ($/MWh$^2$) | b ($/MWh) | c |
|---|---|---|---|
| 1 | 0.00375 | 2 | 0 |
| 2 | 0.0175 | 1.7 | 0 |
| 5 | 0.0625 | 1 | 0 |
| 8 | 0.00834 | 3.25 | 0 |
| 11 | 0.025 | 3 | 0 |
| 13 | 0.025 | 3 | 0 |

## Table A2.4 Line flows and losses for IEEE 30 bus system without SVC

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 173.247 | -21.098 | -168.062 | 30.788 | 5.185 | 9.69 |
| 1 | 3 | 87.725 | 4.655 | -84.609 | 2.313 | 3.115 | 6.969 |
| 2 | 4 | 43.621 | 3.998 | -42.605 | -4.787 | 1.016 | -0.789 |
| 2 | 5 | 82.401 | 1.75 | -79.448 | 6.251 | 2.953 | 8.001 |
| 2 | 6 | 60.34 | 0.573 | -58.392 | 1.397 | 1.948 | 1.97 |
| 3 | 4 | 82.209 | -3.513 | -81.352 | 5.109 | 0.858 | 1.595 |
| 4 | 6 | 72.165 | -16.216 | -71.531 | 17.504 | 0.635 | 1.288 |
| 4 | 12 | 44.191 | 14.295 | -44.191 | -9.607 | 0 | 4.688 |
| 5 | 7 | -14.752 | 11.808 | 14.925 | -13.437 | 0.173 | -1.63 |
| 6 | 7 | 38.106 | -3.087 | -37.725 | 2.537 | 0.381 | -0.55 |
| 6 | 8 | 29.546 | -8.698 | -29.436 | 8.168 | 0.111 | -0.531 |
| 6 | 9 | 27.82 | -7.599 | -27.82 | 9.221 | 0 | 1.622 |
| 6 | 10 | 15.887 | 0.628 | -15.887 | 0.666 | 0 | 1.294 |
| 6 | 28 | 18.563 | -0.145 | -18.506 | -0.975 | 0.057 | -1.119 |
| 8 | 28 | -0.564 | -0.307 | 0.567 | -4.037 | 0.002 | -4.344 |
| 9 | 11 | 0 | -16.39 | 0 | 16.897 | 0 | 0.507 |
| 9 | 10 | 27.82 | 7.169 | -27.82 | -6.345 | 0 | 0.824 |
| 10 | 20 | 8.742 | 3.423 | -8.667 | -3.254 | 0.076 | 0.17 |
| 10 | 17 | 5.059 | 4.256 | -5.046 | -4.222 | 0.013 | 0.034 |
| 10 | 21 | 18.293 | 11.769 | -18.141 | -11.443 | 0.152 | 0.326 |
| 10 | 22 | 5.814 | 3.229 | -5.784 | -3.168 | 0.03 | 0.061 |
| 12 | 13 | 0 | -10.726 | 0 | 10.87 | 0 | 0.144 |
| 12 | 14 | 7.803 | 2.43 | -7.73 | -2.277 | 0.074 | 0.153 |
| 12 | 15 | 17.661 | 6.869 | -17.448 | -6.45 | 0.213 | 0.419 |
| 12 | 16 | 7.527 | 3.533 | -7.468 | -3.41 | 0.058 | 0.123 |
| 14 | 15 | 1.53 | 0.677 | -1.524 | -0.672 | 0.006 | 0.005 |
| 15 | 18 | 6.298 | 1.878 | -6.255 | -1.79 | 0.043 | 0.088 |
| 15 | 23 | 4.474 | 2.744 | -4.448 | -2.692 | 0.026 | 0.052 |
| 16 | 17 | 3.968 | 1.61 | -3.954 | -1.578 | 0.014 | 0.032 |
| 18 | 19 | 3.055 | 0.89 | -3.049 | -0.878 | 0.006 | 0.012 |
| 19 | 20 | -6.451 | -2.522 | 6.467 | 2.554 | 0.016 | 0.031 |
| 21 | 23 | 0.641 | 0.243 | -0.641 | -0.243 | 0 | 0 |
| 22 | 24 | 5.784 | 3.168 | -5.737 | -3.096 | 0.047 | 0.073 |
| 23 | 24 | 1.89 | 1.336 | -1.883 | -1.322 | 0.007 | 0.014 |
| 24 | 25 | -1.08 | 2.017 | 1.089 | -2.001 | 0.009 | 0.017 |
| 25 | 26 | 3.545 | 2.367 | -3.5 | -2.3 | 0.045 | 0.067 |
| 25 | 27 | -4.634 | -0.366 | 4.657 | 0.409 | 0.023 | 0.044 |
| 27 | 29 | 6.19 | 1.669 | -6.104 | -1.506 | 0.086 | 0.163 |
| 27 | 30 | 7.092 | 1.663 | -6.93 | -1.358 | 0.162 | 0.306 |
| 28 | 27 | 17.939 | 5.012 | -17.939 | -3.741 | 0 | 1.27 |
| 29 | 30 | 3.704 | 0.606 | -3.67 | -0.542 | 0.034 | 0.063 |

**Table A2.5 Line flows and losses of IEEE 30 bus system with SVC located at bus 30 identified by conventional method**

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 173.217 | -21.091 | -168.034 | 30.776 | 5.183 | 9.684 |
| 1 | 3 | 87.742 | 4.17 | -84.628 | 2.791 | 3.114 | 6.96 |
| 2 | 4 | 43.578 | 3.446 | -42.568 | -4.255 | 1.011 | -0.808 |
| 2 | 5 | 82.359 | 1.754 | -79.409 | 6.235 | 2.95 | 7.989 |
| 2 | 6 | 60.396 | -0.142 | -58.446 | 2.113 | 1.95 | 1.971 |
| 3 | 4 | 82.228 | -3.991 | -81.371 | 5.583 | 0.857 | 1.593 |
| 4 | 6 | 72.622 | -16.973 | -71.978 | 18.291 | 0.644 | 1.318 |
| 4 | 12 | 43.717 | 14.044 | -43.717 | -9.471 | 0 | 4.573 |
| 5 | 7 | -14.791 | 11.184 | 14.957 | -12.83 | 0.166 | -1.648 |
| 6 | 7 | 38.137 | -2.487 | -37.757 | 1.932 | 0.38 | -0.556 |
| 6 | 8 | 29.693 | -5.812 | -29.586 | 5.267 | 0.107 | -0.545 |
| 6 | 9 | 27.453 | -8.013 | -27.453 | 9.604 | 0 | 1.591 |
| 6 | 10 | 15.689 | 0.197 | -15.689 | 1.06 | 0 | 1.257 |
| 6 | 28 | 19.451 | -4.289 | -19.387 | 3.19 | 0.065 | -1.099 |
| 8 | 28 | -0.414 | -2.145 | 0.414 | -2.221 | 0 | -4.366 |
| 9 | 11 | 0 | -15.402 | 0 | 15.848 | 0 | 0.446 |
| 9 | 10 | 27.453 | 5.798 | -27.453 | -5.015 | 0 | 0.783 |
| 10 | 20 | 8.797 | 3.544 | -8.72 | -3.372 | 0.077 | 0.172 |
| 10 | 17 | 5.18 | 4.622 | -5.165 | -4.585 | 0.014 | 0.037 |
| 10 | 21 | 18.08 | 10.975 | -17.938 | -10.67 | 0.142 | 0.306 |
| 10 | 22 | 5.285 | 1.815 | -5.264 | -1.772 | 0.021 | 0.043 |
| 12 | 13 | 0 | -9.592 | 0 | 9.707 | 0 | 0.115 |
| 12 | 14 | 7.706 | 2.258 | -7.635 | -2.111 | 0.071 | 0.147 |
| 12 | 15 | 17.41 | 6.145 | -17.208 | -5.748 | 0.201 | 0.397 |
| 12 | 16 | 7.402 | 3.159 | -7.347 | -3.044 | 0.055 | 0.115 |
| 14 | 15 | 1.435 | 0.511 | -1.43 | -0.506 | 0.005 | 0.004 |
| 15 | 18 | 6.243 | 1.757 | -6.201 | -1.672 | 0.042 | 0.085 |
| 15 | 23 | 4.195 | 1.998 | -4.175 | -1.958 | 0.02 | 0.04 |
| 16 | 17 | 3.847 | 1.244 | -3.835 | -1.215 | 0.012 | 0.029 |
| 18 | 19 | 3.001 | 0.772 | -2.996 | -0.76 | 0.006 | 0.012 |
| 19 | 20 | -6.504 | -2.64 | 6.52 | 2.672 | 0.016 | 0.032 |
| 21 | 23 | 0.438 | -0.532 | -0.438 | 0.532 | 0 | 0 |
| 22 | 24 | 5.264 | 1.772 | -5.231 | -1.721 | 0.033 | 0.051 |
| 23 | 24 | 1.413 | -0.174 | -1.41 | 0.179 | 0.003 | 0.005 |
| 24 | 25 | -2.058 | -0.858 | 2.067 | 0.874 | 0.009 | 0.015 |
| 25 | 26 | 3.543 | 2.364 | -3.5 | -2.3 | 0.043 | 0.064 |
| 25 | 27 | -5.61 | -3.238 | 5.653 | 3.319 | 0.043 | 0.081 |
| 27 | 29 | 6.196 | -1.992 | -6.112 | 2.152 | 0.084 | 0.16 |
| 27 | 30 | 7.124 | -3.608 | -6.939 | 3.957 | 0.185 | 0.349 |
| 28 | 27 | 18.973 | -0.969 | -18.973 | 2.281 | 0 | 1.312 |
| 29 | 30 | 3.712 | -3.052 | -3.661 | 3.147 | 0.051 | 0.096 |

# APPENDIX 3

# IEEE 57 BUS SYSTEM

The single line diagram of IEEE 57 bus system is shown in Figure A 3.1. Bus data, line data and generator cost coefficients data of IEEE 57 bus system are shown in Tables A3.1-A 3.3 respectively.

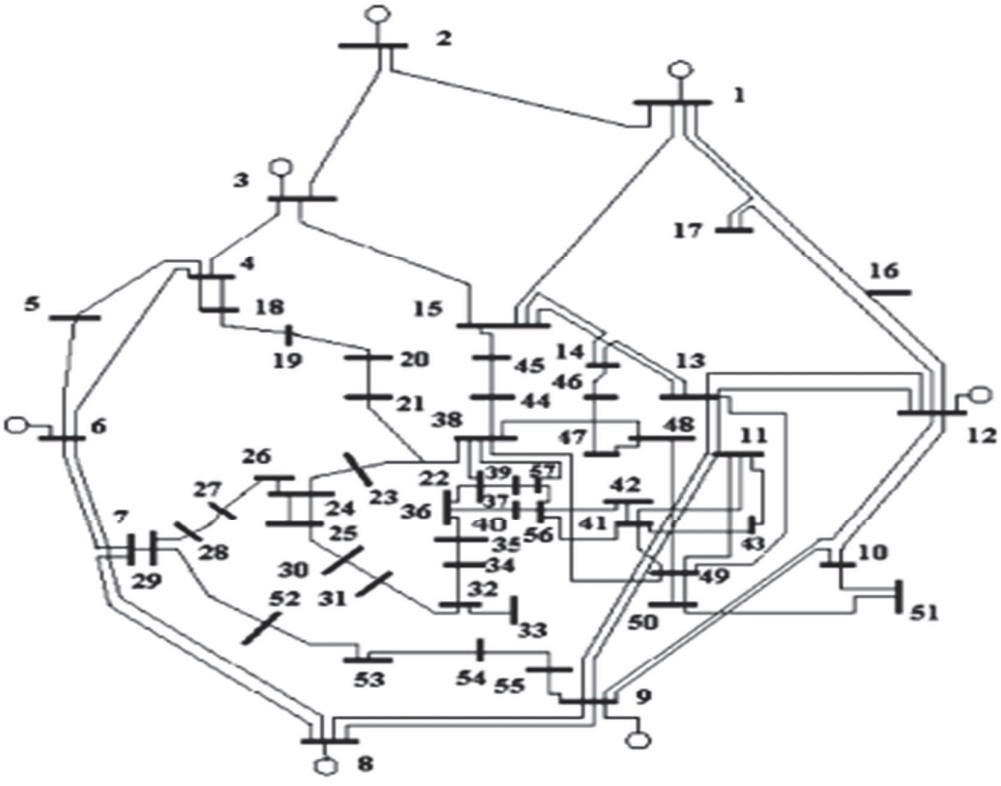


**Figure A3.1 Single line diagram of IEEE 57 bus system**

## Table A3.1 Bus data for IEEE 57 bus system

| Bus No. | Bus Type* | Voltage specified (p.u.) | Voltage angle (p.u.) | P-Generated MW | Q-Generated MVAR | P-Load MW | Q-Load MVAR | Q-Generated max MVAR | Q-Generated min MVAR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.040 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 2 | 1.010 | 0 | 0.0 | -0.8 | 3.0 | 88.0 | -17.0 | 50.0 |
| 3 | 2 | 0.985 | 0 | 40.0 | -1.0 | 41.0 | 21.0 | -10.0 | 60.0 |
| 4 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 3 | 1.000 | 0 | 0.0 | 0.0 | 13.0 | 4.0 | 0.0 | 0.0 |
| 6 | 2 | 0.980 | 0 | 0.0 | 0.8 | 75.0 | 2.0 | -8.0 | 25.0 |
| 7 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | 2 | 1.005 | 0 | 450.0 | 62.1 | 150.0 | 22.0 | -140.0 | 200.0 |
| 9 | 2 | 0.980 | 0 | 0.0 | 2.2 | 121.0 | 26.0 | -3.0 | 9.0 |
| 10 | 3 | 1.000 | 0 | 0.0 | 0.0 | 5.0 | 2.0 | 0.0 | 0.0 |
| 11 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | 2 | 1.015 | 0 | 310.0 | 128.5 | 377.0 | 24.0 | -150.0 | 155.0 |
| 13 | 3 | 1.000 | 0 | 0.0 | 0.0 | 18.0 | 2.3 | 0.0 | 0.0 |
| 14 | 3 | 1.000 | 0 | 0.0 | 0.0 | 10.5 | 5.3 | 0.0 | 0.0 |
| 15 | 3 | 1.000 | 0 | 0.0 | 0.0 | 22.0 | 5.0 | 0.0 | 0.0 |
| 16 | 3 | 1.000 | 0 | 0.0 | 0.0 | 43.0 | 3.0 | 0.0 | 0.0 |
| 17 | 3 | 1.000 | 0 | 0.0 | 0.0 | 42.0 | 8.0 | 0.0 | 0.0 |
| 18 | 3 | 1.000 | 0 | 0.0 | 0.0 | 27.2 | 9.8 | 0.0 | 0.0 |
| 19 | 3 | 1.000 | 0 | 0.0 | 0.0 | 3.3 | 0.6 | 0.0 | 0.0 |
| 20 | 3 | 1.000 | 0 | 0.0 | 0.0 | 2.3 | 1.0 | 0.0 | 0.0 |
| 21 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 22 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 23 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.3 | 2.1 | 0.0 | 0.0 |
| 24 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.3 | 3.2 | 0.0 | 0.0 |
| 26 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 27 | 3 | 1.000 | 0 | 0.0 | 0.0 | 9.3 | 0.5 | 0.0 | 0.0 |
| 28 | 3 | 1.000 | 0 | 0.0 | 0.0 | 4.6 | 2.3 | 0.0 | 0.0 |
| 29 | 3 | 1.000 | 0 | 0.0 | 0.0 | 17.0 | 2.6 | 0.0 | 0.0 |
| 30 | 3 | 1.000 | 0 | 0.0 | 0.0 | 3.6 | 1.8 | 0.0 | 0.0 |
| 31 | 3 | 1.000 | 0 | 0.0 | 0.0 | 5.8 | 2.9 | 0.0 | 0.0 |
| 32 | 3 | 1.000 | 0 | 0.0 | 0.0 | 1.6 | 0.8 | 0.0 | 0.0 |
| 33 | 3 | 1.000 | 0 | 0.0 | 0.0 | 3.8 | 1.9 | 0.0 | 0.0 |
| 34 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 35 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.0 | 3.0 | 0.0 | 0.0 |
| 36 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 37 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 38 | 3 | 1.000 | 0 | 0.0 | 0.0 | 14.0 | 7.0 | 0.0 | 0.0 |
| 39 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 41 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.3 | 3.0 | 0.0 | 0.0 |
| 42 | 3 | 1.000 | 0 | 0.0 | 0.0 | 7.1 | 4.4 | 0.0 | 0.0 |
| 43 | 3 | 1.000 | 0 | 0.0 | 0.0 | 2.0 | 1.0 | 0.0 | 0.0 |
| 44 | 3 | 1.000 | 0 | 0.0 | 0.0 | 12.0 | 1.8 | 0.0 | 0.0 |
| 45 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 46 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 47 | 3 | 1.000 | 0 | 0.0 | 0.0 | 29.7 | 11.6 | 0.0 | 0.0 |
| 48 | 3 | 1.000 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 49 | 3 | 1.000 | 0 | 0.0 | 0.0 | 18.0 | 8.5 | 0.0 | 0.0 |
| 50 | 3 | 1.000 | 0 | 0.0 | 0.0 | 21.0 | 10.5 | 0.0 | 0.0 |
| 51 | 3 | 1.000 | 0 | 0.0 | 0.0 | 18.0 | 5.3 | 0.0 | 0.0 |
| 52 | 3 | 1.000 | 0 | 0.0 | 0.0 | 4.9 | 2.2 | 0.0 | 0.0 |
| 53 | 3 | 1.000 | 0 | 0.0 | 0.0 | 20.0 | 10.0 | 0.0 | 0.0 |
| 54 | 3 | 1.000 | 0 | 0.0 | 0.0 | 4.1 | 1.4 | 0.0 | 0.0 |
| 55 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.8 | 3.4 | 0.0 | 0.0 |
| 56 | 3 | 1.000 | 0 | 0.0 | 0.0 | 7.6 | 2.2 | 0.0 | 0.0 |
| 57 | 3 | 1.000 | 0 | 0.0 | 0.0 | 6.7 | 2.0 | 0.0 | 0.0 |

* Bus Type: (1) swing bus, (2) generator bus, and (3) load bus

## Table A3.2 Line data for IEEE 57 bus system

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 1 | 2 | 0.0083 | 0.028 | 0.0645 | 1 |
| 2 | 3 | 0.0298 | 0.085 | 0.0409 | 1 |
| 3 | 4 | 0.0112 | 0.0366 | 0.019 | 1 |
| 4 | 5 | 0.0625 | 0.132 | 0.0129 | 1 |
| 4 | 6 | 0.043 | 0.148 | 0.0174 | 1 |
| 6 | 7 | 0.02 | 0.102 | 0.0138 | 1 |
| 6 | 8 | 0.0339 | 0.173 | 0.0235 | 1 |
| 8 | 9 | 0.0099 | 0.0505 | 0.0274 | 1 |
| 9 | 10 | 0.0369 | 0.1679 | 0.022 | 1 |
| 9 | 11 | 0.0258 | 0.0848 | 0.0109 | 1 |
| 9 | 12 | 0.0648 | 0.295 | 0.0386 | 1 |
| 9 | 13 | 0.0481 | 0.158 | 0.0203 | 1 |
| 13 | 14 | 0.0132 | 0.0434 | 0.0055 | 1 |
| 13 | 15 | 0.0269 | 0.0869 | 0.0115 | 1 |
| 1 | 15 | 0.0178 | 0.091 | 0.0494 | 1 |
| 1 | 16 | 0.0454 | 0.206 | 0.0273 | 1 |
| 1 | 17 | 0.0238 | 0.108 | 0.0143 | 1 |
| 3 | 15 | 0.0162 | 0.053 | 0.0272 | 1 |
| 4 | 18 | 0 | 0.555 | 0 | 0.97 |
| 4 | 18 | 0 | 0.43 | 0 | 0.978 |
| 5 | 6 | 0.0302 | 0.0641 | 0.0062 | 1 |
| 7 | 8 | 0.0139 | 0.0712 | 0.0097 | 1 |
| 10 | 12 | 0.0277 | 0.1262 | 0.0164 | 1 |
| 11 | 13 | 0.0223 | 0.0732 | 0.0094 | 1 |
| 12 | 13 | 0.0178 | 0.058 | 0.0302 | 1 |
| 12 | 16 | 0.018 | 0.0813 | 0.0108 | 1 |
| 12 | 17 | 0.0397 | 0.179 | 0.0238 | 1 |
| 14 | 15 | 0.0171 | 0.0547 | 0.0074 | 1 |
| 18 | 19 | 0.461 | 0.685 | 0 | 1 |
| 19 | 20 | 0.283 | 0.434 | 0 | 1 |
| 21 | 20 | 0 | 0.7767 | 0 | 1.043 |
| 21 | 22 | 0.0736 | 0.117 | 0 | 1 |
| 22 | 23 | 0.0099 | 0.0152 | 0 | 1 |
| 23 | 24 | 0.166 | 0.256 | 0.0042 | 1 |
| 24 | 25 | 0 | 1.182 | 0 | 1 |
| 24 | 25 | 0 | 1.23 | 0 | 1 |
| 24 | 26 | 0 | 0.0473 | 0 | 1.043 |
| 26 | 27 | 0.165 | 0.254 | 0 | 1 |
| 27 | 28 | 0.0618 | 0.0954 | 0 | 1 |

**Table A3.2 (Continued)**

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 28 | 29 | 0.0418 | 0.0587 | 0 | 1 |
| 7 | 29 | 0 | 0.0648 | 0 | 0.967 |
| 25 | 30 | 0.135 | 0.202 | 0 | 1 |
| 30 | 31 | 0.326 | 0.497 | 0 | 1 |
| 31 | 32 | 0.507 | 0.755 | 0 | 1 |
| 32 | 33 | 0.0392 | 0.036 | 0 | 1 |
| 34 | 32 | 0 | 0.953 | 0 | 0.975 |
| 34 | 35 | 0.052 | 0.078 | 0.0016 | 1 |
| 35 | 36 | 0.043 | 0.0537 | 0.0008 | 1 |
| 36 | 37 | 0.029 | 0.0366 | 0 | 1 |
| 37 | 38 | 0.0651 | 0.1009 | 0.001 | 1 |
| 37 | 39 | 0.0239 | 0.0379 | 0 | 1 |
| 36 | 40 | 0.03 | 0.0466 | 0 | 1 |
| 22 | 38 | 0.0192 | 0.0295 | 0 | 1 |
| 11 | 41 | 0 | 0.749 | 0 | 0.955 |
| 41 | 42 | 0.207 | 0.352 | 0 | 1 |
| 41 | 43 | 0 | 0.412 | 0 | 1 |
| 38 | 44 | 0.0289 | 0.0585 | 0.001 | 1 |
| 15 | 45 | 0 | 0.1042 | 0 | 0.955 |
| 14 | 46 | 0 | 0.0735 | 0 | 0.9 |
| 46 | 47 | 0.023 | 0.068 | 0.0016 | 1 |
| 47 | 48 | 0.0182 | 0.0233 | 0 | 1 |
| 48 | 49 | 0.0834 | 0.129 | 0.0024 | 1 |
| 49 | 50 | 0.0801 | 0.128 | 0 | 1 |
| 50 | 51 | 0.1386 | 0.22 | 0 | 1 |
| 10 | 51 | 0 | 0.0712 | 0 | 0.93 |
| 13 | 49 | 0 | 0.191 | 0 | 0.895 |
| 29 | 52 | 0.1442 | 0.187 | 0 | 1 |
| 52 | 53 | 0.0762 | 0.0984 | 0 | 1 |
| 53 | 54 | 0.1878 | 0.232 | 0 | 1 |
| 54 | 55 | 0.1732 | 0.2265 | 0 | 1 |
| 11 | 43 | 0 | 0.153 | 0 | 0.958 |
| 44 | 45 | 0.0624 | 0.1242 | 0.002 | 1 |
| 40 | 56 | 0 | 1.195 | 0 | 0.958 |
| 56 | 41 | 0.553 | 0.549 | 0 | 1 |
| 56 | 42 | 0.2125 | 0.354 | 0 | 1 |
| 39 | 57 | 0 | 1.355 | 0 | 0.98 |
| 57 | 56 | 0.174 | 0.26 | 0 | 1 |
| 38 | 49 | 0.115 | 0.177 | 0.0015 | 1 |
| 38 | 48 | 0.0312 | 0.0482 | 0 | 1 |
| 9 | 55 | 0 | 0.1205 | 0 | 0.94 |

**Table A3.3 Generator cost coefficients data for IEEE 57 bus system**

| Generator Bus No. | a ($/MWh$^2$) | b ($/MWh) | c |
|---|---|---|---|
| 1 | 0.0017 | 1.7365 | 0 |
| 2 | 0.01 | 10 | 0 |
| 3 | 0.0071 | 7.1429 | 0 |
| 6 | 0.01 | 10 | 0 |
| 8 | 0.0018 | 1.81 | 0 |
| 9 | 0.01 | 10 | 0 |
| 12 | 0.0024 | 2.439 | 0 |

**Table A3.4 Line flows and losses for IEEE 57 bus system without SVC**

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 102.158 | 74.9778 | -100.842 | -84.093 | 1.3163 | -9.1155 |
| 1 | 15 | 149.147 | 34.7925 | -145.221 | -24.879 | 3.9259 | 9.9141 |
| 1 | 16 | 79.4309 | -0.8715 | -76.7807 | 7.1401 | 2.6501 | 6.2686 |
| 1 | 17 | 93.5266 | 3.9345 | -91.5953 | 1.8028 | 1.9314 | 5.7373 |
| 2 | 3 | 97.8419 | -4.6575 | -95.0453 | 4.494 | 2.7966 | -0.1635 |
| 3 | 4 | 59.8417 | -1.4818 | -59.4283 | -0.8292 | 0.4134 | -2.311 |
| 3 | 15 | 34.2036 | -16.644 | -33.9755 | 12.1002 | 0.2281 | -4.5432 |
| 4 | 5 | 13.7138 | -5.6062 | -13.5785 | 3.4293 | 0.1353 | -2.1769 |
| 4 | 6 | 14.3134 | -6.7466 | -14.2097 | 3.7669 | 0.1036 | -2.9797 |
| 4 | 18 | 13.7716 | 6.6229 | -13.7716 | -5.3488 | 0 | 1.2741 |
| 4 | 18 | 17.6295 | 6.559 | -17.6295 | -5.0386 | 0 | 1.5205 |
| 5 | 6 | 0.5785 | -7.4293 | -0.5635 | 6.2753 | 0.0149 | -1.1539 |
| 6 | 7 | -17.7718 | 0.545 | 17.8383 | -2.8616 | 0.0665 | -2.3166 |
| 6 | 8 | -42.4549 | -6.577 | 43.0978 | 5.2269 | 0.6428 | -1.3501 |
| 7 | 8 | -77.5752 | -15.684 | 78.4743 | 18.3746 | 0.899 | 2.6903 |
| 7 | 29 | 59.7369 | 18.5459 | -59.7369 | -16.087 | 0 | 2.4591 |
| 8 | 9 | 178.428 | 19.7841 | -175.258 | -9.0109 | 3.1704 | 10.7732 |
| 9 | 10 | 17.2811 | -8.9544 | -17.1484 | 5.3077 | 0.1327 | -3.6467 |
| 9 | 11 | 12.945 | 2.9021 | -12.8958 | -4.8196 | 0.0492 | -1.9175 |
| 9 | 12 | 2.5318 | -15.85 | -2.428 | 8.6391 | 0.1038 | -7.2112 |
| 9 | 13 | 2.3203 | -1.3754 | -2.3174 | -2.5062 | 0.0029 | -3.8816 |
| 9 | 55 | 19.1794 | 13.151 | -19.1794 | -12.551 | 0 | 0.5995 |
| 10 | 12 | -17.7962 | -20.425 | 17.9876 | 18.0132 | 0.1914 | -2.4112 |
| 10 | 51 | 29.9446 | 13.1168 | -29.9446 | -12.44 | 0 | 0.6773 |
| 11 | 13 | -9.9531 | -4.094 | 9.9789 | 2.3892 | 0.0257 | -1.7048 |
| 11 | 41 | 9.2159 | 3.7575 | -9.2159 | -3.0431 | 0 | 0.7144 |
| 11 | 43 | 13.633 | 5.1562 | -13.633 | -4.8412 | 0 | 0.3149 |
| 12 | 13 | -0.3619 | 61.9729 | 1.0938 | -65.588 | 0.7319 | -3.6147 |
| 12 | 16 | -33.5664 | 8.8865 | 33.7807 | -10.14 | 0.2143 | -1.2536 |
| 12 | 17 | -48.6313 | 9.2335 | 49.5953 | -9.8028 | 0.964 | -0.5692 |
| 13 | 14 | -10.2632 | 23.344 | 10.3564 | -24.08 | 0.0932 | -0.7358 |
| 13 | 15 | -49.0156 | 4.9012 | 49.7015 | -4.9059 | 0.6859 | -0.0046 |
| 13 | 49 | 32.5236 | 35.1593 | -32.5236 | -31.49 | 0 | 3.6698 |

## Table A3.4 (Continued)

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 14 | 15 | -69.067 | -10.376 | 69.9533 | 11.7956 | 0.8862 | 1.4194 |
| 14 | 46 | 48.2106 | 29.1561 | -48.2106 | -27.142 | 0 | 2.0137 |
| 15 | 45 | 37.5415 | 0.8886 | -37.5415 | 0.4867 | 0 | 1.3753 |
| 18 | 19 | 4.2011 | 0.5874 | -4.1139 | -0.4577 | 0.0872 | 0.1296 |
| 19 | 20 | 0.8139 | -0.1423 | -0.8117 | 0.1455 | 0.0021 | 0.0033 |
| 21 | 20 | 1.4883 | 1.1759 | -1.4883 | -1.1455 | 0 | 0.0304 |
| 21 | 22 | -1.4883 | -1.1759 | 1.4909 | 1.1801 | 0.0026 | 0.0042 |
| 22 | 23 | 9.6481 | 6.1121 | -9.6352 | -6.0924 | 0.0128 | 0.0197 |
| 22 | 38 | -11.139 | -7.2922 | 11.1728 | 7.3442 | 0.0338 | 0.052 |
| 23 | 24 | 3.3352 | 3.9924 | -3.2845 | -4.7418 | 0.0507 | -0.7494 |
| 24 | 25 | 6.8776 | 4.1657 | -6.8776 | -3.3767 | 0 | 0.789 |
| 24 | 25 | 6.6092 | 4.0032 | -6.6092 | -3.245 | 0 | 0.7582 |
| 24 | 26 | -10.2022 | -3.4271 | 10.2022 | 3.4886 | 0 | 0.0615 |
| 25 | 30 | 7.1867 | 3.4217 | -7.0895 | -3.2762 | 0.0973 | 0.1455 |
| 26 | 27 | -10.2022 | -3.4886 | 10.4169 | 3.8191 | 0.2147 | 0.3304 |
| 27 | 28 | -19.7169 | -4.3191 | 19.9829 | 4.7298 | 0.2661 | 0.4108 |
| 28 | 29 | -24.5829 | -7.0298 | 24.862 | 7.4216 | 0.279 | 0.3918 |
| 29 | 52 | 17.875 | 6.0651 | -17.3655 | -5.4045 | 0.5094 | 0.6606 |
| 30 | 31 | 3.4895 | 1.4762 | -3.4342 | -1.3919 | 0.0553 | 0.0843 |
| 31 | 32 | -2.3658 | -1.5081 | 2.4151 | 1.5815 | 0.0493 | 0.0734 |
| 32 | 33 | 3.8083 | 1.9076 | -3.8 | -1.9 | 0.0083 | 0.0076 |
| 34 | 32 | 7.8234 | 5.1739 | -7.8234 | -4.2891 | 0 | 0.8848 |
| 34 | 35 | -7.8234 | -5.1739 | 7.8733 | 4.958 | 0.0499 | -0.2159 |
| 35 | 36 | -13.8733 | -7.958 | 13.9928 | 7.9588 | 0.1194 | 0.0008 |
| 36 | 37 | -17.4378 | -11.713 | 17.5743 | 11.8852 | 0.1365 | 0.1723 |
| 36 | 40 | 3.445 | 3.7541 | -3.4367 | -3.7412 | 0.0083 | 0.0129 |
| 37 | 38 | -21.3909 | -14.624 | 21.8462 | 15.1326 | 0.4553 | 0.5086 |
| 37 | 39 | 3.8166 | 2.7388 | -3.8111 | -2.7301 | 0.0055 | 0.0087 |
| 38 | 44 | -24.5423 | 3.659 | 24.718 | -3.5073 | 0.1756 | 0.1517 |
| 38 | 49 | -4.8654 | -11.576 | 5.0402 | 11.5323 | 0.1748 | -0.0431 |
| 38 | 48 | -17.6112 | -21.56 | 17.8496 | 21.9286 | 0.2384 | 0.3683 |
| 39 | 57 | 3.8111 | 2.7301 | -3.8111 | -2.4297 | 0 | 0.3003 |
| 40 | 56 | 3.4367 | 3.7412 | -3.4367 | -3.4374 | 0 | 0.3038 |
| 41 | 42 | 8.8795 | 3.516 | -8.6883 | -3.1909 | 0.1912 | 0.3251 |
| 41 | 43 | -11.633 | -3.2331 | 11.633 | 3.8412 | 0 | 0.6082 |
| 44 | 45 | -36.718 | 1.7073 | 37.5415 | -0.4867 | 0.8235 | 1.2206 |
| 46 | 47 | 48.2106 | 27.1424 | -47.5785 | -25.622 | 0.6321 | 1.5207 |
| 47 | 48 | 17.8785 | 14.0217 | -17.7898 | -13.908 | 0.0887 | 0.1135 |
| 48 | 49 | -0.0598 | -8.0204 | 0.1079 | 7.5878 | 0.0481 | -0.4327 |
| 49 | 50 | 9.3755 | 3.8694 | -9.2983 | -3.746 | 0.0773 | 0.1235 |
| 50 | 51 | -11.7017 | -6.754 | 11.9446 | 7.1395 | 0.2428 | 0.3854 |
| 52 | 53 | 12.4655 | 3.2045 | -12.3307 | -3.0304 | 0.1348 | 0.1741 |
| 53 | 54 | -7.6693 | -6.9696 | 7.8906 | 7.2431 | 0.2213 | 0.2734 |
| 54 | 55 | -11.9906 | -8.6431 | 12.3794 | 9.1514 | 0.3887 | 0.5084 |
| 56 | 41 | -5.4891 | 0.4188 | 5.6694 | -0.2398 | 0.1803 | 0.179 |
| 56 | 42 | -1.5792 | 1.2243 | 1.5883 | -1.2091 | 0.0091 | 0.0152 |
| 57 | 56 | -2.8889 | 0.4297 | 2.905 | -0.4057 | 0.0161 | 0.0241 |

**Table A3.5 Line flows and losses of IEEE 57 bus system with SVC located at bus 31 identified by conventional method**

| From Bus | To Bus | Line Flows SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | 101.9743 | 75.0282 | -100.6603 | -84.151 | 1.314 | -9.1231 |
| 1 | 15 | 149.2849 | 32.7341 | -145.3787 | -22.939 | 3.9062 | 9.7955 |
| 1 | 16 | 79.2476 | -0.8698 | -76.6097 | 7.0829 | 2.6379 | 6.2132 |
| 1 | 17 | 93.3433 | 3.9357 | -91.4194 | 1.7674 | 1.9239 | 5.703 |
| 2 | 3 | 97.6603 | -4.6105 | -94.8741 | 4.4174 | 2.7862 | -0.1931 |
| 3 | 4 | 59.753 | -1.8567 | -59.3408 | -0.4589 | 0.4122 | -2.3156 |
| 3 | 15 | 34.1211 | -19.9866 | -33.8764 | 15.4878 | 0.2446 | -4.4989 |
| 4 | 5 | 13.7047 | -5.529 | -13.5701 | 3.3502 | 0.1346 | -2.1788 |
| 4 | 6 | 14.2828 | -6.641 | -14.1801 | 3.6577 | 0.1027 | -2.9833 |
| 4 | 18 | 13.7506 | 6.3806 | -13.7506 | -5.1273 | 0 | 1.2534 |
| 4 | 18 | 17.6027 | 6.2483 | -17.6027 | -4.7495 | 0 | 1.4988 |
| 5 | 6 | 0.5701 | -7.3502 | -0.5555 | 6.1955 | 0.0146 | -1.1547 |
| 6 | 7 | -17.7735 | -1.1874 | 17.8392 | -1.1377 | 0.0658 | -2.3251 |
| 6 | 8 | -42.491 | -6.5672 | 43.1348 | 5.2224 | 0.6439 | -1.3448 |
| 7 | 8 | -77.8579 | -13.1708 | 78.7502 | 15.8233 | 0.8923 | 2.6525 |
| 7 | 29 | 60.0186 | 14.3085 | -60.0186 | -11.924 | 0 | 2.3841 |
| 8 | 9 | 178.115 | 19.8169 | -174.9554 | -9.0987 | 3.1596 | 10.7181 |
| 9 | 10 | 17.0836 | -9.5335 | -16.9503 | 5.8848 | 0.1333 | -3.6487 |
| 9 | 11 | 13.038 | 1.036 | -12.9912 | -2.9647 | 0.0468 | -1.9287 |
| 9 | 12 | 2.5428 | -15.8526 | -2.4389 | 8.6417 | 0.1039 | -7.2109 |
| 9 | 13 | 2.3545 | -2.5815 | -2.3515 | -1.3075 | 0.003 | -3.8889 |
| 9 | 55 | 18.9364 | 12.7152 | -18.9364 | -12.138 | 0 | 0.5768 |
| 10 | 12 | -17.4973 | -19.6902 | 17.6775 | 17.2246 | 0.1802 | -2.4655 |
| 10 | 51 | 29.4476 | 11.8053 | -29.4476 | -11.169 | 0 | 0.6365 |
| 11 | 13 | -10.0096 | -4.5353 | 10.0362 | 2.8269 | 0.0266 | -1.7084 |
| 11 | 41 | 9.2821 | 3.1497 | -9.2821 | -2.4591 | 0 | 0.6907 |
| 11 | 43 | 13.7187 | 4.3503 | -13.7187 | -4.0442 | 0 | 0.3061 |
| 12 | 13 | -0.3787 | 58.5883 | 1.0364 | -62.456 | 0.6578 | -3.8677 |
| 12 | 16 | -33.3976 | 8.8193 | 33.6097 | -10.083 | 0.2121 | -1.2637 |
| 12 | 17 | -48.4623 | 9.1668 | 49.4194 | -9.7674 | 0.9571 | -0.6005 |
| 13 | 14 | -10.3874 | 21.3068 | 10.4678 | -22.09 | 0.0804 | -0.783 |
| 13 | 15 | -49.0207 | 4.9964 | 49.7043 | -5.0167 | 0.6837 | -0.0203 |
| 13 | 49 | 32.6869 | 32.3334 | -32.6869 | -28.965 | 0 | 3.3684 |
| 14 | 15 | -69.0488 | -8.6176 | 69.9237 | 9.9941 | 0.8749 | 1.3765 |
| 14 | 46 | 48.081 | 25.4074 | -48.081 | -23.543 | 0 | 1.865 |
| 15 | 45 | 37.6271 | -2.5266 | -37.6271 | 3.9085 | 0 | 1.3819 |
| 18 | 19 | 4.1533 | 0.0767 | -4.0699 | 0.0472 | 0.0834 | 0.1239 |
| 19 | 20 | 0.7699 | -0.6472 | -0.7667 | 0.652 | 0.0031 | 0.0048 |
| 21 | 20 | 1.5333 | 1.695 | -1.5333 | -1.652 | 0 | 0.043 |
| 21 | 22 | -1.5333 | -1.695 | 1.537 | 1.701 | 0.0037 | 0.006 |
| 22 | 23 | 9.5549 | 1.003 | -9.5461 | -0.9894 | 0.0089 | 0.0136 |

## Table A3.5 (Continued)

| From Bus | To Bus | Line Flows SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 22 | 38 | -11.092 | -2.704 | 11.1162 | 2.7412 | 0.0243 | 0.0373 |
| 23 | 24 | 3.2461 | -1.1106 | -3.2284 | 0.2761 | 0.0177 | -0.8346 |
| 24 | 25 | 6.9112 | -0.6616 | -6.9112 | 1.2188 | 0 | 0.5572 |
| 24 | 25 | 6.6415 | -0.6358 | -6.6415 | 1.1713 | 0 | 0.5355 |
| 24 | 26 | -10.3243 | 1.0213 | 10.3243 | -0.9672 | 0 | 0.0542 |
| 25 | 30 | 7.2527 | -5.5901 | -7.1443 | 5.7522 | 0.1084 | 0.1621 |
| 26 | 27 | -10.3243 | 0.9672 | 10.5132 | -0.6763 | 0.1889 | 0.2909 |
| 27 | 28 | -19.8132 | 0.1763 | 20.0636 | 0.2102 | 0.2503 | 0.3864 |
| 28 | 29 | -24.6636 | -2.5102 | 24.9221 | 2.8731 | 0.2585 | 0.363 |
| 29 | 52 | 18.0966 | 6.4513 | -17.5736 | -5.7731 | 0.523 | 0.6782 |
| 30 | 31 | 3.5443 | -7.5522 | -3.3278 | 7.8822 | 0.2165 | 0.33 |
| 31 | 32 | -2.4722 | 5.3957 | 2.6341 | -5.1544 | 0.162 | 0.2412 |
| 32 | 33 | 3.8068 | 1.9062 | -3.8 | -1.9 | 0.0068 | 0.0062 |
| 34 | 32 | 8.0409 | -1.8062 | -8.0409 | 2.4482 | 0 | 0.642 |
| 34 | 35 | -8.0409 | 1.8062 | 8.0781 | -2.058 | 0.0372 | -0.2518 |
| 35 | 36 | -14.0781 | -0.942 | 14.1668 | 0.8976 | 0.0888 | -0.0444 |
| 36 | 37 | -17.4427 | -5.6103 | 17.5423 | 5.7361 | 0.0997 | 0.1258 |
| 36 | 40 | 3.2758 | 4.7127 | -3.2657 | -4.697 | 0.0101 | 0.0157 |
| 37 | 38 | -21.3817 | -8.9846 | 21.7338 | 9.3274 | 0.3521 | 0.3429 |
| 37 | 39 | 3.8394 | 3.2485 | -3.8333 | -3.2389 | 0.0061 | 0.0097 |
| 38 | 44 | -24.6173 | 7.0918 | 24.8005 | -6.9291 | 0.1832 | 0.1626 |
| 38 | 49 | -4.746 | -9.3181 | 4.864 | 9.1818 | 0.118 | -0.1363 |
| 38 | 48 | -17.4867 | -16.8423 | 17.6639 | 17.1161 | 0.1772 | 0.2738 |
| 39 | 57 | 3.8333 | 3.2389 | -3.8333 | -2.9068 | 0 | 0.3321 |
| 40 | 56 | 3.2657 | 4.697 | -3.2657 | -4.3272 | 0 | 0.3698 |
| 41 | 42 | 9.0335 | 2.8628 | -8.8476 | -2.5466 | 0.1859 | 0.3161 |
| 41 | 43 | -11.7187 | -2.4536 | 11.7187 | 3.0442 | 0 | 0.5906 |
| 44 | 45 | -36.8005 | 5.1291 | 37.6271 | -3.9085 | 0.8266 | 1.2207 |
| 46 | 47 | 48.081 | 23.5425 | -47.4957 | -22.165 | 0.5853 | 1.3776 |
| 47 | 48 | 17.7957 | 10.5649 | -17.7233 | -10.472 | 0.0724 | 0.0927 |
| 48 | 49 | 0.0593 | -6.6439 | -0.0274 | 6.1782 | 0.032 | -0.4658 |
| 49 | 50 | 9.8503 | 5.105 | -9.7591 | -4.9593 | 0.0912 | 0.1457 |
| 50 | 51 | -11.2409 | -5.5407 | 11.4476 | 5.8688 | 0.2067 | 0.3281 |
| 52 | 53 | 12.6736 | 3.5731 | -12.5335 | -3.3922 | 0.14 | 0.1808 |
| 53 | 54 | -7.4665 | -6.6078 | 7.67 | 6.8592 | 0.2035 | 0.2514 |
| 54 | 55 | -11.77 | -8.2592 | 12.1364 | 8.7384 | 0.3665 | 0.4793 |
| 56 | 41 | -5.4847 | 1.1314 | 5.6673 | -0.9501 | 0.1826 | 0.1813 |
| 56 | 42 | -1.733 | 1.8777 | 1.7476 | -1.8534 | 0.0146 | 0.0243 |
| 57 | 56 | -2.8667 | 0.9068 | 2.8834 | -0.8819 | 0.0167 | 0.0249 |

# APPENDIX 4

# IEEE 118 BUS SYSTEM

The single line diagram of IEEE 118 bus system is shown in Figure A4.1. Bus data, line data and generator cost coefficients data of IEEE 118 bus system are shown in Tables A4.1- A4.3.

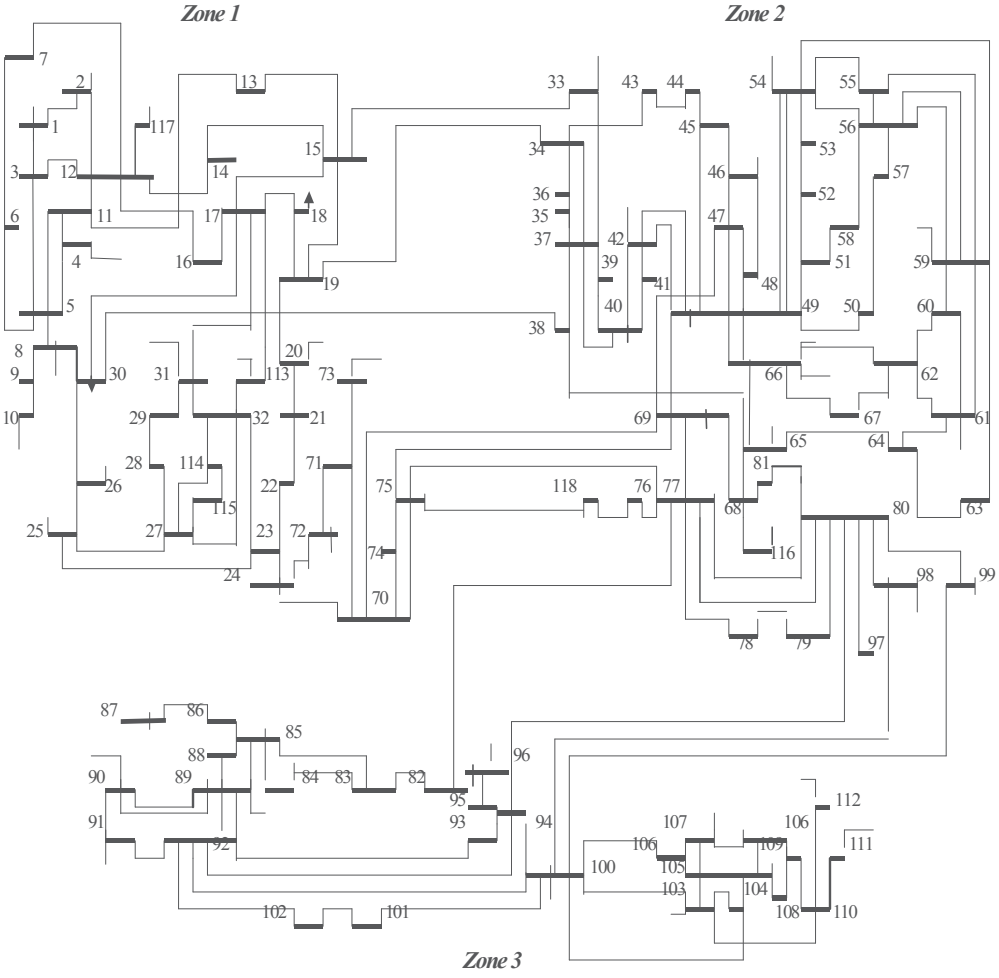


**Figure A4.1 Single line diagram of IEEE 118 bus system**

# Table A4.1 Bus data for IEEE 118 bus system

| Bus No. | Bus Type* | Voltage specified (p.u.) | Voltage angle (p.u.) | P-Generated MW | Q-Generated MVAR | P-Load MW | Q-Load MVAR | Q-Generated max MVAR | Q-Generated min MVAR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.955 | 0 | 0.0 | 0.0 | 51.0 | 27.0 | 15.0 | -5.0 |
| 2 | 3 | 1 | 0 | 0.0 | 0.0 | 20.0 | 9.0 | 0.0 | 0.0 |
| 3 | 3 | 1 | 0 | 0.0 | 0.0 | 39.0 | 10.0 | 0.0 | 0.0 |
| 4 | 2 | 0.998 | 0 | -9.0 | 0.0 | 30.0 | 12.0 | 300.0 | -300.0 |
| 5 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 2 | 0.99 | 0 | 0.0 | 0.0 | 52.0 | 22.0 | 50.0 | -13.0 |
| 7 | 3 | 1 | 0 | 0.0 | 0.0 | 19.0 | 2.0 | 0.0 | 0.0 |
| 8 | 2 | 1.015 | 0 | -28.0 | 0.0 | 0.0 | 0.0 | 300.0 | -300.0 |
| 9 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 2 | 1.05 | 0 | 450.0 | 0.0 | 0.0 | 0.0 | 200.0 | -147.0 |
| 11 | 3 | 1 | 0 | 0.0 | 0.0 | 70.0 | 23.0 | 0.0 | 0.0 |
| 12 | 2 | 0.99 | 0 | 85.0 | 0.0 | 47.0 | 10.0 | 120.0 | -35.0 |
| 13 | 3 | 1 | 0 | 0.0 | 0.0 | 34.0 | 16.0 | 0.0 | 0.0 |
| 14 | 3 | 1 | 0 | 0.0 | 0.0 | 14.0 | 1.0 | 0.0 | 0.0 |
| 15 | 2 | 0.97 | 0 | 0.0 | 0.0 | 90.0 | 30.0 | 30.0 | -10.0 |
| 16 | 3 | 1 | 0 | 0.0 | 0.0 | 25.0 | 10.0 | 0.0 | 0.0 |
| 17 | 3 | 1 | 0 | 0.0 | 0.0 | 11.0 | 3.0 | 0.0 | 0.0 |
| 18 | 2 | 0.973 | 0 | 0.0 | 0.0 | 60.0 | 34.0 | 50.0 | -16.0 |
| 19 | 2 | 0.963 | 0 | 0.0 | 0.0 | 45.0 | 25.0 | 24.0 | -8.0 |
| 20 | 3 | 1 | 0 | 0.0 | 0.0 | 18.0 | 3.0 | 0.0 | 0.0 |
| 21 | 3 | 1 | 0 | 0.0 | 0.0 | 14.0 | 8.0 | 0.0 | 0.0 |
| 22 | 3 | 1 | 0 | 0.0 | 0.0 | 10.0 | 5.0 | 0.0 | 0.0 |
| 23 | 3 | 1 | 0 | 0.0 | 0.0 | 7.0 | 3.0 | 0.0 | 0.0 |
| 24 | 2 | 0.992 | 0 | -13.0 | 0.0 | 0.0 | 0.0 | 300.0 | -300.0 |
| 25 | 2 | 1.05 | 0 | 220.0 | 0.0 | 0.0 | 0.0 | 140.0 | -47.0 |
| 26 | 2 | 1.015 | 0 | 314.0 | 0.0 | 0.0 | 0.0 | 1000.0 | -1000.0 |
| 27 | 2 | 0.968 | 0 | -9.0 | 0.0 | 62.0 | 13.0 | 300.0 | -300.0 |
| 28 | 3 | 1 | 0 | 0.0 | 0.0 | 17.0 | 7.0 | 0.0 | 0.0 |
| 29 | 3 | 1 | 0 | 0.0 | 0.0 | 24.0 | 4.0 | 0.0 | 0.0 |
| 30 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 31 | 2 | 0.967 | 0 | 7.0 | 0.0 | 43.0 | 27.0 | 300.0 | -300.0 |
| 32 | 2 | 0.964 | 0 | 0.0 | 0.0 | 59.0 | 23.0 | 42.0 | -14.0 |
| 33 | 3 | 1 | 0 | 0.0 | 0.0 | 23.0 | 9.0 | 0.0 | 0.0 |
| 34 | 2 | 0.986 | 0 | 0.0 | 0.0 | 59.0 | 26.0 | 24.0 | -8.0 |
| 35 | 3 | 1 | 0 | 0.0 | 0.0 | 33.0 | 9.0 | 0.0 | 0.0 |
| 36 | 2 | 0.98 | 0 | 0.0 | 0.0 | 31.0 | 17.0 | 24.0 | -8.0 |
| 37 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 38 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 39 | 3 | 1 | 0 | 0.0 | 0.0 | 27.0 | 11.0 | 0.0 | 0.0 |
| 40 | 2 | 0.97 | 0 | -46.0 | 0.0 | 20.0 | 23.0 | 300.0 | -300.0 |
| 41 | 3 | 1 | 0 | 0.0 | 0.0 | 37.0 | 10.0 | 0.0 | 0.0 |
| 42 | 2 | 0.985 | 0 | -59.0 | 0.0 | 37.0 | 23.0 | 300.0 | -300.0 |
| 43 | 3 | 1 | 0 | 0.0 | 0.0 | 18.0 | 7.0 | 0.0 | 0.0 |
| 44 | 3 | 1 | 0 | 0.0 | 0.0 | 16.0 | 8.0 | 0.0 | 0.0 |
| 45 | 3 | 1 | 0 | 0.0 | 0.0 | 53.0 | 22.0 | 0.0 | 0.0 |
| 46 | 2 | 1.005 | 0 | 19.0 | 0.0 | 28.0 | 10.0 | 100.0 | -100.0 |
| 47 | 3 | 1 | 0 | 0.0 | 0.0 | 34.0 | 0.0 | 0.0 | 0.0 |
| 48 | 3 | 1 | 0 | 0.0 | 0.0 | 20.0 | 11.0 | 0.0 | 0.0 |
| 49 | 2 | 1.025 | 0 | 204.0 | 0.0 | 87.0 | 30.0 | 210.0 | -85.0 |
| 50 | 3 | 1 | 0 | 0.0 | 0.0 | 17.0 | 4.0 | 0.0 | 0.0 |
| 51 | 3 | 1 | 0 | 0.0 | 0.0 | 17.0 | 8.0 | 0.0 | 0.0 |
| 52 | 3 | 1 | 0 | 0.0 | 0.0 | 18.0 | 5.0 | 0.0 | 0.0 |
| 53 | 3 | 1 | 0 | 0.0 | 0.0 | 23.0 | 11.0 | 0.0 | 0.0 |
| 54 | 2 | 0.955 | 0 | 48.0 | 0.0 | 113.0 | 32.0 | 300.0 | -300.0 |
| 55 | 2 | 0.952 | 0 | 0.0 | 0.0 | 63.0 | 22.0 | 23.0 | -8.0 |
| 56 | 2 | 0.954 | 0 | 0.0 | 0.0 | 84.0 | 18.0 | 15.0 | -8.0 |
| 57 | 3 | 1 | 0 | 0.0 | 0.0 | 12.0 | 3.0 | 0.0 | 0.0 |
| 58 | 3 | 1 | 0 | 0.0 | 0.0 | 12.0 | 3.0 | 0.0 | 0.0 |
| 59 | 2 | 0.985 | 0 | 155.0 | 0.0 | 277.0 | 113.0 | 180.0 | -60.0 |

## Table A4.1 (Continued)

| Bus No. | Bus Type* | Voltage specified (p.u.) | Voltage angle (p.u.) | P-Generated MW | Q-Generated MVAR | P-Load MW | Q-Load MVAR | Q-Generated max MVAR | Q-Generated min MVAR |
|---|---|---|---|---|---|---|---|---|---|
| 60 | 3 | 1 | 0 | 0.0 | 0.0 | 78.0 | 3.0 | 0.0 | 0.0 |
| 61 | 2 | 0.995 | 0 | 160.0 | 0.0 | 0.0 | 0.0 | 300.0 | -100.0 |
| 62 | 2 | 0.998 | 0 | 0.0 | 0.0 | 77.0 | 14.0 | 20.0 | -20.0 |
| 63 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 64 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 65 | 2 | 1.005 | 0 | 391.0 | 0.0 | 0.0 | 0.0 | 200.0 | -67.0 |
| 66 | 3 | 1.05 | 0 | 392.0 | 0.0 | 39.0 | 18.0 | 200.0 | -67.0 |
| 67 | 3 | 1 | 0 | 0.0 | 0.0 | 28.0 | 7.0 | 0.0 | 0.0 |
| 68 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 69 | 1 | 1.035 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70 | 2 | 0.984 | 0 | 0.0 | 0.0 | 66.0 | 20.0 | 32.0 | -10.0 |
| 71 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 72 | 2 | 0.98 | 0 | -12.0 | 0.0 | 0.0 | 0.0 | 100.0 | -100.0 |
| 73 | 2 | 0.991 | 0 | -6.0 | 0.0 | 0.0 | 0.0 | 100.0 | -100.0 |
| 74 | 2 | 0.958 | 0 | 0.0 | 0.0 | 68.0 | 27.0 | 9.0 | -6.0 |
| 75 | 3 | 1 | 0 | 0.0 | 0.0 | 47.0 | 11.0 | 0.0 | 0.0 |
| 76 | 2 | 0.943 | 0 | 0.0 | 0.0 | 68.0 | 36.0 | 23.0 | -8.0 |
| 77 | 2 | 1.006 | 0 | 0.0 | 0.0 | 61.0 | 28.0 | 70.0 | -20.0 |
| 78 | 3 | 1 | 0 | 0.0 | 0.0 | 71.0 | 26.0 | 0.0 | 0.0 |
| 79 | 3 | 1 | 0 | 0.0 | 0.0 | 39.0 | 32.0 | 0.0 | 0.0 |
| 80 | 2 | 1.04 | 0 | 477.0 | 0.0 | 130.0 | 26.0 | 280.0 | -165.0 |
| 81 | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 82 | 3 | 1 | 0 | 0.0 | 0.0 | 54.0 | 27.0 | 0.0 | 0.0 |
| 83 | 3 | 1 | 0 | 0.0 | 0.0 | 20.0 | 10.0 | 0.0 | 0.0 |
| 84 | 3 | 1 | 0 | 0.0 | 0.0 | 11.0 | 7.0 | 0.0 | 0.0 |
| 85 | 2 | 0.985 | 0 | 0.0 | 0.0 | 24.0 | 15.0 | 23.0 | -8.0 |
| 86 | 3 | 1 | 0 | 0.0 | 0.0 | 21.0 | 10.0 | 0.0 | 0.0 |
| 87 | 2 | 1.015 | 0 | 4.0 | 0.0 | 0.0 | 0.0 | 1000.0 | -100.0 |
| 88 | 3 | 1 | 0 | 0.0 | 0.0 | 48.0 | 10.0 | 0.0 | 0.0 |
| 89 | 2 | 1.005 | 0 | 607.0 | 0.0 | 0.0 | 0.0 | 300.0 | -210.0 |
| 90 | 2 | 0.985 | 0 | -85.0 | 0.0 | 78.0 | 42.0 | 300.0 | -300.0 |
| 91 | 2 | 0.98 | 0 | -10.0 | 0.0 | 0.0 | 0.0 | 100.0 | -100.0 |
| 92 | 2 | 0.993 | 0 | 0.0 | 0.0 | 65.0 | 10.0 | 9.0 | -3.0 |
| 93 | 3 | 1 | 0 | 0.0 | 0.0 | 12.0 | 7.0 | 0.0 | 0.0 |
| 94 | 3 | 1 | 0 | 0.0 | 0.0 | 30.0 | 16.0 | 0.0 | 0.0 |
| 95 | 3 | 1 | 0 | 0.0 | 0.0 | 42.0 | 31.0 | 0.0 | 0.0 |
| 96 | 3 | 1 | 0 | 0.0 | 0.0 | 38.0 | 15.0 | 0.0 | 0.0 |
| 97 | 3 | 1 | 0 | 0.0 | 0.0 | 15.0 | 9.0 | 0.0 | 0.0 |
| 98 | 3 | 1 | 0 | 0.0 | 0.0 | 34.0 | 8.0 | 0.0 | 0.0 |
| 99 | 2 | 1.01 | 0 | -42.0 | 0.0 | 0.0 | 0.0 | 100.0 | -100.0 |
| 100 | 2 | 1.017 | 0 | 252.0 | 0.0 | 37.0 | 18.0 | 155.0 | -50.0 |
| 101 | 3 | 1 | 0 | 0.0 | 0.0 | 22.0 | 15.0 | 0.0 | 0.0 |
| 102 | 3 | 1 | 0 | 0.0 | 0.0 | 5.0 | 3.0 | 0.0 | 0.0 |
| 103 | 2 | 1.001 | 0 | 40.0 | 0.0 | 23.0 | 16.0 | 40.0 | -15.0 |
| 104 | 2 | 0.971 | 0 | 0.0 | 0.0 | 38.0 | 25.0 | 23.0 | -8.0 |
| 105 | 2 | 0.965 | 0 | 0.0 | 0.0 | 31.0 | 26.0 | 23.0 | -8.0 |
| 106 | 3 | 1 | 0 | 0.0 | 0.0 | 43.0 | 16.0 | 0.0 | 0.0 |
| 107 | 2 | 0.952 | 0 | -22.0 | 0.0 | 28.0 | 12.0 | 200.0 | -200.0 |
| 108 | 3 | 1 | 0 | 0.0 | 0.0 | 2.0 | 1.0 | 0.0 | 0.0 |
| 109 | 3 | 1 | 0 | 0.0 | 0.0 | 8.0 | 3.0 | 0.0 | 0.0 |
| 110 | 2 | 0.973 | 0 | 0.0 | 0.0 | 39.0 | 30.0 | 23.0 | -8.0 |
| 111 | 2 | 0.98 | 0 | 36.0 | 0.0 | 0.0 | 0.0 | 1000.0 | -100.0 |
| 112 | 2 | 0.975 | 0 | -43.0 | 0.0 | 25.0 | 13.0 | 1000.0 | -100.0 |
| 113 | 2 | 0.993 | 0 | -6.0 | 0.0 | 0.0 | 0.0 | 200.0 | -100.0 |
| 114 | 3 | 1 | 0 | 0.0 | 0.0 | 8.0 | 3.0 | 0.0 | 0.0 |
| 115 | 3 | 1 | 0 | 0.0 | 0.0 | 22.0 | 7.0 | 0.0 | 0.0 |
| 116 | 2 | 1.005 | 0 | -184.0 | 0.0 | 0.0 | 0.0 | 1000.0 | -1000.0 |
| 117 | 3 | 1 | 0 | 0.0 | 0.0 | 20.0 | 8.0 | 0.0 | 0.0 |
| 118 | 3 | 1 | 0 | 0.0 | 0.0 | 33.0 | 15.0 | 0.0 | 0.0 |

* Bus Type: (1) swing bus, (2) generator bus, and (3) load bus

## Table A4.2 Line data for IEEE 118 bus system

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 1 | 2 | 0.0303 | 0.0999 | 0.0127 | 1 |
| 1 | 3 | 0.0129 | 0.0424 | 0.0054 | 1 |
| 4 | 5 | 0.0018 | 0.008 | 0.001 | 1 |
| 3 | 5 | 0.0241 | 0.108 | 0.0142 | 1 |
| 5 | 6 | 0.0119 | 0.054 | 0.0071 | 1 |
| 6 | 7 | 0.0046 | 0.0208 | 0.0027 | 1 |
| 8 | 9 | 0.0024 | 0.0305 | 0.581 | 1 |
| 8 | 5 | 0 | 0.0267 | 0 | 0.985 |
| 9 | 10 | 0.0026 | 0.0322 | 0.615 | 1 |
| 4 | 11 | 0.0209 | 0.0688 | 0.0087 | 1 |
| 5 | 11 | 0.0203 | 0.0682 | 0.0087 | 1 |
| 11 | 12 | 0.006 | 0.0196 | 0.0025 | 1 |
| 2 | 12 | 0.0187 | 0.0616 | 0.0079 | 1 |
| 3 | 12 | 0.0484 | 0.16 | 0.0203 | 1 |
| 7 | 12 | 0.0086 | 0.034 | 0.0044 | 1 |
| 11 | 13 | 0.0222 | 0.0731 | 0.0094 | 1 |
| 12 | 14 | 0.0215 | 0.0707 | 0.0091 | 1 |
| 13 | 15 | 0.0744 | 0.2444 | 0.0313 | 1 |
| 14 | 15 | 0.0595 | 0.195 | 0.0251 | 1 |
| 12 | 16 | 0.0212 | 0.0834 | 0.0107 | 1 |
| 15 | 17 | 0.0132 | 0.0437 | 0.0222 | 1 |
| 16 | 17 | 0.0454 | 0.1801 | 0.0233 | 1 |
| 17 | 18 | 0.0123 | 0.0505 | 0.0065 | 1 |
| 18 | 19 | 0.0112 | 0.0493 | 0.0057 | 1 |
| 19 | 20 | 0.0252 | 0.117 | 0.0149 | 1 |
| 15 | 19 | 0.012 | 0.0394 | 0.005 | 1 |
| 20 | 21 | 0.0183 | 0.0849 | 0.0108 | 1 |
| 21 | 22 | 0.0209 | 0.097 | 0.0123 | 1 |
| 22 | 23 | 0.0342 | 0.159 | 0.0202 | 1 |
| 23 | 24 | 0.0135 | 0.0492 | 0.0249 | 1 |
| 23 | 25 | 0.0156 | 0.08 | 0.0432 | 1 |
| 26 | 25 | 0 | 0.0382 | 0 | 0.96 |
| 25 | 27 | 0.0318 | 0.163 | 0.0882 | 1 |
| 27 | 28 | 0.0191 | 0.0855 | 0.0108 | 1 |
| 28 | 29 | 0.0237 | 0.0943 | 0.0119 | 1 |
| 30 | 17 | 0 | 0.0388 | 0 | 0.96 |
| 8 | 30 | 0.0043 | 0.0504 | 0.257 | 1 |
| 26 | 30 | 0.008 | 0.086 | 0.454 | 1 |
| 17 | 31 | 0.0474 | 0.1563 | 0.0199 | 1 |
| 29 | 31 | 0.0108 | 0.0331 | 0.0042 | 1 |
| 23 | 32 | 0.0317 | 0.1153 | 0.0587 | 1 |
| 31 | 32 | 0.0298 | 0.0985 | 0.0126 | 1 |
| 27 | 32 | 0.0229 | 0.0755 | 0.0096 | 1 |
| 15 | 33 | 0.038 | 0.1244 | 0.016 | 1 |
| 19 | 34 | 0.0752 | 0.247 | 0.0316 | 1 |
| 35 | 36 | 0.0022 | 0.0102 | 0.0013 | 1 |
| 35 | 37 | 0.011 | 0.0497 | 0.0066 | 1 |
| 33 | 37 | 0.0415 | 0.142 | 0.0183 | 1 |
| 34 | 36 | 0.0087 | 0.0268 | 0.0028 | 1 |
| 34 | 37 | 0.0026 | 0.0094 | 0.0049 | 1 |

## Table A4.2 (Continued)

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 38 | 37 | 0 | 0.0375 | 0 | 0.935 |
| 37 | 39 | 0.0321 | 0.106 | 0.0135 | 1 |
| 37 | 40 | 0.0593 | 0.168 | 0.021 | 1 |
| 30 | 38 | 0.0046 | 0.054 | 0.211 | 1 |
| 39 | 40 | 0.0184 | 0.0605 | 0.0078 | 1 |
| 40 | 41 | 0.0145 | 0.0487 | 0.0061 | 1 |
| 40 | 42 | 0.0555 | 0.183 | 0.0233 | 1 |
| 41 | 42 | 0.041 | 0.135 | 0.0172 | 1 |
| 43 | 44 | 0.0608 | 0.2454 | 0.0303 | 1 |
| 34 | 43 | 0.0413 | 0.1681 | 0.0211 | 1 |
| 44 | 45 | 0.0224 | 0.0901 | 0.0112 | 1 |
| 45 | 46 | 0.04 | 0.1356 | 0.0166 | 1 |
| 46 | 47 | 0.038 | 0.127 | 0.0158 | 1 |
| 46 | 48 | 0.0601 | 0.189 | 0.0236 | 1 |
| 47 | 49 | 0.0191 | 0.0625 | 0.008 | 1 |
| 42 | 49 | 0.0715 | 0.323 | 0.043 | 1 |
| 42 | 49 | 0.0715 | 0.323 | 0.043 | 1 |
| 45 | 49 | 0.0684 | 0.186 | 0.0222 | 1 |
| 48 | 49 | 0.0179 | 0.0505 | 0.0063 | 1 |
| 49 | 50 | 0.0267 | 0.0752 | 0.0094 | 1 |
| 49 | 51 | 0.0486 | 0.137 | 0.0171 | 1 |
| 51 | 52 | 0.0203 | 0.0588 | 0.007 | 1 |
| 52 | 53 | 0.0405 | 0.1635 | 0.0203 | 1 |
| 53 | 54 | 0.0263 | 0.122 | 0.0155 | 1 |
| 49 | 54 | 0.073 | 0.289 | 0.0369 | 1 |
| 49 | 54 | 0.0869 | 0.291 | 0.0365 | 1 |
| 54 | 55 | 0.0169 | 0.0707 | 0.0101 | 1 |
| 54 | 56 | 0.0027 | 0.0095 | 0.0037 | 1 |
| 55 | 56 | 0.0049 | 0.0151 | 0.0019 | 1 |
| 56 | 57 | 0.0343 | 0.0966 | 0.0121 | 1 |
| 50 | 57 | 0.0474 | 0.134 | 0.0166 | 1 |
| 56 | 58 | 0.0343 | 0.0966 | 0.0121 | 1 |
| 51 | 58 | 0.0255 | 0.0719 | 0.0089 | 1 |
| 54 | 59 | 0.0503 | 0.2293 | 0.0299 | 1 |
| 56 | 59 | 0.0825 | 0.251 | 0.0285 | 1 |
| 56 | 59 | 0.0803 | 0.239 | 0.0268 | 1 |
| 55 | 59 | 0.0474 | 0.2158 | 0.0282 | 1 |
| 59 | 60 | 0.0317 | 0.145 | 0.0188 | 1 |
| 59 | 61 | 0.0328 | 0.15 | 0.0194 | 1 |
| 60 | 61 | 0.0026 | 0.0135 | 0.0073 | 1 |
| 60 | 62 | 0.0123 | 0.0561 | 0.0073 | 1 |
| 61 | 62 | 0.0082 | 0.0376 | 0.0049 | 1 |
| 63 | 59 | 0 | 0.0386 | 0 | 0.96 |
| 63 | 64 | 0.0017 | 0.02 | 0.108 | 1 |
| 64 | 61 | 0 | 0.0268 | 0 | 0.985 |
| 38 | 65 | 0.009 | 0.0986 | 0.523 | 1 |
| 64 | 65 | 0.0027 | 0.0302 | 0.19 | 1 |
| 49 | 66 | 0.018 | 0.0919 | 0.0124 | 1 |
| 49 | 66 | 0.018 | 0.0919 | 0.0124 | 1 |
| 62 | 66 | 0.0482 | 0.218 | 0.0289 | 1 |

## Table A4.2 (Continued)

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 62 | 67 | 0.0258 | 0.117 | 0.0155 | 1 |
| 65 | 66 | 0 | 0.037 | 0 | 0.935 |
| 66 | 67 | 0.0224 | 0.1015 | 0.0134 | 1 |
| 65 | 68 | 0.0014 | 0.016 | 0.319 | 1 |
| 47 | 69 | 0.0844 | 0.2778 | 0.0355 | 1 |
| 49 | 69 | 0.0985 | 0.324 | 0.0414 | 1 |
| 68 | 69 | 0 | 0.037 | 0 | 0.935 |
| 69 | 70 | 0.03 | 0.127 | 0.061 | 1 |
| 24 | 70 | 0.0022 | 0.4115 | 0.051 | 1 |
| 70 | 71 | 0.0088 | 0.0355 | 0.0044 | 1 |
| 24 | 72 | 0.0488 | 0.196 | 0.0244 | 1 |
| 71 | 72 | 0.0446 | 0.18 | 0.0222 | 1 |
| 71 | 73 | 0.0087 | 0.0454 | 0.0059 | 1 |
| 70 | 74 | 0.0401 | 0.1323 | 0.0168 | 1 |
| 70 | 75 | 0.0428 | 0.141 | 0.018 | 1 |
| 69 | 75 | 0.0405 | 0.122 | 0.062 | 1 |
| 74 | 75 | 0.0123 | 0.0406 | 0.0052 | 1 |
| 76 | 77 | 0.0444 | 0.148 | 0.0184 | 1 |
| 69 | 77 | 0.0309 | 0.101 | 0.0519 | 1 |
| 75 | 77 | 0.0601 | 0.1999 | 0.0249 | 1 |
| 77 | 78 | 0.0038 | 0.0124 | 0.0063 | 1 |
| 78 | 79 | 0.0055 | 0.0244 | 0.0032 | 1 |
| 77 | 80 | 0.017 | 0.0485 | 0.0236 | 1 |
| 77 | 80 | 0.0294 | 0.105 | 0.0114 | 1 |
| 79 | 80 | 0.0156 | 0.0704 | 0.0094 | 1 |
| 68 | 81 | 0.0018 | 0.0202 | 0.404 | 1 |
| 81 | 80 | 0 | 0.037 | 0 | 0.935 |
| 77 | 82 | 0.0298 | 0.0853 | 0.0409 | 1 |
| 82 | 83 | 0.0112 | 0.0367 | 0.019 | 1 |
| 83 | 84 | 0.0625 | 0.132 | 0.0129 | 1 |
| 83 | 85 | 0.043 | 0.148 | 0.0174 | 1 |
| 84 | 85 | 0.0302 | 0.0641 | 0.0062 | 1 |
| 85 | 86 | 0.035 | 0.123 | 0.0138 | 1 |
| 86 | 87 | 0.0283 | 0.2074 | 0.0222 | 1 |
| 85 | 88 | 0.02 | 0.102 | 0.0138 | 1 |
| 85 | 89 | 0.0239 | 0.173 | 0.0235 | 1 |
| 88 | 89 | 0.0139 | 0.0712 | 0.0097 | 1 |
| 89 | 90 | 0.0518 | 0.188 | 0.0264 | 1 |
| 89 | 90 | 0.0238 | 0.0997 | 0.053 | 1 |
| 90 | 91 | 0.0254 | 0.0836 | 0.0107 | 1 |
| 89 | 92 | 0.0099 | 0.0505 | 0.0274 | 1 |
| 89 | 92 | 0.0393 | 0.1581 | 0.0207 | 1 |
| 91 | 92 | 0.0387 | 0.1272 | 0.0163 | 1 |
| 92 | 93 | 0.0258 | 0.0848 | 0.0109 | 1 |
| 92 | 94 | 0.0481 | 0.158 | 0.0203 | 1 |
| 93 | 94 | 0.0223 | 0.0732 | 0.0094 | 1 |
| 94 | 95 | 0.0132 | 0.0434 | 0.0056 | 1 |
| 80 | 96 | 0.0356 | 0.182 | 0.0247 | 1 |
| 82 | 96 | 0.0162 | 0.053 | 0.0272 | 1 |
| 94 | 96 | 0.0269 | 0.0869 | 0.0115 | 1 |

## Table A4.2 (Continued)

| From Bus | To Bus | Resistance (p.u.) | Reactance (p.u) | Half line charging admittance (p.u.) | Tap ratio |
|---|---|---|---|---|---|
| 80 | 97 | 0.0183 | 0.0934 | 0.0127 | 1 |
| 80 | 98 | 0.0238 | 0.108 | 0.0143 | 1 |
| 80 | 99 | 0.0454 | 0.206 | 0.0273 | 1 |
| 92 | 100 | 0.0648 | 0.295 | 0.0236 | 1 |
| 94 | 100 | 0.0178 | 0.058 | 0.0302 | 1 |
| 95 | 96 | 0.0171 | 0.0547 | 0.0074 | 1 |
| 96 | 97 | 0.0173 | 0.0885 | 0.012 | 1 |
| 98 | 100 | 0.0397 | 0.179 | 0.0238 | 1 |
| 99 | 100 | 0.018 | 0.0813 | 0.0108 | 1 |
| 100 | 101 | 0.0277 | 0.1262 | 0.0164 | 1 |
| 92 | 102 | 0.0123 | 0.0559 | 0.0073 | 1 |
| 101 | 102 | 0.0246 | 0.112 | 0.0147 | 1 |
| 100 | 103 | 0.016 | 0.0525 | 0.0268 | 1 |
| 100 | 104 | 0.0451 | 0.204 | 0.0271 | 1 |
| 103 | 104 | 0.0466 | 0.1584 | 0.0204 | 1 |
| 103 | 105 | 0.0535 | 0.1625 | 0.0204 | 1 |
| 100 | 106 | 0.0605 | 0.229 | 0.031 | 1 |
| 104 | 105 | 0.0099 | 0.0378 | 0.0049 | 1 |
| 105 | 106 | 0.014 | 0.0547 | 0.0072 | 1 |
| 105 | 107 | 0.053 | 0.183 | 0.0236 | 1 |
| 105 | 108 | 0.0261 | 0.0703 | 0.0092 | 1 |
| 106 | 107 | 0.053 | 0.183 | 0.0236 | 1 |
| 108 | 109 | 0.0105 | 0.0288 | 0.0038 | 1 |
| 103 | 110 | 0.0391 | 0.1813 | 0.0231 | 1 |
| 109 | 110 | 0.0278 | 0.0762 | 0.0101 | 1 |
| 110 | 111 | 0.022 | 0.0755 | 0.01 | 1 |
| 110 | 112 | 0.0247 | 0.064 | 0.031 | 1 |
| 17 | 113 | 0.0091 | 0.0301 | 0.0038 | 1 |
| 32 | 113 | 0.0615 | 0.203 | 0.0259 | 1 |
| 32 | 114 | 0.0135 | 0.0612 | 0.0081 | 1 |
| 27 | 115 | 0.0164 | 0.0741 | 0.0099 | 1 |
| 114 | 115 | 0.0023 | 0.0104 | 0.0014 | 1 |
| 68 | 116 | 0.0003 | 0.004 | 0.082 | 1 |
| 12 | 117 | 0.0329 | 0.14 | 0.0179 | 1 |
| 75 | 118 | 0.0145 | 0.0481 | 0.006 | 1 |
| 76 | 118 | 0.0164 | 0.0544 | 0.0068 | 1 |

**Table A4.3 Generator cost coefficients data for IEEE 118 bus system**

| Generator Bus No. | a ($/MWh$^2$) | b ($/MWh) | c |
|---|---|---|---|
| 1 | 0.009282 | 0.007692 | 0.000020 |
| 4 | 0.009282 | 0.007692 | 0.000020 |
| 6 | 0.009282 | 0.007692 | 0.000020 |
| 8 | 0.009282 | 0.007692 | 0.000020 |
| 10 | 0.001987 | 0.003777 | 0.000003 |
| 12 | 0.001987 | 0.003777 | 0.000003 |
| 15 | 0.009282 | 0.007692 | 0.000020 |
| 18 | 0.002975 | 0.005223 | 0.000004 |
| 19 | 0.009282 | 0.007692 | 0.000020 |
| 24 | 0.009282 | 0.007692 | 0.000020 |
| 25 | 0.001987 | 0.003777 | 0.000003 |
| 26 | 0.009661 | 0.003154 | 0.000001 |
| 27 | 0.009282 | 0.007692 | 0.000020 |
| 31 | 0.009282 | 0.007692 | 0.000020 |
| 32 | 0.002975 | 0.005223 | 0.000004 |
| 34 | 0.009282 | 0.007692 | 0.000020 |
| 36 | 0.002975 | 0.005223 | 0.000004 |
| 40 | 0.009282 | 0.007692 | 0.000020 |
| 42 | 0.009282 | 0.007692 | 0.000020 |
| 46 | 0.002975 | 0.005223 | 0.000004 |
| 49 | 0.008207 | 0.003614 | 0.000001 |
| 54 | 0.008207 | 0.003614 | 0.000001 |
| 55 | 0.002975 | 0.005223 | 0.000004 |
| 56 | 0.002975 | 0.005223 | 0.000004 |
| 59 | 0.011431 | 0.003895 | 0.000001 |
| 61 | 0.011431 | 0.003895 | 0.000001 |
| 62 | 0.002975 | 0.005223 | 0.000004 |
| 65 | 0.018805 | 0.002444 | 0.000003 |
| 66 | 0.018805 | 0.002444 | 0.000003 |
| 69 | 0.001987 | 0.003777 | 0.000003 |
| 70 | 0.021786 | 0.004534 | 0.000013 |
| 72 | 0.009282 | 0.007692 | 0.000020 |

**Table A4.3 (Continued)**

| Generator Bus No. | a ($/MWh$^2$) | b ($/MWh) | c |
|---|---|---|---|
| 73 | 0.009282 | 0.007692 | 0.000020 |
| 74 | 0.005261 | 0.011049 | 0.000008 |
| 76 | 0.002975 | 0.005223 | 0.000004 |
| 77 | 0.002975 | 0.005223 | 0.000004 |
| 80 | 0.001987 | 0.003777 | 0.000003 |
| 85 | 0.009282 | 0.007692 | 0.000020 |
| 87 | 0.009661 | 0.003154 | 0.000001 |
| 89 | 0.001987 | 0.003777 | 0.000003 |
| 90 | 0.005261 | 0.011049 | 0.000008 |
| 91 | 0.017237 | 0.006724 | 0.000003 |
| 92 | 0.001987 | 0.003777 | 0.000003 |
| 99 | 0.001987 | 0.003777 | 0.000003 |
| 100 | 0.001987 | 0.003777 | 0.000003 |
| 103 | 0.005261 | 0.011049 | 0.000008 |
| 104 | 0.002975 | 0.005223 | 0.000004 |
| 105 | 0.002975 | 0.005223 | 0.000004 |
| 107 | 0.005261 | 0.011049 | 0.000008 |
| 110 | 0.017237 | 0.006724 | 0.000003 |
| 111 | 0.002975 | 0.005223 | 0.000004 |
| 112 | 0.002975 | 0.005223 | 0.000004 |
| 113 | 0.002975 | 0.005223 | 0.000004 |
| 116 | 0.017237 | 0.006724 | 0.000003 |

## Table A4.4 Line flows and losses for IEEE 118 bus system without SVC

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | -12.3559 | -13.0402 | 12.4535 | 11.0054 | 0.0976 | -2.0348 |
| 1 | 3 | -38.6441 | -18.1792 | 38.8996 | 18.0184 | 0.2555 | -0.1608 |
| 2 | 12 | -32.4535 | -20.0054 | 32.7358 | 19.4232 | 0.2823 | -0.5822 |
| 3 | 5 | -68.097 | -15.9177 | 69.3439 | 18.7431 | 1.2469 | 2.8254 |
| 3 | 12 | -9.8026 | -12.1007 | 9.9059 | 8.5497 | 0.1033 | -3.551 |
| 4 | 5 | -102.9718 | -52.2913 | 103.2073 | 53.1487 | 0.2355 | 0.8573 |
| 4 | 11 | 63.9718 | -1.2258 | -63.113 | 2.3329 | 0.8588 | 1.107 |
| 5 | 6 | 88.3175 | 7.9071 | -87.388 | -5.1064 | 0.9296 | 2.8007 |
| 5 | 11 | 77.2955 | 4.8464 | -76.0857 | -2.5026 | 1.2098 | 2.3437 |
| 6 | 7 | 35.388 | -4.7375 | -35.3284 | 4.4688 | 0.0596 | -0.2687 |
| 7 | 12 | 16.3284 | -6.4688 | -16.3017 | 5.7181 | 0.0267 | -0.7507 |
| 8 | 9 | -440.635 | -89.7336 | 445.2546 | 24.4289 | 4.6196 | -65.3047 |
| 8 | 5 | 338.1642 | 116.8319 | -338.1642 | -84.645 | 0 | 32.1868 |
| 8 | 30 | 74.4709 | 23.5196 | -74.1343 | -71.128 | 0.3366 | -47.6088 |
| 9 | 10 | -445.2546 | -24.4289 | 450 | -51.042 | 4.7454 | -75.4711 |
| 11 | 12 | 34.2694 | -31.3877 | -34.1382 | 31.3302 | 0.1313 | -0.0575 |
| 11 | 13 | 34.9293 | 8.5574 | -34.6294 | -9.3687 | 0.2998 | -0.8113 |
| 12 | 14 | 18.1375 | -1.0419 | -18.0653 | -0.4939 | 0.0722 | -1.5358 |
| 12 | 16 | 7.5081 | 3.3175 | -7.4918 | -5.3396 | 0.0163 | -2.0221 |
| 12 | 117 | 20.1525 | 5.1973 | -20 | -8 | 0.1525 | -2.8027 |
| 13 | 15 | 0.6294 | -6.6313 | -0.6185 | 0.7012 | 0.011 | -5.9301 |
| 14 | 15 | 4.0653 | -0.5061 | -4.0529 | -4.3054 | 0.0124 | -4.8114 |
| 15 | 17 | -103.978 | -8.0176 | 105.4687 | 8.611 | 1.4907 | 0.5934 |
| 15 | 19 | 11.8545 | 38.1887 | -11.6501 | -38.471 | 0.2044 | -0.2821 |
| 15 | 33 | 6.7948 | -4.5961 | -6.7728 | 1.5964 | 0.022 | -2.9996 |
| 16 | 17 | -17.5082 | -4.6604 | 17.6544 | 0.6619 | 0.1462 | -3.9985 |
| 17 | 18 | 79.7991 | 30.0189 | -78.896 | -27.571 | 0.9031 | 2.4475 |
| 17 | 31 | 14.9396 | 13.1479 | -14.7242 | -16.289 | 0.2154 | -3.1411 |
| 17 | 113 | 2.1877 | 14.4374 | -2.1671 | -15.13 | 0.0206 | -0.693 |
| 18 | 19 | 18.896 | 14.9689 | -18.8254 | -15.728 | 0.0706 | -0.7589 |
| 19 | 20 | -10.4566 | 5.2482 | 10.4982 | -7.8035 | 0.0417 | -2.5552 |
| 19 | 34 | -4.0679 | -14.5576 | 4.191 | 8.8965 | 0.123 | -5.6611 |
| 20 | 21 | -28.4982 | 4.8035 | 28.667 | -6.0037 | 0.1687 | -1.2002 |
| 21 | 22 | -42.667 | -1.9963 | 43.0813 | 1.6331 | 0.4143 | -0.3633 |
| 22 | 23 | -53.0813 | -6.6331 | 54.1145 | 7.5184 | 1.0332 | 0.8853 |
| 23 | 24 | 8.274 | 10.9622 | -8.2403 | -15.778 | 0.0337 | -4.8162 |
| 23 | 25 | -162.304 | -25.9255 | 166.4885 | 38.304 | 4.1845 | 12.3785 |
| 23 | 32 | 92.9156 | 4.4449 | -90.1437 | -5.6751 | 2.7719 | -1.2302 |
| 24 | 70 | -6.2213 | -2.9739 | 6.2222 | -6.8017 | 0.001 | -9.7756 |
| 24 | 72 | 1.4616 | 3.3085 | -1.4443 | -7.9838 | 0.0172 | -4.6753 |
| 25 | 27 | 143.2705 | 30.0497 | -136.8937 | -15.352 | 6.3768 | 14.6977 |
| 26 | 25 | 89.7591 | 21.5682 | -89.7591 | -18.656 | 0 | 2.9121 |
| 26 | 30 | 224.2409 | -14.1173 | -220.2584 | -34.073 | 3.9825 | -48.19 |
| 27 | 28 | 32.7825 | -0.5745 | -32.5631 | -0.4552 | 0.2194 | -1.0298 |
| 27 | 32 | 12.4079 | 0.5207 | -12.3698 | -2.1923 | 0.0381 | -1.6716 |
| 27 | 115 | 20.7033 | 4.3981 | -20.6233 | -5.8703 | 0.08 | -1.4723 |
| 28 | 29 | 15.5631 | -6.5448 | -15.4934 | 4.6177 | 0.0697 | -1.9271 |
| 29 | 31 | -8.5066 | -8.6177 | 8.5229 | 7.8946 | 0.0163 | -0.7231 |

## Table A4.4 (Continued)

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 30 | 17 | 231.0494 | 92.5902 | -231.0494 | -69.877 | 0 | 22.7131 |
| 30 | 38 | 63.3432 | 12.6109 | -63.1 | -50.094 | 0.2433 | -37.4831 |
| 31 | 32 | -29.7987 | 11.3835 | 30.1319 | -12.622 | 0.3332 | -1.2384 |
| 32 | 113 | 3.9905 | -17.3105 | -3.8329 | 12.8698 | 0.1575 | -4.4408 |
| 32 | 114 | 9.3911 | 2.4324 | -9.3768 | -3.8753 | 0.0143 | -1.4429 |
| 33 | 37 | -16.2272 | -10.5964 | 16.3743 | 7.5034 | 0.1471 | -3.093 |
| 34 | 36 | 31.5672 | 48.9549 | -31.2668 | -48.585 | 0.3003 | 0.3696 |
| 34 | 37 | -96.6364 | -28.2861 | 96.8974 | 28.263 | 0.2609 | -0.0231 |
| 34 | 43 | 1.8783 | 7.8675 | -1.8355 | -11.812 | 0.0428 | -3.9447 |
| 35 | 36 | -0.2559 | 21.5616 | 0.2668 | -21.77 | 0.0109 | -0.2082 |
| 35 | 37 | -32.7441 | -30.5616 | 32.9685 | 30.2789 | 0.2243 | -0.2827 |
| 37 | 39 | 55.2424 | 9.1578 | -54.2297 | -8.447 | 1.0128 | 0.7109 |
| 37 | 40 | 44.5457 | 2.3302 | -43.3601 | -3.0519 | 1.1857 | -0.7217 |
| 38 | 37 | 246.0283 | 102.4295 | -246.0283 | -77.533 | 0 | 24.8961 |
| 38 | 65 | -182.9283 | -52.3355 | 186.1533 | -14.109 | 3.225 | -66.4444 |
| 39 | 40 | 27.2297 | -2.553 | -27.0852 | 1.562 | 0.1445 | -0.991 |
| 40 | 41 | 15.8631 | 1.0639 | -15.8239 | -2.0783 | 0.0392 | -1.0144 |
| 40 | 42 | -11.4178 | -6.5829 | 11.5061 | 2.421 | 0.0883 | -4.1619 |
| 41 | 42 | -21.1761 | -7.9217 | 21.3903 | 5.3503 | 0.2142 | -2.5714 |
| 42 | 49 | -64.4482 | 5.0498 | 67.5718 | 0.3714 | 3.1236 | 5.4212 |
| 42 | 49 | -64.4482 | 5.0498 | 67.5718 | 0.3714 | 3.1236 | 5.4212 |
| 43 | 44 | -16.1645 | 4.8121 | 16.3683 | -9.7496 | 0.2038 | -4.9375 |
| 44 | 45 | -32.3683 | 1.7496 | 32.6195 | -2.8591 | 0.2512 | -1.1095 |
| 45 | 46 | -36.0728 | -11.3928 | 36.6603 | 10.1279 | 0.5874 | -1.2649 |
| 45 | 49 | -49.5467 | -7.7481 | 51.334 | 8.1634 | 1.7873 | 0.4153 |
| 46 | 47 | -30.9902 | -1.2677 | 31.3515 | -0.7548 | 0.3614 | -2.0225 |
| 46 | 48 | -14.6701 | -2.5721 | 14.7982 | -1.8377 | 0.1281 | -4.4098 |
| 47 | 49 | -9.5326 | -10.8214 | 9.5678 | 9.2644 | 0.0352 | -1.557 |
| 47 | 69 | -55.819 | 11.5762 | 58.5508 | -10.051 | 2.7318 | 1.5251 |
| 48 | 49 | -34.7982 | -9.1623 | 35.0214 | 8.4839 | 0.2232 | -0.6785 |
| 49 | 50 | 53.7203 | 13.4136 | -52.9342 | -13.123 | 0.7861 | 0.2905 |
| 49 | 51 | 66.7002 | 20.4288 | -64.4137 | -17.379 | 2.2865 | 3.0503 |
| 49 | 54 | 37.8307 | 13.0603 | -36.6369 | -15.577 | 1.1937 | -2.5163 |
| 49 | 54 | 37.8074 | 11.1858 | -36.4385 | -13.766 | 1.3689 | -2.5796 |
| 49 | 66 | -131.845 | 4.2055 | 134.8284 | 8.3564 | 2.9834 | 12.562 |
| 49 | 66 | -131.845 | 4.2055 | 134.8284 | 8.3564 | 2.9834 | 12.562 |
| 49 | 69 | -46.4354 | 10.5967 | 48.6664 | -12.043 | 2.231 | -1.446 |
| 50 | 57 | 35.9342 | 9.1231 | -35.2684 | -10.468 | 0.6658 | -1.3452 |
| 51 | 52 | 28.5811 | 6.2391 | -28.3934 | -6.987 | 0.1877 | -0.7478 |
| 51 | 58 | 18.8326 | 3.1393 | -18.7316 | -4.5124 | 0.1011 | -1.3731 |
| 52 | 53 | 10.3934 | 1.987 | -10.3391 | -5.4409 | 0.0543 | -3.4539 |
| 53 | 54 | -12.6609 | -5.5591 | 12.7131 | 3.0007 | 0.0522 | -2.5584 |
| 54 | 55 | 7.0918 | 1.4525 | -7.0815 | -3.2457 | 0.0104 | -1.7932 |
| 54 | 56 | 18.5858 | 4.3299 | -18.5747 | -4.9583 | 0.0111 | -0.6285 |
| 54 | 59 | -30.3153 | -7.5265 | 30.8349 | 4.267 | 0.5196 | -3.2594 |
| 55 | 56 | -21.4678 | -5.8087 | 21.4943 | 5.5512 | 0.0265 | -0.2576 |

## Table A4.4 (Continued)

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 55 | 59 | -34.4508 | -8.2813 | 35.0885 | 5.8878 | 0.6377 | -2.3934 |
| 56 | 57 | -23.0443 | -9.0782 | 23.2684 | 7.4683 | 0.2241 | -1.6099 |
| 56 | 58 | -6.7121 | -3.6717 | 6.7316 | 1.5124 | 0.0195 | -2.1593 |
| 56 | 59 | -27.9077 | -4.1964 | 28.6161 | 1.0019 | 0.7083 | -3.1945 |
| 56 | 59 | -29.2555 | -3.931 | 30.0126 | 1.1451 | 0.7571 | -2.7859 |
| 59 | 60 | -43.2796 | 3.5634 | 43.901 | -4.399 | 0.6215 | -0.8356 |
| 59 | 61 | -51.6779 | 5.0197 | 52.5968 | -4.6201 | 0.9189 | 0.3996 |
| 60 | 61 | -112.0098 | 8.5086 | 112.3479 | -8.2186 | 0.3381 | 0.29 |
| 60 | 62 | -9.8913 | -7.1096 | 9.9085 | 5.7334 | 0.0173 | -1.3762 |
| 61 | 62 | 25.4435 | -13.8475 | -25.3748 | 13.188 | 0.0687 | -0.6595 |
| 62 | 66 | -37.1966 | -17.2545 | 37.9662 | 14.6705 | 0.7696 | -2.584 |
| 62 | 67 | -24.3371 | -14.4045 | 24.5334 | 12.1392 | 0.1963 | -2.2654 |
| 63 | 59 | 151.5946 | 67.4959 | -151.5946 | -57.058 | 0 | 10.4381 |
| 63 | 64 | -151.5946 | -67.4959 | 152.0761 | 52.5074 | 0.4815 | -14.9885 |
| 64 | 61 | 30.3882 | 14.0106 | -30.3882 | -13.71 | 0 | 0.3009 |
| 64 | 65 | -182.4643 | -66.5181 | 183.4541 | 40.0527 | 0.9898 | -26.4653 |
| 65 | 66 | 7.8187 | 72.2477 | -7.8187 | -70.557 | 0 | 1.6912 |
| 65 | 68 | 13.5739 | -22.3861 | -13.5701 | -41.897 | 0.0038 | -64.283 |
| 66 | 67 | 53.1958 | 19.2679 | -52.5334 | -19.139 | 0.6624 | 0.1287 |
| 68 | 69 | -126.1432 | 112.8361 | 126.1432 | -103.63 | 0 | 9.2054 |
| 68 | 81 | -44.4127 | -4.5977 | 44.4696 | -75.551 | 0.0569 | -80.1487 |
| 68 | 116 | 184.1259 | -66.3415 | -184 | 51.3059 | 0.1259 | -15.0357 |
| 69 | 70 | 108.4089 | 16.0713 | -104.9745 | -13.973 | 3.4344 | 2.0983 |
| 69 | 75 | 110.0545 | 20.4771 | -105.1972 | -18.289 | 4.8572 | 2.1886 |
| 69 | 77 | 62.3422 | 6.7506 | -61.1774 | -13.756 | 1.1648 | -7.0048 |
| 70 | 71 | 16.6586 | -12.3779 | -16.6203 | 11.6795 | 0.0383 | -0.6985 |
| 70 | 74 | 16.2162 | 12.8902 | -16.02 | -15.419 | 0.1962 | -2.5286 |
| 70 | 75 | -0.1226 | 9.9372 | 0.1829 | -13.166 | 0.0603 | -3.2285 |
| 71 | 72 | 10.6079 | -0.941 | -10.5557 | -3.1462 | 0.0522 | -4.0872 |
| 71 | 73 | 6.0124 | -10.7385 | -6 | 9.6514 | 0.0124 | -1.087 |
| 74 | 75 | -51.98 | -6.1909 | 52.3465 | 6.4423 | 0.3665 | 0.2515 |
| 75 | 77 | -34.5737 | -9.5675 | 35.3751 | 7.385 | 0.8014 | -2.1824 |
| 75 | 118 | 40.2416 | 23.5794 | -39.9003 | -23.548 | 0.3412 | 0.0315 |
| 76 | 77 | -61.1236 | -21.0505 | 63.1772 | 24.3975 | 2.0536 | 3.347 |
| 76 | 118 | -6.8764 | -9.6826 | 6.9003 | 8.5479 | 0.0239 | -1.1347 |
| 77 | 78 | 45.6287 | 20.0447 | -45.5354 | -21.011 | 0.0932 | -0.9663 |
| 77 | 80 | -96.8903 | -37.2888 | 98.6718 | 37.4304 | 1.7815 | 0.1416 |
| 77 | 80 | -44.5194 | -20.496 | 45.2038 | 20.5537 | 0.6845 | 0.0577 |
| 77 | 82 | -2.5939 | 27.7151 | 2.8947 | -34.914 | 0.3007 | -7.1992 |
| 78 | 79 | -25.4646 | -4.9889 | 25.501 | 4.5 | 0.0365 | -0.489 |
| 79 | 80 | -64.501 | -36.5 | 65.3401 | 38.332 | 0.839 | 1.832 |
| 80 | 96 | 18.7453 | 23.1128 | -18.4108 | -26.489 | 0.3345 | -3.3763 |
| 80 | 97 | 26.2174 | 27.8075 | -25.957 | -29.146 | 0.2604 | -1.3386 |
| 80 | 98 | 28.8683 | 8.3329 | -28.6634 | -10.448 | 0.2049 | -2.1151 |
| 80 | 99 | 19.4837 | 8.1833 | -19.2723 | -12.962 | 0.2114 | -4.7784 |
| 81 | 80 | -44.4696 | 75.5511 | 44.4696 | -73.049 | 0 | 2.5019 |
| 82 | 83 | -47.0599 | 24.0035 | 47.396 | -26.533 | 0.3362 | -2.5293 |

## Table A4.4 (Continued)

| From Bus | To Bus | Line Flows without SVC | | | | Line losses without SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 82 | 96 | -9.8348 | -16.0891 | 9.8817 | 10.9723 | 0.047 | -5.1169 |
| 83 | 84 | -25.1278 | 10.4696 | 25.6321 | -11.864 | 0.5043 | -1.3943 |
| 83 | 85 | -42.2682 | 6.0632 | 43.102 | -6.5383 | 0.8338 | -0.4751 |
| 84 | 85 | -36.6321 | 4.8639 | 37.0662 | -5.1301 | 0.434 | -0.2662 |
| 85 | 86 | 17.1725 | -7.3537 | -17.0531 | 5.091 | 0.1194 | -2.2627 |
| 85 | 88 | -50.2505 | 7.5558 | 50.7874 | -7.5025 | 0.5368 | 0.0533 |
| 85 | 89 | -71.0901 | 0.6376 | 72.3371 | 3.7354 | 1.247 | 4.373 |
| 86 | 87 | -3.9469 | -15.091 | 4 | 11.0216 | 0.0531 | -4.0694 |
| 88 | 89 | -98.7874 | -2.4975 | 100.1789 | 7.7056 | 1.3915 | 5.2081 |
| 89 | 90 | 58.1652 | -4.7158 | -56.4279 | 5.7931 | 1.7373 | 1.0772 |
| 89 | 90 | 110.7261 | -5.4295 | -107.8372 | 7.0363 | 2.889 | 1.6069 |
| 89 | 92 | 201.9596 | -8.0252 | -197.959 | 22.9631 | 4.0006 | 14.9379 |
| 89 | 92 | 63.633 | -6.9414 | -62.0483 | 9.1846 | 1.5847 | 2.2431 |
| 90 | 91 | 1.2651 | 4.4687 | -1.2567 | -6.507 | 0.0084 | -2.0383 |
| 91 | 92 | -8.7433 | -8.8972 | 8.7957 | 5.8891 | 0.0524 | -3.0081 |
| 92 | 93 | 57.759 | -9.4109 | -56.868 | 10.2043 | 0.8911 | 0.7933 |
| 92 | 94 | 52.2929 | -12.9722 | -50.9002 | 13.5591 | 1.3926 | 0.5869 |
| 92 | 100 | 31.4919 | -15.59 | -30.7246 | 14.3153 | 0.7673 | -1.2747 |
| 92 | 102 | 44.6678 | -7.444 | -44.4133 | 7.1592 | 0.2545 | -0.2848 |
| 93 | 94 | 44.868 | -17.2043 | -44.3458 | 17.0879 | 0.5222 | -0.1164 |
| 94 | 95 | 41.0609 | 11.7907 | -40.8129 | -12.05 | 0.248 | -0.2587 |
| 94 | 96 | 19.9769 | -6.7093 | -19.8586 | 4.8421 | 0.1183 | -1.8671 |
| 94 | 100 | 4.2082 | -51.7284 | -3.7722 | 47.0712 | 0.4361 | -4.6572 |
| 95 | 96 | -1.1871 | -18.9505 | 1.2468 | 17.7156 | 0.0597 | -1.2349 |
| 96 | 97 | -10.8591 | -22.0409 | 10.957 | 20.1461 | 0.0979 | -1.8947 |
| 98 | 100 | -5.3366 | 2.448 | 5.3566 | -7.3124 | 0.02 | -4.8644 |
| 99 | 100 | -22.7277 | -4.5751 | 22.821 | 2.7776 | 0.0933 | -1.7974 |
| 100 | 101 | -16.782 | 21.8273 | 17.0056 | -24.121 | 0.2236 | -2.2937 |
| 100 | 103 | 120.6168 | 14.3068 | -118.3211 | -12.178 | 2.2957 | 2.1289 |
| 100 | 104 | 56.7051 | 10.5912 | -55.2248 | -9.2436 | 1.4803 | 1.3475 |
| 100 | 106 | 60.7793 | 9.4338 | -58.525 | -6.9709 | 2.2543 | 2.4629 |
| 101 | 102 | -39.0056 | 9.121 | 39.4133 | -10.159 | 0.4076 | -1.0382 |
| 103 | 104 | 32.1605 | 1.8457 | -31.6627 | -4.0709 | 0.4978 | -2.2252 |
| 103 | 105 | 42.5465 | 1.3069 | -41.5544 | -2.1967 | 0.9921 | -0.8898 |
| 103 | 110 | 60.6142 | -2.0243 | -59.1529 | 4.3611 | 1.4613 | 2.3368 |
| 104 | 105 | 48.8875 | 2.5588 | -48.6346 | -2.5209 | 0.2529 | 0.0379 |
| 105 | 106 | 8.5228 | 4.0056 | -8.5086 | -5.2801 | 0.0142 | -1.2745 |
| 105 | 107 | 26.7051 | -2.3634 | -26.2992 | -0.5716 | 0.4059 | -2.935 |
| 105 | 108 | 23.961 | -11.1272 | -23.7705 | 9.9208 | 0.1905 | -1.2063 |
| 106 | 107 | 24.0336 | -3.7489 | -23.7008 | 0.5791 | 0.3328 | -3.1698 |
| 108 | 109 | 21.7705 | -10.9208 | -21.7046 | 10.3914 | 0.0659 | -0.5295 |
| 109 | 110 | 13.7046 | -13.3914 | -13.6028 | 11.77 | 0.1019 | -1.6214 |
| 110 | 111 | -35.7029 | 0.9561 | 36 | -1.8438 | 0.2971 | -0.8877 |
| 110 | 112 | 69.4586 | -30.6142 | -68 | 28.5117 | 1.4586 | -2.1025 |
| 114 | 115 | 1.3768 | 0.8753 | -1.3767 | -1.1297 | 0.0001 | -0.2544 |

**Table A4.5 Line flows and losses of IEEE 118 bus system with SVC located at bus 44 identified by conventional method**

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 1 | 2 | -12.3228 | -13.0509 | 12.4203 | 11.0155 | 0.0974 | -2.0354 |
| 1 | 3 | -38.6772 | -18.1551 | 38.9329 | 17.9951 | 0.2557 | -0.16 |
| 2 | 12 | -32.4203 | -20.0155 | 32.7022 | 19.4322 | 0.2819 | -0.5834 |
| 3 | 5 | -68.1737 | -15.8772 | 69.4231 | 18.7134 | 1.2493 | 2.8362 |
| 3 | 12 | -9.7592 | -12.1179 | 9.8622 | 8.5661 | 0.1031 | -3.5518 |
| 4 | 5 | -103.126 | -51.9458 | 103.3612 | 52.8028 | 0.2354 | 0.857 |
| 4 | 11 | 64.1257 | -0.7068 | -63.2629 | 1.8281 | 0.8629 | 1.1212 |
| 5 | 6 | 88.4683 | 7.835 | -87.5357 | -5.0205 | 0.9326 | 2.8145 |
| 5 | 11 | 77.4583 | 5.3363 | -76.2422 | -2.9706 | 1.2161 | 2.3657 |
| 6 | 7 | 35.5357 | -4.7706 | -35.4756 | 4.5042 | 0.0601 | -0.2664 |
| 7 | 12 | 16.4756 | -6.5042 | -16.4484 | 5.7553 | 0.0272 | -0.7489 |
| 8 | 9 | -440.635 | -89.7336 | 445.2546 | 24.4289 | 4.6196 | -65.3047 |
| 8 | 5 | 338.7108 | 116.976 | -338.711 | -84.6875 | 0 | 32.2883 |
| 8 | 30 | 73.9242 | 27.2726 | -73.5747 | -74.6365 | 0.3495 | -47.3639 |
| 9 | 10 | -445.255 | -24.4289 | 450 | -51.0422 | 4.7454 | -75.4711 |
| 11 | 12 | 34.3748 | -33.3645 | -34.2352 | 33.3347 | 0.1396 | -0.0299 |
| 11 | 13 | 35.1303 | 11.5071 | -34.8122 | -12.2529 | 0.3181 | -0.7458 |
| 12 | 14 | 18.3566 | 2.6113 | -18.28 | -4.1278 | 0.0766 | -1.5165 |
| 12 | 16 | 7.6101 | 4.2378 | -7.5916 | -6.2493 | 0.0186 | -2.0115 |
| 12 | 117 | 20.1525 | 5.1973 | -20 | -8 | 0.1525 | -2.8027 |
| 13 | 15 | 0.8122 | -3.7471 | -0.8111 | -2.1385 | 0.001 | -5.8855 |
| 14 | 15 | 4.28 | 3.1278 | -4.2497 | -7.8186 | 0.0303 | -4.6908 |
| 15 | 17 | -103.533 | -24.6071 | 105.1074 | 25.5336 | 1.5749 | 0.9264 |
| 15 | 19 | 11.4686 | 13.2765 | -11.4277 | -14.0858 | 0.0409 | -0.8092 |
| 15 | 33 | 7.1248 | -5.4995 | -7.0978 | 2.5751 | 0.027 | -2.9244 |
| 16 | 17 | -17.4084 | -3.7507 | 17.5516 | -0.2447 | 0.1432 | -3.9954 |
| 17 | 18 | 80.1713 | 24.9822 | -79.2915 | -22.6272 | 0.8798 | 2.3549 |
| 17 | 31 | 14.7861 | 11.5806 | -14.5936 | -14.7869 | 0.1926 | -3.2063 |
| 17 | 113 | 2.07 | 6.2273 | -2.0656 | -6.9717 | 0.0044 | -0.7444 |
| 18 | 19 | 19.2915 | 14.8826 | -19.2194 | -15.635 | 0.0721 | -0.7524 |
| 19 | 20 | -10.6002 | 5.304 | 10.6429 | -7.8545 | 0.0427 | -2.5504 |
| 19 | 34 | -3.7526 | -10.7527 | 3.8137 | 4.9506 | 0.061 | -5.8021 |
| 20 | 21 | -28.6429 | 4.8545 | 28.8134 | -6.0463 | 0.1705 | -1.1918 |
| 21 | 22 | -42.8134 | -1.9537 | 43.2306 | 1.604 | 0.4172 | -0.3497 |
| 22 | 23 | -53.2306 | -6.604 | 54.2695 | 7.5164 | 1.0389 | 0.9124 |
| 23 | 24 | 8.3229 | 10.9169 | -8.2892 | -15.7333 | 0.0336 | -4.8164 |
| 23 | 25 | -162.59 | -25.8516 | 166.7886 | 38.3027 | 4.1986 | 12.4511 |
| 23 | 32 | 92.9976 | 4.4183 | -90.2209 | -5.631 | 2.7767 | -1.2127 |
| 24 | 70 | -6.196 | -2.9747 | 6.1969 | -6.8022 | 0.001 | -9.7769 |
| 24 | 72 | 1.4852 | 3.3026 | -1.468 | -7.9779 | 0.0172 | -4.6753 |
| 25 | 27 | 143.4444 | 30.0543 | -137.053 | -15.2823 | 6.3913 | 14.772 |
| 26 | 25 | 90.233 | 21.5829 | -90.233 | -18.6414 | 0 | 2.9415 |
| 26 | 30 | 223.767 | -11.9743 | -219.79 | -36.1062 | 3.9773 | -48.0805 |
| 27 | 28 | 32.8417 | -0.5857 | -32.6214 | -0.4406 | 0.2202 | -1.0262 |
| 27 | 32 | 12.4731 | 0.5016 | -12.4346 | -2.1719 | 0.0385 | -1.6703 |
| 27 | 115 | 20.7383 | 4.3911 | -20.6581 | -5.8623 | 0.0802 | -1.4712 |

## Table A4.5 (Continued)

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 28 | 29 | 15.6214 | -6.5594 | -15.5512 | 4.6343 | 0.0702 | -1.9251 |
| 29 | 31 | -8.4488 | -8.6343 | 8.465 | 7.911 | 0.0162 | -0.7233 |
| 30 | 17 | 230.6865 | 93.9063 | -230.687 | -71.079 | 0 | 22.8273 |
| 30 | 38 | 62.678 | 16.8365 | -62.4238 | -53.9467 | 0.2542 | -37.1102 |
| 31 | 32 | -29.8714 | 11.4083 | 30.2062 | -12.6414 | 0.3348 | -1.2331 |
| 32 | 113 | 4.0931 | -17.3396 | -3.9344 | 12.9025 | 0.1587 | -4.437 |
| 32 | 114 | 9.3562 | 2.4401 | -9.342 | -3.8834 | 0.0142 | -1.4433 |
| 33 | 37 | -15.9022 | -11.5751 | 16.0557 | 8.5629 | 0.1535 | -3.0122 |
| 34 | 36 | 30.5077 | 11.9811 | -30.4109 | -12.232 | 0.0968 | -0.2509 |
| 34 | 37 | -94.6265 | -55.5797 | 94.9423 | 55.7749 | 0.3157 | 0.1951 |
| 34 | 43 | 1.3051 | -1.6731 | -1.3043 | -2.4272 | 0.0008 | -4.1003 |
| 35 | 36 | 0.5911 | 9.1594 | -0.5891 | -9.4079 | 0.002 | -0.2485 |
| 35 | 37 | -33.5911 | -18.1594 | 33.7552 | 17.6159 | 0.1641 | -0.5436 |
| 37 | 39 | 55.0465 | 4.7712 | -54.0494 | -4.085 | 0.9971 | 0.6863 |
| 37 | 40 | 44.2128 | -1.9358 | -43.039 | 1.2117 | 1.1738 | -0.7241 |
| 38 | 37 | 244.0125 | 110.13 | -244.013 | -84.7891 | 0 | 25.3406 |
| 38 | 65 | -181.589 | -56.183 | 184.7987 | -10.0066 | 3.21 | -66.1896 |
| 39 | 40 | 27.0494 | -6.915 | -26.8992 | 5.947 | 0.1502 | -0.968 |
| 40 | 41 | 15.6104 | 1.1421 | -15.5724 | -2.1605 | 0.038 | -1.0184 |
| 40 | 42 | -11.6722 | -6.5003 | 11.7635 | 2.3484 | 0.0913 | -4.1518 |
| 41 | 42 | -21.4276 | -7.8395 | 21.646 | 5.2821 | 0.2184 | -2.5574 |
| 42 | 49 | -64.7048 | 5.1683 | 67.8544 | 0.3706 | 3.1497 | 5.5389 |
| 42 | 49 | -64.7048 | 5.1683 | 67.8544 | 0.3706 | 3.1497 | 5.5389 |
| 43 | 44 | -16.6957 | -4.5728 | 16.8721 | -0.6917 | 0.1764 | -5.2645 |
| 44 | 45 | -32.8721 | 19.4 | 33.2084 | -20.2636 | 0.3364 | -0.8635 |
| 45 | 46 | -36.416 | -1.3084 | 36.9578 | -0.1566 | 0.5418 | -1.465 |
| 45 | 49 | -49.7925 | -0.428 | 51.5267 | 0.6382 | 1.7343 | 0.2101 |
| 46 | 47 | -31.1731 | -1.1965 | 31.5387 | -0.8116 | 0.3657 | -2.0081 |
| 46 | 48 | -14.7848 | -2.5302 | 14.9148 | -1.8733 | 0.1301 | -4.4035 |
| 47 | 49 | -9.6075 | -10.8156 | 9.643 | 9.2594 | 0.0355 | -1.5562 |
| 47 | 69 | -55.9312 | 11.6272 | 58.6746 | -10.064 | 2.7434 | 1.5632 |
| 48 | 49 | -34.9148 | -9.1267 | 35.1394 | 8.4519 | 0.2245 | -0.6748 |
| 49 | 50 | 53.6689 | 13.4251 | -52.8841 | -13.1383 | 0.7848 | 0.2868 |
| 49 | 51 | 66.6382 | 20.4407 | -64.3553 | -17.4005 | 2.2829 | 3.0402 |
| 49 | 54 | 37.7755 | 13.0685 | -36.5844 | -15.5956 | 1.191 | -2.527 |
| 49 | 54 | 37.7536 | 11.1962 | -36.3878 | -13.7863 | 1.3658 | -2.59 |
| 49 | 66 | -132.168 | 4.3079 | 135.1657 | 8.3296 | 2.9982 | 12.6374 |
| 49 | 66 | -132.168 | 4.3079 | 135.1657 | 8.3296 | 2.9982 | 12.6374 |
| 49 | 69 | -46.5191 | 10.6373 | 48.7585 | -12.0555 | 2.2394 | -1.4182 |
| 50 | 57 | 35.8841 | 9.1383 | -35.2199 | -10.4879 | 0.6642 | -1.3496 |
| 51 | 52 | 28.5621 | 6.2447 | -28.3746 | -6.9932 | 0.1875 | -0.7485 |
| 51 | 58 | 18.7932 | 3.1558 | -18.6925 | -4.5299 | 0.1007 | -1.3741 |
| 52 | 53 | 10.3746 | 1.9932 | -10.3205 | -5.4478 | 0.0542 | -3.4546 |
| 53 | 54 | -12.6795 | -5.5522 | 12.7319 | 2.9944 | 0.0523 | -2.5579 |
| 54 | 55 | 7.0762 | 1.4562 | -7.0658 | -3.2495 | 0.0103 | -1.7933 |
| 54 | 56 | 18.5366 | 4.3439 | -18.5256 | -4.9726 | 0.011 | -0.6286 |
| 54 | 59 | -30.3724 | -7.5096 | 30.8938 | 4.2584 | 0.5214 | -3.2511 |

## Table A4.5 (Continued)

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 55 | 56 | -21.4282 | -5.8217 | 21.4546 | 5.5638 | 0.0264 | -0.2578 |
| 55 | 59 | -34.506 | -8.2646 | 35.1456 | 5.8798 | 0.6396 | -2.3848 |
| 56 | 57 | -22.9965 | -9.0998 | 23.2199 | 7.4879 | 0.2234 | -1.6119 |
| 56 | 58 | -6.6732 | -3.6897 | 6.6925 | 1.5299 | 0.0193 | -2.1598 |
| 56 | 59 | -27.9548 | -4.177 | 28.6655 | 0.9896 | 0.7107 | -3.1874 |
| 56 | 59 | -29.3046 | -3.9103 | 30.0642 | 1.1318 | 0.7596 | -2.7785 |
| 59 | 60 | -43.3112 | 3.5727 | 43.9336 | -4.404 | 0.6224 | -0.8314 |
| 59 | 61 | -51.7126 | 5.0303 | 52.6328 | -4.6249 | 0.9202 | 0.4054 |
| 60 | 61 | -112.059 | 8.5176 | 112.397 | -8.2261 | 0.3384 | 0.2915 |
| 60 | 62 | -9.875 | -7.1135 | 9.8923 | 5.7372 | 0.0173 | -1.3764 |
| 61 | 62 | 25.4854 | -13.8562 | -25.4165 | 13.1976 | 0.0689 | -0.6586 |
| 62 | 66 | -37.1676 | -17.2631 | 37.9362 | 14.6749 | 0.7687 | -2.5882 |
| 62 | 67 | -24.3082 | -14.4127 | 24.5041 | 12.1459 | 0.196 | -2.2668 |
| 63 | 59 | 151.7452 | 67.4847 | -151.745 | -57.0297 | 0 | 10.455 |
| 63 | 64 | -151.745 | -67.4847 | 152.2276 | 52.5061 | 0.4823 | -14.9786 |
| 64 | 61 | 30.5152 | 13.9899 | -30.5152 | -13.6871 | 0 | 0.3028 |
| 64 | 65 | -182.743 | -66.496 | 183.7354 | 40.0621 | 0.9926 | -26.4339 |
| 65 | 66 | 8.4335 | 72.2494 | -8.4335 | -70.5549 | 0 | 1.6945 |
| 65 | 68 | 14.0324 | -22.4212 | -14.0284 | -41.8599 | 0.004 | -64.2811 |
| 66 | 67 | 53.1659 | 19.2718 | -52.5041 | -19.1459 | 0.6618 | 0.1259 |
| 68 | 69 | -125.766 | 112.819 | 125.766 | -103.645 | 0 | 9.1736 |
| 68 | 81 | -44.3315 | -4.6034 | 44.3883 | -75.5468 | 0.0568 | -80.1501 |
| 68 | 116 | 184.1259 | -66.3553 | -184 | 51.3197 | 0.1259 | -15.0356 |
| 69 | 70 | 108.3688 | 16.0754 | -104.937 | -13.9873 | 3.4321 | 2.0882 |
| 69 | 75 | 110.023 | 20.4827 | -105.168 | -18.3017 | 4.8547 | 2.181 |
| 69 | 77 | 62.2813 | 6.7656 | -61.1186 | -13.7772 | 1.1627 | -7.0116 |
| 70 | 71 | 16.6346 | -12.3725 | -16.5964 | 11.6737 | 0.0382 | -0.6988 |
| 70 | 74 | 16.2214 | 12.8887 | -16.0251 | -15.4172 | 0.1963 | -2.5285 |
| 70 | 75 | -0.1162 | 9.9346 | 0.1765 | -13.1632 | 0.0603 | -3.2286 |
| 71 | 72 | 10.584 | -0.9355 | -10.532 | -3.1526 | 0.052 | -4.0881 |
| 71 | 73 | 6.0124 | -10.7382 | -6 | 9.6512 | 0.0124 | -1.087 |
| 74 | 75 | -51.9749 | -6.1947 | 52.3413 | 6.4459 | 0.3664 | 0.2513 |
| 75 | 77 | -34.5835 | -9.5634 | 35.3853 | 7.3823 | 0.8018 | -2.1811 |
| 75 | 118 | 40.234 | 23.5823 | -39.8928 | -23.5511 | 0.3412 | 0.0313 |
| 76 | 77 | -61.1311 | -21.0475 | 63.1851 | 24.3959 | 2.054 | 3.3484 |
| 76 | 118 | -6.8689 | -9.6858 | 6.8928 | 8.5511 | 0.0239 | -1.1347 |
| 77 | 78 | 45.6119 | 20.0491 | -45.5187 | -21.0156 | 0.0932 | -0.9665 |
| 77 | 80 | -96.9253 | -37.2749 | 98.7078 | 37.4194 | 1.7825 | 0.1444 |
| 77 | 80 | -44.5363 | -20.4905 | 45.2211 | 20.5496 | 0.6848 | 0.0591 |
| 77 | 82 | -2.6022 | 27.718 | 2.9029 | -34.917 | 0.3008 | -7.199 |
| 78 | 79 | -25.4813 | -4.9844 | 25.5178 | 4.4957 | 0.0365 | -0.4888 |
| 79 | 80 | -64.5178 | -36.4957 | 65.3571 | 38.329 | 0.8393 | 1.8333 |
| 80 | 96 | 18.7488 | 23.1121 | -18.4143 | -26.4883 | 0.3345 | -3.3762 |
| 80 | 97 | 26.2209 | 27.8069 | -25.9605 | -29.1453 | 0.2604 | -1.3385 |
| 80 | 98 | 28.8703 | 8.3325 | -28.6654 | -10.4475 | 0.2049 | -2.115 |
| 80 | 99 | 19.4857 | 8.183 | -19.2743 | -12.9613 | 0.2114 | -4.7783 |
| 81 | 80 | -44.3883 | 75.5468 | 44.3883 | -73.0474 | 0 | 2.4994 |

## Table A4.5 (Continued)

| From Bus | To Bus | Line Flows with SVC | | | | Line losses with SVC | |
|---|---|---|---|---|---|---|---|
| | | Sending End | | Receiving End | | Real Power Losses (MW) | Reactive Power losses (MVAR) |
| | | Psend (MW) | Qsend (MVAR) | Precv (MW) | Qrecv (MVAR) | | |
| 82 | 83 | -47.0612 | 24.0042 | 47.3974 | -26.5334 | 0.3362 | -2.5292 |
| 82 | 96 | -9.8418 | -16.0871 | 9.8887 | 10.9703 | 0.047 | -5.1168 |
| 83 | 84 | -25.1283 | 10.4699 | 25.6327 | -11.8641 | 0.5043 | -1.3942 |
| 83 | 85 | -42.269 | 6.0635 | 43.1028 | -6.5385 | 0.8338 | -0.475 |
| 84 | 85 | -36.6327 | 4.8641 | 37.0667 | -5.1303 | 0.4341 | -0.2662 |
| 85 | 86 | 17.1725 | -7.3537 | -17.0531 | 5.091 | 0.1194 | -2.2627 |
| 85 | 88 | -50.2512 | 7.556 | 50.7881 | -7.5026 | 0.5368 | 0.0534 |
| 85 | 89 | -71.0908 | 0.6378 | 72.3379 | 3.7354 | 1.247 | 4.3732 |
| 86 | 87 | -3.9469 | -15.091 | 4 | 11.0216 | 0.0531 | -4.0694 |
| 88 | 89 | -98.7881 | -2.4974 | 100.1796 | 7.7056 | 1.3915 | 5.2082 |
| 89 | 90 | 58.1651 | -4.7158 | -56.4279 | 5.793 | 1.7372 | 1.0772 |
| 89 | 90 | 110.726 | -5.4294 | -107.837 | 7.0363 | 2.889 | 1.6068 |
| 89 | 92 | 201.9587 | -8.0251 | -197.958 | 22.9629 | 4.0006 | 14.9377 |
| 89 | 92 | 63.6327 | -6.9414 | -62.0481 | 9.1845 | 1.5847 | 2.2431 |
| 90 | 91 | 1.2649 | 4.4688 | -1.2566 | -6.507 | 0.0084 | -2.0383 |
| 91 | 92 | -8.7434 | -8.8971 | 8.7959 | 5.889 | 0.0524 | -3.0081 |
| 92 | 93 | 57.7587 | -9.4109 | -56.8676 | 10.2042 | 0.8911 | 0.7933 |
| 92 | 94 | 52.2925 | -12.9722 | -50.8999 | 13.559 | 1.3926 | 0.5869 |
| 92 | 100 | 31.4916 | -15.5899 | -30.7243 | 14.3152 | 0.7673 | -1.2748 |
| 92 | 102 | 44.6675 | -7.444 | -44.4129 | 7.1592 | 0.2545 | -0.2848 |
| 93 | 94 | 44.8676 | -17.2042 | -44.3455 | 17.0878 | 0.5222 | -0.1164 |
| 94 | 95 | 41.061 | 11.7906 | -40.813 | -12.0494 | 0.248 | -0.2587 |
| 94 | 96 | 19.977 | -6.7094 | -19.8586 | 4.8423 | 0.1183 | -1.8671 |
| 94 | 100 | 4.2074 | -51.728 | -3.7714 | 47.0708 | 0.436 | -4.6572 |
| 95 | 96 | -1.187 | -18.9506 | 1.2467 | 17.7158 | 0.0597 | -1.2349 |
| 96 | 97 | -10.8625 | -22.04 | 10.9605 | 20.1453 | 0.0979 | -1.8947 |
| 98 | 100 | -5.3346 | 2.4475 | 5.3546 | -7.312 | 0.02 | -4.8645 |
| 99 | 100 | -22.7257 | -4.5756 | 22.819 | 2.7781 | 0.0933 | -1.7975 |
| 100 | 101 | -16.7817 | 21.8272 | 17.0053 | -24.1209 | 0.2236 | -2.2937 |
| 100 | 103 | 121.1385 | -4.8683 | -118.868 | 6.862 | 2.2708 | 1.9937 |
| 100 | 104 | 56.4169 | 10.622 | -54.9505 | -9.3372 | 1.4664 | 1.2849 |
| 100 | 106 | 60.5484 | 9.457 | -58.3102 | -7.0549 | 2.2383 | 2.4021 |
| 101 | 102 | -39.0053 | 9.1209 | 39.4129 | -10.1592 | 0.4076 | -1.0383 |
| 103 | 104 | 32.3073 | 8.1156 | -31.7739 | -10.2603 | 0.5334 | -2.1447 |
| 103 | 105 | 42.9613 | 7.3267 | -41.929 | -8.1349 | 1.0323 | -0.8081 |
| 103 | 110 | 60.5991 | 3.3851 | -59.1549 | -1.1737 | 1.4442 | 2.2113 |
| 104 | 105 | 48.7244 | 2.5984 | -48.4731 | -2.5667 | 0.2513 | 0.0316 |
| 105 | 106 | 8.7107 | 3.9362 | -8.6961 | -5.2092 | 0.0146 | -1.273 |
| 105 | 107 | 26.7325 | -2.3698 | -26.3258 | -0.5624 | 0.4067 | -2.9322 |
| 105 | 108 | 23.9589 | -11.1265 | -23.7684 | 9.9201 | 0.1904 | -1.2064 |
| 106 | 107 | 24.0063 | -3.7359 | -23.6742 | 0.5633 | 0.332 | -3.1726 |
| 108 | 109 | 21.7684 | -10.9201 | -21.7026 | 10.3906 | 0.0659 | -0.5295 |
| 109 | 110 | 13.7026 | -13.3906 | -13.6007 | 11.7692 | 0.1019 | -1.6215 |
| 110 | 111 | -35.7029 | 0.9561 | 36 | -1.8438 | 0.2971 | -0.8877 |
| 110 | 112 | 69.4586 | -30.6142 | -68 | 28.5117 | 1.4586 | -2.1025 |
| 114 | 115 | 1.342 | 0.8834 | -1.3419 | -1.1377 | 0.0001 | -0.2544 |

# APPENDIX 5

# CALCULATION OF L INDEX

The admittance bus ($Y_{BUS}$) matrix is obtained for IEEE 14 bus system and it is given in Table A5.1. The $Y_{LL}$ matrix of IEEE 14 bus system have been formed from Y bus matrix considering admittances of transmission lines connected between load buses and it is shown in Table A5.2. The $Y_{LG}$ matrix of IEEE 14 bus system have been formed have been formed from Y bus matrix considering admittances of transmission lines connected between load buses and generator buses and it is shown in Table A5.3. The C matrix of IEEE 14 bus system can be found using Equation (3.5). The C matrix of IEEE 14 bus system is shown in Table A5.4. L index at load bus can be calculated using Equation (3.4). The values of L index of IEEE 14 bus are given in Figure 4.1. Similarly using Equation (3.4) L index values have been determined for IEEE 30 bus, IEEE 57 bus and IEEE 118 bus systems.

## Table A5.1 $Y_{BUS}$ matrix of IEEE 14 bus system

### Columns 1 through 8

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6.0250 - 19.4471i | -4.9991 +15.2631i | 0 | 0 | -1.0259 + 4.2350i | 0 | 0 | 0 |
| -4.9991 +15.2631i | 9.5213 - 30.2721i | -1.1350 + 4.7819i | -1.6860 + 5.1158i | -1.7011 + 5.1939i | 0 | 0 | 0 |
| 0 | -1.1350 + 4.7819i | 3.1210 - 9.8224i | -1.9860 + 5.0688i | 0 | 0 | 0 | 0 |
| 0 | -1.6860 + 5.1158i | -1.9860 + 5.0688i | 10.5130 - 38.6542i | -6.8410 +21.5786i | 0 | 0 + 4.8895i | 0 |
| -1.0259 + 4.2350i | -1.7011 + 5.1939i | 0 | -6.8410 +21.5786i | 9.5680 - 35.5336i | 0 + 4.2574i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 + 4.2574i | 6.5799 - 17.3407i | 0 | 0 |
| 0 | 0 | 0 | 0 + 4.8895i | 0 | 0 | 0 -19.5490i | 0 + 5.6770i |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 + 5.6770i | 0 - 5.6770i |
| 0 | 0 | 0 | 0 + 1.8555i | 0 | 0 | 0 + 9.0901i | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -1.9550 + 4.0941i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -1.5260 + 3.1760i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -3.0989 + 6.1028i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### Columns 9 through 14

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 + 1.8555i | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | -1.9550 + 4.0941i | -1.5260 + 3.1760i | -3.0989 + 6.1028i | 0 |
| 0 + 9.0901i | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 5.3261 -24.2825i | -3.9020 +10.3654i | 0 | 0 | 0 | -1.4240 + 3.0291i |
| -3.9020 +10.3654i | 5.7829 -14.7683i | -1.8809 + 4.4029i | 0 | 0 | 0 |
| 0 | -1.8809 + 4.4029i | 3.8359 - 8.4970i | 0 | 0 | 0 |
| 0 | 0 | 0 | 4.0150 - 5.4279i | -2.4890 + 2.2520i | 0 |
| 0 | 0 | 0 | -2.4890 + 2.2520i | 6.7249 - 10.6697i | -1.1370 + 2.3150i |
| -1.4240 + 3.0291i | 0 | 0 | 0 | -1.1370 + 2.3150i | 2.5610 - 5.3440i |

## Table A5.2 $Y_{LL}$ matrix of IEEE 14 bus system

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10.5130 - 38.6542i | -6.8410 +21.5786i | 0 + 4.8895i | 0 + 1.8555i | 0 | 0 | 0 | 0 | 0 |
| -6.8410 + 21.5786i | 9.5680 - 35.5336i | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 + 4.8895i | 0 | 0 -19.5490i | 0 + 9.0901i | 0 | 0 | 0 | 0 | 0 |
| 0 + 1.8555i | 0 | 0 + 9.0901i | 5.3261 - 24.2825i | -3.9020 +10.3654i | 0 | 0 | 0 | -1.4240 + 3.0291i |
| 0 | 0 | 0 | -3.9020 +10.3654i | 5.7829 - 14.7683i | -1.8809 + 4.4029i | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | -1.8809 + 4.4029i | 3.8359 - 8.4970i | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 4.0150 - 5.4279i | -2.4890 + 2.2520i | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | -2.4890 + 2.2520i | 6.7249 - 10.6697i | -1.1370 + 2.3150i |
| 0 | 0 | 0 | -1.4240 + 3.0291i | 0 | 0 | 0 | -1.1370 + 2.3150i | 2.5610 - 5.3440i |

## Table A5.3 $Y_{LG}$ matrix of IEEE 14 bus system

| | | | | |
|---|---|---|---|---|
| 0 | -1.6860 + 5.1158i | -1.9860 + 5.0688i | 0 | 0 |
| -1.0259 + 4.2350i | -1.7011 + 5.1939i | 0 | 0 + 4.2574i | 0 |
| 0 | 0 | 0 | 0 | 0 + 5.6770i |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | -1.9550 + 4.0941i | 0 |
| 0 | 0 | 0 | -1.5260 + 3.1760i | 0 |
| 0 | 0 | 0 | -3.0989 + 6.1028i | 0 |
| 0 | 0 | 0 | 0 | 0 |

## Table A5.4 C Matrix of IEEE 14 bus system

| | | | | |
|---|---|---|---|---|
| 0.1146 + 0.0027i | 0.3731 + 0.0285i | 0.2313 + 0.0268i | 0.1676 - 0.0218i | 0.1034 - 0.0342i |
| 0.1887 + 0.0018i | 0.3768 + 0.0356i | 0.1414 + 0.0227i | 0.2153 - 0.0389i | 0.0645 - 0.0182i |
| 0.0514 - 0.0019i | 0.1677 + 0.0026i | 0.1043 + 0.0056i | 0.2209 + 0.0299i | 0.4619 - 0.0356i |
| 0.0488 - 0.0056i | 0.1601 - 0.0099i | 0.0998 - 0.0023i | 0.3849 + 0.0759i | 0.3133 - 0.0583i |
| 0.0403 - 0.0051i | 0.1322 - 0.0096i | 0.0824 - 0.0028i | 0.4924 + 0.0685i | 0.2584 - 0.0511i |
| 0.0206 - 0.0030i | 0.0678 - 0.0063i | 0.0423 - 0.0023i | 0.7401 + 0.0405i | 0.1321 - 0.0289i |
| 0.0035 + 0.0001i | 0.0115 + 0.0010i | 0.0071 + 0.0009i | 0.9553 - 0.0012i | 0.0230 - 0.0008i |
| 0.0070 - 0.0012i | 0.0232 - 0.0026i | 0.0145 - 0.0010i | 0.9113 + 0.0153i | 0.0450 - 0.0107i |
| 0.0306 - 0.0038i | 0.1005 - 0.0073i | 0.0627 - 0.0021i | 0.6143 + 0.0518i | 0.1964 - 0.0387i |

# APPENDIX 6

# NEWTON RAPHSON POWER FLOW PROGRAM AND ITS OUTPUT

The Newton-Raphson power flow program given in Program A5.1 and its outputs are given in Table 4.2, Table A1.4, Table 4.7, Table A2.4, Table 4.11, Table A3.4, Table 4.17 and Table A4.4.

Program A5.1 Program for Newton-Raphson Load Flow Analysis

```
N=enter the no. of bus
nbus = n;                    % IEEE-14, IEEE-30, IEEE-57..
Y = ybusppg(nbus);           % Calling ybusppg.m to get Y-Bus Matrix..
busd = busdatas(nbus);       % Calling busdatas..
lined=linedatas(nbus);
fb = lined(:,1);
nbranch = length(fb);
BMva = 100; % Base MVA..
basemva=100;
bus = busd(:,1);             % Bus Number..
type = busd(:,2);            % Type of Bus 1-Slack, 2-PV, 3-PQ..
V = busd(:,3);               % Specified Voltage..
del = busd(:,4);             % Voltage Angle..
if nbus==57
Pg = busd(:,7)/BMva;         % PGi..
Qg = busd(:,8)/BMva;         % QGi..
```

```
Pl = busd(:,5)/BMva;          % PLi..
Ql = busd(:,6)/BMva;          % QLi..
else
Pg = busd(:,5)/BMva;          % PGi..
Qg = busd(:,6)/BMva;          % QGi..
Pl = busd(:,7)/BMva;          % PLi..
Ql = busd(:,8)/BMva;          % QLi..
end
Qmin = busd(:,9)/BMva;     % Minimum Reactive Power Limit..
Qmax = busd(:,10)/BMva;  % Maximum Reactive Power Limit..
P = Pg - Pl;                    % Pi = PGi - PLi..
Q = Qg - Ql;                   % Qi = QGi - QLi..
Psp = P;                        % P Specified..
Qsp = Q;                        % Q Specified..
G = real(Y);                   % Conductance matrix..
B = imag(Y);                   % Susceptance matrix..
pv = find(type == 2 | type == 1);  % PV Buses..
pq = find(type == 3) ;          % PQ Buses..
npv = length(pv)      ;          % No. of PV buses..
npq = length(pq)       ;          % No. of PQ buses..
Tol = 1;
Iter = 1;
while (Tol > 1e-5)   % Iteration starting..
P = zeros(nbus,1);
Q = zeros(nbus,1);
% Calculate P and Q
for i = 1:nbus
for k = 1:nbus
P(i) = P(i) + V(i)* V(k)*(G(i,k)*cos(del(i)-del(k)) + B(i,k)*sin(del(i)-del(k)));
```

```
Q(i) = Q(i) + V(i)* V(k)*(G(i,k)*sin(del(i)-del(k)) - B(i,k)*cos(del(i)-
del(k)));
end
end
% Checking Q-limit violations..
if Iter <= 50 && Iter > 2    % Only checked up to 50th iterations..
for n = 2:nbus
if type(n) == 2
QG = Q(n)+Ql(n);
if QG < Qmin(n)
V(n) = V(n) + 0.01;
elseif QG > Qmax(n)
V(n) = V(n) - 0.01;
end
end
end
end
end
% Calculate change from specified value
dPa = Psp-P;
dQa = Qsp-Q;
k = 1;
dQ = zeros(npq,1);
for i = 1:nbus
if type(i) == 3
dQ(k,1) = dQa(i);
k = k+1;
end
end
dP = dPa(2:nbus);
M = [dP; dQ];       % Mismatch Vector
```

```
% Jacobian
% J1 - Derivative of Real Power Injections with Angles..
J1 = zeros(nbus-1,nbus-1);
for i = 1:(nbus-1)
m = i+1;
for k = 1:(nbus-1)
n = k+1;
if  n == m
for n = 1:nbus
J1(i,k) = J1(i,k) + V(m)* V(n)*(-G(m,n)*sin(del(m)-del(n)) + ….
B(m,n)*cos(del(m)-del(n)));
end
J1(i,k) = J1(i,k) - V(m)^2*B(m,m);
else
J1(i,k) = V(m)* V(n)*(G(m,n)*sin(del(m)-del(n)) -….
B(m,n)*cos(del(m)-del(n)));
end
end
end
% J2 - Derivative of Real Power Injections with V..
J2 = zeros(nbus-1,npq);
for i = 1:(nbus-1)
m = i+1;
for k = 1:npq
n = pq(k);
if n == m
for n = 1:nbus
J2(i,k) = J2(i,k) + V(n)*(G(m,n)*cos(del(m)-del(n)) +…..
B(m,n)*sin(del(m)-del(n)));
end
```

```
J2(i,k) = J2(i,k) + V(m)*G(m,m);
else
J2(i,k) = V(m)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
end
end
end
% J3 - Derivative of Reactive Power Injections with Angles..
J3 = zeros(npq,nbus-1);
for i = 1:npq
m = pq(i);
for k = 1:(nbus-1)
n = k+1;
if n == m
for n = 1:nbus
J3(i,k) = J3(i,k) + V(m)* V(n)*(G(m,n)*cos(del(m)-del(n)) + …
B(m,n)*sin(del(m)-del(n)));
end
J3(i,k) = J3(i,k) - V(m)^2*G(m,m);
else
J3(i,k) = V(m)* V(n)*(-G(m,n)*cos(del(m)-del(n)) -…..
B(m,n)*sin(del(m)-del(n)));
end
end
end
% J4 - Derivative of Reactive Power Injections with V..
J4 = zeros(npq,npq);
for i = 1:npq
m = pq(i);
for k = 1:npq
n = pq(k);
```

```
if n == m
for n = 1:nbus
J4(i,k) = J4(i,k) + V(n)*(G(m,n)*sin(del(m)-del(n)) - …
B(m,n)*cos(del(m)-del(n)));
end
J4(i,k) = J4(i,k) - V(m)*B(m,m);
else
J4(i,k) = V(m)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
end
end
end
J = [J1 J2; J3 J4];              % Jacobian Matrix..
X = inv(J)*M;                    % Correction Vector
dTh = X(1:nbus-1);               % Change in Voltage Angle..
dV = X(nbus:end);                % Change in Voltage Magnitude..
% Updating State Vectors..
del(2:nbus) = dTh + del(2:nbus);    % Voltage Angle..
k = 1;
for i = 2:nbus
if  type(i) == 3
V(i) = dV(k) + V(i);        % Voltage Magnitude..
k = k+1;
end
end
Iter = Iter + 1;
Tol = max(abs(M));                % Tolerance..
end
Del = 180/pi*del;
% E1 = [V Del]; % Bus Voltages and angles..
disp('------------------------------');
```

```
disp('|  Bus  |    V    |  Angle   |');
disp('|  No   |   pu    |  Degree  |');
disp('------------------------------');
for m = 1:nbus
fprintf('%4g', m), fprintf('    %8.4f', V(m)), fprintf('    %8.4f', Del(m));
fprintf('\n');
end
disp('------------------------------');
V1 = pol2rect(V,del);           % Converting polar to rectangular..
V=V1;
S =P+j*Q;
 j=sqrt(-1);
 i=sqrt(-1);
linedata = linedatas(nbus); % Calling "linedata3.m" for Line Data...
nl = linedata(:,1);     % From bus number...
nr = linedata(:,2);     % To bus number...
if nbus==118
r = linedata(:,7);      % Resistance, R...
x = linedata(:,8);      % Reactance, X...
Bc = linedata(:,9);    % Ground Admittance, B/2...
Bc=i*Bc/2;
a = linedata(:,15);      % Tap setting value..
else
r = linedata(:,3);      % Resistance, R...
x = linedata(:,4);      % Reactance, X...
Bc = linedata(:,5);    % Ground Admittance, B/2...
a = linedata(:,6);      % Tap setting value..
Bc=i*Bc;
end
z = r + i*x;            % Z matrix...
```

```
y = 1./z;               % To get inverse of each element...
nbr = length(nl);           % no. of branches...
if nbus ==118
for k=1:nbr
if a(k)==0.0
a(k)=1;end
end
end
SLT = 0;
fprintf('\n')
fprintf('                        Line Flow and Losses \n\n')
fprintf('    --Line--  Power at bus & line flow    --Line loss--  Transformer\n')
fprintf('    from  to    MW      Mvar     MVA       MW      Mvar      tap\n')
for n = 1:nbus
busprt = 0;
for L = 1:nbr;
if busprt == 0
fprintf('   \n'), fprintf('%6g', n), fprintf('      %9.3f', P(n)*basemva)
fprintf('%9.3f', Q(n)*basemva), fprintf('%9.3f\n', abs(S(n)*basemva))
busprt = 1;
else, end
if nl(L)==n      k = nr(L);
In = (V(n) - a(L)*V(k))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(n);
Ik = (V(k) - V(n)/a(L))*y(L) + Bc(L)*V(k);
Snk = V(n)*conj(In)*basemva;
Skn = V(k)*conj(Ik)*basemva;
SL  = Snk + Skn;
SLT = SLT + SL;
elseif nr(L)==n  k = nl(L);
In = (V(n) - V(k)/a(L))*y(L) + Bc(L)*V(n);
```

```
Ik = (V(k) - a(L)*V(n))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(k);
Snk = V(n)*conj(In)*basemva;
Skn = V(k)*conj(Ik)*basemva;
SL  = Snk + Skn;
SLT = SLT + SL;
else, end
if nl(L)==n | nr(L)==n
fprintf('%12g', k),
fprintf('%9.3f', real(Snk)), fprintf('%9.3f', imag(Snk))
fprintf('%9.3f', abs(Snk)),
fprintf('%9.3f', real(SL)),
if nl(L) ==n & a(L) ~= 1
fprintf('%9.3f', imag(SL)), fprintf('%9.3f\n', a(L))
else, fprintf('%9.3f\n', imag(SL))
end
else, end
end
end
SLT = SLT/2;
fprintf('   \n'), fprintf('    Total loss                    ')
fprintf('%9.3f', real(SLT)), fprintf('%9.3f\n', imag(SLT))
clear Ik In SL SLT Skn Snk
% Program to form Admittance And Impedance Bus Formation....
% with Transformer Tap setting..
function ybus = ybusppg(num)  % Returns ybus
linedata = linedatas(num); % Calling "linedata3.m" for Line Data...
fb = linedata(:,1);     % From bus number...
tb = linedata(:,2);     % To bus number...
nbus = max(max(fb),max(tb));    % no. of buses...
if nbus==118
```

```
r = linedata(:,7);      % Resistance, R...
x = linedata(:,8);      % Reactance, X...
b = linedata(:,9);    % Ground Admittance, B/2...
b=i*b/2;
a = linedata(:,15);      % Tap setting value..
else
r = linedata(:,3);      % Resistance, R...
x = linedata(:,4);      % Reactance, X...
b = linedata(:,5);    % Ground Admittance, B/2...
a = linedata(:,6);      % Tap setting value..
b=i*b;
end
z = r + i*x;            % Z matrix...
y = 1./z;               % To get inverse of each element...
nbranch = length(fb);           % no. of branches...
ybus = zeros(nbus,nbus);        % Initialise YBus...
if nbus ==118
for k=1:nbranch
if a(k)==0.0
a(k)=1;end
end
end
% Formation of the Off Diagonal Elements...
for k = 1:nbranch
ybus(fb(k),tb(k)) = ybus(fb(k),tb(k))-y(k)/a(k);
ybus(tb(k),fb(k)) = ybus(fb(k),tb(k));
end
% Formation of Diagonal Elements....
for m = 1:nbus
for n = 1:nbranch
```

```
if fb(n) == m
ybus(m,m) = ybus(m,m) + y(n)/(a(n)^2) + b(n);
elseif tb(n) == m
ybus(m,m) = ybus(m,m) + y(n) + b(n);
end
end
end
```