Design Project: Eagle Power System Upgrade Proposal

Anupam Gopal and Dagmar Niebur
Electrical and Computer Engineering Dept.
Drexel University

The following system upgrade was proposed and published as part of design problem 4.1, 5.1 and 10.1 in A. R. Bergen and V. J. Vittal *Power Systems Analysis*, Prentice Hall, 2000.

This system upgrade will be conducted on the test system presented below using Mathpower 3.0.

MATPOWER is a public domain Matlab based software which can be downloaded from http://www.pserc.cornell.edu/matpower/ or http://blackbird.pserc.cornell.edu/matpower/3.0/download.html.

Problem Description:

Upgrade the Eagle Power System with 40-MW steel mill load and base case loads increased by 30% and with regulating transformers.

You are asked to upgrade the base system design (developed in Lab project-1 and 2, case-2) and obtain a minimum transmission system to serve the load and generation subject to the following specifications:

1. Provide sufficient capacity in the transmission lines and transformers for a 30% growth in existing load, assuming constant power factor.

2. A new steel mill with an estimated load of 40 MW at unity power factor is to be located as shown in Figure 1.1. Design a suitable transmission configuration to supply this new load.

3. Transmission voltages of 161kV or 69kV can be used. Bundled conductors are not to be used at these voltages. More details are specified in te requirement section.

4. Each power source (generator) should be connected to the rest of the system by at least three 161 kV lines. Even if one line fails, the remaining two should be capable of carrying the required load.

5. Seek a *minimum* cost design. Do not oversize conductors without justification.

6. The maximum number of available transformers is six.

7. It is unlikely that you can justify using the same conductor size at both 161 kV and 69 kV.

8. Line routes should follow transmission line routing regulations (road right-of-way).

9. The system should be *(n-1)*-secure, *i.e.* there should be neither branch overloads nor voltage violations for the base case as well as all single branch and generator outages.

Critical System Specification:

Verify all the items specified in the base case design.

1. ***Satisfactory system operation:*** All volt ages should be in the range from 0.96 *to 1.04* p.u. with no overloaded lines or transformers.

2. ***Loads:*** From the power flow summary report, determine the total load in the system, the losses, and the total generation.

3. ***Regulating Transformers:*** Set each transformer *to* regulate the voltage on the 69- kV bus. Select a scheduled voltage and include it in the bus data. Specify a tap range *of (0.9 to* 1.1 per unit) 62.1 kV *to* 75.9 kV. Make full use of the transformer taps before you decide to purchase capacitors.

If any *of* the criteria are violated, you will need *to* modify your design and re-do the analysis until the modified system meets the criteria.

Transmission Line, Power Flow and Contingency Analysis Requirements

1. **Transmission line requirements**: Write a Matlab program to calculate impedances of all the new transmission lines. The resistance of the lines should be calculated at 50°c. It is common in several power flow programs to represent the line capacitance in terms of the megavolt-amperes-reactive (MVAr) generated by the total capacitance or susceptance at rated voltage as shown in Table 1.1. This quantity should be calculated for all new transmission lines.

2. ***Generation:*** Make OWL (bus 1) the swing bus. *For* the generation at SWIFT (bus 2) and at PARROT (bus 3), make Qmin on each-100.00 MVA, make Qmax on each 250.0 MVA, and make Pmax on each 430 MW. Change the P-gen at each bus *to* appropriate values. Since the voltage is usually highest at generators and since *1.04* is at the upper limit *of* acceptable voltages, schedule the voltage on the three generators at *or* near *1.04* p.u.

   For cases where you remove lines or transformers, set the power generation at bus 2 and at bus 3 to 270 MW. For the generator outage cases, you should select the power schedules (suggest that the two remaining generators share the load approximately equally). Also for the generator outage cases, change the bus at which you drop a generator to a PQ bus with zero load. (It is not sufficient to set *P* generated to zero; it would continue to regulate voltage and output volt-amperes reactive). For the cases at which you schedule each generator at its maximum, lower the generation at the other two buses (suggest that the two share the remaining generation approximately equally).

3. ***Areas:*** Assign urban buses *to* a different area than rural buses. Use area interchange data *for* each area (this is needed *if* your power flow program provides this option), including the maximum and minimum acceptable voltages.

4. ***Data Checking:*** Since data *must* be in the *correct* columns in data input *to* the power flow program, spend time checking the computer output. Also check *to* see that all lines are connected *to* the *correct* buses.

Keep in mind that a change that solves one problem may create problems in other cases. It is suggested that you try all the outage cases before you consider any change to your system.

System Upgrade Report:

1. Title page and table of contents.

2. An executive summary. Important information about the project that executives would want to know without reading the complete report. At least include the total number of lines at each voltage level, total line miles and cost at each voltage level, total number of transformers and cost, total number of new substations and cost, total number and size of capacitor banks and cost, and total project cost. Make the executive summary a separate document from the main report (include project title and the names of all members in your group).

3. A map of the system with modifications showing the line routes and voltages.

4. A one-line diagram of the system showing the bus, line, transformer, and load connections.

5. Specifications of a representative transmission structure for each voltage level to be used for conductor spacings and impedance calculation for the modified transmission structures. Include a drawing of each structure. Cite the reference of the source of the structures.

6. Specifications of each line in the system: location (bus connections), voltage, length, conductor size, cost estimate, impedance and shunt capacitive susceptance in per unit, and MVA and ,current ratings. For the modified transmission system dealing with the addition ef the new steel mill load, show a sample impedance and susceptance calculation in an appendix.

7. Specification of each transformer in the system: location, size, cost.

8. Specification of each added substation: location, cost.

9. Number and title all figures.

10. Number and title all tables.

11. The power flow of each of the three cases showing the voltages and the loadings.

12. A summary of the power flow output of all contingency cases and of the system with no outages. All cases should contain all system changes, although you may choose to switch capacitors on and off from case to case.

13. Document all changes made in the base case design.

14. The current cost estimate including all system changes.

15. List of references.

Data Specifications:

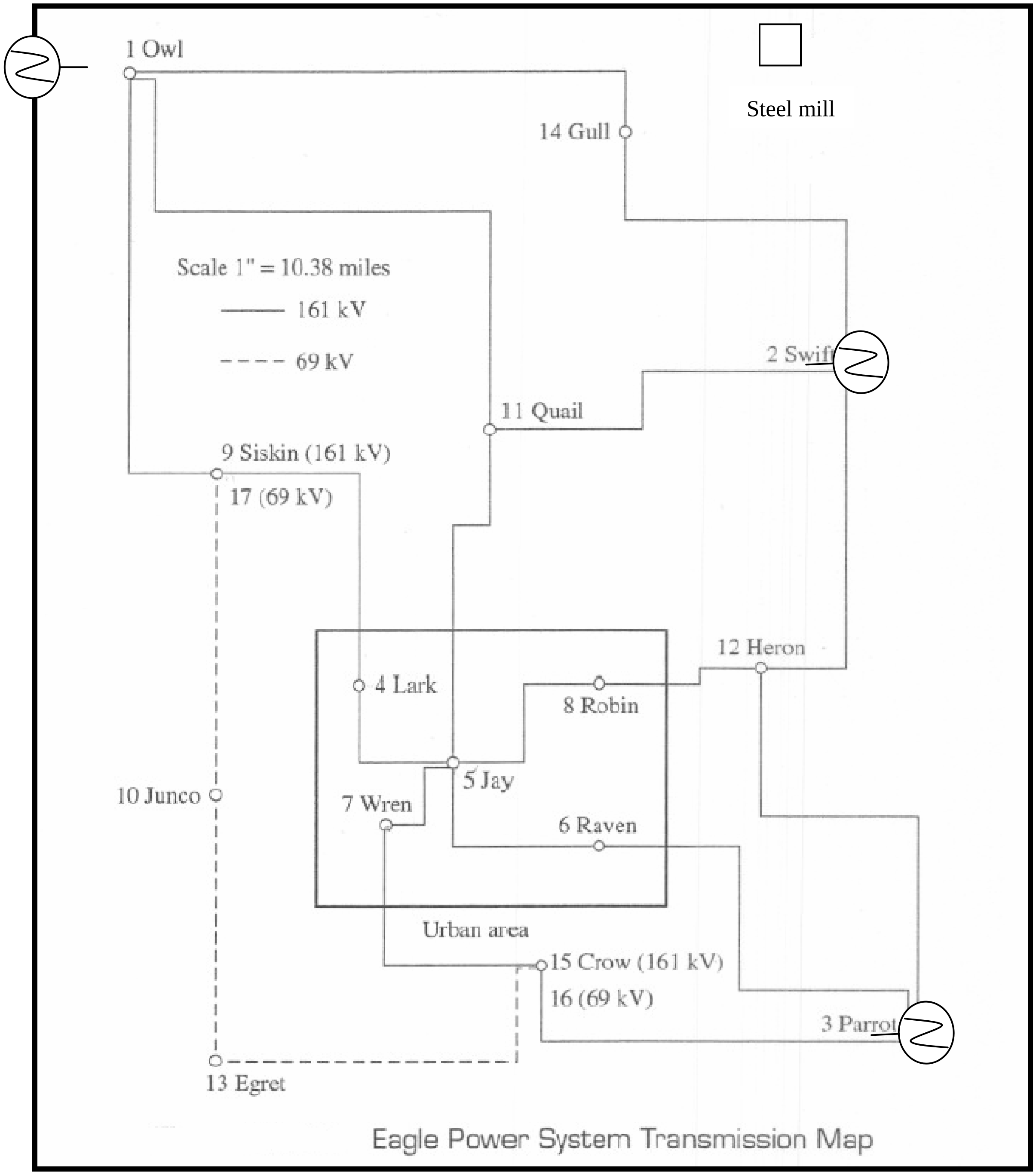

Figure:1.1 Eagle Power System Transmission Map(showing proposed sight of new steel mill)

Table 1.1 Transmission Line Parameters

Bus#	Bus#	Bus Name	Bus Name	Miles	Conductor	R-Ω	X-Ω	BMVA[1]
1	9	Owl 161	Siskin 161	24.0	Drake	3.085	17.47	3.629
1	11	Owl 161	Quail 161	36.7	Drake	4.718	26.70	5.550
1	14	Owl 161	Gull 161	28.2	Drake	3.629	20.53	4.264
2	11	Swift 161	Quail 161	21.5	Drake	2.774	15.66	3.251
2	12	Swift 161	Heron 161	20.3	Drake	2.618	14.78	3.070
2	14	Swift 161	Gull 161	24.0	Drake	3.085	17.47	3.629
3	6	Parrot 161	Raven 161	27.6	Drake	3.551	20.09	4.174
3	12	Parrot 161	Heron 161	27.6	Drake	3.551	20.09	4.174
3	15	Parrot 161	Crow 161	23.6	Drake	3.033	17.16	3.569
4	5	Lark 161	Jay 161	8.4	Dove	1.529	6.30	1.232
4	9	Lark 161	Siskin 161	18.8	Drake	2.411	13.69	2.843
5	6	Jay 161	Raven 161	10.8	Dove	1.970	8.09	1.584
5	7	Jay 161	Wren 161	6.0	Dove	1.089	4.48	.880
5	8	Jay 161	Robin 161	10.9	Dove	1.996	8.17	1.599
7	15	Wren 161	Crow 161	14.6	Drake	1.866	10.63	2.208
8	12	Robin 161	Heron 161	9.8	Drake	1.270	7.13	1.482
5	11	Jay 161	Quail 161	19.5	Drake	2.514	14.18	2.949
10	13	Junco 69	Egret 69	14.3	Hawk	3.033	10.15	.408
10	17	Junco 69	Siskin 69	16.2	Hawk	3.433	11.49	.462
13	16	Egret 69	Crow 69	21.9	Hawk	4.642	15.54	.624

1The BMVA is the volt-amperes reactive generated by the total susceptance corresponding to the line charging of the transmission line at the rated voltage.

Table 1.2 Existing Loads at Various Busses

Bus #	Bus Name	Load-MW	Load-MVAr
1	Owl		
2	Swift		
3	Parrot		
4	Lark	60	10
5	Jay	100	30
6	Raven	80	15
7	Wren	90	20
8	Robin	40	5
9	Siskin	10	5
10	Junco	15	10
11	Quail	75	15
12	Heron	40	15
13	Egret	30	10
14	Gull	35	10
15	Crow	10	0
		585	145

A. *Conductors available:* the following conductors from Table A3 in Grainger and Stevenson:

Partridge, Hawk, Dove, Drake, and Cardinal.

B. *Line costs:*

Line costs (including the conductors, right-of-way, structures, shield wire, etc) cost in $/mi.

	161 kV		69 kV	
Conductor size	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		

C. *Substation costs:* You may assume that the basic substation site exists at each bus 1-15. If you add a substation, then you must add to your costs the basic site cost for the new substation. Do *not* add the site cost for buses 1-15.

Basic site cost: Land, fence, grading, structures $300,000

Each line breaker and line termination: every line must have a circuit breaker at each end of the line.

161 kV $95,000 per three-phase breaker

69kV $48,000 per three-phase breaker

Transformer and associated equipment including circuit breakers 161/69 kV:

60 MVA $900,000

120 MVA $1,000,000

180 MVA $1,100,000

D. *Capacitor costs:*

Installation, associated equipment $60,000 per bank

Capacitors *$300/100* kVAr

E. *Power Source Rating*: Each power source is rated 490 MW, with a minimum voltampere reactive limit of -100 MVAr and a maximum voltampere reactive limit of 250 MVAr.

F. *The maximum current carrying capacity (or ampacity) of the allowable conductors:*

Partridge	475A
Hawk	659A
Dove	726 A
Drake	907A,
Cardinal	996A.

G. *Use the transmission line configurations at the 161 kV and at the 69 kV levels given in Figure 1.2.*

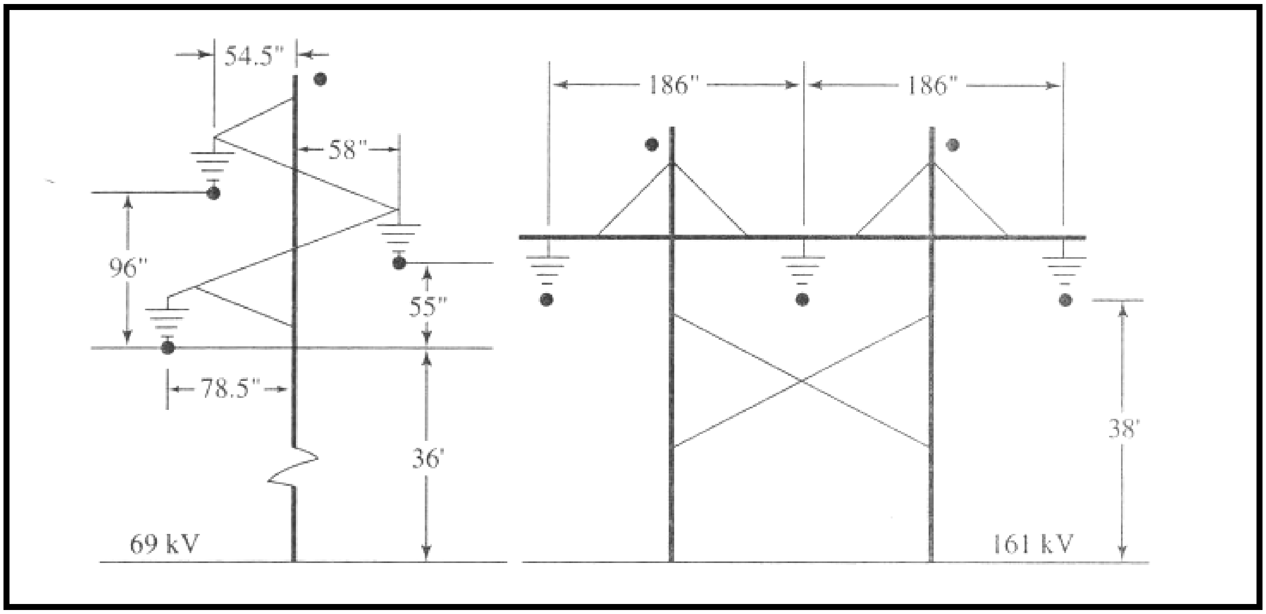

Figure 1.2

ECE-P 412 Winter 2004 Power System Analysis II - Design Project February 17, 2005

Appendix **A sample impedance and susceptance calculation**

Conductor: Dove

Distance: Bus 2. (Swift 161) to Bus 18 (Steel Mill) $= 18.165 miles$.

Impedance for a Dove Conductor:

From Table A3:

Resistance (at 50°C, ac-60Hz)	$0.1826\ Ohms/mile$
Inductive reactance (phase-to-neutral, 60 Hz and 1 ft spacing)	$X_a = 0.420\ Ohms/mile$
Capacitive reactance (phase-to-neutral, 60 Hz and 1 ft spacing)	$X_c = 0.0965\ MOhms \times mile$
Geometric mean madius	$D_s = GMR = 0.0314ft$
Outside diameter	$d = 0.927''$

Transmission Line Spacing based on Tower Structure

provided by Bergen and Vittal :

$$d_{ab} = 186'',\ d_{bc} = 186'' \text{ and } d_{ca} = 372''$$

Geometric Mean Distance between phases (line spacing) of non-bundled conductors:

The equivalent distance between the conductors is

$$\begin{aligned} D_{eq} &= D_m = \sqrt[3]{D_{12}D_{23}D_{31}} \\ &= \sqrt[3]{186 * 186 * 372} = \sqrt[3]{12\,869\,712} = 234.35'' = 19.5288' = 19'6'' \end{aligned}$$

Per-phase inductance

From the lecture (Stevenson Grainger 4.9) we have

$$\begin{aligned} X_d &= 2.022 \times 10^{-3} f \ln D_m \\ &= 2.022 \times 10^{-3} \times 60 \ln 19.5288 \\ &= 0.360\,55\ \Omega/mile \\ X_L &= X_a + X_d = 0.420 + 0.360\,36 = 0.780\,36\Omega/mi \end{aligned}$$

Alternatively from the lecture (Stevenson Grainger 4.10) we compute

$$\begin{aligned} L &= 2 \times 10^{-7} \ln \frac{D_{eq}}{D_s} = 2 \times 10^{-7} \ln \frac{19.529}{0.0314} \\ &= 1.286\,6 \times 10^{-6} H/m = 1.286\,6 \times 10^{-6} \times 1.60934 = 2.070\,6 \times 10^{-6}\Omega/mi \\ X_L &= \omega L = 2\pi 60 \times 2.070\,6 \times 10^{-6}\Omega/mi = 0.78058\Omega/mi \end{aligned}$$

Per-phase shunt capacitance

From the lecture (Stevenson Grainger 5.3) we have

$$
\begin{aligned}
X_d' &= \frac{1.779}{f} \times 10^6 \ln D_m \ \Omega \times miles \\
&= \frac{1.779}{60} \times 10^6 \ln 19.5288 \ \Omega \times miles \\
&= 88117 \ \Omega \times miles = 0.088117 \ M\Omega \times miles \\
X_L &= X_c + X_d' = 0.0965 + 0.088117 = 0.18462 \ M\Omega \times mi
\end{aligned}
$$

Alternatively we compute the outside radius

$$
r = \frac{d}{2} = \frac{0.927}{2}" = \frac{0.927}{2 \times 12}' = 3.8625 \times 10^{-2}
$$

and then from Stevenson-Grainger, chapter 5.5, eq. 5.34 we obtain

$$
\begin{aligned}
C_{an} = C_{bn} &= \frac{2\pi k}{\ln\left(\frac{D_m}{r}\right)} = \frac{2\pi \times 8.85 \times 10^{-12}}{\ln\left(\frac{19.5288}{3.8625 \times 10^{-2}}\right)} = 8.9317 \times 10^{-12} F/m \\
X_C &= \frac{1}{2\pi f C} = \frac{1}{2\pi f \frac{2\pi k}{\ln\left(\frac{D}{r}\right)}} = \frac{2.862}{f} \times 10^9 \ln \frac{D}{r} \ \Omega m \\
&= \frac{2.862}{60} \times 10^9 \ln\left(\frac{19.5288}{3.8625 \times 10^{-2}}\right) \Omega m \\
&= 2.9697 \times 10^8 \Omega m \\
&= \frac{2.9697 \times 10^8}{1609.34} = 1.8453 \times 10^5 \Omega \times mile
\end{aligned}
$$

Line impedance per unit length

$$
z = R + jX_L = 0.1826 + j0.78058 \Omega/mi
$$

Shunt susceptance per unit length:

$$
\begin{aligned}
b &= \omega C = 2 \times \pi \times 60 \times 8.9317 \times 10^{-12} S/m \\
&= 3.3672 \times 10^{-9} S/m \\
&= 3.3672 \times 10^{-9} \times 1609.34 = 5.4190 \times 10^{-6}
\end{aligned}
$$

or alternatively

$$
b = \frac{1}{X_C} = \frac{1}{1.8453 \times 10^5} = 5.4192 \times 10^{-6} S/mile
$$

Actual Line Impedance and shunt admittance for Bus 2. (Swift 161) to Bus 18 (Steel Mill)

$$
\begin{aligned}
Z_{2-18} &= z \times length = (0.1826 + j0.78058) \times 18.165 \\
&= 3.3169 + 14.179 j \Omega \\
B/2 &= b \times length = 5.4192 \times 10^{-6} \times 18.165 \\
&= 9.8440 \times 10^{-5} S
\end{aligned}
$$

$BMVA_{3\phi}$:

$$
Q_{3\phi} = V_{LL}^2 \times B = 161^2 \times 9.8440 \times 10^{-5} = 2.5517 MVar
$$