

Final Project: Power System Analysis and Design

EE 581

April 19, 2012

1 Introduction

The project makes use of your power-flow solver for system analysis and design. The system of interest is the Eagle Power System (adopted from [1]) displayed as a one-line diagram in figures 1 and 2. The three specific tasks assigned to you are:

1. Create a base case data set (in p.u.) and solve power-flow for the system as shown in figures 1 and 2; towers shown in figure 3; and line, load, generator, transmission line, and transformer data provided in tables 1, 2, 3 and 4. Check data to verify connections, distances and general consistency. Solve power-flow for the base case and check that satisfactory operation is achieved using the criteria below:
 - (a) All voltages should be in the range from 0.94 to 1.06 p.u.
 - (b) All transmission lines should be carrying less power than their thermal and practical stability limits.
 - (c) All generation should satisfy real and reactive power limits.
2. Modify the existing power system network to accommodate a new (40 MW, unity power factor) steel mill to be placed as shown in figures 1 and 2. Choose a “low-cost” design that satisfies the above criteria for satisfactory operation and the following design guidelines:
 - (a) Total generation capacity is 1,500 MW, so there should be ample generation to supply the increase in total load. Generation does should be added or moved.
 - (b) Transmission voltages of 161kV or 69kV, tower configurations shown in figure 3 and conductors listed in table 5 are available.
 - (c) Seek a minimum cost design. The price of various equipment (from which you may select) and installation is specified later in this document.
 - (d) Line routes should follow existing transmission lines to take advantage of the right-of-way. These are assumed to only run North-South or East-West.
 - (e) Buses with loads under 30 MVA should be served at 69 kV and buses with loads over 50 MVA should be served at 161 kV. Buses with loads between 30 and 50 MVA may be served at either voltage.
 - (f) Achieve enough redundancy that each load has two transmission lines, each from a different bus.

2 Report

Write a report that documents your analysis and design process to include development of the base case data and power-flow, and the new design's configuration, cost, power-flow and performance.

3 System Description

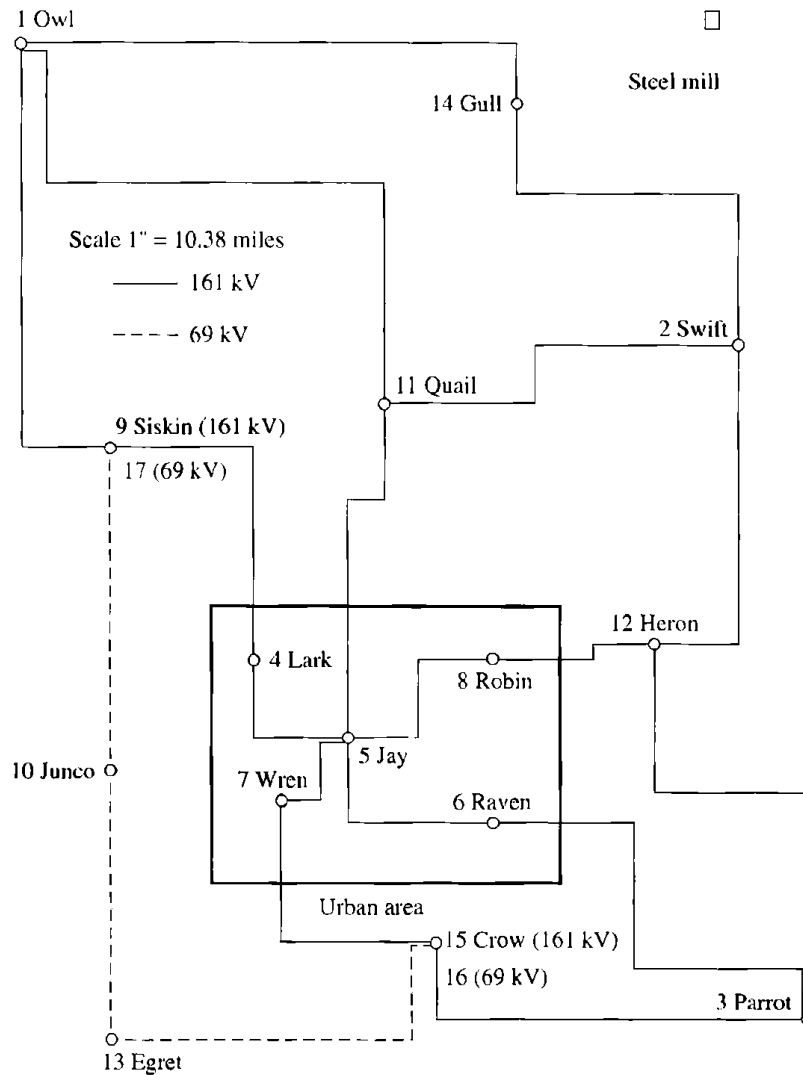


Figure 1: 17-bus Eagle Power System (one-line, geographic diagram).

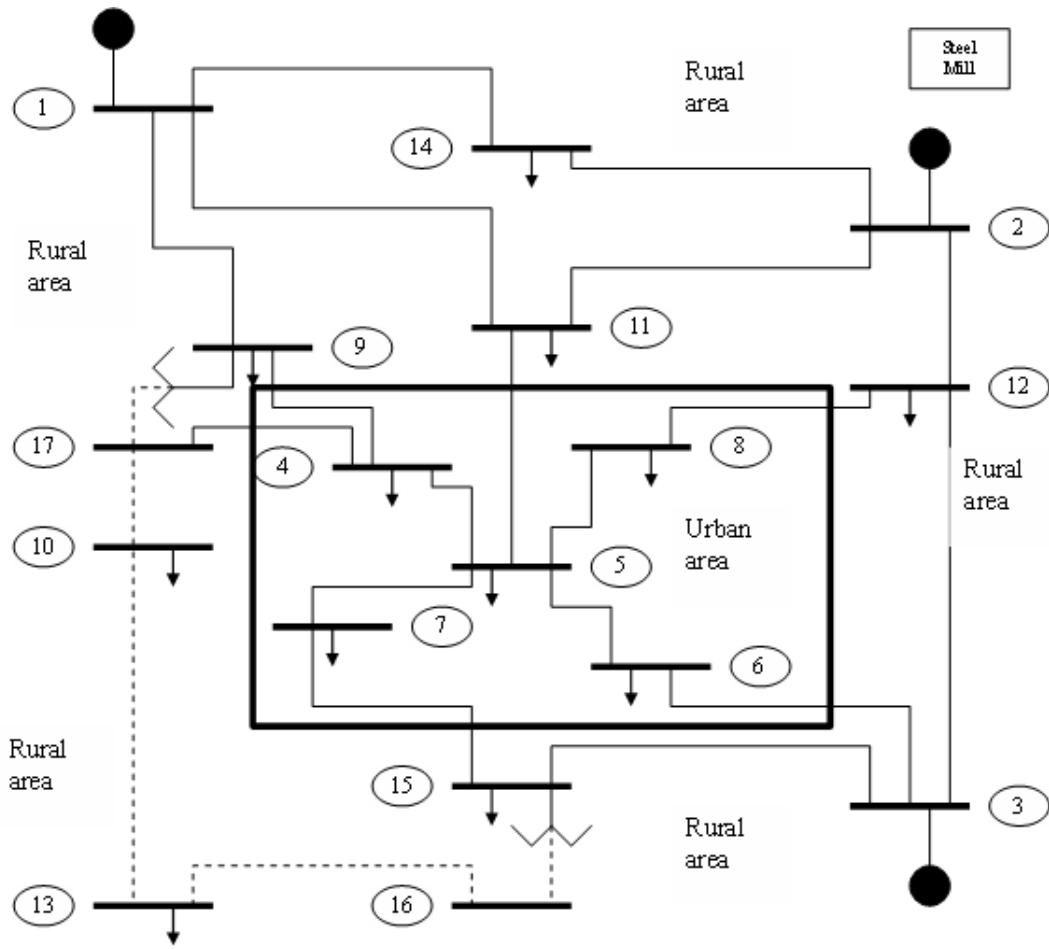


Figure 2: 17-bus Eagle Power System (one-line, engineering diagram).

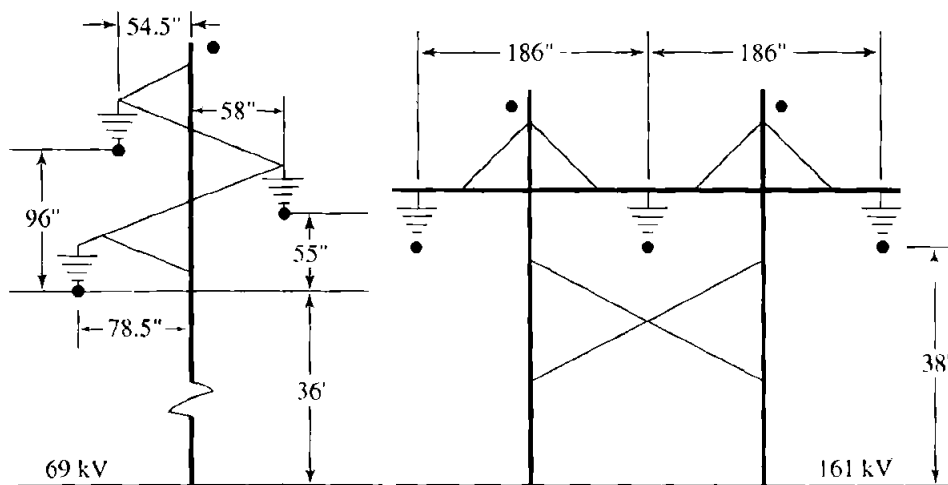


Figure 3: 69 kV and 161 kV tower structures.

| Name | No. | V (p.u.) | δ ($^\circ$) | P_G (MW) | P_L (MW) | Q_L (MW) |
|-----------|-----|----------|-----------------------|------------|------------|------------|
| Owl161 | 1 | 1.04 | 0 | | | |
| Swift161 | 2 | 1.04 | | 190 | | |
| Parrot161 | 3 | 1.04 | | 190 | | |
| Lark161 | 4 | | | | 60 | 10 |
| Jay161 | 5 | | | | 100 | 30 |
| Raven161 | 6 | | | | 80 | 15 |
| Wren161 | 7 | | | | 90 | 20 |
| Robin161 | 8 | | | | 40 | 5 |
| Siskin161 | 9 | | | | | |
| Junco69 | 10 | | | | 15 | 10 |
| Quail161 | 11 | | | | 75 | 15 |
| Heron161 | 12 | | | | 40 | 15 |
| Egret69 | 13 | | | | 30 | 10 |
| Gull161 | 14 | | | | 35 | 10 |
| Crow161 | 15 | | | | | |
| Crow69 | 16 | | | | 10 | 0 |
| Siskin69 | 17 | | | | 10 | 5 |
| | | | | | 585 | 145 |

Table 1: Bus data for 17-bus system (base case).

| Bus No. | Bus No. | Conductor | Miles |
|---------|---------|-----------|-------|
| 1 | 9 | Drake | 24.0 |
| 1 | 11 | Drake | 36.7 |
| 1 | 14 | Drake | 28.2 |
| 2 | 11 | Drake | 21.5 |
| 2 | 12 | Drake | 20.3 |
| 2 | 14 | Drake | 24.0 |
| 3 | 6 | Drake | 27.6 |
| 3 | 12 | Drake | 27.6 |
| 3 | 15 | Drake | 23.6 |
| 4 | 5 | Dove | 8.4 |
| 4 | 9 | Drake | 18.8 |
| 5 | 6 | Dove | 10.8 |
| 5 | 7 | Dove | 6.0 |
| 5 | 8 | Dove | 10.9 |
| 7 | 15 | Drake | 14.6 |
| 8 | 12 | Drake | 9.8 |
| 5 | 11 | Drake | 19.5 |
| 10 | 13 | Hawk | 14.3 |
| 10 | 17 | Hawk | 16.2 |
| 13 | 16 | Hawk | 21.9 |

Table 2: Line data for 17-bus system (base case).

| Voltage Ratings | Apparent Power Rating | Leakage Reactance (X) |
|-----------------|-----------------------|-----------------------|
| 69 kV-161 kV | 60 MVA | 0.08 p.u. |

Table 3: Transformer data for 17-bus system.

| Scheduled Voltage | Reactive Power Limits (Q_{min} , Q_{max}) | Real Power Limits (P_{min} , P_{max}) |
|-------------------|---|---|
| 1.04 p.u. | -300 MVAR, 300 MVAR | 0 W, 500 MW |

Table 4: Generator set-points and limits for 17-bus system

4 Equipment and Construction Costs

4.1 Conductors available and line costs

Line costs are provided in table 5 for the tower-conductor combinations available. Costs are in \$ per mile and include the costs of conductors, right-of-way, structures, shield wires, etc.

| Conductor Type | 161 kV | | 69 kV | |
|----------------|---------|---------|---------|--------|
| | Urban | Rural | Urban | Rural |
| Partridge | | | 109,000 | 75,000 |
| Hawk | | | 113,000 | 83,000 |
| Dove | 243,000 | 106,000 | 115,000 | 85,000 |
| Drake | 257,000 | 115,000 | 126,000 | 92,000 |
| Cardinal | 264,000 | 120,000 | | |

Table 5: Line costs in \$/mile.

4.2 Substation costs

Assume space exists for expansion at existing substations (buses 1-17), but if you add a new substation the cost will be \$300,000 for land, fences, grading, structures, etc.

New transmission lines require a circuit breaker (switch) and termination at each end of the line. The cost of a circuit breaker and its installation is given in table 6.

The cost of new 69 kV-161 kV transformers (including installation and circuit breakers) is shown in table 7.

| Rated Voltage | Price |
|---------------|----------|
| 69 kV | \$48,000 |
| 161 kV | \$95,000 |

Table 6: Cost of three-phase circuit breaker.

| Rating | Price |
|---------|-------------|
| 60 MVA | \$900,000 |
| 120 MVA | \$1,000,000 |
| 180 MVA | \$1,100,000 |

Table 7: Cost of 69 kV-161 kV, three-phase transformers.

4.3 Capacitor costs

Capacitor banks can be added to a load bus to increase the load's power factor and to increase the bus voltage during heavy load conditions. The costs associated with a three-phase capacitor bank are given in table 8.

| Item | Price |
|---------------------------------------|--------------------|
| Installation and associated equipment | \$60,000 per bank |
| Capacitors | \$300 per 100 kVAR |

Table 8: Costs associated with three-phase capacitor banks.

References

- [1] Arthur R. Bergen and Vijay Vittal, *Power Systems Analysis*, 2nd Ed., Prentice Hall, Upper Saddle River, NJ, 2000.