Industrial Systems

- Problem Example
- Basic System Overview
- Complex System
- Fine Detail
(c) 2.4 KV system:

I = \frac{10,000}{(1.732 \times 2.623)}
= 2201 A

(d) 0.48 KV system:

I = \frac{10,000}{(1.732 \times 0.525)}
= 11,000 A

(5) Summarize the base data in table

**SUMMARY**

**System Base Values**

(Base Power 10 000 kVA)

<table>
<thead>
<tr>
<th>Bus</th>
<th>Base kV</th>
<th>Base Z</th>
<th>Base I</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>69.00</td>
<td>476.1</td>
<td>83.67</td>
</tr>
<tr>
<td>4</td>
<td>14.427</td>
<td>20.82</td>
<td>400.2</td>
</tr>
<tr>
<td>8</td>
<td>14.427</td>
<td>20.82</td>
<td>400.2</td>
</tr>
<tr>
<td>24</td>
<td>14.427</td>
<td>20.82</td>
<td>400.2</td>
</tr>
<tr>
<td>31</td>
<td>14.427</td>
<td>20.82</td>
<td>400.2</td>
</tr>
<tr>
<td>32</td>
<td>14.427</td>
<td>20.82</td>
<td>400.2</td>
</tr>
<tr>
<td>36</td>
<td>2.623</td>
<td>0.02756</td>
<td>11 000.0</td>
</tr>
<tr>
<td>37</td>
<td>0.525</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(6) Convert transformer impedances to per unit using

\[ Z_p = \frac{Z}{Z_{base}} \times \frac{S_{base}}{S_{rated}} \]

(a) T2:

\[ Z = \frac{(1.0 + j8.0)}{100} \times \frac{(66^2 / 69^2)}{(10 / 15)} \]

\[ = 0.00610 + j0.04880 \]

(b) T13:

\[ Z = \frac{(0.8 + j5.75)}{100} \times \frac{(2.4^2 / 2.623^2)}{(10 / 15)} \]

\[ = 0.02679 + j0.19255 \]

(c) T14:

\[ Z = \frac{(0.8 + j5.75)}{100} \times \frac{(13.2^2 / 14.427^2)}{(10 / 1)} \]

\[ = 0.06697 + j0.48135 \]
Operating Voltages

Each Section: Use \( V_{op} = \frac{V_T}{\sqrt{3}} \)

1. Bus 4: \( KV = 69.0 \times \frac{13.8}{66} \) turns ratio of \( T_2 \)
   \[ = 14.427 \, KV \]

2. Bus 36: \( KV = 14.427 \times \frac{2.4}{13.2} \) turns ratio of \( T_{13} \)
   \[ = 2.623 \, KV \]

3. Bus 37: \( KV = 14.427 \times \frac{0.48}{13.2} \) turns ratio of \( T_{14} \)
   \[ = 0.525 \, KV \]

Base impedance each section

(3) Calculate base impedances: \( \frac{Z_{op}}{Z_{in}} \) for each bus

(a) 69 KV system:
   \[ Z = \frac{(69^2 \times 10^3)}{(10,000)} = 476.1 \, \Omega \]

(b) 13.8 KV system:
   \[ Z = \frac{(14.427^2 \times 10^3)}{(10,000)} \quad \text{really 14.4} \]
   \[ = 20.82 \, \Omega \quad \text{really 2.62} \]

(c) 2.4 KV system:
   \[ Z = \frac{(2.623^2 \times 10^3)}{(10,000)} \]
   \[ = 0.688 \, \Omega \]

(d) 0.48 KV system:
   \[ Z = \frac{(0.525^2 \times 10^3)}{(10,000)} \]
   \[ = 0.02756 \, \Omega \]

4. Calculate base currents: \( I_{op} = \frac{\text{base KVA}}{\sqrt{3} \times \text{base KV}} \)

(a) 69 KV system:
   \[ I = \frac{10,000}{1.732 \times 69.0} = 83.67 \, \text{A} \]

(b) 13.8 KV system:
   \[ I = \frac{10,000}{1.732 \times 14.427} = 400.2 \, \text{A} \]
Look at each trf.
Get rated values
1. \( X_{pu}^R \)
2. \( V_R^R \) Base primary
3. \( S_R^R \) from V-A values

Calculate operating values
1. \( V_{op}^o \) for all buses from given \( V_{op} = 69 kV \)
2. Given \( S_{op} = 10 MVA \)

Change \( X_{pu}^R \rightarrow X_{pu}^{op} \)
Per Unit with 1-line diagram

- T2 in operating
- 69kV base

- 4 wire lines
- in 13.8kV base

Impedance Diagram Per Unit Data
(Base MVA = 10)
Problem #1

The steps in reducing the raw data to per unit are as follows:

1. Select base power: $S = 10,000$ MVA
2. Determine base voltages
   - (a) Select bus 2 nominal voltage of 69 KV as base
   - (b) Calculate base voltages at other system levels

Type wires: 1-3c, various diameters
Handout T13 Ratings

$S_R = 2.5 \text{ MVA}$

$V_R = 13.2 \text{ KV} / 2.47 \text{ KV}$
- prim
- sec

$Z_{pu (trf)} = 0.8 + j 5.75 \%$

Operating Conditions

Operation in System:

$S_{op} = 2.62 \text{ MVA}$
- pri

$V_{op} = 2.62 \text{ KV}$
- sec

$V_{op} = 2.62 \text{ KV}$

$S_{op} = \frac{10}{2.47}$

Section 6.6, pg 41

$Z_{pu} = (0.8 + j 5.75) \times \left(\frac{2.4}{2.6}\right) \left(\frac{10}{2.5}\right)$

Solve for $Z_{pu}$

New $X_{pu}$

$V_{op} = 0.027 + j 0.19$

Same method for other trf

Finish for HW
Wire impedances P.U.

Assume $T = 20^\circ C$ std spacing

$$Z_{wire}^{pu} = \text{Actual } Z_{wire} \text{ from tables and length} \text{ look up}$$

Two lines $\triangle P$ and $\triangle B$

$$Z_{op} \text{ Base} \equiv \frac{V_{op}^2}{S_{op}} = \frac{(14.4 \text{ kV})^2}{10 \text{ MVA}} = \frac{10 \text{ MVA}}{20.8 \Omega}$$

Bus

Line $\triangle$

510' l-3C 400 Kcmil

$$Z_{wire}^2 = 0.15 + j0.19$$

$$(Z_{op}^{pu})_{op} = \frac{0.15 + j0.19}{20.8}$$

Line $\triangle$

2865' l-3C 3/0 AWG 8

$$Z_{wire}^8 = 0.19 + j0.12$$
(7) Calculate line impedance in ohms: \( z = \text{actual ohms} / \text{base ohms} \)

Lines 7, 8, 18, and 19 are 3/C, copper cables, paper insulated, shielded conductors; dielectric constant: 3.7

(a) Line 7:
\[
\begin{align*}
z &= (0.01515 + j0.01887) / 20.82 \\
&= 0.000728 + j0.000906 \text{ per unit}
\end{align*}
\]

(b) Line 8:
\[
\begin{align*}
z &= (0.19138 + j0.12119) / 20.82 \\
&= 0.009192 + j0.005821 \text{ per unit}
\end{align*}
\]
\[
Y = Z_c / -jX_c = 20.82 / -j8530 \\
= 0 + j0.002413 \text{ per unit}
\]

(c) Line 18:
\[
\begin{align*}
z &= (0.16864 + j0.02074) / 20.82 \\
&= 0.00810 + j0.001 \text{ per unit}
\end{align*}
\]

(d) Line 19:
\[
\begin{align*}
z &= (0.24056 + j0.02959) / 20.82 \\
&= 0.01155 + j0.00142 \text{ per unit}
\end{align*}
\]

(8) Calculate \( X_{d'} \) of two synchronous machines in per unit using equation from (6)

(a) Synchronous motor on bus 8:
\[
X_{d'} = j0.28 * ((13.2^2) / (14.427^2)) * (10,000 / 9,800) \\
= j0.2392
\]

(b) Generator G1:
\[
X_{d'} = j0.20 * ((13.8^2) / (14.427^2)) * (10,000 / (8500/0.8)) \\
= j0.1722
\]
Generator Rating: \( G_1 \)

\[ V_r = 13.8 \text{ kV}, \quad pF = .8 \]

\[ P_r = 8 \text{ MW} \]

\[ S_r = \frac{8}{.8} = 10 \text{ MVA} \]

\[ X_{pu} = 0.20 \text{ rated} \]

Generator Operation

\[ V_{op} = 14.427 \text{ kV} \]

\[ S_{op} = 10,000 \text{ kVA} = 10 \text{ MVA} \]

\[ X_{pu \text{ (operation)}} = j0.2 \left( \frac{13.8}{14.42} \right) \left( \frac{10}{8} \right) \]

Section 8.6, p. 35

\[ X_{op} = j0.17 \quad V_{op} \quad S_{op} \]
Motor Ratings: \( M_1 \)

\[
V_R = 13.2 \text{ kV}
\]

\[
S_R = 9100 \text{ kVA}
\]

\[
X'_2 = 0.28 \text{ pu rated}
\]

Motor Operation

\[
V_{op} = 14.427 \text{ kV}
\]

\[
S_{op} = 10,000 \text{ kVA}
\]

Section 8a, Page 5

\[
X_{2'}\text{ (op)} = \frac{X(\text{rating})}{V_{op}} \left( \frac{V_R}{V_{op}} \right)^2 \frac{S_{op}}{S_R}
\]

\[
= j0.28 \left( \frac{13.2}{14.42} \right)^2 \left( \frac{10,000}{9100} \right)
\]

\[
X_{pu}\text{ (motor 1)} = j0.239
\]

Now simplify with \( \text{pu line diagram} \) for HW
Fig 26.20 PT5U

Bus Symbol

24.9 kV
MV bus bar

line convention is △

8 feeders rated 200 A

fault
* Equivalent circuit for entire system.
- Transformers simplified to inductors.

P.U. Solution Format

Our reward

Next Devil in Details
Large Industrial Power System

- Redundant/failsafe approach
- Dual Back-up
- Two 69KV lines with
  - individual breakers
  - WCB 10,000
  - Lines 267 Kmil
- Parallel buses 1 & 2
- Connected by normally open circuit/switcher
- For redundancy if one 69KV fails
  - Two transformers $T_1$, $T_2$
  - 69 - 13.8KV
- 60KV surge arrestors
  - Find it on what bus?
  - Ground a line to ground rated impedance
Symbol Definitions

- Surge arrester (used to contain 3rd harmonic)
- Surge capacitor
- Rectifier bank
- Reactor non-magnetic core
- 3-Φ, neutral ungrounded
- 3-Φ, neutral grounded (allowed to test for balance)
- Air circuit breaker, removable type DIT
- Circuit breaker, non-rotor (oil or vacuum)
- Air circuit breaker, draw out type
- Disconnecting fuse, non-rotor
- Fuse
- Switch
- Potential Transformer
- Ground
- Two winding Power Transformer

- Three phase, then wire delta connection
- Pava indicator
- H-Ω flag
- AC machine (generator or motor)
- Circuit breaker
- Capacitor bank (used to compensate reactive load)
1. Top of page Cap Bank: Role?
   Look at 18.8 kV bus

2. Lots of fuses
   Disconnected fuse on all motors

3. Circuit Breakers:
   Air breaker
   Oil, SF₆ breaker

4. Allows for?

5. Surge spark gap on 13.8 kV line
   69 kV surge cap on 69 kV line
   \[\text{Diagram of surge protector}\]

6. \[\text{Diagram of electrical component}\]
Composite Single-Line Diagram for Typical Large Industrial Power System
Large Industrial Power System

- Redundant/failsafe approach – Dual backup
- Two 69 kV lines with individual breakers

  → Lines 10,000 ft of 267 kMil
  → Parallel Buses 1 & 2 connected by normally open air circuit breaker for redundancy if one 69kV fails
  → Two transformers T1: Δ - Y & T2: Δ - Y 69 – 13.8 kV w/60 kV surge arrestors
  → 400A line to ground rated impedance

Two redundant 13.8kV busses, 3 and 4

Normally open switch air circuit breaker

---

Both 3 and 4 have 1.5 MVAR “C” compensation due to 17 motors downline to reduce I<sub>in</sub> and pF↑

---

Lines @ 13.8 kV
Each has air circuit breaker

Total of 8 13.8 kV lines

Throughout the system there are 25 lines
  17 lines @13.8 kV
  8 lines @ 480 V
There are 15 Transformers
There are 16 Motors at various HP
Throughout the system are 25 flag lines. Can you find?

17 lines @ 13.8 KV
8 lines @ 480 V

There are 15 Transformers

There are 16 Motors at various HP

Reality begins need for PSSE

There are 40 Busses

2 @ 69 kV
19 @ 13.8 kV
4 @ 2.4 kV
1 @ 4.16 kV
13 @ 480 V
1 @ 460 V

Note: Bus #38 dedicated to lighting

What next?
<table>
<thead>
<tr>
<th>Line</th>
<th>First Connection Bus Number</th>
<th>Protection First Connection has</th>
<th>Second Connection Bus Number</th>
<th>Protection Second Connection has</th>
<th>Line Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>30</td>
<td>Air circuit breaker, drawout type</td>
<td>38</td>
<td>X</td>
<td>0.480</td>
</tr>
<tr>
<td>25</td>
<td>30</td>
<td>Drawout fuse and Air circuit breaker, drawout type</td>
<td>35</td>
<td>X</td>
<td>0.480</td>
</tr>
</tbody>
</table>

You are able to see that Buses 17, 18, 19, 20 and 21 and others in this system services a numerous number of motors. There are many different number of motors in this one line diagram, which operate at different hp and have different ratings. This table shows all the motors in this system.

<table>
<thead>
<tr>
<th>Buss Number</th>
<th>Group &gt; 51 hp</th>
<th>Group &lt; 50 hp</th>
<th>Any thing else</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>X</td>
<td>X</td>
<td>9000hp Synchronous</td>
<td>9000hp</td>
</tr>
<tr>
<td>11</td>
<td>500hp</td>
<td>X</td>
<td>X</td>
<td>500hp</td>
</tr>
<tr>
<td>17</td>
<td>850hp</td>
<td>500hp</td>
<td>X</td>
<td>1350hp</td>
</tr>
<tr>
<td>18</td>
<td>850hp</td>
<td>500hp</td>
<td>X</td>
<td>1350hp</td>
</tr>
<tr>
<td>19</td>
<td>2500hp</td>
<td>X</td>
<td>1250hp</td>
<td>3750hp</td>
</tr>
<tr>
<td>20</td>
<td>1750hp</td>
<td>X</td>
<td>2000hp</td>
<td>3750hp</td>
</tr>
<tr>
<td>21</td>
<td>X</td>
<td>750hp</td>
<td>X</td>
<td>750hp</td>
</tr>
<tr>
<td>22</td>
<td>X</td>
<td>X</td>
<td>150hp</td>
<td>150hp</td>
</tr>
<tr>
<td>23</td>
<td>X</td>
<td>X</td>
<td>150hp</td>
<td>150hp</td>
</tr>
<tr>
<td>28</td>
<td>400hp</td>
<td>500hp</td>
<td>X</td>
<td>900hp</td>
</tr>
<tr>
<td>29</td>
<td>625hp</td>
<td>465hp</td>
<td>X</td>
<td>1090hp</td>
</tr>
<tr>
<td>30</td>
<td>400hp</td>
<td>500hp</td>
<td>X</td>
<td>900hp</td>
</tr>
<tr>
<td>33</td>
<td>300hp</td>
<td>X</td>
<td>X</td>
<td>300hp</td>
</tr>
<tr>
<td>34</td>
<td>75hp</td>
<td>35hp</td>
<td>X</td>
<td>110hp</td>
</tr>
<tr>
<td>35</td>
<td>300hp</td>
<td>X</td>
<td>X</td>
<td>300hp</td>
</tr>
<tr>
<td>36</td>
<td>X</td>
<td>X</td>
<td>2500hp IND. Motor</td>
<td>2500hp</td>
</tr>
<tr>
<td>37</td>
<td>700hp</td>
<td>300hp</td>
<td>X</td>
<td>1000hp</td>
</tr>
</tbody>
</table>

Each one of these motors might be connected to a protection device or transformer but will start at a bus some where. There are 40 buses though out the system. The following table shows all the voltages of each Bus.
### Buses

<table>
<thead>
<tr>
<th>Bus</th>
<th>Voltage on the Bus in (kV)</th>
<th>Bus</th>
<th>Voltage on the Bus in (kV)</th>
<th>Bus</th>
<th>Voltage on the Bus in (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69</td>
<td>15</td>
<td>13.8</td>
<td>29</td>
<td>0.480</td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>16</td>
<td>13.8</td>
<td>30</td>
<td>0.480</td>
</tr>
<tr>
<td>3</td>
<td>13.8</td>
<td>17</td>
<td>0.480</td>
<td>31</td>
<td>13.8</td>
</tr>
<tr>
<td>4</td>
<td>13.8</td>
<td>18</td>
<td>0.480</td>
<td>32</td>
<td>13.8</td>
</tr>
<tr>
<td>5</td>
<td>13.8</td>
<td>19</td>
<td>2.4</td>
<td>33</td>
<td>0.480</td>
</tr>
<tr>
<td>6</td>
<td>13.8</td>
<td>20</td>
<td>2.4</td>
<td>34</td>
<td>0.480</td>
</tr>
<tr>
<td>7</td>
<td>13.8</td>
<td>21</td>
<td>0.480</td>
<td>35</td>
<td>0.480</td>
</tr>
<tr>
<td>8</td>
<td>13.8</td>
<td>22</td>
<td>0.480</td>
<td>36</td>
<td>2.4</td>
</tr>
<tr>
<td>9</td>
<td>13.8</td>
<td>23</td>
<td>0.480</td>
<td>37</td>
<td>0.480</td>
</tr>
<tr>
<td>10</td>
<td>13.8</td>
<td>24</td>
<td>13.8</td>
<td>38</td>
<td>0.480</td>
</tr>
<tr>
<td>11</td>
<td>2.4</td>
<td>25</td>
<td>13.8</td>
<td>39</td>
<td>4.16</td>
</tr>
<tr>
<td>12</td>
<td>13.8</td>
<td>26</td>
<td>13.8</td>
<td></td>
<td>Not labeled</td>
</tr>
<tr>
<td>13</td>
<td>13.8</td>
<td>27</td>
<td>13.8</td>
<td></td>
<td>0.460</td>
</tr>
<tr>
<td>14</td>
<td>13.8</td>
<td>28</td>
<td>0.480</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With out transformers the power industry would probably not exist. This leads me to my next table. Transformers help us with transporting electricity because higher the voltage the less loss we will have. \( P = \frac{V^2}{R} \). You can see that there are a total of 15 transformers in this system.

### Transformer Data

<table>
<thead>
<tr>
<th></th>
<th>Old MVA Base</th>
<th>New MVA Base</th>
<th>Primary Windings</th>
<th>Primary Voltage</th>
<th>Primary Connection</th>
<th>Secondary Windings</th>
<th>Secondary Voltage</th>
<th>Secondary Connection</th>
<th>Old (PU) Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>15</td>
<td>15</td>
<td>△</td>
<td>69kV</td>
<td>Bus 1</td>
<td>Y</td>
<td>13.8kV</td>
<td>Bus 3</td>
<td>0.08</td>
</tr>
<tr>
<td>T2</td>
<td>15</td>
<td>15</td>
<td>△</td>
<td>69kV</td>
<td>Bus 2</td>
<td>Y</td>
<td>13.8kV</td>
<td>Bus 4</td>
<td>0.08</td>
</tr>
<tr>
<td>T3</td>
<td>1.725</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 5</td>
<td>Y</td>
<td>4.16kV</td>
<td>Bus 39</td>
<td>0.06</td>
</tr>
<tr>
<td>T4</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 6</td>
<td>Y</td>
<td>2.4kV</td>
<td>Bus 11</td>
<td>0.055</td>
</tr>
<tr>
<td>T5</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 12</td>
<td>Y</td>
<td>480V</td>
<td>Bus 17</td>
<td>0.0675</td>
</tr>
<tr>
<td>T6</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 13</td>
<td>Y</td>
<td>480V</td>
<td>Bus 18</td>
<td>0.0675</td>
</tr>
<tr>
<td>T7</td>
<td>3.75</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 14</td>
<td>Y</td>
<td>2.4kV</td>
<td>Bus 19</td>
<td>0.055</td>
</tr>
<tr>
<td>T8</td>
<td>3.75</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 15</td>
<td>Y</td>
<td>2.4kV</td>
<td>Bus 20</td>
<td>0.055</td>
</tr>
<tr>
<td>T9</td>
<td>0.75</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 16</td>
<td>Y</td>
<td>480V</td>
<td>Bus 21</td>
<td>0.0575</td>
</tr>
<tr>
<td>T10</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 25</td>
<td>Y</td>
<td>480V</td>
<td>Bus 28</td>
<td>0.0575</td>
</tr>
<tr>
<td>T11</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 26</td>
<td>Y</td>
<td>480V</td>
<td>Bus 29</td>
<td>0.0575</td>
</tr>
<tr>
<td>T12</td>
<td>1.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 27</td>
<td>Y</td>
<td>480V</td>
<td>Bus 30</td>
<td>0.0575</td>
</tr>
<tr>
<td>T13</td>
<td>2.5</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 31</td>
<td>△</td>
<td>2.4kV</td>
<td>Bus 36</td>
<td>0.0575</td>
</tr>
<tr>
<td>T14</td>
<td>1</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 32</td>
<td>△</td>
<td>480V</td>
<td>Bus 37</td>
<td>0.0575</td>
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<tr>
<td>RT</td>
<td>1.725</td>
<td>15</td>
<td>△</td>
<td>13.8kV</td>
<td>Bus 5</td>
<td>Y</td>
<td>480V</td>
<td>Not Stated</td>
<td>0.06</td>
</tr>
</tbody>
</table>

The following table is the per unit diagram of this whole system and you can see how easily per unit can convert a one line diagram.
Bus 24 is critical. How can you tell?

Separate
10 MVA
UPS Generator
Protected by 15kV Surge Capacitor

Substantial Protection
Backup
Surge Fault

25 lines (each connect) two buses
Each bus is protected!
Lots of transformers (15)

Many motor loads (16)
One lighting load @ 480

One UPS generator: Find it!

Redundancy Points: Where? Why?
There are 40 busses

2 @ 69 kV
19 @ 13.8 kV
4 @ 2.4 kV
1 @ 4.16 kV
13 @ 480 V
1 @ 460 V

Note:
Bus #38
Dedicated to
"lighting"

Bus 24 is critical

Separate UPS
Generator
Protected by 15 kV
surge capacitor

pF = 0.8
$X_d = 9\%$
10 MVA

Substantial Protection
Backup
Surge
Fault
Fig 1
Composite Single-Line Diagram for Typical Large Industrial Power System
Two redundant 13.8KV Buses

Normally open switch
Air circuit breaker

3 → Distribution Buses

3 feeds E, F, G, H

4 feeds I, J, K, L, M

Both 3 and 4 have 1.5 MVAR "C" Compensation due to 17 Motors downline to reduce I_in and PF↑

3

4

5 → 8

lines@13.8KV each has air circuit breaker

Total of 8 13.8KV lines K & L in parallel
<table>
<thead>
<tr>
<th>Line</th>
<th>First Connection Bus Number</th>
<th>Protection First Connection has</th>
<th>Second Connection Bus Number</th>
<th>Protection Second Connection has</th>
<th>Line Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>Air circuit breaker, removable type DH</td>
<td>13</td>
<td>X</td>
<td>13.8</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Air circuit breaker, removable type DH</td>
<td>5</td>
<td>X</td>
<td>13.8</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Air circuit breaker, removable type DH</td>
<td>26</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>Air circuit breaker, removable type DH</td>
<td>6</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Air circuit breaker, removable type DH</td>
<td>15</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Air circuit breaker, removable type DH</td>
<td>7</td>
<td>X</td>
<td>13.8</td>
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<tr>
<td>7</td>
<td>4</td>
<td>Air circuit breaker, removable type DH</td>
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</tr>
<tr>
<td>8</td>
<td>4</td>
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<td>Air circuit breaker, removable type DH</td>
<td>13.8</td>
</tr>
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<td>9</td>
<td>X</td>
<td>25</td>
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</tr>
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<td>10</td>
<td>X</td>
<td>12</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>X</td>
<td>13</td>
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<td>13.8</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>X</td>
<td>27</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>Switch</td>
<td>14</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>X</td>
<td>27</td>
<td>Disconnecting switch, nondrawout</td>
<td>13.8</td>
</tr>
<tr>
<td>15</td>
<td>7</td>
<td>X</td>
<td>16</td>
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<tr>
<td>16</td>
<td>17</td>
<td>Drawout fuse and Air circuit breaker, drawout type</td>
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<td>X</td>
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<tr>
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<tr>
<td>18</td>
<td>24</td>
<td>Air circuit breaker, removable type DH</td>
<td>31</td>
<td>X</td>
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<tr>
<td>19</td>
<td>24</td>
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<td>X</td>
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<tr>
<td>20</td>
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<td>X</td>
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<td>21</td>
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<td>X</td>
<td>0.480</td>
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<tr>
<td>22</td>
<td>29</td>
<td>Air circuit breaker, drawout type</td>
<td>38</td>
<td>X</td>
<td>0.480</td>
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<tr>
<td>23</td>
<td>29</td>
<td>Drawout fuse and Air circuit breaker, drawout type</td>
<td>34</td>
<td>X</td>
<td>0.480</td>
</tr>
</tbody>
</table>
ROCKET SCIENCE
Large Industrial Power System

- Redundant/failsafe approach – Dual backup
- Two 69 kV lines with individual breakers

- Lines 10,000 ft of 267 kMil

- Parallel Buses 1 & 2 connected by normally open air circuit breaker for redundancy if one 69kV fails
- Two transformers $T_1: \Delta - Y \& T_2: \Delta - Y$ 69 - 13.8 kV w/60 kV surge arrestors
- 400A line to ground rated impedance

Two redundant 13.8kV busses, 5 and 4

Normally open switch air circuit breaker

Both 3 and 4 have 1.5 MVAR "C" compensation due to 17 motors downline to reduce $I_{in}$ and $\varphi$

Lines @ 13.8 kV
Each has air circuit breaker

Total of 8 13.8 kV lines

Throughout the system there are 25 lines
17 lines @13.8 kV
8 lines @ 480 V
There are 15 Transformers
There are 16 Motors at various HP