Electrical Machines

Alternators (Synchronous Generators)
Example (1)
Calculate the value of the distribution factor for a 3-phase winding of 4-pole alternator having 36 slots.

Example (2)
Calculate the distribution factor for a single phase alternator having 6 slots/pole (i) when all slots are wound, and (ii) when only four adjacent slots per pole are wound, the remaining slots being unwound.

Example (3)
An alternator has 9 slots per pole. If each coil spans 8 slot pitches, what is the value of pitch factor.

Example (4)
The stator of 3-phase alternator has 9 slots per pole and carries a balanced 3-phase, double-layer winding. The coils are short-pitched and the coil pitch is 7 slots. Find the distribution factor and pitch factor.

Example (5)
Calculate the pitch factor for a winding having 24 stator slots when the coil spans 5 slots.

Example (6)
A 3-phase, 50 Hz, star connected alternator has 180 conductor per phase and flux per pole is 0.0543 Wb. Find (i) e.m.f. generated per phase, ans (ii) e.m.f. between line terminals. Assume the winding to be full-pitched and distribution factor to be 0.96.

Example (7)
Find the number of armature conductors in series per phase required for the armature of a 3-phase, 50 Hz, 10-pole alternator. The winding is star-connected to give a line voltage of 11 kV. The flux per pole is 0.16 Wb. Assume $K_p = 1$ and $K_d = 0.96$. 
Example (8)

The armature of an 8-pole, 3-phase, 50 Hz alternator has 18 slots and 10 conductor per slot. A flux of 0.04 Wb is entering the armature from one pole. Calculate the induced e.m.f. per phase.

Example (9)

A 3-phase, 16-pole synchronous generator has a star-connected winding with 144 slots and 10 conductors per slot. The flux per pole is 0.03 Wb, sinusoidally distributed and the speed is 375 r.p.m. Calculate (i) the frequency, and (ii) the induced e.m.f.

Example (10)

A 3-phase, star-connected alternator on open circuit is required to generate a line voltage of 3.6 kV at 50 Hz when driven at 500 r.p.m. The stator has 3 slots per pole per phase and 10 conductors per slot. Calculate (i) the number of poles, and (ii) useful flux per pole. Assume all the conductors per phase to be connected in series and the coils to be full-pitch.

Example (11)

A 4-pole, 3-phase, 50 Hz, star connected alternator has 60 slots with 4 conductors per slot. Coils are short-pitched by 3 slots. If the phase spread is 60 degree, find the line voltage induced for a flux per pole of 0.943 Wb, distributed sinusoidally. All the turns per phase are in series.

Example (12)

A 12-pole, 3-phase, star-connected alternator has 72 slots. The flux per pole is 0.0988 Wb. Calculate:

(i) The speed of rotation if the frequency of the generated e.m.f. is 50 Hz.
(ii) The terminal e.m.f. for full-pitch coils and 8 conductors per slot.
(iii) The terminal e.m.f. if the coil span is reduced to 2/3 of the pole pitch.
Example (13)

A 500 kVA, 3-phase, star-connected alternator has a rated line-to-line voltage of 3300 V. the resistance and synchronous reactance per phase are 0.3 Ω and 4 Ω respectively. Calculate the line value of e.m.f. generated at full-load, 0.8 power factor lagging.

Example (14)

A 1000 kVA, 2300 V, 3-phase, star-connected alternator has a resistance of 0.309 Ω per phase and synchronous reactance of 3.31 Ω per phase. Calculate the change of line voltage when the rated output of 1000 kVA at power factor of 0.8 lagging is switched off. Assume the speed and exciting current to remain unaltered.

Example (15)

A 1500 kVA, 6.6 kV, 3-phase, star-connected alternator has effective armature resistance of 0.5 Ω/phase and a synchronous reactance of 5 Ω/phase. Find the percentage change in terminal voltage when the rated output of 1500 kVA at (i) unity power factor, (ii) 0.8 lagging power factor, and (iii) 0.8 leading power factor is switched off. The speed and excitation current remain unchanged.

Example (16)

A 60 kVA, 220 V, 50 Hz, single-phase alternator has effective resistance of 0.016 Ω and an armature leakage reactance of 0.07 Ω. Find the voltage induced in the armature when the alternator is delivering rated current at a load power factor of (i) unity, (ii) 0.7 lagging, and (iii) 0.7 leading.

Example (17)

A 50 kVA, 500 V, single-phase a.c. generator gave the following test results:

Open circuit test: a field current of 12 A produced an e.m.f. of 300 volts.

Short circuit test: a field current of 12 A caused a current of 175 A to flow in the short-circuited armature.
The effective armature resistance is 0.2 Ω.

(i) Calculate the synchronous impedance and synchronous reactance.

(ii) If the a.c. generator is supplying full-load current of 100 A at 0.8 power factor lagging, to what value would the terminal voltage rise if the load was removed? Also find voltage regulation for this load and power factor.

**Example (18)**

A 1200 kVA, 3300 V, 50 Hz, three-phase, star-connected alternator has armature resistance of 0.25 Ω per phase. A field current of 40 A produces a short-circuit current of 200 A and an open circuit e.m.f. of 100 V (line to line). Find the voltage regulation on (i) full-load 0.8 power factor lagging, and (ii) full-load 0.8 power factor leading.

**Example (19)**

A 3-phase, star-connected alternator is rated at 1600 kVA, 13500 V. the armature resistance and synchronous reactance are 1.5 Ω and 30 Ω respectively per phase. Calculate the percentage voltage regulation for a load of 1280 kW at 0.8 leading power factor.

**Example (20)**

If a field excitation of 10 A in a certain alternator gives a current of 150 A on short-circuit and a terminal voltage of 900 V (-phase value) on open circuit, find the internal voltage drop with a load current of 60 A.

**Example (21)**

A 3-phase, 50 Hz, star-connected, 1000 kVA, 2300 V alternator gives a short-circuit current of 400 A for a certain field excitation. With the same excitation, the open-circuit voltage was 1328 V (phase value). The d.c. resistance between two lines is 0.412 Ω. Find (i) effective armature resistance, (ii) synchronous reactance, and (iii) the full-load voltage regulation at 0.8 power factor lagging.
Example (22)

A 1500 kVA, 6600 V, 3-phase, star-connected alternator with a resistance of 0.4 Ω and reactance of 6 Ω per phase delivers full-load current at power factor 0.8 lagging and normal rated voltage. Estimate the terminal voltage for the same excitation and load current at 0.8 power factor leading.

Example (23)

A 3-phase, 10 kVA, 400 V, 50 Hz, Y-connected alternator supplies the rated load of 0.8 power factor lagging. If the armature resistance is 0.5 Ω/phase and synchronous reactance is 10 Ω/phase, find (i) voltage regulation, and (ii) power angle.

Example (24)

A 10 MVA, 6.6 kV, 3-phase, star-connected alternator gave open-circuit and short-circuit test figures as under:

<table>
<thead>
<tr>
<th>Field current in [A]</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line e.m.f. in [kV]</td>
<td>2.4</td>
<td>4.8</td>
<td>6.1</td>
<td>7.1</td>
<td>7.6</td>
<td>7.9</td>
</tr>
<tr>
<td>Short-circuit current in [A]</td>
<td>288</td>
<td>528</td>
<td>875</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Find the voltage regulation on full-load at a power factor of 0.8 lagging. Armature resistance per phase is 0.13 Ω.
3-Phase Synchronous Generator

(Alternator)

(output)

3-Phase Supply

Slator

(Armature)

(Armature winding)

3-Phase Winding

Rotor

(Field)

DREAM
01012045000 - 01012046000

Alternators (Synchronous Generators)

- بحسب المولد الترموزي ثلاثي الوجه (Alternator) يولد له مزدوج ثلاثي.

- ويجعل المولد مزدوج الوجه (Alternator) من المولد ولفل للفل Finds Ни

- ينبع من عملية ال (D.C. Gen)

Commutator

1. لا يكون له منصبه النورس (Commutator)

2. العضو الذي ينتج فيه اللف ولفل (Armature)

- عضو الإستناثما النورس

- مولد單 الكهربائي الملفات الذي ينتج فيه اللف ولفل

- نورس مركزية

- يتم التعديل إلى الكرتي مساحة دوره كلبكلال كلاك اللف ولفل رضي كوبن،

- افتتاح نقط شفاطس إزالة ورشة كوبن (نوع - مولدات أجهزة اللف ولفل

السائق (ملعات اجهزة للف ولفل ولفل نقطة كبيرة)

4. يتم تشغيل المولد rotor بسرعات عالية بمبابة ذات السرعة والبيئة المطلوبة.
Construction of Alternator

1- Stator

2- Rotor

i) Salient (Projecting) Pole type.

ii) Non-Salient (Cylindrical) Pole type.

(Salient Poles)

 advertisers: 01012045000 - 01012046000

120 → 400 r.p.m.
Alternators (Synchronous Generators)

Cylindrical Poles

-al د-القطان الأسطواني

ذالكت سرية الـ rotor عالي دافئ ذو الدائرة صغير وضوء كبير

1500 or 3000 r.p.m.

 الكم الا قطان صغير

Alternator operation

1- تقديم ملفات العضو الأول شبار سغر ضئيل قلالة قياس

2- عند إعداد العضو الدوار فإن هذا الشكل يدرس رفع العضو وربط ملفات

العضو الثالثة الرأسية

3- تقول 20 مع ملفات العضو الثالثة ووضع هذه ملفات كتب كتوم

بجهاذ شف راية ذو زاوية (120°)

4- ثم إذا وضع على زوجة حفر (p):

\[ P = \frac{NP}{120} \]

\[ N: \text{rotor speed r.p.m} \]

\[ P: \text{no of Poles} \]
A.C. Armature winding

Full-Pitch Coil

$\text{Span} = 180^\circ \text{ electrical}$

Fractional-Pitch Coil

$\text{Span} < 180^\circ \text{ electrical}$
Armature Winding of Alternator

(2-Pole, 3-Phase, double-layer, full-pitch)

Armature arrangement:

- Each phase has a double-layer winding with 12 slots per phase.
- The phase belt is 60°.

Winding Factors \[ \leftarrow \] Distribution Factor "Kd"
Pitch Factor "Kp"

[5]
i) Distribution Factor  
(breadth Factor)  
\[ K_d \]  

\[ \text{Phasor AB} \]  
\[ \text{Phasor BC} \]  
\[ \text{Phasor CD} \]  

\[ K_d = \frac{\text{e.m.f. with distributed winding}}{\text{e.m.f. with concentrated winding}} \]

\[ = \frac{\text{Phasor sum of coil e.m.f.'s / Phase}}{\text{Arithmetic sum of coil e.m.f.'s / Phase}} \]

\[ \alpha = \text{Slot angle} = \frac{180^\circ \text{ electrical}}{\text{No. of slots / Pole}} \]

\[ n = \text{Slats Per Pole Per Phase} \]

\[ K_d = \frac{|AD|}{|AB| + |BC| + |CD|} = \frac{2 A_x}{n \times 2 A_y} \]

\[ K_d = \frac{n A_x \sin (n \alpha / 2)}{n \times A_x \sin (\alpha / 2)} < 1 \]

\[ \frac{n A_x \sin (n \alpha / 2)}{n \times A_x \sin (\alpha / 2)} \]

Distribution Factor  "Distribution Factor "
ii) Pitch Factor "Kp" (Chording Factor)

\[ K_p = \frac{\text{e.m.f. induced in short-pitch coil}}{\text{e.m.f. induced in full-pitch coil}} \]

\[ E_A = E_B, \quad E_R = 2E_A \cos \left(\frac{\beta}{2}\right) \]

\[ \therefore K_p = \frac{2E_A \cos \left(\frac{\beta}{2}\right)}{2E_A} \]

\[ K_p = \cos \left(\frac{\beta}{2}\right) \]

- For Full-Pitch \( \rightarrow K_p = 1 \)
- For Short-Pitch \( \rightarrow K_p < 1 \)
- For Fractional-Pitch \( \rightarrow \)

\[ \beta = \text{Integer number} \times \alpha \]

Ex (10-1)

3- \( \Phi \) alternator, \( P = 4 \), no of slots = 36

\[ K_d = ?? \]
Alternators (Synchronous Generators)

Solution

\[ \text{no of slots per pole} = \frac{36}{4} = 9 \text{ slots} \]

Slot angle, \( \alpha = \frac{180}{9} = 20^\circ \text{ elec} \)

\[ \text{no of slots / pole / phase} = \frac{9}{3} = 3 \text{ slots} \]

\[ K_d = \frac{\sin (n\alpha/2)}{n \sin (\alpha/2)} = \frac{\sin (3 \times 20/2)}{3 \sin (20/2)} = 0.96 \]

Ex (10-2)

1. A alternator, \( \text{no of slots / pole} = 6 \),

\[ K_d = ?? \text{ at } \]

i) all slots are wound.

ii) 4 adjacent slots are wound.

Solution

i) \( n = 6 \) slots / pole / phase

\[ \alpha = \frac{180}{6} = 30^\circ \text{ elec} \]

\[ K_d = \frac{\sin (n\alpha/2)}{n \sin (\alpha/2)} = 0.644 \]
ii) \( n = 4 \) slots / Pole / Phase

\[
\alpha = \frac{180}{6} = 30^\circ \text{ elec}
\]

\[
K_d = \frac{\sin (4 \times 30/2)}{4 \times \sin (30/2)} = 0.837
\]

\[\text{Ex } (10-3)\]

No of slots / Pole = 9,

each Coil spans 8 slot Pitches, \( K_P = ?? \)

\[\text{Solution}\]

Slot angle, \( \alpha = \frac{180^\circ}{\text{No of slots / Pole}} = \frac{180^\circ}{9} \]

\( \alpha = 20^\circ \text{ elec} \)

Coil Pitch = 8 \times 20^\circ = 160^\circ \text{ elec}

\[
\therefore \text{Coil is Short Pitched by } 180^\circ - 160^\circ = 20^\circ \text{ elec}
\]

Pitch Factor, \( K_P = \cos (13/2) = \cos 10^\circ \)

\( K_P = 0.985 \)
Ex (10-4)

3-Φ alternator, 9 slots/Pole, Coil Pitch = 7 slots.

\[ K_p = ?? \quad K_d = ?? \]

**Solution**

Slot angle, \( \alpha = \frac{180^\circ}{\text{no of slots/Pole}} = 20^\circ \text{ "elec"} \)

\[ n = \frac{9}{3} = 3 \text{ slots/Pole/Phase} \]

Coil is short-pitched by 2 slots

\[ \beta = 2 \times 20^\circ = 40^\circ \]

\[ K_d = \frac{\sin(\alpha/2)}{n \cdot \sin(\alpha/2)} = 0.9598 \]

\[ K_p = \cos(\beta/2) = 0.9397 \]

**E. M. F. Equation of An Alternator**

\[ E = N \cdot \Phi \cdot Z \]

- \( E \): EMF
- \( N \): No. of Conductors or Coil sides in series Per Phase
- \( \Phi \): Flux Per Pole [web]
- \( Z \): No. of rotor Poles
Alternators (Synchronous Generators)

N: rotor speed in [r.p.m]

\[ e_{ave} = \frac{d\phi}{dt} = \frac{P \cdot \phi}{60 / N} = \frac{P \cdot \phi \cdot N}{60} \]

\[ \therefore \text{Average e.m.f./Phase} = Z \cdot e_{ave} = \frac{P \cdot \phi \cdot N \cdot Z}{60} \]

\[ N = \frac{120P}{P} \text{ r.p.m} \]

\[ \therefore \text{Average e.m.f./Phase} = 2f \cdot \phi \cdot Z \text{ volt} \]

R.M.S. e.m.f./Phase = Average e.m.f./Phase \times \text{Form Factor}

\[ = 2f \cdot \phi \cdot Z \times 1.11 \]

\[ E_{\text{rms}} = 2.22 f \cdot \phi \cdot Z \text{ [Volt]} \]

\[ T = \text{no. of Turns / Phase} \]

\[ Z = 2T \]

\[ E_{\text{rms}} = 4.44 K_d K_p P \cdot \phi \cdot T \text{ [Volt]} \]
Ex (10.10)

8-Φ, Y. Connected alternator, \( E_{\text{line}} = 3600 \) volt,
\( f = 50 \) Hz, \( N = 500 \) r.p.m., 3 slots / Pole / Phase,
10 Conductors / slot, Full-Pitch.

i) No. of Poles = ??

ii) Flux / Pole = ??

Solution

\[
P = \frac{NP}{120} \Rightarrow P = 12 \text{ Pole.}
\]

i) E.M.F./Phase = \( \frac{3600}{\sqrt{3}} \) = 2080 volt

No. of Slots / Phase = \( 3 \times 12 = 36 \) slots

No. of Conductors / Phase = \( 36 \times 10 \)

= 360 Conductor

No. of Slots / Pole = \( 3 \times 3 = 9 \) slots

\[ \frac{\text{No. of slots / Pole}}{\text{No. of phases}} = \frac{\text{No. of slots / Phase}}{\text{No. of phases}} \]

Slot angle, \( \alpha = \frac{180^\circ}{9} = 20^\circ \) "elec"
Alternators (Synchronous Generators)

\[ K_d = \frac{\sin (n\alpha/2)}{n \sin (\alpha/2)} = \frac{\sin (3\times 20/2)}{3 \times \sin (20/2)} = 0.96 \]

Full-Pitch \[ \rightarrow K_P = 1 \]

\[ E_{ph} \text{ r.m.s.} = 2.22 \times K_P \times K_d \times E_f \times \Phi \]

\[ \frac{600}{\sqrt{3}} = 2080 \]

\[ \Phi = 0.0543 \] [web]

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Ex (10-11)

\( P = 4, \ 3 - \Phi \) Y-Connected alternator, 60 slots,
4 Conductors / slot, Coils are shunted by 3 slots,
Phase spread = 60°, \( \Phi = 0.943 \) [web/Pole],
Sinusoidal flux \( E_{line} = ?? \)

Solution

10. of slots / Pole / Phase, \( n = \frac{60}{4 \times 3} = 5 \) slots

No. of slots / Pole = \( \frac{60}{4} = 15 \) slot

[13]
Alternators (Synchronous Generators)

Slot angle, $\alpha = \frac{180^\circ \text{ "elec"}}{\text{no. of slots / Pole}} = \frac{180^\circ}{15}$

$\alpha = 12^\circ \text{ "elec"}$

Phase spread $= n \cdot \alpha$

$K_d = \frac{\sin (n\alpha / 2)}{n \sin(\alpha / 2)} = 0.957$

 Coil is short-pitched by $B = 3 \times 12 = 36^\circ \text{ "elec"}$

$K_p = \cos \left(\frac{B}{2}\right) = 0.95$

$\text{no. of Conductors / Phase} = 4 \cdot \frac{\text{Conductor}}{\text{Slot}} \cdot \frac{\text{no. of Slots}}{\text{Phase}}$

$= 4 \times \frac{60}{3} = 80 \frac{\text{Conductor}}{\text{Phase}}$

$E_{ph \text{ r.m.s.}} = 2.77 \cdot K_p \cdot K_d \cdot P \cdot \Phi \cdot Z$

$= 7613 \text{ Volt}$

$E_{line} = \sqrt{3} \cdot E_{ph} = 13.185 \text{ kV}$

**Ex (10-12)**

$P = 12, \ 3 \cdot \Phi \ Y \text{-connected alternator, 72 slots,} \Phi = 0.0988 \text{ [web/Pole]}$
i) \( N = ? \) at \( f = 50 \text{ Hz} \)

ii) Terminal E.M.F. at Full-Pitch, 8 Conductor/slot

iii) \( \frac{2}{3} \) if the coil span is reduced to \( \frac{2}{3} \) of the Pole Pitch

**Solution**

i) \( N = \frac{120f}{P} \rightarrow 50 \)

\[ N = \frac{120 \times 50}{12} = 500 \text{ r.p.m.} \]

ii) Slot angle \[ \alpha = \frac{180^\circ \text{ "elec"}}{\text{no. of slots / pole}} = \frac{180^\circ}{(72/12)} \]

\[ \alpha = 30^\circ \text{ "elec"} \rightarrow \text{Slot angle} \]

Full-Pitch \( \rightarrow K_D = 1 \)

\[ K_d = \frac{\sin \left( \frac{n \alpha}{2} \right)}{n \sin \left( \frac{\alpha}{2} \right)} = 0.966 \]

no. of slots/Phase \( \rightarrow \frac{72}{3} = 24 \text{ slot} \)

no. of Conductors/Phase \( \rightarrow 8 \frac{\text{Conductor}}{\text{Slot}} \times 24 \frac{\text{Slot}}{\text{Phase}} = 192 \text{ Conductor} \)

\[ E_{ph \text{ r.m.s.}} = 2.22 \times K_p K_d \times f \Phi = 2.034 \text{ KV} \]
Terminal Voltage, $E_{line} = 3.573$ KU

iii) Pole Pitch = $180^\circ$ "elec"

Coil Pitch = $\frac{2}{3} \times 180 = 120^\circ$ "elec"

:: Coil is short. Pitched by $B = 60^\circ$ "elec"

$K_p = \cos \left(\frac{B}{2}\right) = 0.866$

:: $E_{line} = 3.573 \times 0.866 = 3.051$ KU

Armature Reaction in Alternator

In case of armature reaction in alternator, there are no saturation in the magnetic circuit.

- Consequently, the generated voltage will be equal to the output voltage of the alternator.

- In addition, the armature reaction (U.P.F.) will cause a phase shift between the generated voltage and the terminal voltage.

- This phase shift is equal to $90^\circ$ in the case of zero power factor (lagging).

- Therefore, the phase shift is zero for $90^\circ$ power factor.

[16]
Alternators (Synchronous Generators)

No-Load

Zero P.F. lagging load

Zero P.F. leading load

Armature Flux

Main Flux

Unity P.F.

Zero P.F. Lagging

Zero P.F. Leading

0.7 P.F. Lag
Alternators (Synchronous Generators)

Upon applying the voltage to the stator, the following equilibrium condition is observed:

1. The stator magnetic field remains constant and is not affected by the load.

2. The load is connected to a voltage source.

3. No-load e.m.f. (E)

4. Load voltage (E - V = Ia (R + jXl))

5. Terminal voltage (V)

Equivalent Circuit

\[
E_o = E + Ia \cdot jX_{AR}
\]

- \( E_o \): No-load e.m.f.
- \( E \): Load induced e.m.f. after armature reaction.
- \( V \): Terminal voltage "Load Voltage".
\[ X_s = X_{AR} + X_L \]

*\( X_L \): Leakage Reactance of Armature

*\( X_{AR} \): Armature Reaction equivalent Reactance

*\( R_a \): Armature Resistance

*\( X_s \): Synchronous Reactance

\[ Z_s = R + j \cdot X_s \]

\[ E_0 = V + I_a \cdot Z_s = V + I_a \cdot (R_a + j \cdot X_s) \]

\[ E_0 = \sqrt{(V \cos \phi + I_a \cdot R_a)^2 + (V \sin \phi \pm I_a \cdot X_s)^2} \]

*For lagging P.F.

*For leading P.F.*
Voltage Regulation

\[
\% \text{ Voltage Regulation} = \frac{E_o - V_{FL}}{V_{FL}} \times 100
\]

\[E_o: \text{ No-Load Voltage.}\]
\[V_{FL}: \text{ Full-Load Voltage.}\]

Determination of Voltage Regulation

1. Synchronous Impedance or E.M.F. method.
2. Ampere-Turn or M.M.F. method.
Alternators (Synchronous Generators)

1. Armature Resistance ($R_a$)
2. Open Circuit Characteristics (O.C.C.)
3. Short Circuit Characteristics (S.C.C.)

\[ 2R_{dc} = \frac{V}{I} \]
\[ R_{dc} = \frac{1}{2} \cdot \frac{V}{I} \]
\[ R_{dc} \parallel 2R_{dc} = \frac{V}{I} \]
\[ 2R_{dc} = \frac{3}{2} \cdot \frac{V}{I} \]

(A.C.) (D.C.) (Skin effect)
Synchronous Impedance Method

1. For the D.C. (O.C. C) and S.C. C, the field current If is

2. The equation is given by: $\frac{E_0}{R} = I_f$
3. Synchronous impedance, \( Z_s = \frac{E_1}{I_f} \) (open circuit)
   at the same field current
4. Synchronous reactance, \( X_s = \sqrt{Z_s^2 - R_s^2} \)

\[
E_o = \sqrt{(V \cos \phi + I_a R_s)^2 + (V \sin \phi + I_a X_s)^2}
\]
**Phasor Diagram:**

\[ \delta = \tan^{-1} \left( \frac{\sqrt{\sin \phi + I_a X_s}}{\sqrt{\cos \phi + I_a R_a}} \right) - \phi \]

**Lagging power factor load (Lagging p.f.)**

\((I_a \text{ lags } V) \Rightarrow \phi = -\delta\)

\(\phi: \text{ angle between } I_a, V\)

\(\delta: \text{ angle between } E_0, V\)

*Power (torque) angle*

**Unity power factor load (u.p.f.)**

\((I_a, V \text{ in phase}) \Rightarrow \phi = 0\)

\[ \delta = \tan^{-1} \left( \frac{I_a X_s}{V + I_a R_a} \right) \]

\(\delta: \text{ angle between } E_0, V\)

*Power (torque) angle*

**Leading power factor load (Leading p.f.)**

\((I_a \text{ leads } V) \Rightarrow \phi = +\delta\)

\(\phi: \text{ angle between } I_a, V\)

\[ \delta = \phi - \tan^{-1} \left( \frac{\sqrt{\sin \phi - I_a X_s}}{\sqrt{\cos \phi + I_a R_a}} \right) \]
Ex (13)

\[ S_{\text{rat}} = 500 \text{ KVA}, \quad \text{Y. Connected 3-ph Syn. Gen.} \]
\[ V_{\text{line}} = 3.3 \text{ KV}, \quad (R_a = 0.3 \Omega, \quad X_s = 4 \Omega) \]
\[ E_0 = ?? \quad \text{at Full-Load, 0.8 P.f. lagging} \]

**Solution**

\[ S_{\text{rat}} = 3 \quad V_{\text{rat}} \quad I_{\text{rat}} \quad \text{phase voltage} \]
\[ I_{\text{rat}} = I_{\text{F.L.}} = \frac{S_{\text{rat}}}{3 \cdot V_{\text{rat}}} = \frac{500}{3 \cdot \frac{3.3}{\sqrt{3}}} = 87.5 \text{ A} \]

\[ E_0 = \sqrt{(V \cos \Phi + I_a (R_a))^2 + (V \sin \Phi + I_a X_s)^2} \quad \text{phase e.m.f. phase voltage phase voltage} \]
\[ \text{P.f.} = \cos \Phi = 0.8 \quad \Rightarrow \quad \sin \Phi = 0.6 \]
\[ E_0 = \sqrt{\left(\frac{3300}{\sqrt{3}} \times 0.8 + 87.5 \times 0.3\right)^2 + \left(\frac{3300}{\sqrt{3}} \times 0.6 + 87.5 \times 4\right)^2} \]
\[ E_0 = 2152 \text{ Volt line e.m.f.} = 2152 \times \sqrt{3} \text{ Volts} \]
Ex (14)

\[ S_{\text{rat}} = 1000 \text{ KVA}, \text{ Y. Connected Syn. Gen.} \]
\[ V_{\text{line}} = 2.3 \text{ KV}, R_a = 0.309 \Omega, X_s = 3.31 \Omega \]

Change of line voltage = ?? when rated output of 1000 KVA of 0.8 lagging P.F. is switched off.

Solution

Phase voltage \[ S_{\text{rat}} = 3 \quad V_{\text{rat}} = I_{\text{rat}} \]

\[ I_{\text{F.L.}} = I_{\text{rat}} = \frac{S_{\text{rat}}}{3 \cdot V_{\text{rat}}} = \frac{1000}{3 \cdot 2.3/\sqrt{3}} = 251 \text{ A} \]

Page 24 (Ex 14) (Lagging P.F.) Phasor diagram

\[ E_0 = \sqrt{(V \cos \phi + I_a R_a)^2 + (V \sin \phi + I_a X_s)^2} \]
\[ \frac{2300}{\sqrt{3}} \quad 0.8 \quad 251 \quad 0.309 \quad \frac{2300}{\sqrt{3}} \quad 0.6 \quad 251 \quad 3.31 \]

\[ E_0 = 1987 \text{ volt (Phase voltage)} \]
\[ E_0 (\text{line}) = \sqrt{3} \cdot 1987 = 3441 \text{ volts} \]

\[ \therefore \text{Change in line voltage} = 3441 - 2300 = 1141 \text{ volts} \]
Ex (15)

$S_{rat} = 1500 \text{ KVA}, \ V_{line} = 6.6 \text{ KV}, \ Y \text{- Connected Syn. Gen.}$

$R_a = 0.5 \ \Omega, \ \chi_s = 5 \ \Omega$

Percentage change in terminal voltage = ?? when the rated output of 1500 KVA at 

i) U.P.F, 

ii) 0.8 lag P.F, 

(iii) 0.8 lead P.F is removed

**Solution**

$S_{rat} = 3 \ V_{rat} \cdot I_{rat}$

$I_{F.L} = I_{rat} = \frac{S_{rat}}{3 \ V_{rat}} = \frac{1500}{3 \times 6.6/\sqrt{3}} = 131 \ A$

i) At unity P.F.

\[ E_0 = \sqrt{(Y + I_a R_a)^2 + (I_a X_s)^2} = 3930 \text{ Volt (Phase Voltage)} \]

\[ \frac{3930 - \sqrt{6600/\sqrt{3}}}{6600/\sqrt{3}} \]

Percentage change in terminal voltage = 3.15 %

ii) At 0.8 lag P.F

\[ \sqrt{6600/\sqrt{3}} \]

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Phasor diagram