EEE 401
Energy conversion

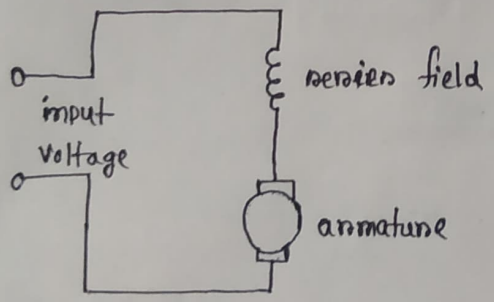
Universal motor

1

A 250w, Single phase, 50 Hz, 220v universal motor runs at 2000 rpm and taken 1.0 A when supplied from a 220v dc. If the motor in connected to 220v ac supply and taken 1.0 A (rms); Calculate the speed (N)
torque (T) and
power factor (φ)

Assume, Ra = 20 ohm
La = 0.4 H

Solution



Here,
P = 250 W
f = 50 Hz
V = 220 v
Ra = 20 ohm
La = 0.4 H
Ia = 1.0 A

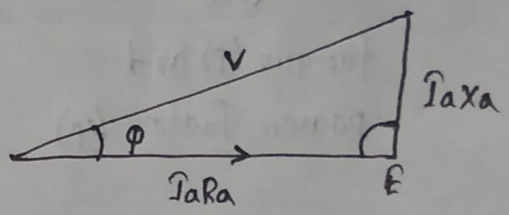
(N, dc) motor speed = 2000 rpm
;

For Dc input,

$$E_{b,dc} = V - I_a R_a$$
$$= 220V - (1 \times 20)$$
$$= 200\ V$$

For Ac input,

$$X_a = 2\pi f L_a$$
$$= 2\pi \times 50 \times 0.4$$
$$= 125.664\ \Omega$$



$$\therefore V^2 = (I_a R_a + E_{b,ac})^2 + (I_a X_a)^2$$
$$\Rightarrow (220)^2 = (20 + E_{b,ac})^2 + (1 \times 125.664)^2$$
$$\Rightarrow 48400 = 400 + (E_{b,ac})^2 + 1579.14$$
$$\Rightarrow 48400 - 400 - 1579.14 = (E_{b,ac})^2$$
$$\Rightarrow (E_{b,ac})^2 = 46420.86$$
$$\therefore E_{b,ac} = 215.46\ V$$

Now,

$$\text{Speed, } N \Rightarrow \frac{E_{b,dc}}{E_{b,ac}} = \frac{N,dc}{N,ac}$$
$$\Rightarrow \frac{200}{215.46} = \frac{2000}{N,ac}$$
$$\therefore N,ac = 2154.6\ \text{rpm}$$

Torque, $T = 9.55 \times \frac{P_{mech}}{N_{ac}}$

$= 9.55 \times \frac{215.46}{2154.5}$

$= 0.956$ Nm

Power factor, $\varphi \Rightarrow \cos\varphi = \frac{E_{b,ac} + I_a R_a}{V}$

$= 1.08$

Ans:

(2) A universal series motor has resistance of 30 ohm and an inductance of 0.5 H. When connected to a 250 v DC supply and loaded to take 0.8 A, it runs at 2000 rpm. Estimate its speed and power factor, when connected to a 250 v, 50 H_z AC supply and loaded to take the same current.

Solution

Here,

$R_a = 30$ ohm

$L_a = 0.5$ H

$V = 250$ v

$I_a = 0.8$ A

$N_{dc} = 2000$ rpm

$f = 50$ H_z

; Speed, $N = ?$

power factor, $\varphi = ?$

For DC input,

$$E_{b,dc} = V - I_a R_a$$
$$= 250 - (0.8 \times 30)$$
$$= 226 \text{ V}$$

For AC input,

$$X_a = 2\pi f L_a$$
$$= 2\pi \times 50 \times 0.5$$
$$= 157.08 \ \Omega$$

$$\therefore V^2 = (I_a R_a + E_{b,ac})^2 + (I_a X_a)^2$$

$$\Rightarrow (250)^2 = (0.8 \times 30 + E_{b,ac})^2 + (0.8 \times 157.08)^2$$

$$\Rightarrow 62500 = 576 + (E_{b,ac})^2 + 15791.44$$

$$\Rightarrow 62500 - 576 - 15791.44 = (E_{b,ac})^2$$

$$\Rightarrow (E_{b,ac})^2 = 46132.56$$

$$\therefore E_{b,ac} = 214.79 \text{ V}$$

Now,

$$\therefore \text{Speed, } N \Rightarrow \frac{E_{b,dc}}{E_{b,ac}} = \frac{N,dc}{N,ac}$$

$$\Rightarrow \frac{226}{214.79} = \frac{2000}{N,ac}$$

$$\therefore N,ac = 1900.7 \text{ rpm}$$

$\therefore$ Power factor, $\cos\varphi = \frac{E_{b,ac} + I_a R_a}{V}$

$= 0.96$

Ans:

AC Series Motor

3/ A AC series motor has resistance of 40 ohm and an inductance of 0.8 H and it runs at 1500 rpm. Estimate its back emf and power factor when connected to a 250 V, 50 Hz AC supply and loaded to take 1.2A current.

Solution

Here,

$R_a = 40$ ohm

$L_a = 0.8$ H

Motor speed = 1500 rpm

$V = 250$ V

$f = 50$ Hz

$I_a = 1.2$ A

We know,

$$E_a = V - I_a R_a$$

$$= 250 - (1.2 \times 40)$$

$$= 202 \text{ V}$$

$$X_a = 2\pi f L_a$$

$$= 2\pi \times 50 \times 0.8 \quad = 251.328 \ \Omega$$

$$\therefore V^2 = (I_a R_a + E_{b,ac})^2 + (I_a X_a)^2$$

$$\Rightarrow (250)^2 = (1.2 \times 40 + E_{b,ac})^2 + (1.2 \times 251.328)^2$$

$$\therefore E_{b,ac} = 120.67 \text{ V}$$

$$\therefore \cos\varphi = \frac{E_{b,ac} + I_a R_a}{V}$$

$$= \frac{120.67 + (1.2 \times 40)}{250}$$

$$= 0.67$$

Ans.

Reluctance motor

4/ A 8kW, 4 pole, 220V, 50 Hz reluctance motor has a torque angle of 30° when operating under rated load conditions.

Calculate :

(1) load torque

(2) torque angle if the voltage drops to 250 V and

(3) will the motor pulled out of synchronism?

Solution

(1) We know,

$$N_S = 120 \times \frac{50}{4} = 1500 \text{ rpm}$$

$$T_{sh} = 9.55 \times \frac{8000}{1500} = 51 \text{ N-m} \quad [\because 8 \text{ kW}]$$

Ans.

(2) We know,

$$(V_1)^2 \sin 2\delta_1 = (V_2)^2 \sin 2\delta_2$$

$$\Rightarrow (220)^2 \sin(2 \times 30^\circ) = (205)^2 \sin 2\delta_2$$

$$\Rightarrow 41915.63 = 42025 \times \sin 2\delta_2$$

$$\Rightarrow \frac{41915.63}{42025} = \sin 2\delta_2$$

$$\Rightarrow \sin^{-1}(0.9973/2) = \delta_2$$

$$\therefore \delta_2 = 42.9^\circ$$

Ans:

(3) Since the new load angle in less than 45°, the motor will not pull out of synchronous.

Stepper Motor

(5) A hybrid VR stepping motor has 8 main poles which have been castellated to have 5 teeth each. If motor has 50 teeth, calculate the stepping angle.

Motor এর teeth stator teeth এর চেয়ে বেশি হলে $(N_r - N_s)$, আর stator teeth, motor এর চেয়ে বেশি হলে $(N_s - N_r)$

Solution

Here,

$N_S = 5 \times 8 = 40$ (number of stator teeth)

$N_r = 50$ (number of motor teeth)

$\therefore$ Step angle, $\beta = \frac{N_r - N_s}{N_r \cdot N_s} \times 360°$

$= \frac{50 - 40}{50 \times 40} \times 360°$

$= 1.8°$

Ans.

(6) A stepper motor has a step angle of 2.5°.

Determine;

(1) resolution

(2) numbers of steps required for the shaft to make 25 revolutions and

(3) shaft speed, if the stepping frequency is 3600 PPS.

Solution

(1) Resolution, $= \frac{360^\circ}{\beta} = \frac{360^\circ}{2.5^\circ}$

$= 144$

Ans.

(2) Here,

1 resolution = total resolution

= 144

∴ 25 resolution = 144 × 25

= 3600

Ans.

(3) Shaft speed, $n = (B \times f)/360$ rps

$$= \frac{2.5 \times 3600}{360}$$

$$= 25 \text{ rps}$$

Ans.

Wind energy

(7) Determine the power in the wind speed is 20 m/s and blade length is 50 m.

Solution

Here,

wind speed, $v = 20$ m/s

blade length, $l = 50$ m

air desity, $\rho = 1.23$ kg/m

We know,

$$A = \pi r^2$$

$$= \pi \times (50)^2$$

$$= \pi \times 2500 = 7853 \text{ m}$$

$$\therefore P = \frac{1}{2} \rho A v^3$$

$$= \frac{1}{2} \times 1.23 \times 7853 \times (20)^3$$

$$= 38637 \text{ W}$$

Ans.

(8) A wind turbine travels with the speed in 10 m/s and has a blade length of 20 m. Determine wind power.

Solution

Here,

Wind speed, $v = 10$ m/s

blade length, $l = 20$ m

$\rho = 1.23$ kg/m

We know,

$$A = \pi r^2$$
$$= \pi \times (20)^2$$
$$= 1256 \text{ m}^2$$

$$\therefore P = \frac{1}{2} \rho A v^3$$
$$= \frac{1}{2} \times 1.23 \times 1256 \times (10)^3$$
$$= 772440 \text{ W}$$

Ans.

Stepper motor

(3) A single-stack, 3 phase VR motor has a step angle of 15°. Find the number of its motor and stator poles.

Solution

We know,

$$\beta = \frac{360^\circ}{m \times N_r}$$

$$\Rightarrow 15^\circ = \frac{360^\circ}{3 \times N_r}$$

$$\Rightarrow N_r = \frac{360^\circ}{45^\circ}$$

$$\therefore N_r = 8$$

When, $N_s > N_r$;

$$\beta = \frac{(N_s - N_r) \times 360^\circ}{N_s \cdot N_r}$$

$$\Rightarrow 15^\circ = \frac{(N_s - 8) \times 360^\circ}{N_s \cdot 8}$$

$$\Rightarrow 120^\circ N_s = 360^\circ N_s - 2880$$

$$\Rightarrow 120N_s - 360N_s = -2880$$

$$\Rightarrow -240N_s = -2880$$

$$\Rightarrow N_s = \frac{2880}{240}$$

$$\therefore N_s = 12$$

When, $N_s < N_r$;

~~$\beta = \frac{(N_s - N_r) \times 360^\circ}{N_s \cdot N_r}$~~

$$\beta = \frac{(N_r - N_s) \times 360^\circ}{N_r \cdot N_s}$$

$$\Rightarrow 15^\circ = \frac{(8 - N_s) \times 360^\circ}{8 N_s}$$

$$\Rightarrow 120N_s = 2880 - 360N_s$$

$$\Rightarrow 120N_s + 360N_s = 2880$$

$$\Rightarrow 480N_s = 2880$$

$$\Rightarrow N_s = \frac{2880}{480}$$

$$\therefore N_s = 6$$

∴ Ans.

(10) A four-stack VR stepper motor has a step angle of 1.8°. Find the number of its rotor and stator teeth.

Solution

We know,

$$\beta = \frac{360^\circ}{m \times N_r}$$

$$\Rightarrow 1.8^\circ = \frac{360^\circ}{4 \times N_r}$$

$$\Rightarrow 7.2 N_r = 360^\circ$$

$$\Rightarrow N_r = \frac{360^\circ}{7.2}$$

$$\therefore N_r = 50$$

When, $N_s > N_r$;

$$\beta = \frac{(N_s - N_r) \times 360^\circ}{N_s \cdot N_r}$$

$$\Rightarrow 1.8^\circ = \frac{(N_s - 50) \times 360^\circ}{N_s \cdot 50}$$

$$\Rightarrow 90 N_s = 360^\circ N_s - 18000$$

$$\Rightarrow 90 N_s - 360 N_s = -18000$$

$$\Rightarrow -270 N_s = -18000$$

$$\Rightarrow N_s = \frac{18000}{270}$$

$$\therefore N_s = 66$$

When, $N_S < N_R$;

$$\beta = \frac{(N_R - N_S) \times 360^\circ}{N_R \cdot N_S}$$

$$\Rightarrow 1.8^\circ = \frac{(50 - N_S) \times 360^\circ}{50 N_S}$$

$$\Rightarrow 90 N_S = 18000 - 360 N_S$$

$$\Rightarrow 90 N_S + 360 N_S = 18000$$

$$\Rightarrow 450 N_S = 18000$$

$$\Rightarrow N_S = \frac{18000}{450}$$

$$\therefore N_S = 40$$

Ans: