

DATA SHEETS FOR IEEE 14 BUS SYSTEM

The IEEE 14 bus system is shown in figure 3.1. The system data is taken from [9]. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be $0.95p.u.$ to $1.05p.u.$ and -45° to $+45^\circ$ respectively.

Table A.1: Line data – IEEE 14 bus system

| Line number | From bus | To bus | Line impedance (<i>p.u.</i>) | | Half line charging susceptance (<i>p.u.</i>) | MVA rating |
|-------------|----------|--------|--------------------------------|-----------|--|------------|
| | | | Resistance | Reactance | | |
| 1 | 1 | 2 | 0.01938 | 0.05917 | 0.02640 | 120 |
| 2 | 1 | 5 | 0.05403 | 0.22304 | 0.02190 | 65 |
| 3 | 2 | 3 | 0.04699 | 0.19797 | 0.01870 | 36 |
| 4 | 2 | 4 | 0.05811 | 0.17632 | 0.02460 | 65 |
| 5 | 2 | 5 | 0.05695 | 0.17388 | 0.01700 | 50 |
| 6 | 3 | 4 | 0.06701 | 0.17103 | 0.01730 | 65 |
| 7 | 4 | 5 | 0.01335 | 0.04211 | 0.00640 | 45 |
| 8 | 4 | 7 | 0 | 0.20912 | 0 | 55 |
| 9 | 4 | 9 | 0 | 0.55618 | 0 | 32 |
| 10 | 5 | 6 | 0 | 0.25202 | 0 | 45 |
| 11 | 6 | 11 | 0.09498 | 0.1989 | 0 | 18 |
| 12 | 6 | 12 | 0.12291 | 0.25581 | 0 | 32 |
| 13 | 6 | 13 | 0.06615 | 0.13027 | 0 | 32 |
| 14 | 7 | 8 | 0 | 0.17615 | 0 | 32 |
| 15 | 7 | 9 | 0 | 0.11001 | 0 | 32 |
| 16 | 9 | 10 | 0.03181 | 0.0845 | 0 | 32 |
| 17 | 9 | 14 | 0.12711 | 0.27038 | 0 | 32 |
| 18 | 10 | 11 | 0.08205 | 0.19207 | 0 | 12 |
| 19 | 12 | 13 | 0.22092 | 0.19988 | 0 | 12 |
| 20 | 13 | 14 | 0.17093 | 0.34802 | 0 | 12 |

Table A.2: Capacity and cost coefficients – IEEE 14 bus system

| Generator number | P_i^{\min} (<i>MW</i>) | P_i^{\max} (<i>MW</i>) | a_i (\$/(<i>MWhr</i>) ²) | b_i (\$/ <i>MWhr</i>) | c_i (\$/hr) |
|------------------|-------------------------------|-------------------------------|---|-----------------------------|------------------|
| G_1 | 10 | 160 | 0.005 | 2.450 | 105.000 |
| G_2 | 20 | 80 | 0.005 | 3.510 | 44.100 |
| G_3 | 20 | 50 | 0.005 | 3.890 | 40.600 |

Table A.3: Transformer tap setting data – IEEE 14 bus system

| From bus | To bus | Tap setting value (<i>p.u.</i>) |
|----------|--------|-----------------------------------|
| 4 | 7 | 0.978 |
| 4 | 9 | 0.969 |
| 5 | 6 | 0.932 |

Table A.4: Bus data – IEEE 14 bus system

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits | |
|------------|----------------------|----------------------|-----------------|-----------------------|-----------------|-----------------------|-----------------------|--------------------|
| | Magnitude ($p.u.$) | Phase angle (degree) | Real power (MW) | Reactive power (MVAR) | Real power (MW) | Reactive power (MVAR) | Q_{\min} (MVAR) | Q_{\max} (MVAR.) |
| | | | | | | | | |
| 1 | 1.060 | 0 | 114.17 | -16.9 | 0 | 0 | 0 | 10 |
| 2 | 1.045 | 0 | 40.00 | 0 | 21.7 | 12.7 | -42.0 | 50.0 |
| 3 | 1.010 | 0 | 0 | 0 | 94.2 | 19.1 | 23.4 | 40.0 |
| 4 | 1 | 0 | 0 | 0 | 47.8 | -3.9 | - | - |
| 5 | 1 | 0 | 0 | 0 | 7.6 | 1.6 | - | - |
| 6 | 1 | 0 | 0 | 0 | 11.2 | 7.5 | - | - |
| 7 | 1 | 0 | 0 | 0 | 0 | 0 | - | - |
| 8 | 1 | 0 | 0 | 0 | 0 | 0 | - | - |
| 9 | 1 | 0 | 0 | 0 | 29.5 | 16.6 | - | - |
| 10 | 1 | 0 | 0 | 0 | 9.0 | 5.8 | - | - |
| 11 | 1 | 0 | 0 | 0 | 3.5 | 1.8 | - | - |
| 12 | 1 | 0 | 0 | 0 | 6.1 | 1.6 | - | - |
| 13 | 1 | 0 | 0 | 0 | 13.8 | 5.8 | - | - |
| 14 | 1 | 0 | 0 | 0 | 14.9 | 5.0 | - | - |

Table A.5: Shunt capacitor data – IEEE 14 bus system

| Bus number | Susceptance ($p.u.$) |
|------------|------------------------|
| 9 | 0.19 |

DATA SHEETS FOR IEEE 30 BUS SYSTEM

The IEEE 30 bus system is shown in figure 3.3. The system data is taken from [47]. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be $0.95p.u.$ to $1.05p.u.$ and -45° to $+45^\circ$ respectively.

Table B.1: Line data – IEEE 30 bus system

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^3$ \$/hr) |
|-------------|----------|--------|---------------------------|-----------|---|--------------|------------------------------------|
| | | | Resistance | Reactance | | | |
| 1 | 1 | 2 | 0.02 | 0.06 | 0.03 | 130 | 216.6125 |
| 2 | 1 | 3 | 0.05 | 0.20 | 0.02 | 130 | 307.2875 |
| 3 | 2 | 4 | 0.06 | 0.18 | 0.02 | 65 | 509.9500 |
| 4 | 2 | 5 | 0.05 | 0.02 | 0 | 130 | 721.5250 |
| 5 | 2 | 6 | 0.06 | 0.18 | 0.02 | 65 | 168.1750 |
| 6 | 3 | 4 | 0.01 | 0.04 | 0 | 130 | 700.000 |
| 7 | 4 | 6 | 0.01 | 0.04 | 0 | 90 | 474.3000 |
| 8 | 4 | 12 | 0 | 0.23 | 0 | 65 | 554.1250 |
| 9 | 5 | 7 | 0.05 | 0.12 | 0.01 | 70 | 62.2000 |
| 10 | 6 | 7 | 0.03 | 0.08 | 0 | 130 | 130.2000 |
| 11 | 6 | 8 | 0.01 | 0.09 | 0 | 32 | 104.6250 |
| 12 | 6 | 9 | 0 | 0.21 | 0 | 65 | 306.9000 |
| 13 | 6 | 10 | 0 | 0.56 | 0 | 32 | 20.9250 |
| 14 | 6 | 28 | 0.07 | 0.06 | 0.01 | 32 | 210.800 |
| 15 | 8 | 28 | 0.06 | 0.20 | 0.02 | 32 | 54.250 |
| 16 | 9 | 11 | 0 | 0.21 | 0 | 65 | 83.7000 |
| 17 | 9 | 10 | 0 | 0.11 | 0 | 65 | 927.6750 |
| 18 | 10 | 20 | 0.09 | 0.21 | 0 | 32 | 117.8000 |
| 19 | 10 | 17 | 0.03 | 0.09 | 0 | 32 | 167.4000 |
| 20 | 10 | 21 | 0.03 | 0.08 | 0 | 32 | 160.4250 |
| 21 | 10 | 22 | 0.07 | 0.15 | 0 | 32 | 195.3000 |

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Table B.1 – continued from previous page

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^3 \$ / \text{hr}$) |
|-------------|----------|--------|---------------------------|-----------|---|------------|--|
| | | | Resistance | Reactance | | | |
| 22 | 12 | 13 | 0 | 0.14 | 0 | 65 | 15.1125 |
| 23 | 12 | 14 | 0.12 | 0.26 | 0 | 32 | 30.2250 |
| 24 | 12 | 15 | 0.07 | 0.13 | 0 | 32 | 97.6250 |
| 25 | 12 | 16 | 0.01 | 0.12 | 0 | 32 | 179.0250 |
| 26 | 14 | 15 | 0.22 | 0.12 | 0 | 16 | 124.7750 |
| 27 | 15 | 18 | 0.11 | 0.22 | 0 | 16 | 80.6000 |
| 28 | 15 | 23 | 0.10 | 0.21 | 0 | 16 | 100.7500 |
| 29 | 16 | 17 | 0.08 | 0.19 | 0 | 16 | 146.4750 |
| 30 | 18 | 19 | 0.06 | 0.13 | 0 | 16 | 235.6000 |
| 31 | 19 | 20 | 0.03 | 0.07 | 0 | 32 | 186.000 |
| 32 | 21 | 22 | 0.01 | 0.22 | 0 | 32 | 166.2375 |
| 33 | 22 | 24 | 0.11 | 0.18 | 0 | 16 | 40.3000 |
| 34 | 23 | 24 | 0.13 | 0.27 | 0 | 16 | 65.1000 |
| 35 | 24 | 25 | 0.19 | 0.33 | 0 | 16 | 210.8000 |
| 36 | 25 | 26 | 0.25 | 0.38 | 0 | 16 | 204.600 |
| 37 | 25 | 27 | 0.11 | 0.21 | 0 | 16 | 83.7000 |
| 38 | 27 | 29 | 0.22 | 0.4 | 0 | 16 | 160.4250 |
| 39 | 27 | 30 | 0.32 | 0.60 | 0 | 16 | 90.6750 |
| 40 | 28 | 27 | 0 | 0.4 | 0 | 65 | 223.2000 |
| 41 | 29 | 30 | 0.24 | 0.45 | 0 | 16 | 216.6125 |

Table B.2: Bus data – IEEE 30 bus system

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits | |
|------------|----------------------|----------------------|-----------------|-----------------------|-----------------|-----------------------|-----------------------|-------------------|
| | Magnitude ($p.u.$) | Phase angle (degree) | Real power (MW) | Reactive power (MVAR) | Real power (MW) | Reactive power (MVAR) | Q_{\min} (MVAR) | Q_{\max} (MVAR) |
| 1 | 1 | 0 | 0 | 0 | 24.963 | -4.638 | -20 | 150 |
| 2 | 1 | 0 | 21.7 | 12.7 | 60.97 | 27.677 | -20 | 60 |
| 3 | 1 | 0 | 2.4 | 1.2 | 0 | 0 | 0 | 0 |
| 4 | 1 | 0 | 7.6 | 1.6 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 22.8 | 10.9 | 0 | 0 | 0 | 0 |
| 8 | 1 | 0 | 30 | 30 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1 | 0 | 5.919 | 2 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 11.2 | 7.5 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 0 | 0 | 37 | 13.949 | -15 | 44.7 |
| 14 | 1 | 0 | 6.2 | 1.6 | 0 | 0 | 0 | 0 |
| 15 | 1 | 0 | 8.2 | 2.5 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 3.5 | 1.8 | 0 | 0 | 0 | 0 |
| 17 | 1 | 0 | 9 | 5.8 | 0 | 0 | 0 | 0 |
| 18 | 1 | 0 | 3.2 | 0.9 | 0 | 0 | 0 | 0 |
| 19 | 1 | 0 | 9.5 | 3.4 | 0 | 0 | 0 | 0 |

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Table B.2 – continued from previous page

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits | |
|------------|------------------------------|-------------------------|-----------------------------|-----------------------------------|-----------------------------|-----------------------------------|----------------------------|----------------------------|
| | Magnitude (<i>p.u.</i>) | Phase angle (degree) | Real power (<i>MW</i>) | Reactive power (<i>MVAR</i>) | Real power (<i>MW</i>) | Reactive power (<i>MVAR</i>) | Q_{\min} (<i>MVAR</i>) | Q_{\max} (<i>MVAR</i>) |
| | | | | | | | | |
| 20 | 1 | 0 | 2.2 | 0.7 | 0 | 0 | 0 | 0 |
| 21 | 1 | 0 | 19.669 | 11.20 | 0 | 0 | 0 | 0 |
| 22 | 1 | 0 | 0 | 0 | 31.59 | 40.34 | -15 | 62.5 |
| 23 | 1 | 0 | 3.2 | 1.6 | 22.2 | 8.13 | -10 | 40 |
| 24 | 1 | 0 | 15 | 6.70 | 0 | 0 | 0 | 0 |
| 25 | 1 | 0 | 1.00 | 0.00 | 0 | 0 | 0 | 0 |
| 26 | 1 | 0 | 3.50 | 2.30 | 0 | 0 | 0 | 0 |
| 27 | 1 | 0 | 0 | 0 | 28.91 | 10.97 | -15 | 48.7 |
| 28 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 1 | 0 | 3.659 | 0.90 | 0 | 0 | 0 | 0 |
| 30 | 1 | 0 | 12.00 | 1.90 | 0 | 0 | 0 | 0 |

Table B.3: Capacity and cost coefficients – IEEE 30 bus system

| Generator number | P_i^{\min} (MW) | P_i^{\max} (MW) | a_i (\$/(MWhr) ²) | b_i (\$/MWhr) | c_i (\$/hr) |
|------------------|----------------------|----------------------|------------------------------------|--------------------|------------------|
| G_1 | 0 | 80 | 0.00375 | 2.0000 | 0.0000 |
| G_2 | 0 | 80 | 0.01750 | 1.7500 | 0.0000 |
| G_3 | 0 | 50 | 0.06250 | 1.0000 | 0.0000 |
| G_4 | 0 | 55 | 0.00834 | 3.2500 | 0.0000 |
| G_5 | 0 | 30 | 0.02500 | 3.0000 | 0.0000 |
| G_6 | 0 | 40 | 0.02500 | 3.0000 | 0.0000 |

Table B.4: Transformer tap setting data – IEEE 30 bus system

| From bus | To bus | Tap setting value (<i>p.u.</i>) |
|----------|--------|-----------------------------------|
| 6 | 9 | 1.0155 |
| 6 | 10 | 0.9629 |
| 4 | 12 | 1.0129 |
| 28 | 27 | 0.9581 |

Table B.5: Shunt capacitor data – IEEE 30 bus system

| Bus number | Susceptance (<i>p.u.</i>) |
|------------|-----------------------------|
| 10 | 19 |
| 24 | 4 |

DATA SHEETS FOR INDIAN UTILITY 62 BUS
SYSTEM

Indian utility 62 bus system is shown in figure 6.1. The system data is taken from [154]. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be $0.95p.u.$ to $1.1p.u.$ and -45° to $+45^\circ$ respectively.

Table C.1: Line data – Indian utility 62 bus system

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^5 \text{₹/yr}$) |
|-------------|----------|--------|---------------------------|-----------|---|--------------|---|
| | | | Resistance | Reactance | | | |
| 1 | 1 | 2 | 0.00305 | 0.01565 | 0.01445 | 150 | 541 |
| 2 | 1 | 4 | 0.00716 | 0.03678 | 0.03397 | 100 | 522 |
| 3 | 1 | 6 | 0.00411 | 0.02113 | 0.01951 | 150 | 321 |
| 4 | 1 | 9 | 0.00229 | 0.01174 | 0.01084 | 150 | 812 |
| 5 | 1 | 10 | 0.01569 | 0.08061 | 0.07443 | 180 | 489 |
| 6 | 1 | 14 | 0.00548 | 0.02813 | 0.10392 | 300 | 256 |
| 7 | 2 | 3 | 0.00289 | 0.01487 | 0.01373 | 180 | 375 |
| 8 | 2 | 6 | 0.00168 | 0.00861 | 0.00795 | 150 | 584 |
| 9 | 3 | 4 | 0.00381 | 0.01957 | 0.01807 | 150 | 489 |
| 10 | 4 | 5 | 0.00716 | 0.03678 | 0.03397 | 180 | 494 |
| 11 | 4 | 14 | 0.00411 | 0.02113 | 0.01951 | 180 | 201 |
| 12 | 4 | 15 | 0.00411 | 0.02113 | 0.01951 | 180 | 628 |
| 13 | 5 | 6 | 0.00575 | 0.01478 | 0.00309 | 180 | 478 |
| 14 | 5 | 8 | 0.00575 | 0.01478 | 0.00309 | 180 | 630 |
| 15 | 6 | 7 | 0.00030 | 0.00157 | 0.00578 | 180 | 676 |
| 16 | 7 | 8 | 0.00049 | 0.00168 | 0.08612 | 90 | 229 |
| 17 | 11 | 10 | 0.00686 | 0.03522 | 0.03252 | 100 | 512 |
| 18 | 11 | 16 | 0.01406 | 0.07223 | 0.06670 | 180 | 579 |
| 19 | 12 | 11 | 0.01905 | 0.09783 | 0.09033 | 150 | 499 |
| 20 | 12 | 13 | 0.01537 | 0.07897 | 0.07292 | 180 | 146 |
| 21 | 12 | 20 | 0.01981 | 0.10174 | 0.09395 | 180 | 582 |

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Table C.1 – continued from previous page

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^5 \text{₹/yr}$) |
|-------------|----------|--------|---------------------------|-----------|---|------------|---|
| | | | Resistance | Reactance | | | |
| 22 | 13 | 14 | 0.01315 | 0.06754 | 0.06237 | 180 | 300 |
| 23 | 13 | 17 | 0.01563 | 0.08030 | 0.07415 | 150 | 282 |
| 24 | 14 | 15 | 0.00520 | 0.02669 | 0.02464 | 150 | 454 |
| 25 | 14 | 16 | 0.00396 | 0.02035 | 0.01879 | 100 | 225 |
| 26 | 14 | 18 | 0.00135 | 0.00693 | 0.02558 | 180 | 489 |
| 27 | 14 | 19 | 0.00707 | 0.03631 | 0.03353 | 300 | 919 |
| 28 | 16 | 17 | 0.00343 | 0.01761 | 0.06504 | 180 | 295 |
| 29 | 17 | 21 | 0.01850 | 0.09548 | 0.08816 | 180 | 184 |
| 30 | 20 | 23 | 0.02042 | 0.10487 | 0.09684 | 180 | 266 |
| 31 | 21 | 22 | 0.01371 | 0.07043 | 0.06504 | 180 | 398 |
| 32 | 22 | 23 | 0.00396 | 0.02035 | 0.07516 | 150 | 390 |
| 33 | 23 | 24 | 0.00305 | 0.01565 | 0.01445 | 300 | 693 |
| 34 | 23 | 25 | 0.00126 | 0.00650 | 0.00600 | 180 | 403 |
| 35 | 24 | 41 | 0.01554 | 0.07993 | 0.07371 | 180 | 714 |
| 36 | 24 | 45 | 0.01219 | 0.06261 | 0.05781 | 100 | 231 |
| 37 | 25 | 26 | 0.00941 | 0.04828 | 0.04459 | 100 | 866 |
| 38 | 25 | 27 | 0.01173 | 0.06026 | 0.05565 | 180 | 309 |
| 39 | 25 | 28 | 0.01062 | 0.05554 | 0.05037 | 150 | 631 |
| 40 | 27 | 29 | 0.00533 | 0.02739 | 0.02529 | 90 | 569 |
| 41 | 29 | 30 | 0.02058 | 0.10573 | 0.09763 | 90 | 895 |
| 42 | 30 | 31 | 0.00992 | 0.05095 | 0.04705 | 90 | 563 |
| 43 | 32 | 31 | 0.01787 | 0.09180 | 0.08477 | 100 | 939 |

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Table C.1 – continued from previous page

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^5 \text{₹/yr}$) |
|-------------|----------|--------|---------------------------|-----------|---|------------|---|
| | | | Resistance | Reactance | | | |
| 44 | 32 | 34 | 0.00396 | 0.02035 | 0.07516 | 100 | 183 |
| 45 | 32 | 36 | 0.00305 | 0.01565 | 0.01445 | 180 | 741 |
| 46 | 32 | 37 | 0.02200 | 0.11301 | 0.10435 | 90 | 318 |
| 47 | 32 | 46 | 0.02095 | 0.10761 | 0.09937 | 90 | 987 |
| 48 | 33 | 32 | 0.01676 | 0.08609 | 0.07949 | 90 | 197 |
| 49 | 34 | 33 | 0.01737 | 0.08922 | 0.08258 | 90 | 126 |
| 50 | 34 | 35 | 0.00701 | 0.02600 | 0.03324 | 90 | 40 |
| 51 | 34 | 37 | 0.01990 | 0.01022 | 0.09438 | 100 | 419 |
| 52 | 35 | 32 | 0.00036 | 0.00184 | 0.00679 | 180 | 899 |
| 53 | 36 | 46 | 0.01828 | 0.09391 | 0.08672 | 180 | 645 |
| 54 | 37 | 46 | 0.00104 | 0.00536 | 0.01980 | 180 | 414 |
| 55 | 38 | 34 | 0.01076 | 0.05525 | 0.05102 | 300 | 516 |
| 56 | 38 | 37 | 0.01044 | 0.05361 | 0.04950 | 100 | 54 |
| 57 | 39 | 37 | 0.00229 | 0.01174 | 0.01084 | 180 | 55 |
| 58 | 39 | 42 | 0.00686 | 0.03522 | 0.03252 | 180 | 374 |
| 59 | 40 | 30 | 0.00716 | 0.03678 | 0.03397 | 180 | 558 |
| 60 | 40 | 41 | 0.00609 | 0.03130 | 0.02891 | 100 | 101 |
| 61 | 41 | 42 | 0.00076 | 0.00391 | 0.01445 | 150 | 417 |
| 62 | 41 | 45 | 0.00335 | 0.01712 | 0.01590 | 300 | 963 |
| 63 | 42 | 43 | 0.00914 | 0.04696 | 0.04336 | 100 | 163 |
| 64 | 42 | 44 | 0.01417 | 0.07278 | 0.06721 | 90 | 432 |
| 65 | 44 | 59 | 0.00884 | 0.04539 | 0.04191 | 100 | 612 |

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Table C.1 – continued from previous page

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^5 \text{₹}/\text{yr}$) |
|-------------|----------|--------|---------------------------|-----------|---|------------|--|
| | | | Resistance | Reactance | | | |
| 66 | 46 | 44 | 0.01676 | 0.08609 | 0.07949 | 300 | 13 |
| 67 | 47 | 46 | 0.00792 | 0.04070 | 0.03758 | 90 | 932 |
| 68 | 47 | 48 | 0.01371 | 0.07043 | 0.06504 | 400 | 96 |
| 69 | 48 | 50 | 0.00066 | 0.00337 | 0.01242 | 400 | 751 |
| 70 | 48 | 54 | 0.01254 | 0.06441 | 0.05948 | 400 | 226 |
| 71 | 49 | 48 | 0.00366 | 0.01878 | 0.06938 | 300 | 206 |
| 72 | 49 | 50 | 0.00670 | 0.03443 | 0.03180 | 300 | 87 |
| 73 | 51 | 53 | 0.01190 | 0.06112 | 0.05644 | 180 | 832 |
| 74 | 51 | 54 | 0.00407 | 0.02090 | 0.01930 | 400 | 557 |
| 75 | 51 | 55 | 0.01417 | 0.07278 | 0.06721 | 400 | 767 |
| 76 | 52 | 53 | 0.01132 | 0.05815 | 0.05369 | 300 | 588 |
| 77 | 52 | 61 | 0.01127 | 0.05791 | 0.05348 | 150 | 560 |
| 78 | 55 | 58 | 0.00670 | 0.03443 | 0.03180 | 90 | 481 |
| 79 | 56 | 58 | 0.00259 | 0.01330 | 0.01229 | 90 | 660 |
| 80 | 57 | 56 | 0.00152 | 0.00783 | 0.00723 | 180 | 913 |
| 81 | 57 | 58 | 0.00183 | 0.00939 | 0.00867 | 400 | 501 |
| 82 | 58 | 12 | 0.01211 | 0.06222 | 0.05745 | 400 | 68 |
| 83 | 58 | 60 | 0.00411 | 0.02113 | 0.01951 | 400 | 292 |
| 84 | 58 | 61 | 0.00335 | 0.01722 | 0.06359 | 400 | 79 |
| 85 | 59 | 61 | 0.00922 | 0.04735 | 0.04372 | 180 | 411 |
| 86 | 60 | 12 | 0.01365 | 0.07012 | 0.06475 | 300 | 431 |
| 87 | 60 | 61 | 0.00244 | 0.01252 | 0.04625 | 300 | 373 |

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Table C.1 – continued from previous page

| Line number | From bus | To bus | Line impedance ($p.u.$) | | Half line charging susceptance ($p.u.$) | MVA rating | Annual cost ($\times 10^5 \text{₹}/\text{yr}$) |
|-------------|----------|--------|---------------------------|-----------|---|------------|--|
| | | | Resistance | Reactance | | | |
| 88 | 61 | 62 | 0.01499 | 0.07701 | 0.07111 | 300 | 475 |
| 89 | 62 | 25 | 0.01383 | 0.07106 | 0.06562 | 150 | 643 |

Table C.2: Bus data – Indian utility 62 bus system

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits (MVAR) | Shunt capacitor data (MVAR) | |
|------------|----------------------|----------------------|-----------------|-----------------------|-----------------|-----------------------|------------------------------|-----------------------------|------------|
| | Magnitude ($p.u.$) | Phase angle (degree) | Real power (MW) | Reactive power (MVAR) | Real power (MW) | Reactive power (MVAR) | | | Q_{\min} |
| 1 | 1.05 | 0 | 0 | 0 | 192.649 | 23.554 | 0 | 450 | 0 |
| 2 | 1.05 | 0 | 0 | 0 | 190.581 | 0 | 0 | 130 | 0 |
| 3 | 1 | 0 | 40 | 10 | 0 | 0 | 0 | 5 | 0 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1.05 | 0 | 0 | 0 | 255.687 | 0 | 0 | 255 | 0 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 0 | 109 | 78 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1.05 | 0 | 66 | 23 | 78.202 | 1.218 | 0 | 100 | 0 |
| 10 | 1 | 0 | 40 | 10 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 161 | 93 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 0 | 155 | 79 | 0 | 0 | 0 | 0 | 0 |
| 13 | 1 | 0 | 132 | 46 | 0 | 0 | 0 | 0 | 0 |

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Table C.2 – continued from previous page

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits (MVAR) | | Shunt capacitor data (MVAR) |
|------------|---------------------------|----------------------|-----------------|-----------------------|-----------------|-----------------------|------------------------------|------------|-----------------------------|
| | Magnitude (<i>p.u.</i>) | Phase angle (degree) | Real power (MW) | Reactive power (MVAR) | Real power (MW) | Reactive power (MVAR) | Q_{\min} | Q_{\max} | |
| 14 | 1.05 | 0 | 0 | 0 | 171.083 | 233.905 | 0 | 500 | 0 |
| 15 | 1 | 0 | 155 | 63 | 0 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 1.05 | 0 | 0 | 0 | 190.612 | 0 | 0 | 0 | 0 |
| 18 | 1 | 0 | 121 | 46 | 0 | 0 | 0 | 0 | 0 |
| 19 | 1 | 0 | 130 | 70 | 0 | 0 | 0 | 0 | 0 |
| 20 | 1 | 0 | 81 | 70 | 0 | 0 | 0 | 0 | 0 |
| 21 | 1.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 1 | 0 | 0 | 64 | 50 | 0 | 0 | 0 | 0 |
| 23 | 1.05 | 0 | 0 | 0 | 151.842 | 147.932 | 0 | 340 | 0 |
| 24 | 1 | 0 | 58 | 34 | 0 | 0 | 0 | 0 | 0 |
| 25 | 1.05 | 0 | 0 | 0 | 250.249 | 86.526 | 0 | 395 | 0 |
| 26 | 1 | 0 | 116 | 52 | 0 | 0 | 0 | 0 | 0 |
| 27 | 1 | 0 | 85 | 35 | 0 | 0 | 0 | 0 | 0 |
| 28 | 1 | 0 | 63 | 8 | 0 | 0 | 0 | 0 | 0 |
| 29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 1 | 0 | 77 | 41 | 0 | 0 | 0 | 0 | 0 |
| 31 | 1 | 0 | 51 | 25 | 0 | 0 | 0 | 0 | 0 |
| 32 | 1.05 | 0 | 0 | 0 | 106.624 | 0 | -100 | 400 | 0 |
| 33 | 1.05 | 0 | 46 | 25 | 62.380 | 0 | 0 | 30 | 0 |

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Table C.2 – continued from previous page

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits (MVAR) | | Shunt capacitor data (MVAR) |
|------------|---------------------------|----------------------|-----------------|-----------------------|-----------------|-----------------------|------------------------------|------------|-----------------------------|
| | Magnitude (<i>p.u.</i>) | Phase angle (degree) | Real power (MW) | Reactive power (MVAR) | Real power (MW) | Reactive power (MVAR) | Q_{\min} | Q_{\max} | |
| 34 | 1 | 0 | 100 | 70 | 134.508 | 41 | 0 | 41 | 0 |
| 35 | 1 | 0 | 107 | 33 | 0 | 0 | 0 | 0 | 0 |
| 36 | 1 | 0 | 20 | 5 | 0 | 0 | 0 | 0 | 0 |
| 37 | 1.05 | 0 | 0 | 0 | 78.533 | 0 | 0 | 87 | 0 |
| 38 | 1 | 0 | 166 | 22 | 0 | 0 | 0 | 0 | 0 |
| 39 | 1 | 0 | 30 | 5 | 0 | 0 | 0 | 0 | 0 |
| 40 | 1 | 0 | 25 | 5 | 0 | 0 | 0 | 0 | 0 |
| 41 | 1 | 0 | 92 | 91 | 0 | 0 | 0 | 0 | 0 |
| 42 | 1 | 0 | 35 | 25 | 0 | 0 | 0 | 0 | 0 |
| 43 | 1 | 0 | 20 | 5 | 0 | 0 | 0 | 0 | 0 |
| 44 | 1 | 0 | 109 | 17 | 0 | 0 | 0 | 0 | 0 |
| 45 | 1 | 0 | 20 | 4 | 0 | 0 | 0 | 0 | 0 |
| 46 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 1.05 | 0 | 0 | 0 | 213.957 | 0 | 0 | 80 | 0 |
| 50 | 1.05 | 0 | 0 | 0 | 92.784 | 0 | 0 | 200 | 0 |
| 51 | 1.05 | 0 | 0 | 0 | 82.957 | 41.542 | 0 | 245 | 0 |
| 52 | 1.05 | 0 | 0 | 0 | 24.608 | 35 | 0 | 35 | 0 |
| 53 | 1 | 0 | 248 | 78 | 0 | 0 | 0.0 | 0 | 0 |

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Table C.2 – continued from previous page

| Bus number | Bus voltage | | Generation | | Load | | Reactive power limits ($MVAR$) | | Shunt capacitor data ($MVAR$) |
|------------|----------------------|----------------------|---------------------|---------------------------|---------------------|---------------------------|----------------------------------|------------|---------------------------------|
| | Magnitude ($p.u.$) | Phase angle (degree) | Real power (MW) | Reactive power ($MVAR$) | Real power (MW) | Reactive power ($MVAR$) | Q_{\min} | Q_{\max} | |
| 54 | 1.05 | 0 | 0 | 0 | 72.633 | 0 | 0 | 100 | 0 |
| 55 | 1 | 0 | 94 | 29 | 0 | 0 | 0 | 0 | 0 |
| 56 | 1.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 1.05 | 0 | 0 | 0 | 219.441 | 0 | 0 | 20 | 0 |
| 58 | 1.05 | 0 | 0 | 0 | 339.708 | 100 | 100 | 420 | 0 |
| 59 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62 | 1 | 0 | 93 | 23 | 0 | 0 | 0 | 0 | 0 |

Table C.3: Capacity and cost coefficients – Indian utility 62 bus system

| Generator number | P_i^{\min} (MW) | P_i^{\max} (MW) | a_i (₹/(MWhr) ²) | b_i (₹/ MWhr) | c_i (₹/hr) |
|------------------|----------------------|----------------------|-----------------------------------|--------------------|-----------------|
| G_1 | 50 | 300 | 0.0070 | 6.80 | 95 |
| G_2 | 50 | 450 | 0.0055 | 4.00 | 30 |
| G_3 | 50 | 450 | 0.0055 | 4.00 | 45 |
| G_4 | 0 | 150 | 0.0025 | 0.85 | 10 |
| G_5 | 50 | 300 | 0.0060 | 4.60 | 20 |
| G_6 | 50 | 450 | 0.0055 | 4.00 | 90 |
| G_7 | 50 | 200 | 0.0065 | 4.70 | 42 |
| G_8 | 50 | 500 | 0.0075 | 5.00 | 46 |
| G_9 | 0 | 600 | 0.0085 | 6.00 | 55 |
| G_{10} | 0 | 100 | 0.0020 | 0.50 | 58 |
| G_{11} | 50 | 150 | 0.0045 | 1.60 | 65 |
| G_{12} | 0 | 100 | 0.0025 | 0.85 | 78 |
| G_{13} | 50 | 300 | 0.0050 | 1.80 | 75 |
| G_{14} | 0 | 150 | 0.0045 | 1.60 | 85 |
| G_{15} | 0 | 500 | 0.0065 | 4.70 | 80 |
| G_{16} | 50 | 150 | 0.0045 | 1.40 | 90 |
| G_{17} | 0 | 100 | 0.0025 | 0.85 | 10 |
| G_{18} | 50 | 300 | 0.0045 | 1.60 | 25 |
| G_{19} | 100 | 600 | 0.0080 | 5.50 | 90 |

Table C.4: Transformer tap setting data – Indian utility 62 bus system

| From bus | To bus | Tap setting value (<i>p.u.</i>) |
|----------|--------|-----------------------------------|
| 1 | 14 | 0.9639 |
| 14 | 15 | 0.9539 |
| 4 | 14 | 1.0158 |
| 13 | 14 | 1.0124 |
| 12 | 13 | 0.9621 |
| 14 | 19 | 0.9630 |
| 14 | 18 | 1.0121 |
| 14 | 16 | 1.0135 |
| 48 | 50 | 0.9630 |
| 49 | 50 | 1.0132 |
| 47 | 18 | 0.9630 |