Electrical Drives I

Week 4-5-6: Solid state dc drives

Four-quadrant operation and inversion

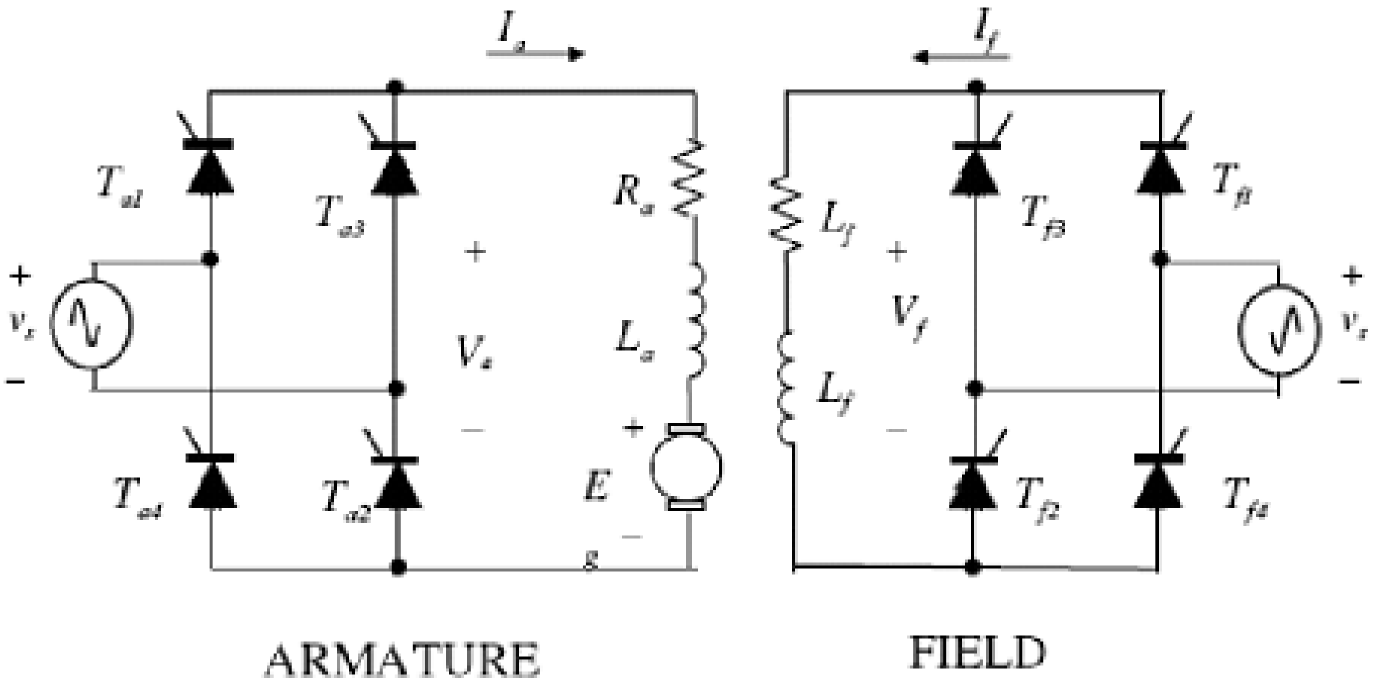
- So far we have looked at the converter as a rectifier, supplying power from the a.c. mains to a d.c. machine running in the positive direction and acting as a motor.

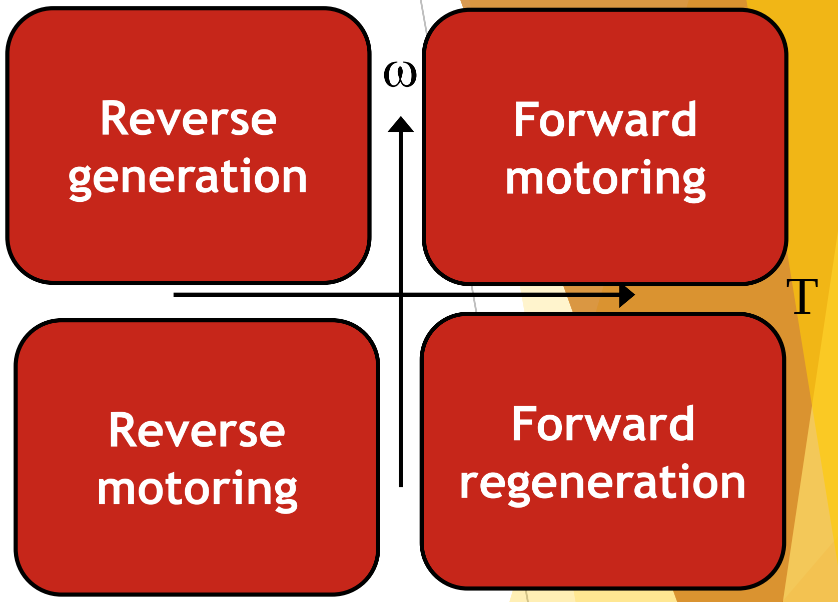
How to operate the motor in the opposite direction, with negative speed and torque in quadrant 3?

Is it possible to operate the machine as a generator, so that power is returned to the a.c. supply, the converter then 'inverting' power rather than rectifying, and the system operating in quadrant 2 or quadrant 4. We need to do this if we want to achieve regenerative braking. Is it possible, and if so how?

Applying a positive voltage V >E, a current flows into the armature and the machine runs as a motor. If we make V< E, the current, torque and power automatically reverse direction, and the machine acts as a generator, converting mechanical energy (its own kinetic energy in the case of regenerative braking) into electrical energy. And if we want to motor or generate with the reverse direction of rotation, all we have to do is to reverse the polarity of the armature supply. The d.c. machine is inherently a four-quadrant device, but needs a supply which can provide positive or negative voltage, and simultaneously handle either positive or negative current.

Controlled Rectifier Fed – Single-phase DC Drives





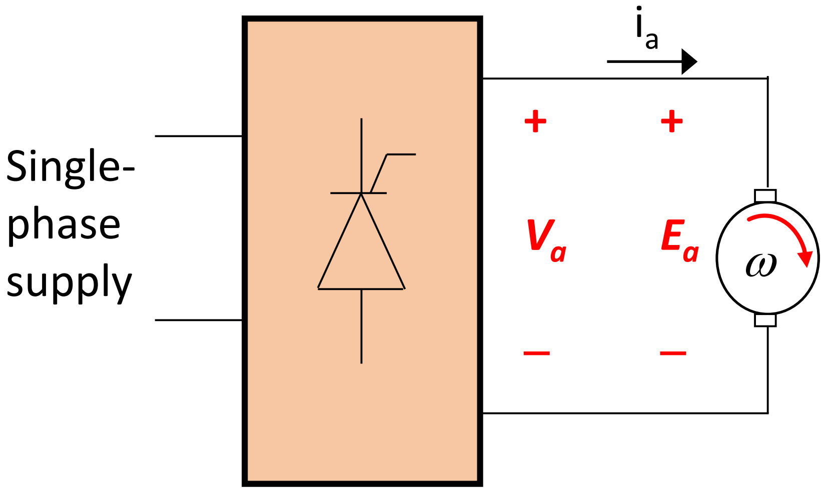
$$I_a = \frac{V_a - E_a}{R_a}$$

$$V_a = \frac{2V_m}{\pi}\cos\alpha_a$$

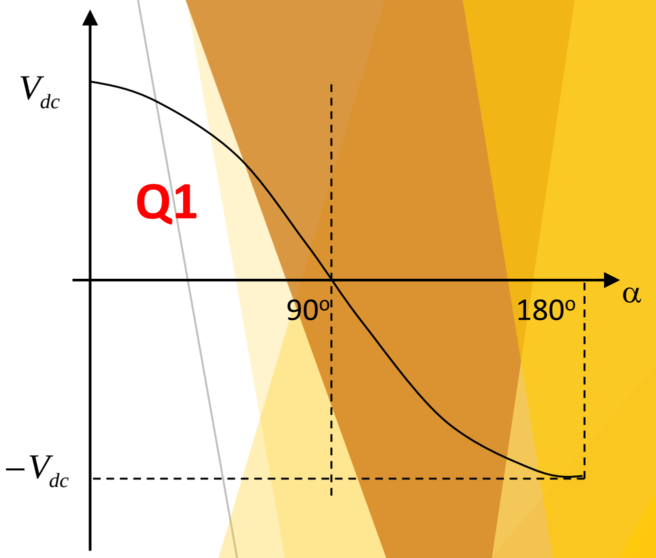
$$V_f = \frac{2V_m}{\pi}\cos\alpha_f$$

Single-converter reversing drives: Quadrant 1

- When the motor is running at full speed forward, the converter delay angle will be small, and the converter output voltage V and current I will both be positive.



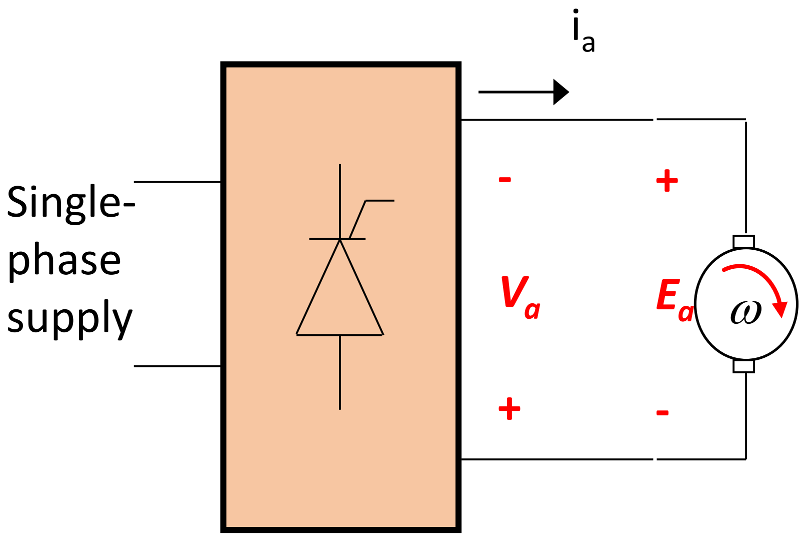
- For **Quadrant 1** operation:
  - ω positive $\rightarrow E_a$ and V_a positive
  - $\alpha_a \leq 90°$
  - I_a positive
  - Rectifier delivers power to motor, i.e. forward motoring.

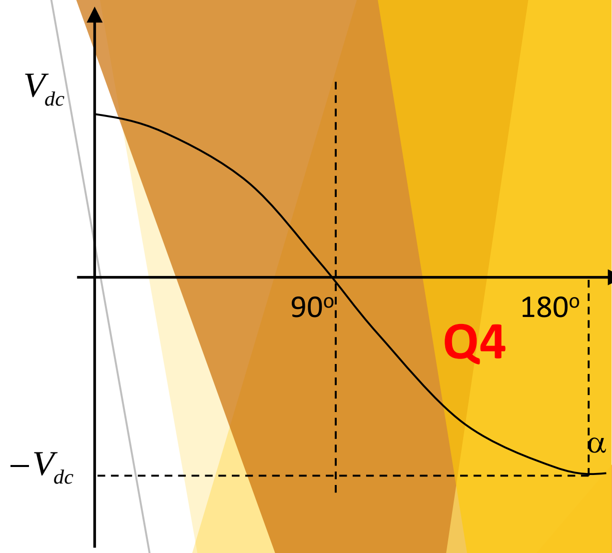


Changing the firing angle of the single phase thyristor converter will change the magnitude of V_a by changing the firing angle, keeping the same direction of current. Thus motor will operate in Q1 and Q4

Single-converter reversing drives: Quadrant 4

- In the inverting mode of operation, $+I_a$ and $-V_a$ make the average power flow negative. This means that the machine acts as a generator and its stored mechanical energy is converted to electrical energy and fed back to the line. This is defined as regenerative braking mode



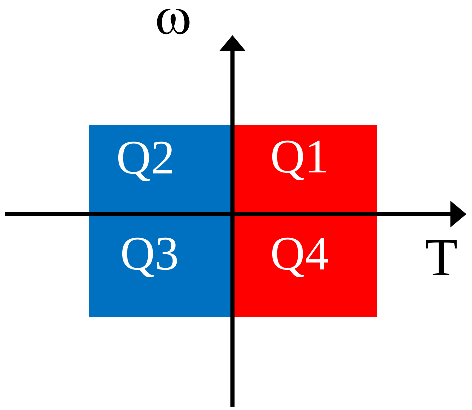


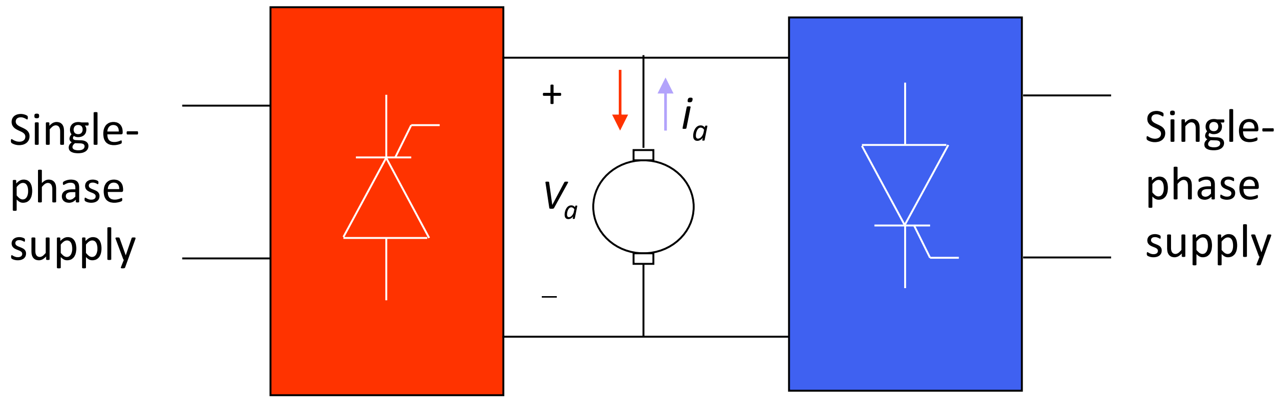
- For **Quadrant 4** operation:
  - ω positive $\rightarrow$ E_a positive and V_a negative
  - $90° \leq \alpha \leq 180°$
  - I_a positive
  - power is flowing back to the mains

    i.e. forward regeneration

Controlled Rectifier Fed – Single-phase DC Drives

- **Four-quadrant drive**
- Converter 1 for operation in 1st and 4th quadrant
- Converter 2 for operation in 2nd and 3rd quadrant
- Limited to applications up to 15 kW





Converter 1

supplies positive current to the motor

Converter 2

supplies negative current to the motor

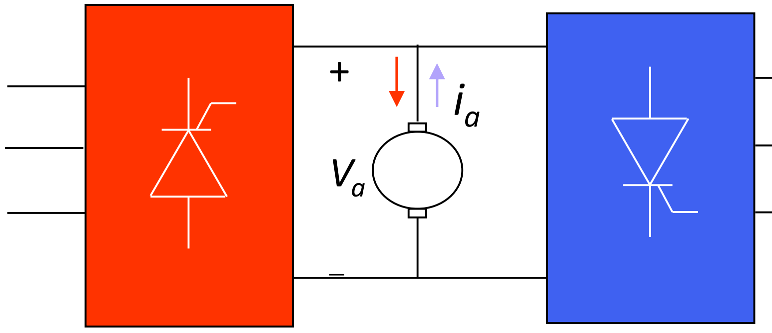
Two rectifiers connected in **anti-parallel** across motor armature

Controlled Rectifier Fed – Three-phase DC Drives

- **Four-quadrant drive**

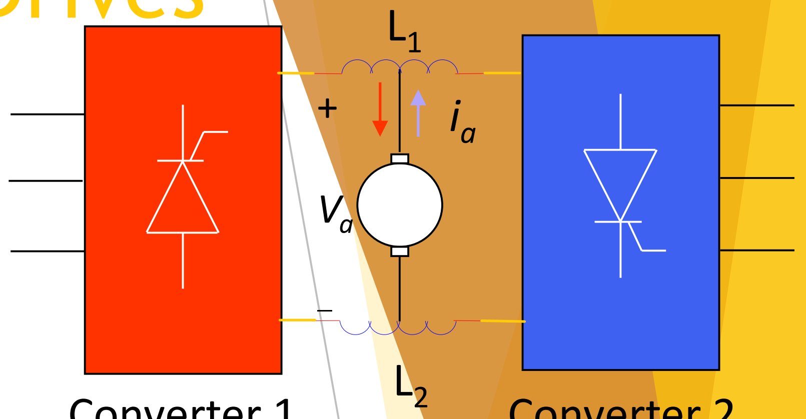
For continuous current:

$$V_a = \frac{3V_{\mathrm{L-L},\,m}}{\pi}\cos\alpha_a$$



Converter 1

Converter 2



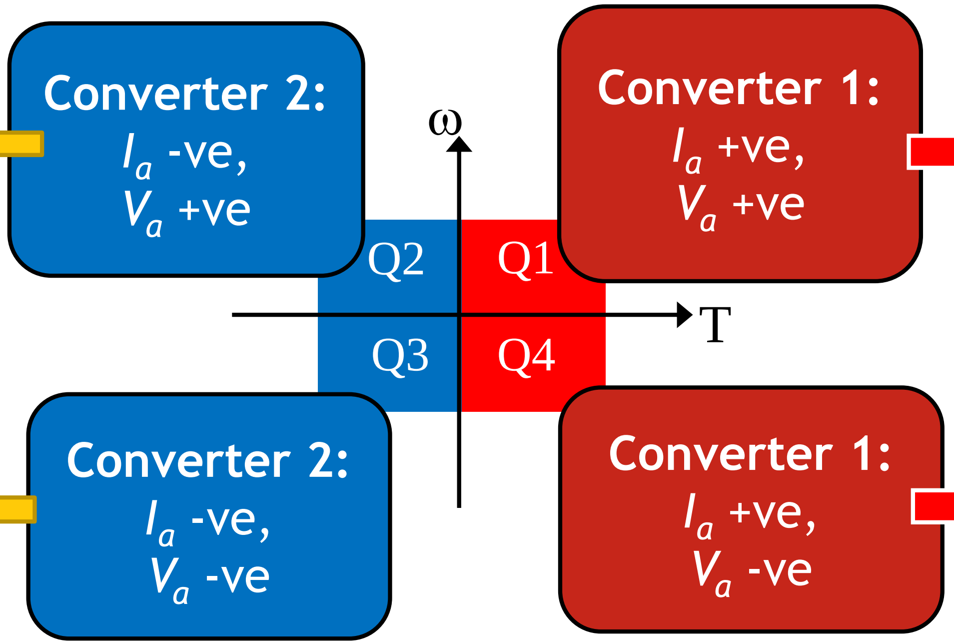
Converter 1

Converter 2

where $V_{\mathrm{L\text{-}L},\,m}$ = peak line-to-line voltage.

- Similar to single-phase drive: $\alpha_{a1} + \alpha_{a2} = \pi$

$$I_a = \frac{V_a - E_a}{R_a} \qquad V_f = \frac{3V_{\mathrm{L\text{-}L},\,m}}{\pi}\cos\alpha_f$$



$90 < \alpha_{a2} < 180°$
$\alpha_{a1} = \pi - \alpha_{a2}$

$0 < \alpha_{a1} < 90°$
$\alpha_{a2} = \pi - \alpha_{a1}$

$0 < \alpha_{a2} < 90°$
$\alpha_{a1} = \pi - \alpha_{a2}$

$90° < \alpha_{a1} < 180°$
$\alpha_{a2} = \pi - \alpha_{a1}$

Rectifier Fed DC Drives Problems

1. **Distortion of Supply**
   - Controlled rectifier introduces harmonics to supply currents and voltages which cause:
     - heating and torque pulsations in motor
     - resonance in power system network – interaction between rectifier RL with capacitor banks in system
   - **Solution** - eliminate most dominant harmonics by:
     - install LC filters at input of converters – tuned to absorb most dominant harmonics (i.e. 5th and 7th harmonics)
     - Use 12-pulse converter – consists of two 6-pulse controlled rectifiers connected in parallel
     - Selective switching of supply input using self-commutating devices (eg. GTOs, IGBTs) in the converter
2. **Low supply power factor**
   - Power factor related to firing angle α of rectifier
   - Low power factor especially during low speed operations
   - **Solution:**
     - Employ pulse-width modulated (PWM) rectifiers using GTOs, IGBTs
       - High power factor
       - Low harmonic supply currents
       - Low efficiency - high switching losses (disadvantage)

Rectifier Fed DC Drives Problems

3. **Effect on motor**

- Ripple in motor current – harmonics present causes torque ripple, heating and derating of motor, solution: extra inductance added in series with La
- Slow response
- Discontinuous current may occur if
  - Inductance is not large enough
  - Motor is lightly loaded
- Effect of discontinuous current
  - Rectifier output voltage increases $\Rightarrow$ motor speed increases (poor speed regulation under open-loop operation)