Open delta

Fed from Three phase source

Supplying Three phase load
Open delta

Fed from Three phase source

A1  ||  A2  ||  B1  ||  B2  ||  C1  ||  C2

a1  --  b1  --  c1

a2  --  b2  --  c2

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\[ V_{ab} = V \angle 0 \]

\[ V_{bc} = V \angle -120 \]

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Applying KVL in loop $a_2b_2c_2a_2$:

$V_{ab} = V \angle 0$

$V_{bc} = V \angle -120$
Applying KVL in loop $a_2b_2c_2a_2$:

\[ V_{ca} = -[V_{ab} + V_{bc}] \]
\[ = -V \angle 0 - V \angle -120 \]
\[ = -V + 0.5V + j0.866V \]
\[ = (0.5 + j0.866)V \]
\[ = V \angle 120 \]
Phase load currents and line currents in open delta:

\[ V_{ca} = V \angle 120 \]
\[ I_{c2a2} = I \angle 120 \]
\[ V_{a2b2} = V \angle 0 \]
\[ I_{a2b2} = I \angle 0 \]
\[ I_{b2c2} = I \angle -120 \]
\[ V_{bc} = V \angle -120 \]
Phase load currents and line currents in open delta:

\[ V_{ca} = V \angle 120 \]

\[ I_{c_2a_2} = I \angle 120 \]
\[ V_{a_2b_2} = V \angle 0 \]

\[ I_{a_2b_2} = I \angle 0 \]
\[ I_{b_2c_2} = I \angle -120 \]

\[ V_{bc} = V \angle -120 \]

\[ I_{a_2} = I_{a_2b_2} - I_{c_2a_2} = I \angle 0 - I \angle 120 = I \angle -30 \]
Phase load currents and line currents in open delta:

\[ V_{ca} = V \angle 120 \]

\[ I_{c2a2} = I \angle 120 \]
\[ V_{a2b2} = V \angle 0 \]
\[ I_{a2b2} = I \angle 0 \]
\[ I_{b2c2} = I \angle -120 \]

\[ V_{b2c2} = V \angle -120 \]

\[ I_{a2} = I_{a2b2} - I_{c2a2} = I \angle 0 - I \angle 120 = I \angle -30 \]

\[ I_{c2} = I_{c2a2} - I_{b2c2} = I \angle 120 - I \angle -120 = I \angle 90 \]

N.B.: Line currents have the same values and angles even if the load was star connected
Active & reactive power of open delta:

1\textsuperscript{st} Transformer:
\[ V_{a_2b_2} = V \angle 0 \]
\[ I_{a_2} = I \angle -30 \]
\[ V_{b_c} = V \angle -120 \]

\[ S_{T1} = V_{a_2b_2} I_{a_2}^* \]
\[ = (V \angle 0)(I \angle 30) \]
\[ = VI \angle 30 \]

\[ S_{T2} = V_{b_c} (-I_{c_2})^* \]
\[ = (V \angle -120)(I \angle 90) \]
\[ = VI \angle -30 \]

\[ \vec{S}_{vv} = \vec{S}_{T1} + \vec{S}_{T2} = \sqrt{3} V_{\text{Line}} \times I_{\text{Line}} \]

\[ \vec{Q}_{T1} = -\vec{Q}_{T2} = \frac{1}{2} (V_{\text{Line}} \times I_{\text{Line}}) \]
De-rating of open delta

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Supplying Three phase load

\[ I_{\text{Line}} = I_{\text{Phase}} \]

\[ S_{\Delta\Delta} = 3V_{\text{phase}} \times I_{\text{Phase}} \]
De-rating of open delta

\[ S_{\Delta\Delta} = 3 \times V_{\text{phase}} \times I_{\text{phase}} \]
\[ \vec{S}_{vv} = \vec{S}_{r1} + \vec{S}_{r2} = \sqrt{3} \times V_{\text{Line}} \times I_{\text{Line}} \]
\[ = \sqrt{3} \times V_{\text{Line}} \times (I_{\text{phase}}) \]
\[ = \sqrt{3} \times V_{\text{Line}} \times I_{\text{phase}} \]
De-rating of open delta

Fed from Three phase source

Supplying Three phase load

\[ I_{\text{Line}} = I_{\text{Phase}} \]

\[ S_{\Delta\Delta} = 3 V_{\text{phase}} \times I_{\text{Phase}} \]

\[ \vec{S}_{vv} = \vec{S}_{r1} + \vec{S}_{r2} = \sqrt{3} \ V_{\text{Line}} \times I_{\text{Line}} \]

\[ = \sqrt{3} \ V_{\text{Line}} \times (I_{\text{Phase}}) \]

\[ = \sqrt{3} \ V_{\text{Line}} \times I_{\text{Phase}} \]

\[ \therefore \frac{S_{vv}}{S_{\Delta\Delta}} \approx \frac{1}{\sqrt{3}} \approx 57.7\% \]
Open delta

**Disadvantages:**

- De-rated operation, 57.7% of ΔΔ bank; \( \times \frac{3}{2} = 86.6\% \) of the capacity of the remaining two transformers

- Average P.F. of V bank < Load P.F. (~ 86.6% of balanced load P.F.);
  The two transformers operate at different power factors; for a balanced load P.F. of \( \cos \phi \), one transformer has a P.F. of \( \cos(30-\phi) \) while the other has a P.F. of \( \cos(30+\phi) \), accordingly voltage regulation differs.

- Accordingly, increasing load (even if perfectly balanced), causes terminal secondary voltages to be unbalanced
Two single phase 150 kVA, 7200/600 V transformers are connected in open delta configuration. Find the maximum three phase load supplied.

Rated Secondary current of either transformer = \( \frac{150000}{600} = 250 \) A
This current should not be exceeded whatever was the type of connection, Accordingly:

\[
\left( S_{\text{Load}} \right)_{\text{maximum}} = \sqrt{3}VI = \sqrt{3} \times 600 \times 250 = 260kVA
\]

Available rating of two transformers = \( 2 \times 150 = 300kVA \)

% Derating = \( \frac{260}{300} = 86.6\% \)

One transformer is producing reactive power, while the other is consuming reactive power. This energy exchange between the two transformers is the reason for limited power output of 57.7% instead of an expected 66.7%
Open Y – Open Delta

Fed from Three phase source

Supplying Three phase load
Open Y – Open Delta

Disadvantages:

- Very large return current flow in neutral of primary