

## 1.4 Multi quadrant Dynamics:

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.

Now consider equilibrium point B which is obtained when the same motor drives another load as shown in the figure. A decrease in speed causes the load torque to become greater than the motor torque, electric drive decelerates and operating point moves away from point B.

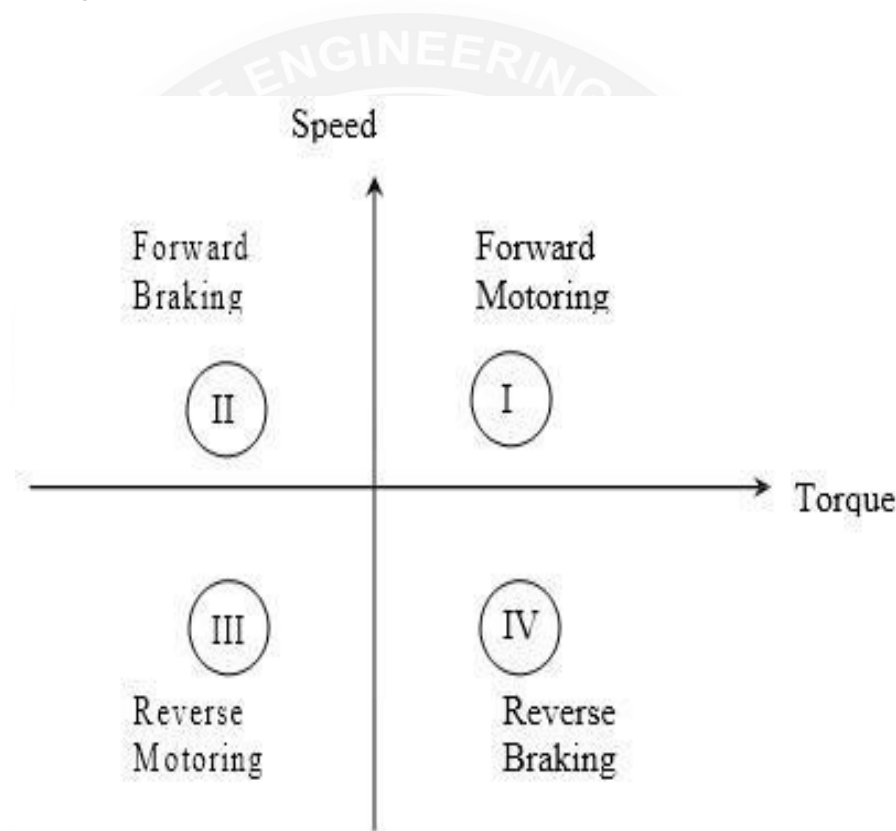
Similarly when working at point B and increase in speed will make motor torque greater than the load torque, which will move the operating point away from point B.

Similarly operation 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 hoist in four quadrants as shown in the figure. Direction of motor and load torques and direction of speed are marked by arrows.

The figure below represents a DC motor attached to an inertial load. Motor can provide motoring and braking operations for both forward and reverse directions.

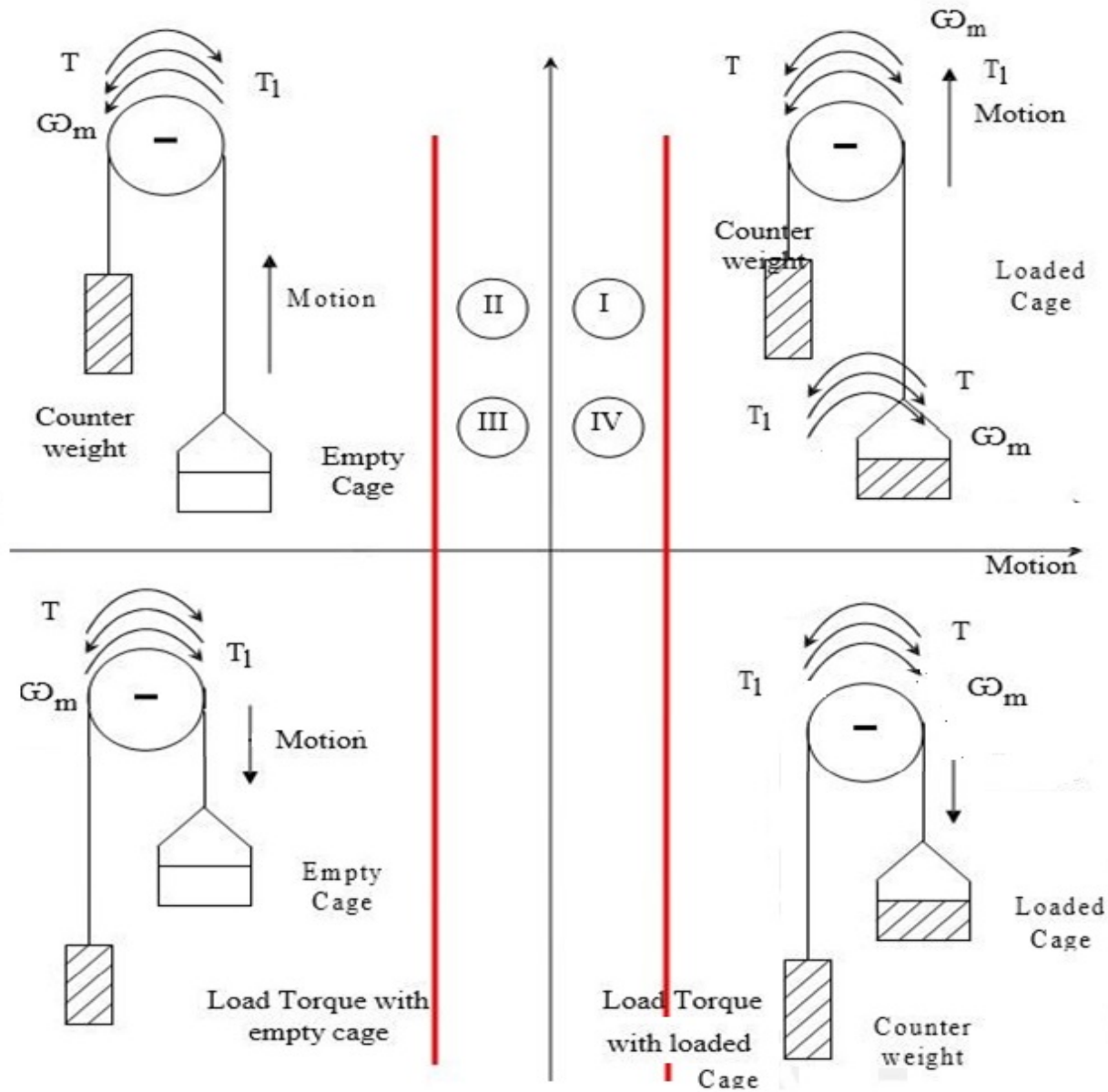
Figure shows the torque and speed co-ordinates for both forward and reverse motions. Power developed by a motor is given by the product of speed and torque. For motoring operations Power developed is positive and for braking operations power developed is negative.



**Figure 1.4.1 Four quadrant operation of drives**

*(Source: "Fundamentals of Electrical Drives" by G.K.Dubey, page-12)*

For better understanding of the above notations, let us consider operation of hoist in four quadrants as shown in the figure. Direction of motor and load torques and direction of speed are marked by arrows.



**Figure 1.4.2 Operation of hoist in four quadrants**

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey, page-13)

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 has a counter weight. Weight of the counter weight 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 counter weight. 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 counter weight and the empty hoist. Its sign is negative because the counter weight is always higher than that of an empty cage. The quadrant I operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counter clockwise 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 counter weight. 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 weight 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 a lesser weight than a counter weight, the motor should produce a torque in CW direction. Since speed is negative and developed power is positive, this is reverse motoring operation. During transient condition, electrical motor can be assumed to be in electrical equilibrium implying that steady state speed torque curves are also applicable to the transient state operation.

