The University of Texas at Austin
Department of Electrical and Computer Engineering
EE 369 - Power System Engineering

**Course Design Project (Spring 2025)**


**Abstract**

For this design project, we will use PowerWorld simulator. We introduce the project background in Section 1. Section 2 details the design procedure, while Section 3 details the simplifying assumptions. Additional system information is provided in Section 4. Last, Section 5 provides some examples/suggestions for you to get started with the project.


# 1 Introduction

As a planning engineer for Island Electric Company (IEC), you have been tasked with determining the transmission system changes required to locate a new 600 MW wind farm in the western portion of your service territory (see Figure 1). IEC uses 345 and 161 kV transmission grids, so your changes are restricted to these existing voltages. The wind farm would like to connect at the 161 kV level and requires at least two transmission lines into the NewWind substation (which can be at either 161 and/or 345 kV). Since the location is usually quite windy, it is expected to have a capacity factor of at least $40\%$. However, the wind also can be quite variable, including during times of maximum system loading, so this generation cannot be counted on for firm capacity. Simultaneous with the addition of the new wind farm, IEC would like to retire the existing 300 MW generator at the Pheasant substation.

Hence, your job is to make recommendations on the least-cost design for the construction of new lines and transformers to ensure that the transmission system in the IEC system is adequate for any base case or first-contingency loading situation when then wind farm is installed and operating at either its maximum output of 600 or 0 MW and with the Pheasant generator removed from service. The first-contingencies of interest here is the loss or failure of a single transmission line or transformer. Note, this will also involve fixing some existing first-contingency violations. Since the wind farm will be built with Type 3 DFAG wind turbines, you can model the wind farm in the power flow as a single equivalent, traditional PV bus generator with a fixed output of either 0 or 600 MW, a voltage setpoint of $1.03$ per unit, and with reactive power limits of $\pm 250$ Mvar.

Table 1 shows the right-of-way distances that are available for the construction of new 161 kV and/or new 345 kV lines. All existing 161 kV only substations are large enough to accomodate 345 kV as well, as in the NewWind substation.

# 2 Design Procedure

1. Load design_case into PowerWorld Simulator, which contains the system power flow case and the disconnected NewWind generator and bus. Perform an initial power flow solution to verify the base

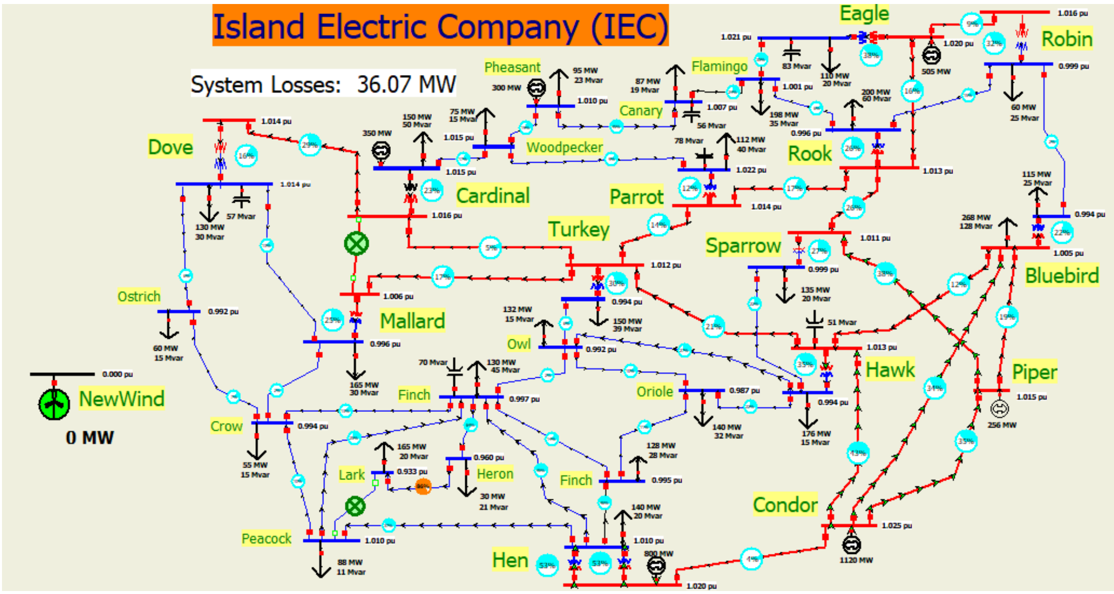



Figure 1: One-line diagram of the design case system.

case system operation. Note that all of the line flows and bus voltage magnitudes are within their limits. Assume all line MVA flows must be at or below 100% of their limit values, and all voltages must be between 0.92 and 1.10 per unit.

2. Repeat the above analysis, considering the impact of any single transmission line or transformer outage. This is known as contingency analysis. To simplify this analysis, PowerWorld Simulator has the ability to automatically perform a contingency analysis study. Select **Tools**, **Contingency Analysis** to show the Contingency Analysis display. Note that the 60 single line/transformer contingencies are already defined. Select **Start Run** to automatically see the impact of removing any single element. Note that there are several existing violations.

3. Open the existing 300 MW generator at the Pheasant substation, and repeat parts 1 and 2.

4. Using the rights-of-way given in Table 1 and the transmission line parameters/costs, iteratively determine the least-expensive system additions so that the base case and all the contingencies result in reliable operation points with the NewWind generation connected with an output of either 0 or 600 MW. When the output is at 0 MW, the wind farm is still considered online and hence should be modeled as a PV bus regulating its voltage to 1.03 per unit. The parameters of the new transmission line(s) need to be derived using a symmetric tower configuration and the conductor types in Table 2. Additional information can be found in Section 4. In addition, the transmission changes you propose will modify the total system losses, indicated by the large field on the one-line diagram. In your design, you should consider the impact on total system losses in the studied condition for the next 5 years. Hence, you should minimize the total construction costs minus the savings associated with any decrease in system losses over the next 5 years.

5. There are two lines that have been disconnected for maintenance (with a cross mark), one between bus 18 and bus 4, above Mallard, and the other between bus 37 and bus 38 (Peacock-Lark). **DO NOT** modify the status of these lines.

6. Write a detailed report discussing the initial system problems, your approach to optimally solving the system problems, and the justification for your final recommendation.

# 3 Simplifying Assumptions

To simplify the analysis, several assumptions are made:

1. You need only consider the base case loading level given with the modification of opening the Pheasant generation. In a real design, typically a number of different operating points/loading levels must be considered.
2. You should consider all the generator real power outputs as fixed values with the exception that the NewWind generator should be studied at both 0 and 600 MW. The change in the total system generation and any changes in the system losses are always picked up by the system slack.
3. You should not modify the status of the capacitors or the transformer taps.
4. You should assume that the system losses remain constant over the 5-year period and need only consider the impact the new design has on the base case losses, assuming the NewWind generation is at 600 MW. The price for losses can be assumed to be **$50/MWh**.
5. You do not need to consider contingencies involving the new transmission lines and possibly any transformers you may be adding.
6. While an appropriate control response to a contingency might be to decrease the wind farm output (by changing the pitch on the wind turbine blades), your supervisor has specifically asked you not to consider this possibility. Therefore, the NewWind generator should always have either a 0 or 600 MW output.

# 4 Additional System Information

Table 1 tabulates the set of buses that can be connected with transmission lines.

| **Right-of-Way/Substation** | **Right-of-Way Distance (km)** |
|---|---|
| NewWind to Ostrich | 15 |
| NewWind to Dove | 55 |
| NewWind to Crow | 30 |
| NewWind to Peacock | 53 |
| NewWind to Hen | 70 |
| Ostrich to Mallard | 45 |
| Peakcock to Hen | 20 |
| Dove to Cardinal | 40 |

Table 1: Available new rights-of-way for design case.

Table 2 tabulates the assumed costs for transmission lines of certain conductor types. The line impedance data and MVA ratings are determined based on the conductor type and tower configuration. The conductor characteristics are given in Table A.4 in Appendix A. For these design problems, assume a symmetric tower configuration. In addition, assume the geometric mean distance (GMD) of 5 m for 161 kV and 8 m 345 kV lines.

| **Conductor Type** | **Current Rating (A)** | **345 kV Lines** | **161 kV Lines** |
|---|---|---|---|
| Crow | 830 | | $390,000/km |
| Condor | 900 | | $410,000/km |
| Cardinal | 1110 | $600,000/km | $430,000/km |
| Pheasant | 1200 | $650,000/km | $450,000/km |
| Falcon | 1380 | $700,000/km | |

Table 2: Assumed costs for transmission lines.

**Transformers**

Transformer costs include the associated circuit breakers, relaying, and installation.

| | |
|---|---|
| 345/161 kV, 560 MVA | $7,500,000 |

Assume that any new 345/161 kV transformer has $0.0004$ per unit resistance and $0.025$ per unit resistance (all on a 100 MVA base).

**Bus Work**

The cost to upgrade a 161 kV substation to also include 345 kV is $3,500,000.

## 5 Examples and Suggestions

This section provides some example steps to help you get started on the project.

### 1) Familiarize Yourself with the System

a) After opening the file *design_case.PWB* into the PowerWorld Simulator, notice that the NewWind generator is not connected to the system.

b) Next, notice that the system losses is 37.06 MW. Note, one goal of this project is to minimize the system losses after adding in the NewWind generator and retiring the generator at the Pheasant Substation.

c) Run the power flow analysis for the initial system by clicking the **Play Button** under **Tools** in Run Mode. All line flows and voltage magnitudes should be within the limits detailed in Step 1 of the design procedure. Next, run the contingency analysis in detailed in Step 2.

d) Repeat the power flow and contingency analysis with the 300 MW generator at the Pheasant substation opened. Note, you can disconnect the generator by opening the breaker. Again, all line flows and voltage magnitudes are within their limits. However, for the contingency analysis, we need to take a few extra steps. Note if not done, you will see that PowerWorld will reset the system back to its “initial state". More specifially, the Pheasant generator breaker will be closed.

i) Check that the breaker status (open/closed) is correct in the one-line diagram.

ii) Select **Tools**, **Contingency Analysis** to show the Contingency Analysis display.

iii) Select **Other >**, **Clear All Contingency Results**. This ensures that in the next step we do not save the prior contingency results as the reference point.

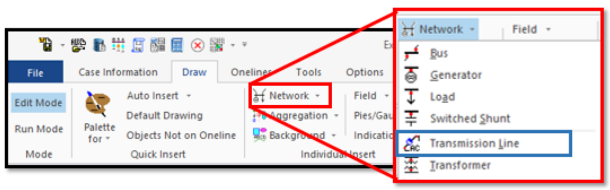
iv) Select **Other >**, **Set As Reference**. This ensures that once the contingency analysis is done, the breaker status will remain as the desired status in step i).

v) Select **Start Run**.

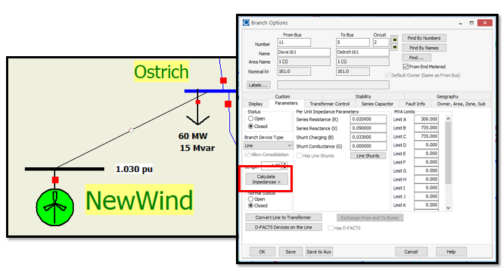
## 2) Adding New Transmission Lines

This section will cover how to add a new transmission line. For the given example, we will be adding a transmission line of conductor type Crow between the NewWind and Ostrich substations.

a) In Edit Mode, select **Draw**, **Network**, and **Transmission Line**.

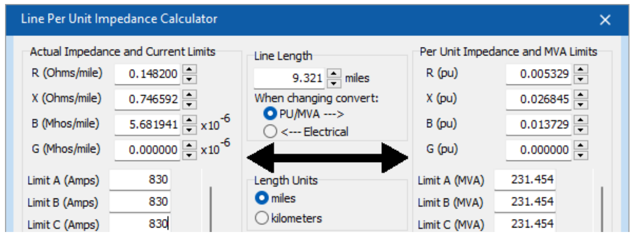



b) Connect the transmission line between the NewWind and Ostrich buses as shown in the figure below in black. Once the line is connected, the “Branch Options" box will pop up. The line parameters will be set using this window.




c) In the “Branch Options" window, select **Calculate Impedances >**.

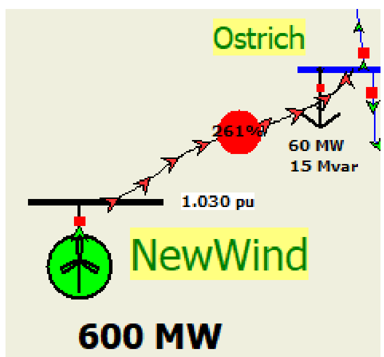
d) In the “Line Per Unit Impedance Calculator" window, the *Actual Impedance and Current Limits* and *Line Length* fields need to be filled. For the actual impedance, the line R, X, and B values need to be computed and entered into the field boxed in red below. Note that these values are computed based on the conductor type chosen in Table 2 and their specifications given in Table A4 in Appendix A. The current limits are given in Table 2 and should be entered in the field boxed in blue below. Last, the line length is given in Table 1 and should be entered into the field boxed in green below. Once the values have been entered, select **OK**, and then **OK**.




e) Somewhere near the middle of the transmission line, there is a small pie chart. It may look like a red dot. Double-click on the pie chart and change the **Size** to at least 60.

### 3) Run Power Flow and Contingency Analysis

Run the power flow analysis on the new system and check if the line flows and voltage magnitudes are within limits. As seen in the figure below, the newly added transmission line is exceeding its capacity limit. Thus, choosing the conductor type Crow and/or the choice of connecting a line between NewWind and Ostrich was not a good decision. In addition, there are 73 violations after running the contingency analysis with the newly added line, which further proves that this was not the correct choice.




*Note that you can change the NewWind Generation from 0 to 600 MW after connecting the transmission line. This is done by double-clicking the NewWind generator and setting the MW Setpoint to 600.*

### 4) Project Goal

In summary, the new system you are tasked to design should achieve the following design specifications:

1. Safe system: the line flows and voltage magnitudes are within their limits.
2. Reliable system: no violations found through contingency analysis.
3. More economical system: the total system losses are minimized.

# Appendix A

**TABLE A.4** Characteristics of aluminum cable, steel, reinforced (Aluminum Company of America)—ACSR

| Code Word | Circular Mils Aluminum | Aluminum | | | Steel | | Outside Diameter (inches) | Copper Equivalent* Circular Mils or A.W.G. | Ultimate Strength (pounds) | Weight (pounds per mile) | Geometric Mean Radius at 60 Hz (feet) | Approx. Current Carrying Capacity† (amps) | $r_a$ Resistance (Ohms per Conductor per Mile) 25°C (77°F) Small Currents | | | | 50°C (122°F) Current Approx. 75% Capacity‡ | | | | $x_a$ Inductive Reactance (ohms per conductor per mile at 1 ft spacing all currents) | $x'_a$ Shunt Capacitive Reactance (megohms per conductor per mile at 1 ft spacing) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Strand Diameter (inches) | | Strand Diameter (inches) | | | | | | | dc | 25 Hz | 50 Hz | 60 Hz | dc | 25 Hz | 50 Hz | 60 Hz | 60 Hz | 60 Hz |
| Joree | 2 515 000 | 76 | ... | 0.1819 | 19 | 0.0849 | 1.880 | | 61 700 | | 0.0621 | | | | | | | | | 0.0450 | 0.337 | 0.0755 |
| Thrasher | 2 312 000 | 76 | ... | 0.1744 | 19 | 0.0814 | 1.802 | | 57 300 | | 0.0595 | | | | | | | | | 0.0482 | 0.342 | 0.0767 |
| Kiwi | 2 167 000 | 72 | 4 | 0.1735 | 7 | 0.1157 | 1.735 | | 49 800 | | 0.0570 | | | | | | | | | 0.0511 | 0.348 | 0.0778 |
| Bluebird | 2 156 000 | 84 | 4 | 0.1602 | 19 | 0.0961 | 1.762 | | 60 300 | | 0.0588 | | | | | | | | | 0.0505 | 0.344 | 0.0774 |
| Chukar | 1 781 000 | 84 | 4 | 0.1456 | 19 | 0.0874 | 1.602 | | 51 000 | | 0.0534 | | | | | | | | | 0.0598 | 0.355 | 0.0802 |
| Falcon | 1 590 000 | 54 | 3 | 0.1716 | 19 | 0.1030 | 1.545 | 1 000 000 | 56 000 | 10 777 | 0.0520 | 1 380 | 0.0587 | 0.0588 | 0.0590 | 0.0591 | 0.0646 | 0.0656 | 0.0675 | 0.0684 | 0.359 | 0.0814 |
| Parrot | 1 510 500 | 54 | 3 | 0.1673 | 19 | 0.1004 | 1.506 | 950 000 | 53 200 | 10 237 | 0.0507 | 1 340 | 0.0618 | 0.0619 | 0.0621 | 0.0622 | 0.0680 | 0.0690 | 0.0710 | 0.0720 | 0.362 | 0.0821 |
| Plover | 1 431 000 | 54 | 3 | 0.1628 | 19 | 0.0977 | 1.465 | 900 000 | 50 400 | 9 699 | 0.0493 | 1 300 | 0.0652 | 0.0653 | 0.0655 | 0.0656 | 0.0718 | 0.0729 | 0.0749 | 0.0760 | 0.365 | 0.0830 |
| Martin | 1 351 000 | 54 | 3 | 0.1582 | 19 | 0.0949 | 1.424 | 850 000 | 47 600 | 9 160 | 0.0479 | 1 250 | 0.0691 | 0.0692 | 0.0694 | 0.0695 | 0.0761 | 0.0771 | 0.0792 | 0.0803 | 0.369 | 0.0838 |
| Pheasant | 1 272 000 | 54 | 3 | 0.1535 | 19 | 0.0921 | 1.382 | 800 000 | 44 800 | 8 621 | 0.0465 | 1 200 | 0.0734 | 0.0735 | 0.0737 | 0.0738 | 0.0808 | 0.0819 | 0.0840 | 0.0851 | 0.372 | 0.0847 |
| Grackle | 1 192 500 | 54 | 3 | 0.1486 | 19 | 0.0892 | 1.338 | 750 000 | 43 100 | 8 082 | 0.0450 | 1 160 | 0.0783 | 0.0784 | 0.0786 | 0.0788 | 0.0862 | 0.0872 | 0.0894 | 0.0906 | 0.376 | 0.0857 |
| Finch | 1 113 000 | 54 | 3 | 0.1436 | 19 | 0.0862 | 1.293 | 700 000 | 40 200 | 7 544 | 0.0435 | 1 110 | 0.0839 | 0.0840 | 0.0842 | 0.0844 | 0.0924 | 0.0935 | 0.0957 | 0.0969 | 0.380 | 0.0867 |
| Curlew | 1 033 500 | 54 | 3 | 0.1384 | 7 | 0.1384 | 1.246 | 650 000 | 37 100 | 7 019 | 0.0420 | 1 060 | 0.0903 | 0.0905 | 0.0907 | 0.0909 | 0.0994 | 0.1005 | 0.1025 | 0.1035 | 0.385 | 0.0878 |
| Cardinal | 954 000 | 54 | 3 | 0.1329 | 7 | 0.1329 | 1.196 | 600 000 | 34 200 | 6 479 | 0.0403 | 1 010 | 0.0979 | 0.0980 | 0.0981 | 0.0982 | 0.1078 | 0.1088 | 0.1118 | 0.1128 | 0.390 | 0.0890 |
| Canary | 900 000 | 54 | 3 | 0.1291 | 7 | 0.1291 | 1.162 | 566 000 | 32 300 | 6 112 | 0.0391 | 970 | 0.104 | 0.104 | 0.104 | 0.104 | 0.1145 | 0.1155 | 0.1175 | 0.1185 | 0.393 | 0.0898 |
| Crane | 874 500 | 54 | 3 | 0.1273 | 7 | 0.1273 | 1.146 | 550 000 | 31 400 | 5 940 | 0.0386 | 950 | 0.107 | 0.107 | 0.107 | 0.108 | 0.1178 | 0.1188 | 0.1218 | 0.1228 | 0.395 | 0.0903 |
| Condor | 795 000 | 54 | 3 | 0.1214 | 7 | 0.1214 | 1.093 | 500 000 | 28 500 | 5 399 | 0.0368 | 900 | 0.117 | 0.118 | 0.118 | 0.119 | 0.1288 | 0.1308 | 0.1358 | 0.1378 | 0.401 | 0.0917 |
| Drake | 795 000 | 26 | 2 | 0.1749 | 7 | 0.1360 | 1.108 | 500 000 | 31 200 | 5 770 | 0.0375 | 900 | 0.117 | 0.117 | 0.117 | 0.117 | 0.1288 | 0.1288 | 0.1288 | 0.1288 | 0.399 | 0.0912 |
| Mallard | 795 000 | 30 | 2 | 0.1628 | 19 | 0.0977 | 1.140 | 500 000 | 38 400 | 6 517 | 0.0393 | 910 | 0.117 | 0.117 | 0.117 | 0.117 | 0.1288 | 0.1288 | 0.1288 | 0.1288 | 0.393 | 0.0904 |
| Crow | 715 500 | 54 | 3 | 0.1151 | 7 | 0.1151 | 1.036 | 450 000 | 26 300 | 4 859 | 0.0349 | 830 | 0.131 | 0.131 | 0.131 | 0.132 | 0.1442 | 0.1452 | 0.1472 | 0.1482 | 0.407 | 0.0932 |
| Starling | 715 500 | 26 | 2 | 0.1659 | 7 | 0.1290 | 1.051 | 450 000 | 28 100 | 5 193 | 0.0355 | 840 | 0.131 | 0.131 | 0.131 | 0.131 | 0.1442 | 0.1442 | 0.1442 | 0.1442 | 0.405 | 0.0928 |
| Redwing | 715 500 | 30 | 2 | 0.1544 | 19 | 0.0926 | 1.081 | 450 000 | 34 600 | 5 865 | 0.0372 | 840 | 0.131 | 0.131 | 0.131 | 0.131 | 0.1442 | 0.1442 | 0.1442 | 0.1442 | 0.399 | 0.0920 |
| Flamingo | 666 600 | 54 | 3 | 0.1111 | 7 | 0.1111 | 1.000 | 419 000 | 24 500 | 4 527 | 0.0337 | 800 | 0.140 | 0.140 | 0.141 | 0.141 | 0.1541 | 0.1571 | 0.1591 | 0.1601 | 0.412 | 0.0943 |
| Rook | 636 000 | 54 | 3 | 0.1085 | 7 | 0.1085 | 0.977 | 400 000 | 23 600 | 4 319 | 0.0329 | 770 | 0.147 | 0.147 | 0.148 | 0.148 | 0.1618 | 0.1638 | 0.1678 | 0.1688 | 0.414 | 0.0950 |
| Grosbeak | 636 000 | 26 | 2 | 0.1564 | 7 | 0.1216 | 0.990 | 400 000 | 25 000 | 4 616 | 0.0335 | 780 | 0.147 | 0.147 | 0.147 | 0.147 | 0.1618 | 0.1618 | 0.1618 | 0.1618 | 0.412 | 0.0946 |
| Egret | 636 000 | 30 | 2 | 0.1456 | 19 | 0.0874 | 1.019 | 400 000 | 31 500 | 5 213 | 0.0351 | 780 | 0.147 | 0.147 | 0.147 | 0.147 | 0.1618 | 0.1618 | 0.1618 | 0.1618 | 0.406 | 0.0937 |
| Peacock | 605 000 | 54 | 3 | 0.1059 | 7 | 0.1059 | 0.953 | 380 500 | 22 500 | 4 109 | 0.0321 | 750 | 0.154 | 0.155 | 0.155 | 0.155 | 0.1695 | 0.1715 | 0.1755 | 0.1775 | 0.417 | 0.0957 |
| Squab | 605 000 | 26 | 2 | 0.1525 | 7 | 0.1186 | 0.966 | 380 500 | 24 100 | 4 391 | 0.0327 | 760 | 0.154 | 0.154 | 0.154 | 0.154 | 0.1700 | 0.1720 | 0.1720 | 0.1720 | 0.415 | 0.0953 |
| Dove | 556 500 | 26 | 2 | 0.1463 | 7 | 0.1138 | 0.927 | 350 000 | 22 400 | 4 039 | 0.0313 | 730 | 0.168 | 0.168 | 0.168 | 0.168 | 0.1849 | 0.1859 | 0.1859 | 0.1859 | 0.420 | 0.0965 |
| Eagle | 556 500 | 30 | 2 | 0.1362 | 7 | 0.1362 | 0.953 | 350 000 | 27 200 | 4 588 | 0.0328 | 730 | 0.168 | 0.168 | 0.168 | 0.168 | 0.1849 | 0.1859 | 0.1859 | 0.1859 | 0.415 | 0.0957 |
| Hawk | 477 000 | 26 | 2 | 0.1355 | 7 | 0.1054 | 0.858 | 300 000 | 19 430 | 3 462 | 0.0290 | 670 | 0.196 | 0.196 | 0.196 | 0.196 | 0.216 | | | | 0.430 | 0.0988 |
| Hen | 477 000 | 30 | 2 | 0.1261 | 7 | 0.1261 | 0.883 | 300 000 | 23 300 | 3 933 | 0.0304 | 670 | 0.196 | 0.196 | 0.196 | 0.196 | 0.216 | | | | 0.424 | 0.0980 |
| Ibis | 397 500 | 26 | 2 | 0.1236 | 7 | 0.0961 | 0.783 | 250 000 | 16 190 | 2 885 | 0.0265 | 590 | 0.235 | | | | 0.259 | | | | 0.441 | 0.1015 |
| Lark | 397 500 | 30 | 2 | 0.1151 | 7 | 0.1151 | 0.806 | 250 000 | 19 980 | 3 277 | 0.0278 | 600 | 0.235 | | Same as dc | | 0.259 | | Same as dc | | 0.435 | 0.1006 |
| Linnet | 336 400 | 26 | 2 | 0.1138 | 7 | 0.0855 | 0.721 | 4/0 | 14 050 | 2 442 | 0.0244 | 530 | 0.278 | | | | 0.306 | | | | 0.451 | 0.1039 |
| Oriole | 336 400 | 30 | 2 | 0.1059 | 7 | 0.1059 | 0.741 | 4/0 | 17 040 | 2 774 | 0.0255 | 530 | 0.278 | | | | 0.306 | | | | 0.445 | 0.1032 |
| Ostrich | 300 000 | 26 | 2 | 0.1074 | 7 | 0.0835 | 0.680 | 188 700 | 12 650 | 2 178 | 0.0230 | 490 | 0.311 | | | | 0.342 | | | | 0.458 | 0.1057 |
| Piper | 300 000 | 30 | 2 | 0.1000 | 7 | 0.1000 | 0.700 | 188 700 | 15 430 | 2 473 | 0.0241 | 500 | 0.311 | | | | 0.342 | | | | 0.462 | 0.1049 |
| Partridge | 266 800 | 26 | 2 | 0.1013 | 7 | 0.0788 | 0.642 | 3/0 | 11 250 | 1 936 | 0.0217 | 460 | 0.350 | | | | 0.385 | | | | 0.465 | 0.1074 |

*Based on copper 97%, aluminum 61% conductivity.
†For conductor at 75°C, air at 25°C, wind 1.4 miles per hour (2 ft/sec), frequency = 60 Hz.
‡"Current Approx. 75% Capacity" is 75% of the "Approx. Current Carrying Capacity in Amps" and is approximately the current which will produce 50°C conductor temp. (25°C rise) with 25°C air temp., wind 1.4 miles per hour.