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Electrical Machines Interview Questions

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Transformers

1. Why is a transformer core built from thin laminations of silicon steel instead of solid iron?

Laminations cut eddy current loss, because insulated thin sheets break up the paths for circulating current and the loss falls roughly with the square of sheet thickness. Silicon in the steel raises its resistivity, which lowers eddy loss further, and it also narrows the hysteresis loop.

2. What does each of the open-circuit and short-circuit tests on a transformer measure, and on which side is each usually done?

The open-circuit test, done on the low-voltage side at rated voltage, gives the core loss and the magnetising branch. The short-circuit test, done on the high-voltage side at rated current, gives the full-load copper loss and the equivalent series impedance. Each side is chosen so that the instruments and supply stay at convenient ratings.

3. What is the difference between an ideal and a practical single-phase transformer?

An ideal transformer has no winding resistance, no leakage flux, no core loss and a core of infinite permeability, so it needs no magnetising current and its voltage ratio equals its turns ratio. A practical one has all four, so it draws a no-load current, loses power and shows a voltage drop on load.

4. A 50 Hz single-phase transformer has a 400-turn primary winding on a core of 0.02 m² cross-section. The peak flux density is 1.2 T. Find the rms emf induced in the primary.

The rms emf induced in the primary is about 2131 V.

WORKING

1. Use the EMF equation $E = 4.44 f N \Phi_m$.
2. $\Phi_m = B_m A = 1.2 \times 0.02 = 0.024$ Wb.
3. $E = 4.44 \times 50 \times 400 \times 0.024$.
4. $E = 2131.2$ V.

5. Why can the secondary voltage of a transformer rise above its no-load value when it supplies a leading power factor load?

Voltage regulation is roughly $I(R\cos\phi - X\sin\phi)/V$ for a leading load, with R and X the equivalent resistance and reactance. The reactive term then has the opposite sign to the resistive drop, so it can cancel it or exceed it. The regulation becomes zero when $\tan\phi = R/X$ and is negative beyond that, so the voltage rises.

6. What conditions must two three-phase transformers meet before they are connected in parallel?

They need the same voltage ratio, the same polarity, the same phase sequence and zero phase displacement between their secondaries, so they must be in the same vector group. Unequal ratios cause a circulating current. For sharing load in proportion to rating, their per-unit impedances should also match.

7. A 1 kVA, 200 V/100 V two-winding transformer is reconnected as a step-down auto-transformer, 300 V input and 200 V output. Each winding carries its rated current. Find the kVA rating of the auto-transformer.

The auto-transformer is rated 3 kVA.

WORKING

1. Rated currents: $1000/100 = 10$ A in the 100 V winding and $1000/200 = 5$ A in the 200 V winding.
2. The 100 V winding is the series winding, so the input current is 10 A.
3. Output current is $10 \times 300/200 = 15$ A, and the 200 V winding then carries $15 - 10 = 5$ A, as rated.
4. Rating $= 300 \times 10 = 3000$ VA.

Energy conversion and DC machines

8. What is back EMF in a DC motor, and how does it regulate the armature current?

Back EMF is the voltage $E_b = K\phi\omega$ induced in the armature as it turns, acting against the supply voltage. The armature current is $I_a = (V - E_b)/R_a$. If load slows the motor, E_b falls and the current rises until torque matches the load.

9. What is the difference between the speed-load characteristics of a DC shunt motor and a DC series motor?

A shunt motor has nearly constant flux, so its speed drops only slightly from no load to full load. In a series motor the flux follows the armature current, so speed falls sharply as load rises and the motor gives high torque at low speed. At very light load a series motor runs very fast.

10. Why must a DC series motor never be started or run with no load?

The field is carried by the armature current, which is very small at no load, so the flux is very small. Speed is roughly $V/(K\phi)$, so it rises until only friction and windage limit it, far above a safe value. The rotor can be damaged, which is why the motor is coupled directly to its load, never by a belt that could slip or break and leave it unloaded.

11. A 220 V DC shunt motor has an armature resistance of 0.4 Ω. At 1000 rpm it draws 25 A in the armature. Find the developed torque.

The developed torque is about 50.1 N·m.

WORKING

1. $E_b = V - I_a R_a = 220 - 25 \times 0.4 = 210$ V.
2. Developed power $= E_b I_a = 210 \times 25 = 5250$ W.
3. $\omega = 2\pi \times 1000/60 = 104.7$ rad/s.
4. $T = 5250/104.7 = 50.1$ N·m.

12. How do armature voltage control and field flux control differ as ways of changing the speed of a separately excited DC motor?

Armature voltage control varies speed from zero up to base speed at constant rated flux, so torque capability stays constant. Field control weakens the flux to raise speed above base speed. The torque available then falls as speed rises, so power stays roughly constant.

Three-phase and single-phase induction machines

13. Why can an induction motor never run at synchronous speed?

At synchronous speed the rotor and the rotating field have no relative motion. The rotor conductors then cut no flux, so no emf or current is induced in them and there is no torque. The rotor therefore settles slightly below synchronous speed, at the slip where torque equals load.

14. A 6-pole, 50 Hz three-phase induction motor runs at 960 rpm. Find the frequency of the rotor currents.

The rotor current frequency is 2 Hz.

WORKING

1. $N_s = 120f/P = 120 \times 50/6 = 1000$ rpm.
2. $s = (N_s - N)/N_s = (1000 - 960)/1000 = 0.04$.
3. $f_r = sf = 0.04 \times 50 = 2$ Hz.

15. How does the air-gap power of a three-phase induction motor divide between rotor copper loss and mechanical power?

For slip s, rotor copper loss is sP_g and the developed mechanical power is $(1 - s)P_g$, so the split is $1 : s : (1 - s)$ for air-gap power, copper loss and mechanical power. This is why a motor running at high slip is inefficient: more of the air-gap power is lost as heat in the rotor.

16. What is the difference between direct-on-line and star-delta starting of an induction motor?

Direct-on-line connects the motor to full voltage, giving the highest starting current and torque. Star-delta starting applies the winding at $1/\sqrt{3}$ of line voltage, which cuts line starting current and starting torque to one third. It suits only a motor designed to run in delta, with all six terminals brought out.

17. Why is a single-phase induction motor not self-starting?

A single-phase winding produces a pulsating field, which is equal to two fields of equal strength rotating in opposite directions. At standstill their torques cancel, so the net starting torque is zero. Once turned in either direction the motor keeps running, but to start it needs an auxiliary winding, often with a series capacitor, or shaded poles.

Synchronous machines

18. What does it mean that a synchronous machine runs at synchronous speed, and what fixes that speed?

In steady state the rotor turns at exactly $n_s = 120f/P$, with no slip, locked to the rotating field of the stator. The speed depends only on supply frequency f and the number of poles P. Load changes the angle between the rotor and the field, not the speed.

19. A three-phase, star-connected, cylindrical-rotor synchronous generator has a synchronous reactance of 10 Ω per phase, with armature resistance neglected. The excitation emf is 4000 V per

phase, the terminal voltage is 3810 V per phase and the load angle is 30°. Find the total power delivered.

Since the emf, terminal voltage and reactance are all per phase values, each phase delivers $EV \sin\delta / X_s = 4000 \times 3810 \times 0.5/10 = 762$ kW. The three phases together deliver $3 \times 762 = 2286$ kW, which is about 2.29 MW.

WORKING

1. Per phase: $P = EV \sin\delta / X_s$.
2. $P = 4000 \times 3810 \times \sin 30^\circ / 10 = 762000$ W.
3. Three phases: $3 \times 762000 = 2286000$ W.

20. How does the power-angle relation of a salient-pole machine differ from that of a cylindrical-rotor machine?

A cylindrical rotor has one reactance and power $P = (EV/X_s)\sin\delta$, with its maximum at 90° if resistance is neglected. A salient-pole rotor has two reactances, $X_d > X_q$, and an added reluctance term proportional to $\sin 2\delta$, so maximum power occurs below 90°.

21. Why does the armature current of a synchronous motor, at constant load, first fall and then rise as the field current is increased?

The motor takes a fixed real power, so the current is smallest when it is purely real, at unity power factor. Below that excitation the current lags and above it the current leads, and the reactive part grows either way. Plotted against field current, this gives a V-shaped curve.

22. Why can a synchronous motor not start on its own, and how is it started?

At standstill the stator field sweeps past the rotor too fast for the rotor to lock on, so the torque alternates in direction and averages to zero. The rotor is usually brought near synchronous speed by damper (cage) windings acting as an induction motor. The DC field is then excited and the rotor pulls into step.

Losses and efficiency of electric machines

23. What is the difference between constant and variable losses in an electric machine?

Constant losses do not change with load: core loss, friction and windage, and in a shunt DC machine the shunt field copper loss. Variable losses grow with load: armature or winding copper loss scales with the square of current. Stray load loss and, in DC machines, brush contact loss also vary.

24. Why is the efficiency of a machine at its maximum when the variable losses equal the constant losses?

With output proportional to current I, efficiency is highest when total loss per unit of output is smallest. Loss per unit current is $P_c/I + IR$. Setting its derivative to zero gives $P_c = I^2R$. So at maximum efficiency the constant loss equals the copper loss that scales as I^2.

25. A 100 kVA transformer has an iron loss of 1 kW and a full-load copper loss of 1.8 kW. Find the load in kVA at which its efficiency is maximum.

Efficiency is maximum at a load of about 74.5 kVA.

WORKING

1. Maximum efficiency occurs where copper loss equals iron loss.
2. Copper loss at fraction x of full load is $1.8x^2$ kW, so $1.8x^2 = 1$.
3. $x = \sqrt{1/1.8} = 0.745$.
4. Load $= 0.745 \times 100 = 74.5$ kVA.

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