Short Circuit (Fault) Analysis

- **FAULT-PROOF SYSTEM**
  - not practical
  - neither economical
  - faults or failures occur in any power system

- In the various parts of the electrical network under short circuit or unbalanced condition, the determination of the magnitudes and phase angles
  - Currents
  - Voltages
  - Impedances
Application of Fault Analysis

1. The determination of the required mechanical strength of electrical equipment to withstand the stresses brought about by the flow of high short circuit currents
2. The selection of circuit breakers and switch ratings
3. The selection of protective relay and fuse ratings
Application of Fault Analysis

4. The setting and coordination of protective devices
5. The selection of surge arresters and insulation ratings of electrical equipment
6. The determination of fault impedances for use in stability studies
7. The calculation of voltage sags caused resulting from short circuits
8. The sizing of series reactors to limit the short circuit current to a desired value
9. To determine the short circuit capability of series capacitors used in series compensation of long transmission lines
10. To determine the size of grounding transformers, resistances, or reactors
Per Unit Calculations
Three-phase Systems

\[ Z_B = \frac{(\text{base voltage, } kV_{L-L})^2 \times 1000}{\text{base } kVA_{3\Phi}} \]

\[ Z_B = \frac{(\text{base voltage, } kV_{L-L})^2}{\text{base } MVA_{3\Phi}} \]
Per Unit Quantities

\[ I_{pu} = \frac{\text{actual current}}{\text{Base Current (} I_B \text{)}} \]

\[ V_{pu} = \frac{\text{actual voltage (} kV \text{)}}{\text{Base Voltage (} kV_B \text{)}} \]

\[ Z_{pu} = \frac{\text{actual impedance}}{\text{Base impedance (} Z_B \text{)}} \]
Changing the Base of Per Unit Quantities

\[ Z_{pu[old]} = \frac{\text{actual impedance, } Z(\Omega)}{\left(\text{base } kV_{old}\right)^2 \times 1000} \]

\[ Z(\Omega) = \frac{Z_{pu[old]} \left(\text{base } kV_{old}\right)^2 \times 1000}{\text{base } kVA_{old}} \]

\[ Z_{B[new]} = \frac{\left(\text{base } kV_{new}\right)^2 \times 1000}{\text{base } kVA_{new}} \]

\[ Z_{pu[new]} = \frac{Z(\Omega)}{Z_{B[new]}} \]
Changing the Base of Per Unit Quantities

\[
Z_{pu[old]} = \frac{\text{actual impedance, } Z(\Omega)}{(\text{base } kV_{[old]}^2 \times 1000)} \cdot \frac{\text{base } kVA_{[old]}}{
\]

\[
Z(\Omega) = Z_{pu[old]} \left(\text{base } kV_{[old]}^2 \times 1000\right)
\]

\[
Z_{B[new]} = \left(\text{base } kV_{[new]}^2 \times 1000\right) \frac{\text{base } kVA_{[new]}}{
\]

\[
Z_{pu[new]} = \frac{Z(\Omega)}{Z_{B[new]}}
\]
<table>
<thead>
<tr>
<th>kVA/hp</th>
<th>hp rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Induction &lt; 100 hp</td>
</tr>
<tr>
<td>1.00</td>
<td>Synchronous 0.8 pf</td>
</tr>
<tr>
<td>0.95</td>
<td>Induction 100 &lt; 999 hp</td>
</tr>
<tr>
<td>0.90</td>
<td>Induction &gt; 1000 hp</td>
</tr>
<tr>
<td>0.80</td>
<td>Synchronous 1.0 pf</td>
</tr>
</tbody>
</table>
SYMMETRICAL COMPONENTS
Positive Sequence

\[ V_{a0} = V_{b0} = V_{c0} \]

Zero Sequence

Negative Sequence

Unbalanced Phasors

Short Circuit Calculations
IEEE Presentation
Symmetrical Components of Unbalanced Three-phase Phasor

\[
\begin{align*}
V_a &= V_{a0} + V_{a1} + V_{a2} \\
V_b &= V_{a0} + a^2 V_{a1} + a V_{a2} \\
V_c &= V_{a0} + a V_{a1} + a^2 V_{a2}
\end{align*}
\]

\[
\begin{align*}
V_{a0} &= \frac{1}{3} (V_a + V_b + V_c) \\
V_{a1} &= \frac{1}{3} (V_a + a V_b + a^2 V_c) \\
V_{a2} &= \frac{1}{3} (V_a + a^2 V_b + a V_c)
\end{align*}
\]
Symmetrical Components of Unbalanced Three-phase Phasor

In matrix form:

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = \begin{bmatrix}
1 & 1 & 1 \\
1 & a^2 & a \\
1 & a & a^2
\end{bmatrix} \begin{bmatrix}
V_{a0} \\
V_{a1} \\
V_{a2}
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & 1 & 1 \\
1 & a & a^2 \\
1 & a^2 & a
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]
Power System Short Circuit Calculations

Sequence Networks
Fault Point

The fault point of a system is that point to which the unbalanced connection is attached to an otherwise balanced system.
Definition of Sequence Networks

Positive-sequence Network

\[ E_{a1} = \] Thevenin’s equivalent voltage as seen at the fault point

\[ Z_1 = \] Thevenin’s equivalent impedance as seen from the fault point

\[ V_{a1} = E_{a1} - I_{a1} Z_1 \]
Definition of Sequence Networks

Negative-sequence Network

\[ Z_2 = \text{Thevenin’s equivalent negative-sequence impedance as seen at the fault point} \]

\[ V_{a2} = -I_{a2}Z_2 \]
Zero-sequence Network

\[ Z_0 = \text{Thevenin’s equivalent zero-sequence impedance as seen at the fault point} \]

\[ V_{a0} = -I_{a0}Z_0 \]
Power System Short Circuit Calculations

Sequence Network Models of Power System Components
Synchronous Machines (Positive Sequence Network)

\[ Z_1 = jx''_d \]
Synchronous Machines (Negative Sequence Network)

\[ Z_2 = j \frac{x''_d + x''_q}{2} \]

Where:

- \( x''_d \) = direct-axis sub-transient reactance
- \( x''_q \) = quadrature-axis sub-transient reactance
Synchronous Machines (Zero Sequence Network)

Solidly-Grounded Neutral

\[ jX_0 \]

\[ n \]

\[ I_0 \]

ground
Synchronous Machines (Zero Sequence Network)

Impedance-Grounded Neutral

\[ jX_0 \]

\[ 3Z_g \]

ground
Synchronous Machines (Zero Sequence Network)

Ungrounded-Wye or Delta Connected Generators

\[ jX_0 \]

[Diagram showing a schematic of a synchronous machine with symbols for zero sequence network, jX₀, and I₀ connected to ground.]
Two-Winding Transformers (Positive Sequence Network)

Standard Symbol

Equivalent Positive-seq. Network

P

S

Z_{PS}
Three-Winding Transformers (Positive Sequence Network)

Standard Symbol

\[ Z_{ps} = Z_p + Z_s \]
\[ Z_{pt} = Z_p + Z_t \]
\[ Z_{st} = Z_s + Z_t \]

Equivalent Positive-Sequence Network

\[ Z_p = \frac{1}{2}(Z_{ps} + Z_{pt} - Z_{st}) \]
\[ Z_s = \frac{1}{2}(Z_{ps} + Z_{st} - Z_{pt}) \]
\[ Z_t = \frac{1}{2}(Z_{pt} + Z_{st} - Z_{ps}) \]
Transformers (Negative Sequence Network)

The negative-sequence network of two-winding and three-winding transformers are modeled in the same way as the positive-sequence network since the positive-sequence and negative-sequence impedances of transformers are equal.
Simplified Derivation of Transformer Zero-Sequence Circuit Modeling

(Thanks to Engr. Antonio C. Coronel, Retired VP, Meralco, and former member, Board of Electrical Engineering)

| Grounded wye            | \( S_1 = 1 \) and \( S_3 = 0 \)  
                          | \( \text{or} \) \( S_2 = 1 \) or \( S_4 = 0 \) |
|-------------------------|-----------------------------------|
| Delta                   | \( S_1 = 0 \) and \( S_3 = 1 \)  
                          | \( \text{or} \) \( S_2 = 0 \) and \( S_4 = 1 \) |
| Ungrounded wye          | \( S_1 = 0 \) and \( S_3 = 0 \)  
                          | \( \text{or} \) \( S_2 = 0 \) and \( S_4 = 0 \) |
Simplified Derivation of Transformer Zero-Sequence Circuit Modeling

Grounded wye – Grounded wye

S1 = 1  S2 = 1  S3 = 0  S4 = 0
Grounded wye – Ungrounded wye

\[ S1 = 1 \]
\[ S2 = 0 \]
\[ S3 = 0 \]
\[ S4 = 0 \]
Simplified Derivation of Transformer Zero-Sequence Circuit Modeling

Grounded wye – Delta

S1 = 1
S2 = 0
S3 = 0
S4 = 1
Simplified Derivation of Transformer
Zero-Sequence Circuit Modeling

Delta – Delta

\[ S1 = 0 \]
\[ S2 = 0 \]
\[ S3 = 0 \]
\[ S4 = 0 \]
Transformers
(Zero-Sequence Circuit Model)

Transformer Connection

Zero-Sequence Circuit Equivalent

\[
\begin{align*}
P & \quad Q \\
P & \quad Q \\
Z_{PQ} &
\end{align*}
\]
Transformers
(Zero-Sequence Circuit Model)

Transformer Connection

Zero-Sequence Circuit Equivalent
Transformers (Zero-Sequence Circuit Model)

Transformer Connection

Zero-Sequence Circuit Equivalent

Short Circuit Calculations
IIEE Presentation
Transformers (Zero-Sequence Circuit Model)
Transmission Lines
(Positive Sequence Network)
Transmission Lines (Negative Sequence Network)

The same model as the positive-sequence network is used for transmission lines inasmuch as the positive-sequence and negative-sequence impedances of transmission lines are the same.
The zero-sequence network model for a transmission line is the same as that of the positive- and negative-sequence networks. The sequence impedance of the model is of course the zero-sequence impedance of the line. This is normally higher than the positive- and negative-sequence impedances because of the influence of the earth’s resistivity and the ground wire/s.
Power System Short Circuit Calculations

Classification of Power System Short Circuits
Shunt Faults

- Single line-to-ground faults
- Double line-to-ground faults
- Line-to-line faults
- Three-phase faults
Series Faults

- One-line open faults
- Two-line open faults
Combination of Shunt and Series Faults

- Single line-to-ground and one-line open
- Double line-to-ground and one-line open faults
- Line-to-line and one-line open faults
- Three-phase and one-line open faults
Combination of Shunt and Series Faults

- Single line-to-ground and two-line open faults
- Double line-to-ground and two-line open faults
- Line-to-line and two-line open faults
- Three-phase and two-line open faults
Balanced Faults

Symmetrical or Three-Phase Faults
Derivation of Sequence Network Interconnections

Boundary conditions:

\[ I_a + I_b + I_c = 0 \]  \hspace{1cm} \text{Eq'n (1)}

\[ V_F = V_a - I_a Z_f = V_b - I_b Z_f = V_c - I_c Z_f \]  \hspace{1cm} \text{Eq'n (2)}
Short Circuit Calculations

$I_{a1} = \frac{E_{a1}}{Z_1 + Z_f}$

$I_f = I_{a0} + I_{a1} + I_{a2}$

$I_f = I_{a1} = \frac{E_{a1}}{Z_1 + Z_f}$

$Z_f = 0$, 

$I_f = I_{a1} = \frac{E_{a1}}{Z_1}$
Unbalanced Faults

Single Line-to-Ground Faults
Derivation of Sequence Network Interconnections

Boundary conditions:

\[ I_b = I_c = 0 \]
\[ V_a = I_a Z_f = 0 \]
\[ I_{a0} = I_{a1} = I_{a2} = \frac{E_{a1}}{Z_0 + Z_1 + Z_2 + 3Z_f} \]

If \( Z_f = 0 \)

\[ I_{a0} = I_{a1} = I_{a2} = \frac{E_{a1}}{Z_0 + Z_1 + Z_2} \]

\( Z_1 = Z_2 \)

\[ I_{a0} = I_{a1} = I_{a2} = \frac{E_{a1}}{Z_0 + 2Z_1} \]

\[ I_f = I_a = I_{a0} + I_{a1} + I_{a2} = 3I_{a1} = 3I_{a0} \]

If \( Z_f = 0 \) and \( Z_1 = Z_2 \)

\[ I_f = I_a = \frac{3E_{a1}}{Z_0 + 2Z_1} \]
Unbalanced Faults

Line-to-Line Faults
Derivation of Sequence Network Interconnections

Boundary conditions:

\[ I_a = 0 \]
\[ I_b = -I_c \]
\[ V_b - I_b Z_f = V_c; \text{ or } V_b - V_c = I_b Z_f \]
\[ I_{a1} = \frac{E_{a1}}{Z_1 + Z_2 + Z_f} \]

If \( Z_f = 0 \) and \( Z_1 = Z_2 \)

\[ I_{a1} = \frac{E_{a1}}{2Z_1} \]

The fault current

\[ I_f = I_b = -I_c = I_{a0} + a^2 I_{a1} + aI_{a2}, \]

\[ I_{ao} = 0; \quad I_{a1} = -I_{a2} \]

\[ I_f = (a^2 - a)I_{a1} = -j\sqrt{3}I_{a1} \]
thus, with $Z_1 = Z_2$

$$I_f = -j\sqrt{3}\left[\frac{E_{a1}}{2Z_1 + Z_f}\right]$$

if $Z_f = 0$

$$|I_f| = -j\sqrt{3}\left[\frac{E_{a1}}{2Z_1}\right] = \left(\frac{\sqrt{3}}{2}\right)\frac{E_{a1}}{Z_1}$$

$$I_{f[3\phi]} = \frac{E_{a1}}{Z_1}$$

$$I_{f[L-L]} = \frac{\sqrt{3}}{2}I_{f[3\phi]}$$
Unbalanced Faults

Double-to-line Ground Fault
Derivation of Sequence Network Interconnections

Boundary conditions:

\[ I_a = 0 \quad \text{Eq'}n \ BC-1 \]

\[ V_b = I_b Z_f + (I_b + I_c) Z_g \quad \text{Eq'}n \ BC-2 \]

\[ V_c = I_c Z_f + (I_b + I_c) Z_g \quad \text{Eq'}n \ BC-3 \]
\[
I_{a1} = \frac{E_{a1}}{Z_1 + Z_f + \frac{(Z_2 + Z_f)(Z_0 + Z_f + 3Z_g)}{Z_2 + Z_0 + 2Z_f + 3Z_g}}
\]
Negative-sequence Component:

\[ I_{a2} = -I_{a1} \left( \frac{Z_0 + Z_f + 3Z_g}{Z_2 + Z_0 + 2Z_f + 3Z_g} \right) \]

Zero-sequence Component:

\[ I_{a0} = -I_{a1} \left( \frac{Z_2 + Z_f}{Z_2 + Z_0 + 2Z_f + 3Z_g} \right) \]

The fault current

\[ I_f = I_b + I_c = (I_{a0} + a^2I_{a1} + aI_{a2}) + (I_{a0} + aI_{a1} + a^2I_{a2}) \]

\[ I_f = 2I_{a0} + (a^2 + a)I_{a1} + (a + a^2)I_{a2} \]

\[ I_f = 2I_{a0} + (-1)I_{a1} + (-1)I_{a2} = 2I_{a0} - (I_{a1} + I_{a2}) \]

but \( I_{a0} + I_{a1} + I_{a2} = 0 \); or \( I_{a0} = -(I_{a1} + I_{a2}) \)

thus, \( I_f = 3I_{a0} \)
If \( Z_f = Z_g = 0 \) and \( Z_1 = Z_2 \)

\[
I_{a1} = \frac{E_{a1}}{Z_1 + \frac{Z_1 Z_0}{Z_1 + Z_0}} = \frac{(Z_1 + Z_0)E_{a1}}{Z_1^2 + 2Z_1 Z_0}
\]

\[
I_{a2} = -I_{a1} \left( \frac{Z_0}{Z_1 + Z_0} \right) = -\left( \frac{E_{a1}}{Z_1 + \frac{Z_1 Z_0}{Z_1 + Z_0}} \right) \left( \frac{Z_0}{Z_1 + Z_0} \right) = -\frac{Z_0 E_{a1}}{Z_1^2 + 2Z_1 Z_0}
\]
If \( Z_f = Z_g = 0 \) and \( Z_1 = Z_2 \)

\[
I_{a1} = \frac{E_{a1}}{Z_1 + \frac{Z_1 Z_0}{Z_1 + Z_0}} = \frac{(Z_1 + Z_0)E_{a1}}{Z_1^2 + 2Z_1 Z_0}
\]

\[
I_{a2} = -I_{a1}\left(\frac{Z_0}{Z_1 + Z_0}\right) = -\left(\frac{E_{a1}}{Z_1 + \frac{Z_1 Z_0}{Z_1 + Z_0}}\right)\left(\frac{Z_0}{Z_1 + Z_0}\right) = -\frac{Z_0 E_{a1}}{Z_1^2 + 2Z_1 Z_0}
\]

\[
I_{a0} = -I_{a1}\left(\frac{Z_1}{Z_1 + Z_0}\right) = \left(\frac{E_{a1}}{Z_1 + \frac{Z_1 Z_0}{Z_1 + Z_0}}\right)\left(\frac{Z_1}{Z_1 + Z_0}\right) = \frac{Z_1 E_{a1}}{Z_1^2 + 2Z_1 Z_0} = \frac{E_{a1}}{Z_1 + 2Z_0}
\]

\[
I_f = 3I_{a0} = \frac{3E_{a1}}{Z_1 + 2Z_0}
\]
Voltage Rise Phenomenon

Single-to-line Ground Fault
Unfaulted Phase B Voltage During Single Line-to-Ground Faults

\[ V_b = V_{a0} + a^2 V_{a1} + a V_{a2} \]

\[ V_b = -\left( \frac{E_{a1}}{2Z_1 + Z_0} \right) Z_0 + a^2 \left[ E_{a1} - \left( \frac{E_{a1}}{2Z_1 + Z_0} \right) Z_1 \right] - a \left( \frac{E_{a1}}{2Z_1 + Z_0} \right) Z_1 \]

\[ V_b = E_{a1} \left[ a^2 - \left( \frac{Z_0 - Z_1}{2Z_1 + Z_0} \right) \right] = E_{a1} \left[ a^2 - \left( \frac{Z_1}{Z_1} \right) \left( \frac{Z_0 - 1}{Z_1} \right) \right] \]

\[ V_b = E_{a1} \left[ a^2 - \left( \frac{Z_0 - 1}{2 + \frac{Z_0}{Z_1}} \right) \right] \]

neglecting resistances, \( R_1 \) and \( R_0 \);

\[ V_b = E_{a1} \left[ a^2 - \left( \frac{X_0 - 1}{2 + \frac{X_0}{X_1}} \right) \right] \]
Unfaulted Phase B Voltage During Single Line-to-Ground Faults

Neglecting resistances R0 & R1

Phase B Voltage (p.u.) vs. X0/X1 ratio.
Fault MVA

\[ MVA_F = I_F \times MVA_{base} \]

where, for \( E_{a1} = 1.0 \) p.u.;

for three – phase fault in p.u. :

\[ I_{F(3\phi)} = \frac{1}{Z_1} \]

for single line - to - ground fault in p.u. :

\[ I_{F(SLG)} = \frac{3}{Z_0 + 2Z_1} \]
Fault MVA

Three-phase fault MVA:

\[ MVA_{F(3\phi)} = I_{F(3\phi)} \text{ (p.u.)} \times MVA_{\text{base}} \]

\[ Z_1 = \frac{1}{I_{F(3\phi)}} \text{ p.u.} \]

Single line-to-ground fault MVA:

\[ MVA_{F(SLG)} = I_{F(SLG)} \text{ (p.u.)} \times MVA_{\text{base}} \]

\[ 2Z_1 + Z_0 = \frac{3}{I_{F(SLG)}} \text{ p.u.} \]

\[ Z_0 = \frac{3}{I_{F(SLG)}} - 2Z_1 \]
Assumptions Made to Simplify Fault Calculations

1. Pre-fault load currents are neglected.
2. Pre-fault voltages are assumed equal to 1.0 per unit.
3. Resistances are neglected (only for 115kV & up).
4. Mutual impedances, when not appreciable are neglected.
5. Off-nominal transformer taps are equal to 1.0 per unit.
6. Positive- and negative-sequence impedances are equal.
Outline of Procedures for Short Circuit Calculations

1. Setup the network impedances expressed in per unit on a common MVA base in the form of a single-line diagram.
2. Determine the single equivalent (Thevenin’s) impedance of each sequence network.
3. Determine the distribution factor giving the current in the individual branches for unit total sequence current.
Outline of Procedures for Short Circuit Calculations

4 Interconnect the three sequence networks for the type of fault under considerations and calculate the sequence currents at the fault point.

5 Determine the sequence current distribution by the application of the distribution factors to the sequence currents at the fault point.

6 Synthesize the phase currents from the sequence currents.
Outline of Procedures for Short Circuit Calculations

7 Determine the sequence voltages throughout the networks from the sequence current distribution and branch impedances
8 Synthesize the phase voltages from the sequence voltage components
9 Convert the pre unit currents and voltages to actual physical units
CIRCUIT BREAKING SIZING
(Asymmetrical Rating Factors)

- **Momentary Rating**
  - Multiplying Factor = 1.6

- **Interrupting Rating**
  - Multiplying Factor
    - 8 cycles = 1.0
    - 5 cycles = 1.1
    - 3 cycles = 1.2
    - 1 ½ cycles = 1.5
EXAMPLE PROBLEM

In the power system shown, determine the momentary and interrupting ratings for primary and secondary circuit breakers of transformer T2.
Solution:

Equivalent 69kV system@ 100MVA:

\[ I_{F(3\phi)} = \begin{bmatrix} 800 \\ 100 \end{bmatrix} = 8 \text{pu} \]

\[ I_{F(SLG)} = \begin{bmatrix} 1000 \\ 100 \end{bmatrix} = 10 \text{pu} \]

\[ x_1 = \frac{1}{8} = 0.125 \text{pu} \]

\[ x_0 = \frac{3}{10} - 2 \times 0.125 = 0.05 \text{pu} \]

T1:

\[ x = 0.08 \begin{bmatrix} 100 \\ 30 \end{bmatrix} = 0.2667 \text{pu} \]

G1:

\[ x'' = 0.10 \begin{bmatrix} 100 \\ 25 \end{bmatrix} = 0.40 \text{pu} \]

\[ x_0 = 0.06 \begin{bmatrix} 100 \\ 25 \end{bmatrix} = 0.24 \text{pu} \]

T2, T3, T3:

\[ x = 0.06 \begin{bmatrix} 100 \\ 75 \end{bmatrix} = 0.80 \text{pu} \]

M1, M2: kVA_B = 0.9 \times 5000 = 4500

or MVA_B = 4.5

\[ x = 0.15 \begin{bmatrix} 100 \\ 4.5 \end{bmatrix} = 3.3333 \text{pu} \]
Solution:

Positive sequence network:
Solution:

Zero sequence network:

- 13.8kV Bus
- 4.16kV Bus
- 13.8kV CB
- 4.16kV CB

- j0.05
- j5.0
- j0.2667
- j5.3167
- j0.24
- j0.80
- j0.80
- j???
- j???
Improper Sequence Network Models
Improper Sequence Network Models

Case 1 Power System Diagram

- **G1**: 1125kVA, Pf=0.8, X^d=0.1835pu
- **T1**: 1000kVA, Z=5.87
- **C3**: 4.6m, 375mm^2, 6/ph
- **C1**: 24.4m, 375mm^2, 6/ph

- **C2**: 24.4m, 375mm^2, 6/ph
- **C4**: 4.6m, 250mm^2, 5/ph

- **G2**: 1250kVA, Pf=0.8, X^d=0.195pu

- **F2**: 208V
- **F3**: 208V
- **F1**: 208V

- **M1**: 40HP, X^d=28%
- **M2**: 75HP, X^d=28%
- **M3**: 10HP, X^d=28%

**Utility**
- SCA=112.5MVA
- X/R = 10.00
Improper Sequence Network Models

Case 1 – Impedance Diagram

Short Circuit Calculations
IIEE Presentation
Incorrect Sequence Network Models

FOR GENERATOR

ONE LINE DIAGRAM

G1 = G2 = G5
P = 1000 kW / 1250 kVA
V = 480 volts
Pf = 0.8

G3 = G4
P = 1250 kW / 1582 kVA
V = 480 volts
Pf = 0.8

ATS GROUP 1
w/ group of small motors
motors (hundreds HP)

ATS GROUP 2

IMPEDEANCE DIAGRAM

Zw = 0.0015
FL
ZL = 0.042
Zeq
ZL = 0.0636
QUESTIONS?
hAvE a GrEaT dAy!