Electric Drives

Short notes for B.Tech EE · EEE · GATE EE

Uncodemy Handwritten Notes · free for students

1. Introduction

- **Electric drive** = a system that controls the motion (speed, torque, position) of a machine using an electric motor.
- Parts: **power source → power modulator (converter) → motor → load**, with a **control unit** and **sensors** for feedback.

```
Source --> Power modulator --> Motor --> Load
              ^                  |
              |                  v
         Control unit <------ Sensors
              ^
         Reference
```

- Advantages over other drives (diesel, steam): wide range of speed and torque, high efficiency, no pollution at the point of use, easy control, can do regenerative braking, available in all ratings.
- **Group drive**: one motor runs many machines through a shaft (old, cheap, inflexible).
- **Individual drive**: one motor per machine. **Multi-motor drive**: several motors on one machine (e.g. rolling mill).

2. Dynamics of Electric Drives

FORMULA Fundamental torque equation: $T - T_L = J \frac{d\omega}{dt}$. T = motor torque, T_L = load torque, J = moment of inertia.

- $T > T_L$ → acceleration. $T < T_L$ → deceleration. $T = T_L$ → steady speed.
- **Equivalent values referred to motor shaft** (gear ratio $a = \omega_{load} / \omega_{motor}$, efficiency η):

FORMULA $J_{eq} = J_m + a^2 J_L$. $T_{L,eq} = a T_L / \eta$. For a linear motion load of mass M at speed v: J term = $M (v / \omega_m)^2$.

➤ Types of load torque

Load	Torque vs speed	Power vs speed	Example
Constant torque	T constant	$P \propto \omega$	Cranes, hoists, conveyors
Fan/pump type	$T \propto \omega^2$	$P \propto \omega^3$	Fans, centrifugal pumps, blowers
Constant power	$T \propto 1/\omega$	P constant	Traction, coilers, lathes
Linear	$T \propto \omega$	$P \propto \omega^2$	Generator with fixed R load

- **Active load**: can drive the motor (gravity load in hoists, vehicle going downhill). **Passive load**: always opposes motion (friction, cutting).

➤ Four-quadrant operation



- In quadrants I and III, power flows from motor to load (motoring). In II and IV, power flows back (braking).
- Hoist: raising load = quadrant I, lowering a heavy load = quadrant IV.

➤ Steady-state stability

FORMULA Equilibrium point is stable if $dT_L/d\omega > dT/d\omega$ at that point.

- In simple words: if speed rises a little, load torque must become larger than motor torque so the drive slows back.

3. Motor Rating and Duty Cycles

- Motor rating is decided mainly by **temperature rise** (insulation class limits).

FORMULA Heating: $\theta = \theta_f (1 - e^{(-t/\tau)}) + \theta_i e^{(-t/\tau)}$. τ = heating time constant. Cooling time constant is longer (poor ventilation at standstill).

Duty classes

Class	Duty
S1	Continuous duty
S2	Short-time duty
S3	Intermittent periodic duty
S4	Intermittent periodic with starting
S5	Intermittent periodic with starting and electric braking
S6	Continuous operation with intermittent load
S7	Continuous operation with starting and braking
S8	Continuous operation with periodic speed changes

- For fluctuating loads use the **equivalent current / torque / power method**: Ieq = sqrt(Σ Ii^2 ti / Σ ti). Check also that peak torque is within the motor's limit.
- **Flywheel** is used with fluctuating (impact) loads like presses; motor with drooping speed-torque curve lets the flywheel give energy.

4. DC Motor Drives

FORMULA Separately excited motor: ω = (V - Ia Ra) / (K Φ). T = K Φ Ia.

- Below base speed: **armature voltage control** at full field (constant torque). Above base speed: **field weakening** (constant power).

Braking of DC motors

Method	How	Note
Regenerative	Eb > V, energy returned to supply	Only above no-load speed; most efficient
Dynamic (rheostatic)	Armature disconnected, connected to a resistor	Energy wasted as heat; braking falls with speed
Plugging (reverse current)	Supply polarity reversed	Very fast but high current; needs extra resistance, must disconnect at zero speed

Converter-fed DC drives

- 1-phase full converter: Va = (2Vm/π) cos α. 3-phase full converter: Va = (3VmL/π) cos α.

- Full converter gives quadrants I and IV. **Dual converter** gives all four quadrants.
- **Chopper drive**: Va = D Vs. Used in battery vehicles; regenerative braking easy with a boost-mode (class B) chopper.

EXAMPLE Separately excited DC motor on a 1-phase full converter, 230 V, 50 Hz, α = 45°. Ra = 0.5 Ω, $K\Phi$ = 1.5 V·s/rad, Ia = 20 A (continuous). Va = 0.9 x 230 x cos 45° = 207.1 x 0.707 = 146.4 V. Eb = 146.4 - 20 x 0.5 = 136.4 V. ω = 136.4/1.5 = 90.9 rad/s, N = 90.9 x 60/(2π) = 868 rpm. Torque = 1.5 x 20 = 30 N·m.

- Discontinuous armature current at light load causes poor speed regulation; add series inductance.

5. Induction Motor Drives

➤ Speed control methods

Method	Range / note	Efficiency
Stator voltage control (AC controller)	Small range, for fans and pumps	Poor at low speed
V/f control (VSI)	Wide range, constant flux	Good
Rotor resistance (slip ring)	Below base speed, high starting torque	Poor (loss in rotor R)
Slip power recovery	Below base speed, slip ring motors	Good (slip power fed back)
Pole changing	Fixed steps only	Good

FORMULA Air-gap flux $\Phi \propto V / f$. Keep V/f constant below base speed so that flux and maximum torque stay constant.

- Above base frequency, V stays at rated value, so flux falls → **field weakening** (constant power, Tmax ∝ 1/f^2).
- At low frequency, add a **voltage boost** to make up for stator resistance drop.
- Under V/f control the slip speed at a given torque is nearly constant, so the speed-torque curves are parallel lines.

EXAMPLE 400 V, 50 Hz, 4-pole motor runs at 1460 rpm at rated torque. With V/f control at 30 Hz: V = 400 x 30/50 = 240 V. Ns = 120 x 30/4 = 900 rpm. Slip speed stays about 40 rpm, so N ≈ 860 rpm at rated torque.

- **Static Kramer drive**: slip power rectified and fed back through a line-commutated inverter (sub-synchronous only).
- **Static Scherbius drive**: uses a cycloconverter or back-to-back converter, so it works both below and above synchronous speed.
- **VSI vs CSI**: VSI fed drives are common (PWM IGBT inverters). CSI drives allow easy regenerative braking.

➤ Braking of induction motors

- **Regenerative**: speed above Ns (e.g. lowering load or reducing frequency in VFD).
- **Plugging**: swap two supply phases; slip near 2; heavy rotor loss.
- **DC dynamic braking**: DC injected into stator winding after disconnecting AC.

6. Advanced Control of AC Drives

- **Scalar control** (V/f): controls only magnitudes; simple; slow dynamic response.
- **Vector control (field oriented control, FOC)**: splits stator current into flux component **id** and torque component **iq**, like field and armature current of a DC motor. Gives fast torque response.
  - Direct FOC (flux measured or estimated) and indirect FOC (uses slip frequency calculation).
- **Direct torque control (DTC)**: controls torque and stator flux directly with hysteresis comparators and a switching table. No PWM modulator, fast response, but more torque ripple.
- **Sensorless control**: speed estimated from voltages and currents instead of an encoder.

REMEMBER FOC = "make an induction motor behave like a separately excited DC motor".

7. Synchronous and Special Motor Drives

- **Synchronous motor drive**: speed = 120 f / P exactly, so speed set by inverter frequency. **Self-controlled mode**: inverter frequency taken from rotor position, so the motor cannot fall out of step.
- **Load commutated inverter (LCI)** drive: over-excited synchronous motor gives leading pf, which commutates the SCRs. Used for large high-speed drives.
- **PMSM**: permanent magnet rotor, sinusoidal back EMF, used with FOC (EVs, servo, compressors).
- **BLDC motor**: trapezoidal back EMF, electronic commutation using **Hall sensors**, 6-step (120°) operation. Used in fans, drones, e-bikes.
- **Stepper motor**: moves in fixed steps for open-loop position control (printers, CNC).
- **Switched reluctance motor (SRM)**: no winding or magnet on rotor, rugged, but noisy and torque ripple.

FORMULA Stepper step angle $\beta = 360° / (m \times Nr)$, m = number of phases, Nr = rotor teeth. Example: 3 phases, 4 rotor teeth → $\beta = 30°$.

Point	BLDC	PMSM
Back EMF shape	Trapezoidal	Sinusoidal
Current shape	Rectangular (quasi-square)	Sinusoidal
Position sensing	Simple Hall sensors	Encoder / resolver (or sensorless)
Torque ripple	More	Less

8. Applications and Energy Saving

Application	Load type	Suitable drive
Electric traction	High starting torque, constant power at high speed	DC series (old), now induction or PMSM with VFD
Cranes and hoists	Constant torque, four quadrant	Slip ring IM, VFD with braking
Fans, pumps	$T \propto \omega^2$	Induction motor with VFD
Rolling mills	Fast reversal	DC drives / AC vector drives
Machine tools	Constant power, precise speed	Vector controlled AC, servo
Textile, paper mills	Many motors in exact speed ratio	Multi-motor drives

- **Fan and pump energy saving**: $P \propto N^3$. Using a VFD instead of a throttle valve saves a lot of energy at reduced flow.

EXAMPLE A pump runs at 80% speed with a VFD. Power = $0.8^3 = 0.512$ of rated power, so saving ≈ 48.8% (ideal case, ignoring losses).

- **Regenerative braking** in lifts, trains and EVs returns energy to the supply or the battery.

TIP In numericals always convert rpm to rad/s: $\omega = 2\pi N / 60$. Most mistakes come from mixing the two.

9. Most Asked Questions (practice)

1. What is an electric drive? Draw its block diagram and state its advantages.
2. Derive the fundamental torque equation. Find equivalent inertia and load torque through gears.
3. Explain the four-quadrant operation of a hoist drive.
4. State and explain the condition for steady-state stability.
5. Explain heating and cooling curves and duty classes of motors.
6. Explain regenerative, dynamic braking and plugging of DC motors.
7. Explain a 1-phase full converter fed DC drive; solve for speed at a given α.
8. Explain V/f control of induction motors. Why is voltage boost needed at low speed?

9. Explain static Kramer and static Scherbius drives.

10. Explain vector control. Compare BLDC and PMSM drives.

> **TIP** For GATE EE, drives questions are mostly converter-fed DC motor speed/torque, V/f control, four quadrants and load torque types. Practise the DC motor + converter combination numericals well.