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Tutorial Sheet-7

Q①

No load speed = 1200 rpm $\simeq N_s$ (Synchronous speed)

N_{FL} = 1140 rpm (Speed at full load)

frequency = 60 Hz

ⓐ ~~No of poles~~ Relation between Synchronous speed ~~and~~, frequency and no of poles is

$$N_s\,(\text{rpm}) = \frac{120f}{P}$$

$$P = \frac{120\times f}{N_s}$$

$$P = \frac{120\times 60}{1200} = 6$$

no of poles are 6

ⓑ

$$\%\ \text{Slip} = \frac{N_s - N_r}{N_s}\times 100$$

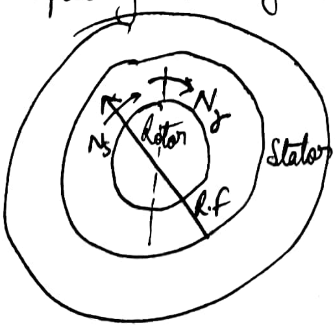
$$N_r = (1-S)N_s = 1140\ \text{rpm}$$

$$\therefore\ \%\ \text{Slip} = \frac{1200-1140}{1200}\times 100 = 5\%$$

ⓒ The frequency of rotor voltage = S.f

$$= 0.05\times 60 = 3\ \text{Hz}$$

ⓓ ① Speed of rotor field w.r.t rotor



here R.f is the magnetic axis of rotor field

Speed of R.f is N_s

Speed of rotor is N_r

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So the relative speed is

$$= N_S - N_r = N_S - (1-S)N_S$$
$$= SN_S = 60 \, rpm$$

(ii) Speed of rotor field w.r.t stator

Since stator is stationary its speed is 0

therefore

Speed of R.f w.r.t stator will be $N_S = 1200 \, rpm$

(iii) Rotor field w.r.t stator field

for interaction between the two fields and to ~~gen~~ generate torque both fields rotate at synchronous speed N_S

Thus Speed of R.f w.r.t S.f = 0 rpm

e) $N_r = (1-S) N_S$

$S = 0.1 \, pu$

thus

$$N_r = (1-0.1) \times 1200 = 1080 \, rpm$$

(f) Rotor frequency $= Sf = 0.1 \times 60 = 6 \, Hz$

(g) Speed of ~~ro~~

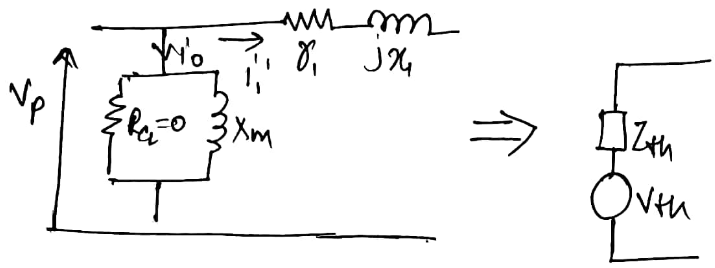
1. rotor field w.r.t to rotor $= 0.1 \times 1200 = 120 \, rpm$
2. rotor field w.r.t to stator $= 1200 \, rpm$
3. rotor field w.r.t stator $= 0 \, rpm$

2 Given

Motor → 460 V, 4 Pole, 50 hP, 60 Hz, 3Ø

$S_{FL} \longrightarrow 0.038$

$r_1 = 0.33\,\Omega$, $X_m = 30\,\Omega$, $x_1 = 0.42\,\Omega$, $x_2' = 0.42$

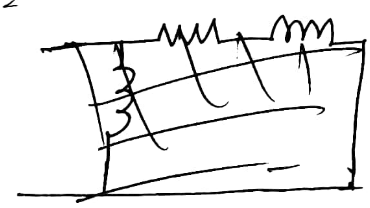


$$V_{th} = \frac{V_1 x_m}{\sqrt{r_1^2 + (x_1 + x_m)^2}} = 261.89 \quad , \quad Z_{th} = R_{th} + jX_{th} = \frac{jx_m(r_1 + jx_1)}{r_1 + j(x_1 + x_m)}$$

$$= 0.3211 + j0.4176$$

$\cancel{Z_{th} = R_{th}} + jX_{th}$

=



given $S_{FL} = 0.038$

for the $P_{sh} = 50 \times 746$ W and neglecting rotational losses

$P_{sh} = P_{mech}$ (P_{mec} = Mechanical power)

$P_{mech} = 3(1-S)\,P_g$ (P_g = air gap power)

$$3 \times \frac{(1-S_{fL})\, i_2^2 r_2}{S_{fL}} = 50 \times 746 \text{ W} = P_{sh}$$

$$\left(\frac{1-S_{fL}}{S_{fL}}\right) \frac{V_{th}^2}{\left(\frac{r_2}{S_{fL}}\right)^2 + (x_2 + x_m)^2} \times r_2 = \frac{50 \times 746}{3}$$

on rearranging the equation

$$692.21\, r_2^2 - 122.76\, r_2 + 0.803 = 0$$

Solving the Quadratic equation gives two roots

$$r_2 = \frac{122.76 \pm \sqrt{(122.76)^2 - 4 \times 692.21 \times 0.803}}{2 \times 692.21}$$

$$r_2 = 0.1705,\ 0.0068\ \Omega$$

(b)

T_{max} = Maximum torque can be written as

$$T_{max} = \frac{3}{2\pi n_s} \frac{V_{th}^2}{\left(R_{th} + \frac{r_2}{S_{mt}}\right)^2 + (x_2 + x_{th})^2} \frac{r_2}{S_{mt}} \quad -(1)$$

for maximum torque

$$S_{mt} = \frac{r_2}{\sqrt{(R_{th})^2 + (x_2 + x_{th})^2}}$$

replacing r_2/S_{mt} in eq. (1)

$$T_{max} = \frac{3}{2\pi n_s} \frac{V_{th}^2}{R_{th} + \sqrt{R_{th}^2 + (x_2 + x_{th})^2}}$$

$$T_{max} = 448.10\, Nm$$

$$S_{max} = \frac{r_2}{\sqrt{R_{th}^2 + (x_2 + x_{th})^2}} \cancel{\times 100} = 0.19$$

Speed at maximum torque $= (1 - 0.19) \times \frac{120 \times 60}{4} = 1458$ rpm

Starting torque can be expressed in terms of maximum torque as

$$T_{st} = \frac{2\,T_{max}}{\frac{1}{S_{mt}} + S_{mt}}$$

$$T_{st} = \frac{2 \times 448.10}{\frac{1}{0.19} + 0.19} = 198\ N\text{-}m$$

Q3 Given

Motor → 460V, 100hp, 4pole, Δ-connected, 60Hz, 3ϕ

S_{FL} → 0.05, η efficiency = 0.92 at load P.f = 0.87

$T_{est} = 1.9\, T_{eFL}$, $I_{st} = 8.5\, I_{eFL}$

Ans a

$$\eta = \frac{\text{output power}}{\text{input power}}$$

$$i/p \text{ power} = \frac{100 \times 746}{0.92}$$

Now input power $P_{in} = \sqrt{3}\, V_L \times i_{rated} \times \cos\theta$

$$i_{rated} = \frac{P_{in}}{\sqrt{3} \times V_L \times \cos\phi} = \frac{100 \times 746}{0.92 \times \sqrt{3} \times 460 \times 0.87}$$

$= 116.98$ amp

$I_{st} = 8.5 \times I_{rated} = 8.5 \times 116.98 = 994.33$ amp

Now $\frac{T_{st}}{T_{FL}} = \left(\frac{i_{st}}{i_{FL}}\right)^2 \times S_{FL}$

$$\frac{i_{st}}{i_{FL}} = \sqrt{\frac{1.9}{0.05}}$$

$i_{st} = 161.3\,A$

full load power generated

$$\frac{100 \times 746}{0.92} = 3 \times \left(\frac{161.3}{\sqrt{3}}\right)^2 r_2 \left(\frac{1-S_{fl}}{S_{fl}}\right)$$ (Since it is a Δ connected machine)

$$\boxed{r_2 = 0.164\,\Omega}$$

for rated conditions

$$\frac{100 \times 746}{0.92} = 3 \times \left(\frac{I_{rated}}{\sqrt{3}}\right)^2 \times r_2 \times \left(\frac{1-S_{rated}}{S_{rated}}\right)$$

$$\boxed{S_{rated} = 0.02693}$$

Now

$$\frac{T_{st}}{T_{rated}} = \left(\frac{I_{st}}{I_{rated}}\right)^2 \times S_{rated}$$

$$\boxed{T_{est} = 1.9456\, T_{rated}}$$

Since $T_{est} \propto (V_s)^2$

let n be the reduction in supply voltage

$$T_{est} \propto n^2 (V_s)^2$$

$$n^2 = \frac{1}{1.9456}$$

$$n = 0.716$$

thus Applied voltage $= 0.716 \times 460 = 329.7\,V$

Starting current $= n \cdot I_{st}$

$= 0.7169 \times 994.33$

$= 712.8A$

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$\eta = 0.9$ at load of 50 h.p

total mechanical loss

$$P_m = \tfrac{1}{3} P_{nL} \quad (P_{nL} = \text{no load loss})$$

~~now no load losses contain core loss + Mechanical loss~~

$$\cancel{P_m = \tfrac{1}{3}(P_m + P_{iL})}$$

$$P_{oh} = 2 P_{iL} \quad (P_{oh} = \text{ohmic losses})$$

now efficiency

$$\eta = \frac{P_{sh}}{P_{sh} + P_f + P_{oh}}$$

here P_f are core + mechanical losses (fix losses)

$$P_f = P_m + P_{iL}$$

Since $P_m = \tfrac{1}{3} P_{iL}$

$$P_f = \tfrac{1}{3} P_{iL} + P_{iL}$$

$$P_f = 1.33 P_{iL}$$

and $P_{oh} = 2 P_{iL}$

$$\eta = \frac{P_{sh}}{P_{sh} + 3.33 P_{iL}}$$

$$0.9 = \frac{50 \times 746}{50 \times 746 + 3.33 P_{iL}}$$

$$\boxed{P_{iL} = 1.244 \text{ KW}}$$

$P_{M} = \frac{1}{3} P_{iL}$

$P_{M} = \frac{1}{3}(1.244)\ kW$

Now mechanical power

$P_{mech} = P_{sh} - P_{M}$

also $P_{mec} = (1-S) P_g$ — ①

and ohmic losses

$P_{oh} = S P_g$ — ②

on dividing ① and ②

$$\frac{(1-S)}{S} = \frac{P_{mec}}{P_{oh}}$$

$$\boxed{S = 0.032}$$

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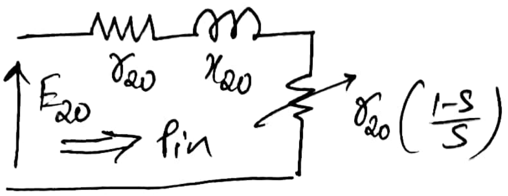
$$V_1 = \frac{200}{\sqrt{3}} = 115.47\ V$$

$r_{20} = 0.1\ \Omega, \quad x_{20} = 0.9\ \Omega$



$$\frac{N_{rotor}}{N_{stator}} = 0.67$$

(a) $$P_{in} = \frac{3 I_2^2 r_{20}}{s} = T \times \omega_s$$

$$T = \frac{3}{2\pi n_s} \cdot \frac{E_{20}^2}{\left(\frac{r_{20}}{s}\right)^2 + x_{20}^2} \cdot \frac{r_{20}}{s}$$

$T = 40.478$ N-m

(b) $$I_2 = \frac{0.67 \times 115.47}{\sqrt{\left(\frac{0.1}{0.54}\right)^2 + (0.9)^2}} = 29.116\ A$$

Total mech power o/p

$$= 3 \times 29.116^2 \times 0.1 \times \left(\frac{1-0.04}{0.04}\right)$$

$= 6.1$ KW

(c) at max torque $\quad S_{mt} = \dfrac{r_{20}}{x_{20}}$

$$T_{max} = \frac{3}{2\pi n_s} \frac{E_{20}^2}{2 x_{20}^2} x_{20}$$

$T_{max} = 63.504$ N-m

(d) Speed at max torque $= \frac{120 \times 50}{4}(1-0.11)$

$= 1335$ rpm

(e) At max power condition, current is

$$i_2 = \frac{0.67 \times 115.47}{\sqrt{\left(\frac{0.1}{0.11}\right)^2 + (0.9)^2}} = 60.4774 \text{ Amp}$$

max mech power $= 3 i_2^2 r_2 \left(\frac{1-S_{max}}{S_{max}}\right)$

$= 8.952$ kW

Q.6 3Ø I/m 60V developed between slip rings

perphase rotor voltage $= \frac{60}{\sqrt{3}}$ V

$r_{20} = 0.6\,\Omega$, $x_{20} = 4\,\Omega$, $r_{ext} = 5\,\Omega$, $x_{ext} = 2\,\Omega$

(a) Standstill rotor phase current $= \frac{60}{\sqrt{3}\sqrt{(5.6)^2 + (6)^2}} = 4.22$ A

(b) with 4% slip $= \frac{60/\sqrt{3}}{\sqrt{\left(\frac{0.6}{0.04}\right)^2 + (4)^2}} = 2.23$ A

Q7 Per phase rotor resistance $r_{20} = 0.2\,\Omega$

$N_{r1} = 960$ rpm, $N_{r2} = 800$ rpm

$$S_{FL} = \frac{1000 - 960}{1000} = 0.04$$

$$S_{FL}' = \frac{1000 - 800}{1000} = 0.2$$

$$\frac{T_{FL}}{T_{max}} = \frac{2}{\frac{S_{max}}{S_{FL}} + \frac{S_{FL}}{S_{max}}}$$

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T_{FL}. for $T_{FL_1} = T_{FL_2}$ the condition is

$$\frac{S_{max_1}}{S_{FL}} + \frac{S_{FL}}{S_{max_1}} = \frac{S_{max_2}}{S_{FL}'} + \frac{S_{FL}'}{S_{max_2}}$$

$$S_{max_1} = \frac{r_2}{x_{20}} = \frac{0.2}{x_{20}}$$

$$S_{max_2} = \frac{R}{x_{20}}$$

$$\frac{0.2}{x_{20} \times 0.04} + \frac{0.04 \times x_{20}}{0.2} = \frac{R}{x_{20} \times 0.2} + \frac{0.2\, x_{20}}{R}$$

$$(1-R)\left[\frac{5}{x_{20}} - \frac{0.2\, x_{20}}{R}\right) = 0$$

R should be equal to 1

therefore extra resistance $= 0.8\,\Omega$

Q8 full load slip $S_{FL} = 0.05$

Slip at maximum torque $S_{max} = 0.25$

$$T_{max} = 2.5\, T_{FL}$$

$$\frac{T_{st}}{T_{max}} = \frac{2}{\frac{1}{S_{mt}} + S_{mt}}$$

$$= \frac{2}{\frac{1}{0.25} + 0.25}$$

$$T_{st} = 0.4705 \times T_{max}$$

$$T_{st} = 0.4705 \times 2.5 \times T_{FL} = 1.176\, T_{FL}$$

I_1 I_2

Or $\frac{T_{FL}}{T_{max}} = \frac{2}{\frac{S_{FL}}{S_{max}} + \frac{S_{max}}{S_{FL}}} = \frac{2}{\frac{0.05}{0.25} + \frac{0.25}{0.05}}$

$T_{max} = 2.6\, T_{FL}$

$T_{st} = 1.223\, T_{FL}$

Q9 500HP, wound rotor i/m rotor resistance is increased by 5 times

(a) The expression of load torque is

$$T = \frac{3}{2\pi n_s} \frac{V_{th}^2}{\left(\frac{R_{rotor}}{S_{FL}}\right)^2 + X^2} \times \frac{R_{rotor}}{S_{FL}}$$

Now if $R_2' = 5 \times R_{rotor}$

slip will change to $= 5 \times S_{FL} = 0.075$

(b) Rotor ohmic loss at full load torque $= 5.69$ KW

Since resistance is increased by 5 times

new ohmic loss will be $= 5.69 \times 5 = 28.45$ KW

(c) ~~at~~ Shaft power output if mechanical loss are neglected

$$= 3 I_2^2 R_{rotor} \left(\frac{1 - S_{FL}}{S_{FL}}\right)$$

Now Since both R_{rotor} and S_{FL} change ~~in same proportion with~~ ~~change~~ thus P_{sh} ~~remains unchang~~es

I_2 ~~will change with rotor resistance~~

So

Now du...
hence...

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Now during resistance change I_2' and $\frac{R_{rotor}}{S_{fL}}$ remains unchanged

hence

$$\frac{500}{m} - \frac{1-S_{fL}}{S_{fL}} = \frac{1-0.015}{1-0.075}$$

$m = 469.543$

(d) at maximum torque

$$S_{max} = \frac{R_{rotor}}{X_{rotor}} = 5 \times \frac{6}{100} = 0.3$$

(e) Rotor current at max torque $= \frac{E_{20}}{\sqrt{2}\, X_{rotor}}$

Current remains same $= 2.82\, I_{2fL}$

(f) Rotor torque at 20% slip $= 3.95\, \cancel{T_{st}}\, I_{2fL}$

~~R~~ now Torque at 0.2 slip

$$\frac{T_{02}}{T_{max}} = \frac{1}{\frac{0.2}{0.06} + \frac{0.06}{0.2}} = \frac{3.95\, I_{2fL}}{I_{max}}$$

for modified condition

$T_{st}' = 3.95\, \cancel{T}_{st}$

(g) Relation between T_{max} and T_{fL}

$$T_{max} = 3.95\, T_{fL} \left(0.3 + \frac{1}{0.3}\right)$$

$$\frac{T_{st}'}{T_{max}} = \frac{\cancel{3}}{0.3 + 1/0.3}$$

Since $T_{st}' = 3.95\, T_{fL}$

$$3 I_{2s}^{2} \times 5 R_{rotor} = 3.95 \times 3 \times I_{2fL}'^{2}\; \frac{5 R_{rotor}}{5 \times 0.015}$$

$$I_{2st}' = 7.257\, I_{2fL}$$

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