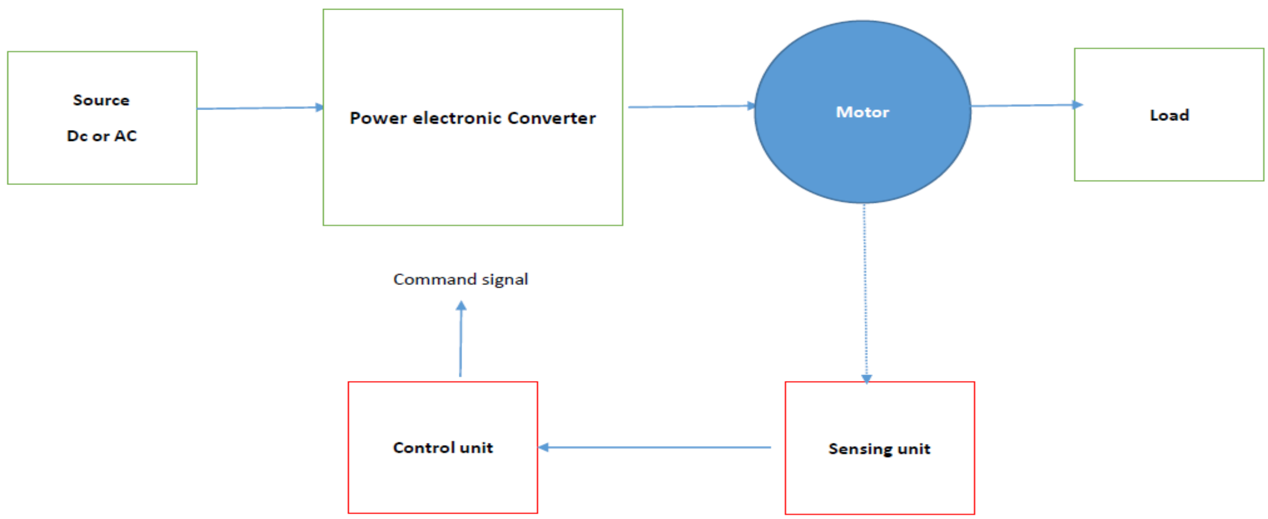
Electrical Drive and special Machines

A Drive is power electronics board or circuits, which are used to control the speed of electrical motors.

The block diagram of electrical drive is shown below :



Advantages of Electrical Drive

1. They have **flexible control characteristics**. The steady state and dynamic characteristics of electric drives can be shaped to satisfy the load requirements.

2. Drives can be **provided with automatic fault detection systems**. Programmable logic controller and computers can be employed to automatically control the drive operations in a desired sequence.

3. They are **available in wide range of torque**, speed and power.

4. They are **adaptable to almost any operating conditions** such as explosive and radioactive environments

5. It can **operate in all the four quadrants of speed-torque planes.**

6. They can be **started instantly** and can immediately be fully loaded

7. Control gear requirement for speed control, starting and braking is usually **simple and easy to operate.**

Electrical Machines

Most commonly used electrical machines for speed control applications are the following

1- **DC Machines**

Shunt, series, compound, separately excited DC motors and switched reluctance machines.

2- **AC Machines**

Induction, wound rotor, synchronous, PM synchronous and synchronous reluctance machines.

3- **Special Machines**

Brush less DC motors, stepper motors, switched reluctance motors are used.

Ac Drive and DC Drive

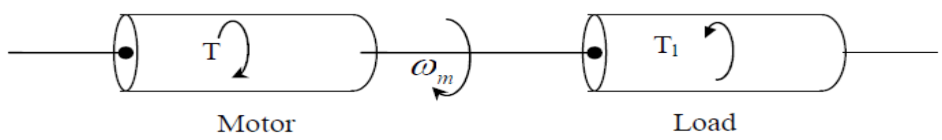
DC DRIVES	AC DRIVES
The power circuit and control circuit is simple and inexpensive	The power circuit and control circuit are complex
It requires frequent maintenance	Less Maintenance
The commutator makes the motor bulky, costly and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel cage induction motors
Fast response and wide speed range of control, can be achieved smoothly by conventional and solid state control	In solid state control the speed range is wide and conventional method is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits

Dynamics of Motor Load System

Fundamentals of Torque Equations

A motor generally drives a load (Machines) through *some transmission system*. While motor always rotates, the load may rotate or *undergo a translational motion*.

Load speed may be different from that of motor, and if the load has many parts, their speed may be different and while some parts rotate others may go through a translational motion. Equivalent rotational system of motor and load is shown in the figure.



Notations Used:

J = Moment of inertia of motor load system referred to the motor shaft $kg-m^2$

ω_m = Instantaneous angular velocity of motor shaft, rad/sec.

T = Instantaneous value of developed motor torque, N-m

T_l = Instantaneous value of load torque, referred to the motor shaft N-m

Load torque includes friction and wind age torque of motor. Motor-load system shown in figure can be described by the following fundamental torque equation.

$$T - T_l = \frac{d}{dt}(J\omega_m) = J\frac{d\omega_m}{dt} + \omega_m\frac{dJ}{dt} \text{------------} (1)$$

Equation (1) is applicable to variable inertia drives such as mine winders, reel drives, Industrial robots.

For drives with constant inertia $\frac{dJ}{dt} = 0$

$$\therefore T = T_l + J\frac{d\omega_m}{dt} \text{------------}(2)$$

Equation (2) shows that torque developed by motor is counter balanced by load torque T_l and a dynamic torque $\left(J\frac{d\omega_m}{dt}\right)$. Torque component $\left(J\frac{d\omega_m}{dt}\right)$ is called dynamic torque because it is present only during the transient operations.

Note:

Energy associated with dynamic torque $\left(J\frac{d\omega_m}{dt}\right)$ is stored in the form of kinetic energy given by $\frac{J\omega_m^2}{2}$.

Components of Load Torques:

The load torque T_l can be further divided in to following components

(i) Friction Torque (T_F)

Friction will be present at the motor shaft and also in various parts of the load. T_F is the equivalent value of various friction torques referred to the motor shaft.

(ii) **Windage Torque (T_W)**

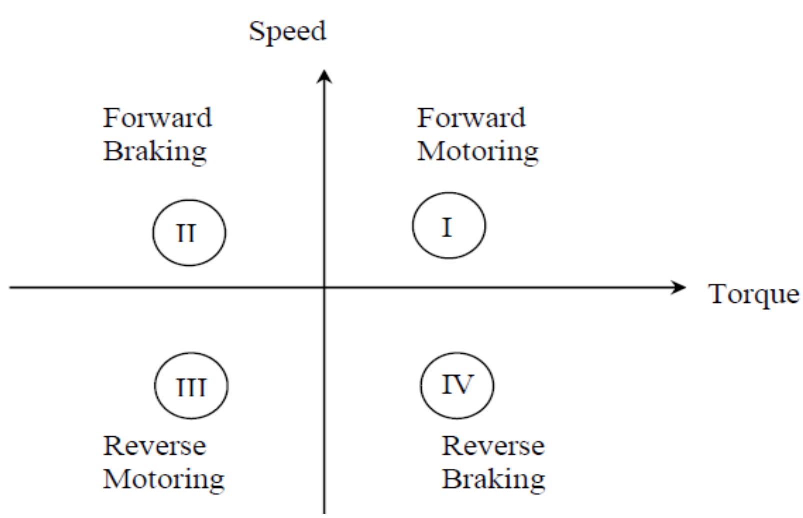
When motor runs, wind generates a torque opposing the motion. This is known as windage torque.

(iii) **Torque required to do useful mechanical work.**

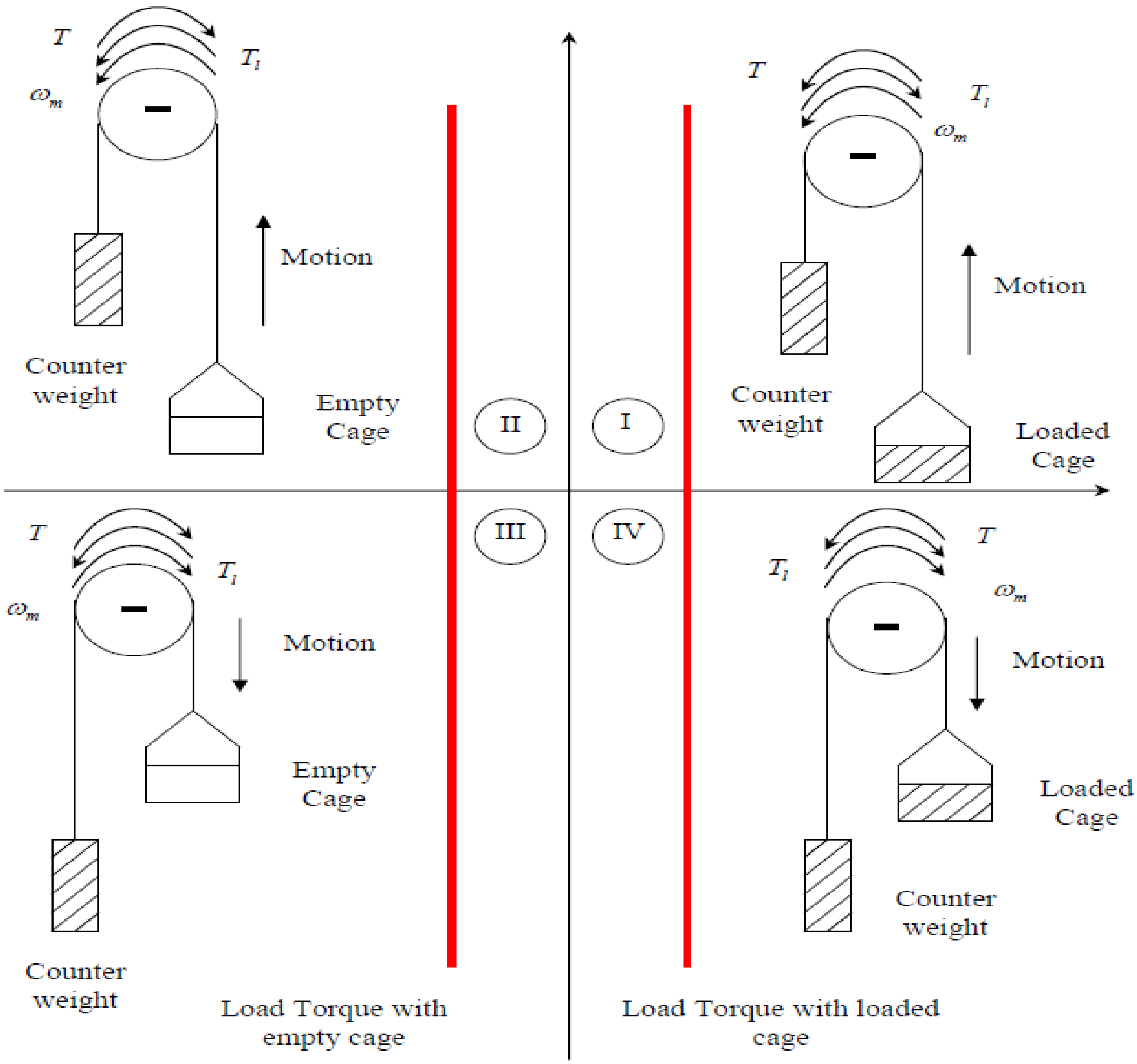
Nature of this torque depends upon particular application. It may be constant and independent of speed. It may be some function of speed, it may be time invariant or time variant, its nature may also change with the load's mode of operation.

Multi quadrant Operation:

For consideration of multi quadrant operation of drives, it is useful to establish suitable conventions about the signs of torque and speed. *A motor operates in two modes – Motoring and braking.* In *motoring*, it converts *electrical energy into mechanical energy*, which *supports its motion*. In *braking it works as a generator* converting *mechanical energy into electrical energy* and thus opposes the motion. Motor can provide motoring and braking operations for *both forward and reverse directions.* Figure shows the torque and speed co-ordinates for both forward and reverse motions. Power developed by a motor is given by the product of speed and torque. *For motoring operations power developed is positive and for braking operations power developed is negative*.



In quadrant I, developed power is positive, hence machine works as a motor supplying mechanical energy. Operation in quadrant I is therefore called Forward Motoring. In quadrant II, power developed is negative. Hence, machine works under braking opposing the motion. Therefore, operation in quadrant II is known as forward braking. Similarly, operations in quadrant III and IV can be identified as reverse motoring and reverse braking since speed in these quadrants is negative. For better understanding of the above notations, let us consider operation of hoists in four quadrants as shown in the figure. Direction of motor and load torques, and direction of speed are marked by arrows.

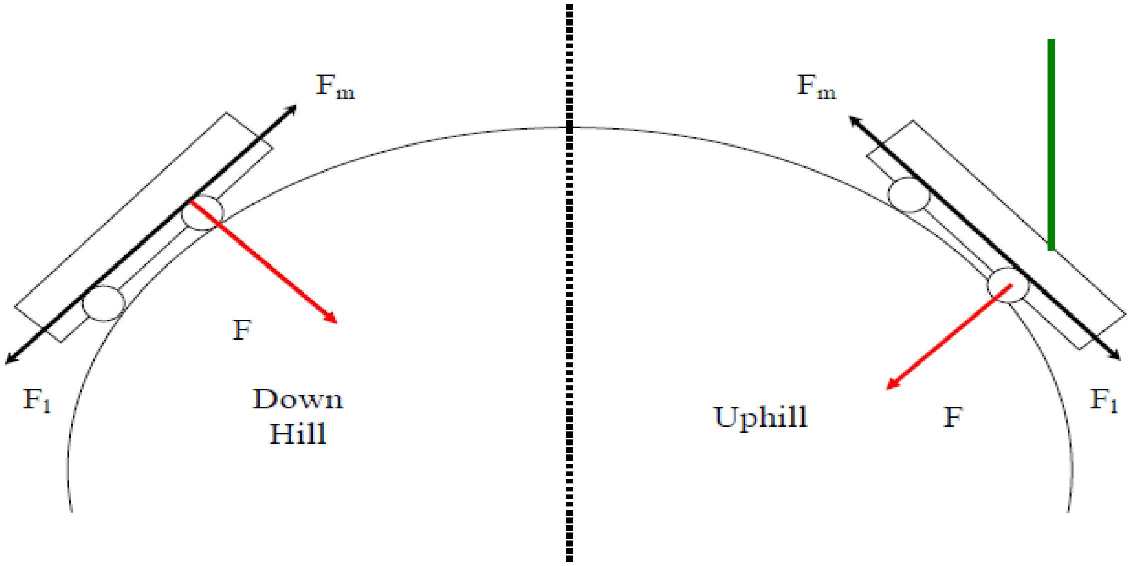


A hoist consists of a rope wound on a drum coupled to the motor shaft one end of the rope is tied to a cage which is used to transport man or material from one level to another level. Other end of the rope is counterweight. Weight of the counterweight is chosen to be higher than the weight of empty cage but lower than of a fully loaded cage. Forward direction of motor speed will be one which gives upward motion of the cage. Load torque line in quadrants I and IV represents speed-torque characteristics of the loaded hoist. This torque is the difference of torques due to loaded hoist and counterweight. The load torque in quadrants II and III is the speed torque characteristics for an empty hoist. This torque is the difference of torques due to counterweight and the empty hoist. Its sign is negative because the counterweight is always higher than that of an empty cage. The quadrant operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counterclockwise direction here. This motion will be obtained if the motor produces positive torque in CCW direction equal to the magnitude of load torque TL1. Since developed power is positive, this is forward motoring operation. Quadrant IV is obtained when a loaded cage is lowered. Since the weight of the loaded cage is higher than that of the counterweight. It is able to overcome due to gravity itself. In order to limit the cage within a safe value, motor must produce a positive torque T equal to TL2 in anticlockwise direction. As both power and speed are negative, drive is operating in reverse braking operation. Operation in quadrant II is obtained when an empty cage is moved up. Since a counter weigh is heavier than an empty cage, its able to pull it up. In order to limit the speed within a safe value, motor must produce a braking torque equal to TL2 in clockwise direction. Since speed is positive and developed power is negative, it's forward braking operation. Operation in quadrant III is obtained when an empty cage is lowered. Since an empty cage has lesser weight than a counterweight, the motor should produce a torque in CW direction. Since speed is negative and developed power is positive, this is reverse motoring operation. Steady State Stability.

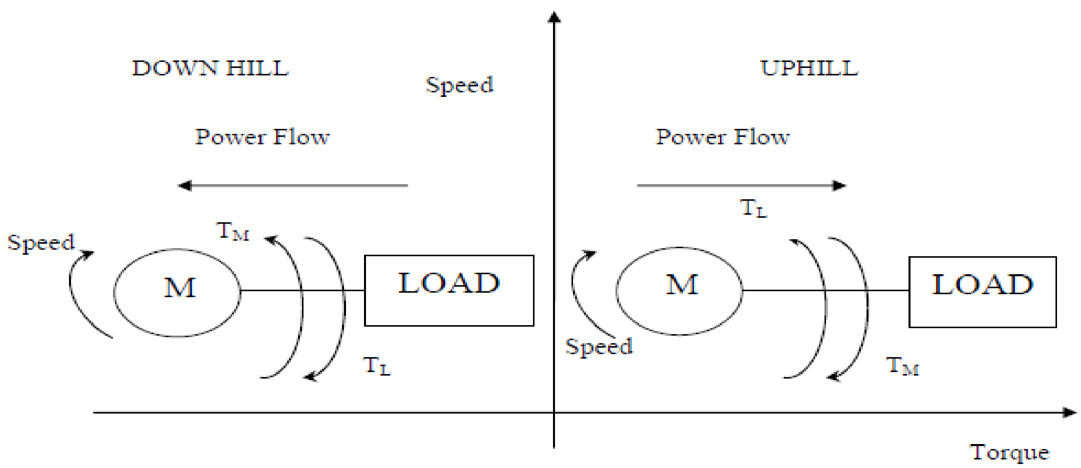
Equilibrium speed of motor-load system can be obtained when motor torque equals the load torque. Electric drive system will operate in steady state at this speed, provided it is the speed of stable state equilibrium. Concept of steady state stability has been developed to readily evaluate the stability of an equilibrium point from the steady state speed torque curves of the motor and load system.

Basics of Regenerative Braking

In the regenerative braking operation, the motor operates as generator, while it is still connected to the supply. Here, the motor speed is greater than the synchronous speed. Mechanical energy is converted into electrical energy, part of which is returned to the supply and rest of the energy is last as heat in the winding and bearings of electrical machines pass smoothly from motoring region to generating region, when over driven by the load. An example of regenerative braking is shown in the figure below. Here an electric motor is driving a trolley bus in the uphill and downhill direction. The gravity force can be resolved into two components in the uphill direction. One is perpendicular to the load surface (F) and another one is parallel to the road surface Fl. The parallel force pulls the motor towards bottom of the hill. If we neglect the rotational losses, the motor must produce force Fm opposite to Fl to move the bus in the uphill direction.



This operation is indicated as shown in the figure below in the first quadrant. Here the power flow is from the motor to load.



Now we consider that the same bus is traveling downhill, the gravitational force doesn't change its direction, but the load torque pushes the motor towards the bottom of the hill. The motor produces a torque in the reverse direction because the direction of the motor torque is always opposite to the direction of the load torque. Here the motor is still in the same direction on both sides of the hill. This is known as regenerative braking. The energy exchange under regenerative braking operation is power flows from mechanical load to source. Hence, the load is driving the machine, and the machine is generating electric power that is returned to the supply.