Brushless-DC Motor Commutation – Field-Oriented Control

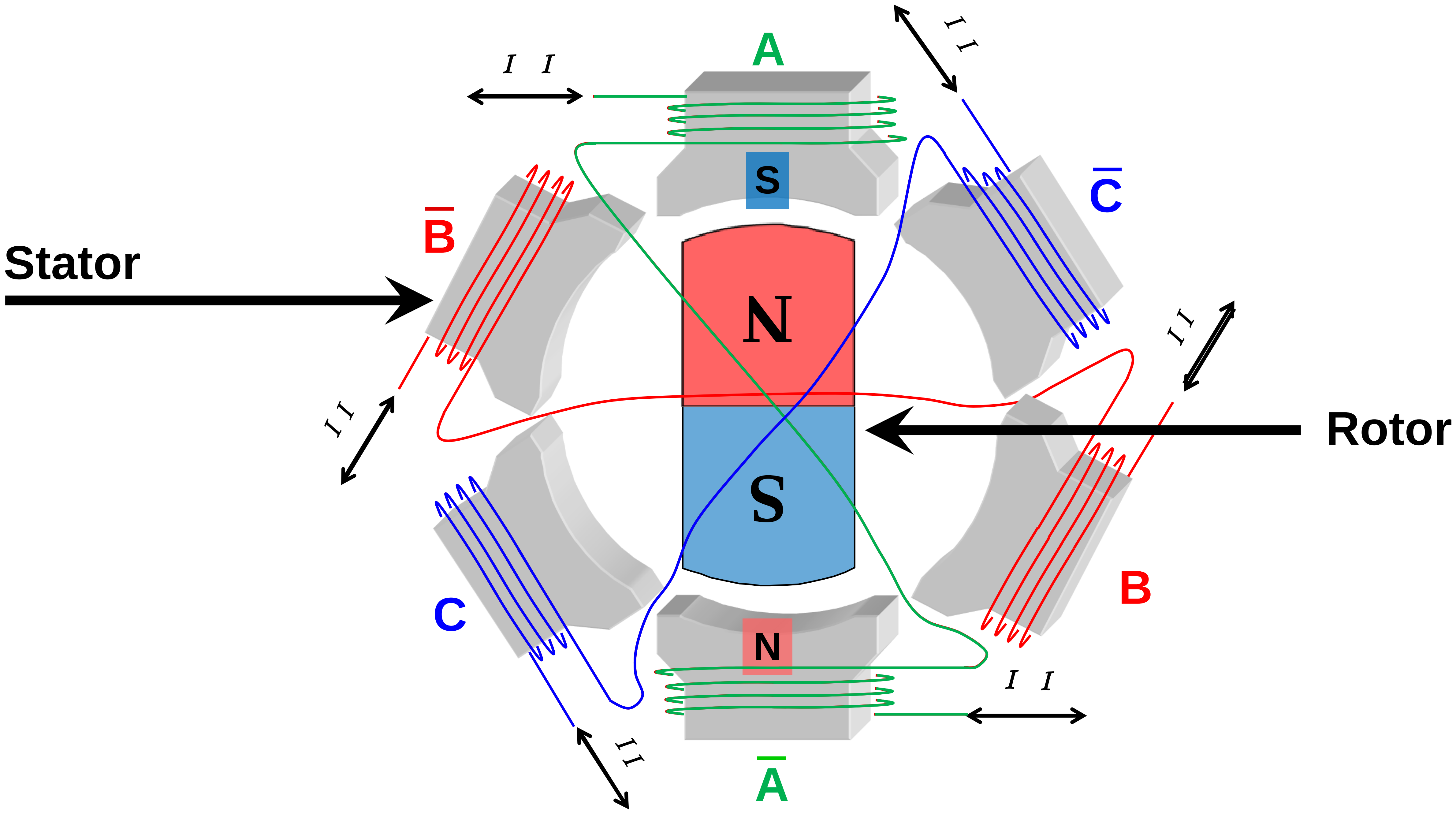
TI Precision Labs – Motor Drivers

Presented and prepared by Andrew Liu

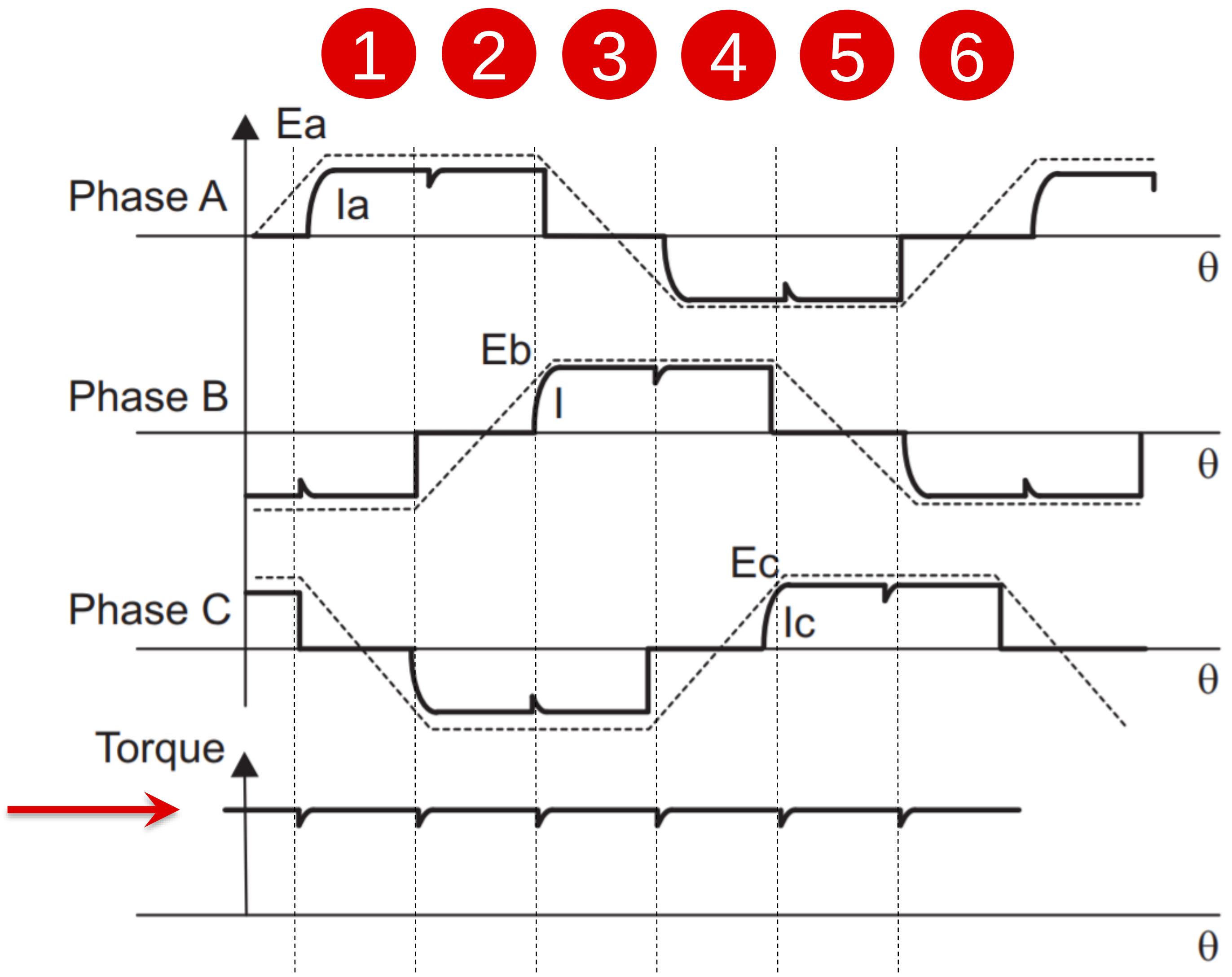
Overview

- BLDC motor construction
- Commutation methods (trap, sine, FOC)
- FOC mathematics and control block diagram
- FOC applications
- Conclusion and additional resources

Brushless-DC motor construction



Trapezoidal commutation



Difficulty: Low

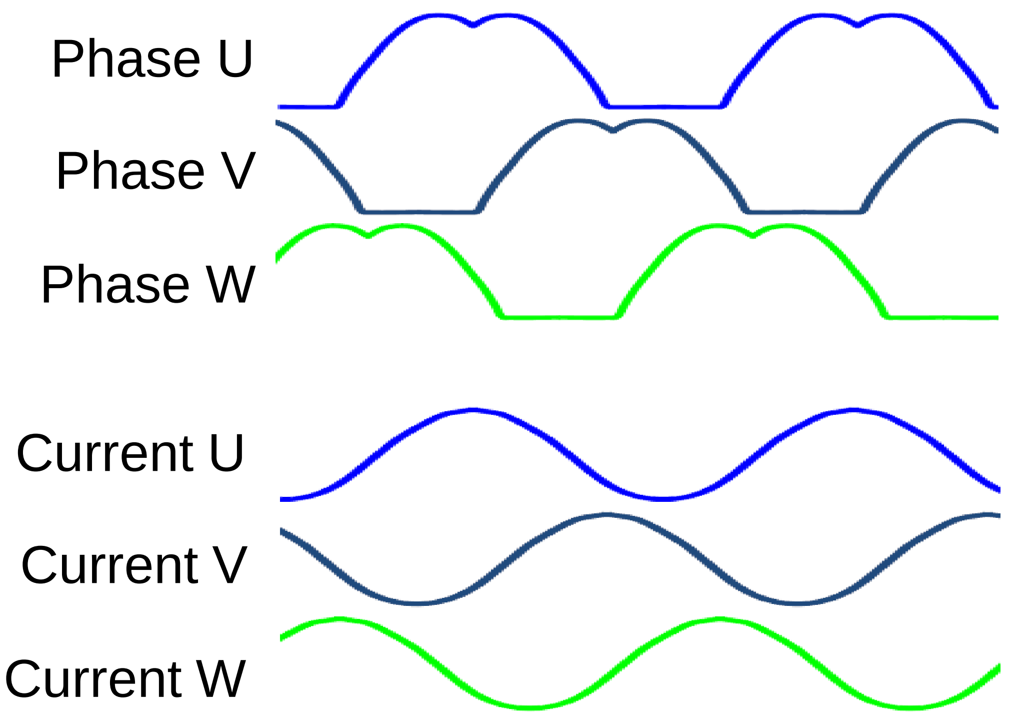
Advantages:

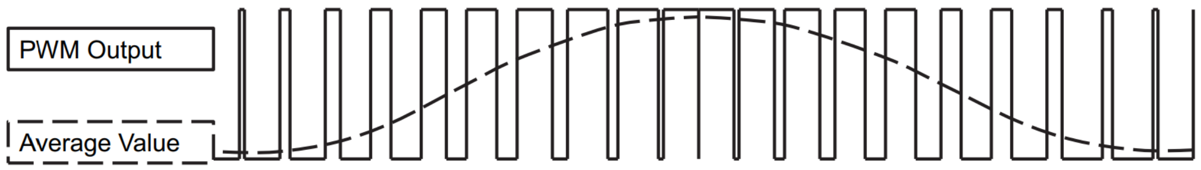
- Simple control scheme (6 states)
- High speed and high torque
- Low switching losses (1xPWM)

Disadvantages:

- High torque ripple
- High audible electrical noise
- Not maximizing torque output and motor efficiency

Sinusoidal commutation (180°)





Difficulty: Medium

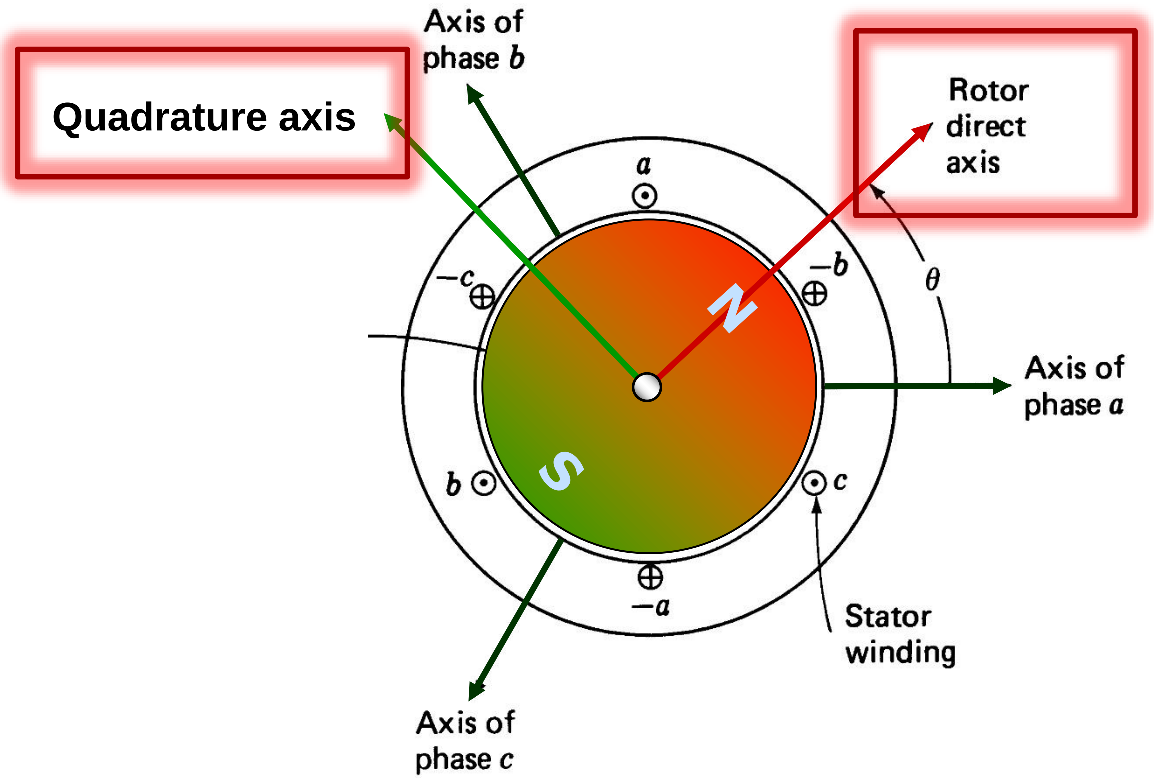
Advantages:

- Low audible noise
- High motor efficiency
- Low torque ripple for stable loads

Disadvantages:

- High switching losses (3x PWM)
- More complex control vs trapezoidal
- High torque ripple for dynamic loads
- Not maximizing torque output and motor efficiency

Field-Oriented Control (FOC)



Difficulty: High

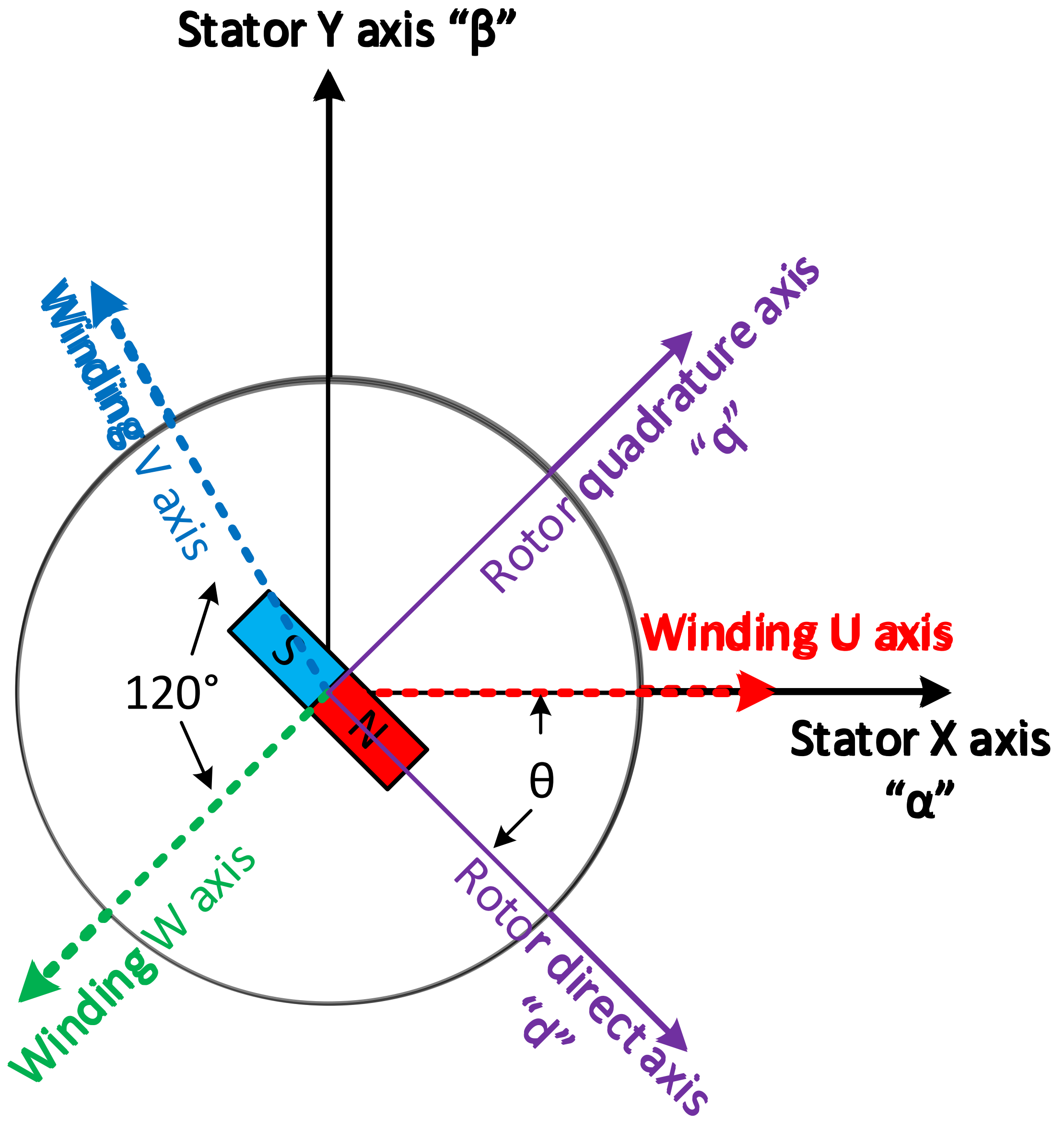
Advantages:

- Highest torque and motor efficiency
- Lowest audible noise and torque ripple
- High motor speed (+field weakening)

Disadvantages:

- High switching losses (3x PWM)
- Complex control and real-time calculations needed from MCU

Control system variables



Rotor Angle:

$$\theta$$

Motor phase currents:

$$I_U, I_V, I_W$$

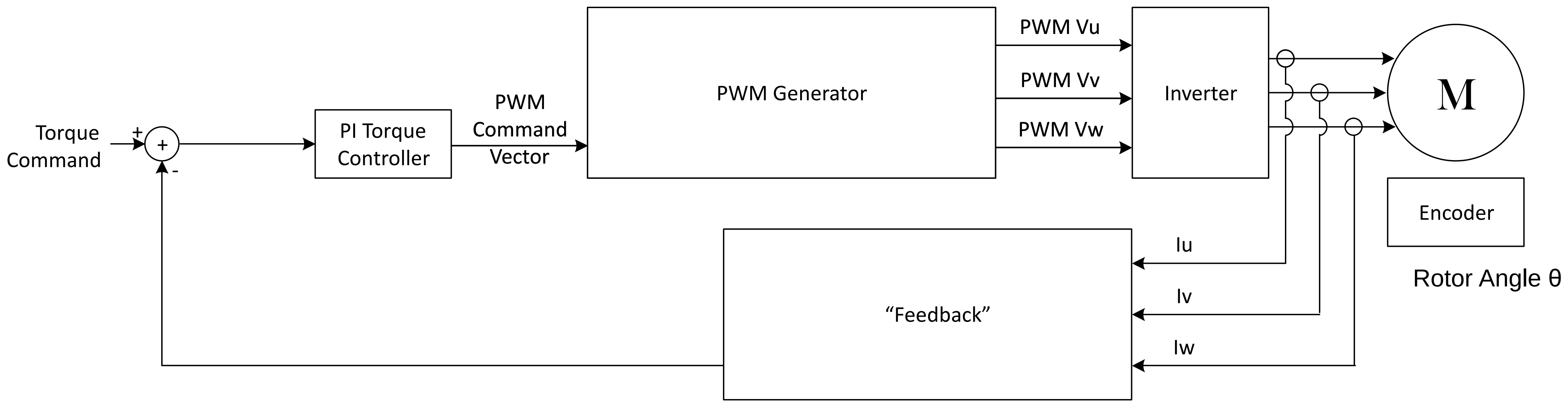
Fixed X,Y coordinate plane:

$$\mathrm{I}_\alpha, I_\beta$$

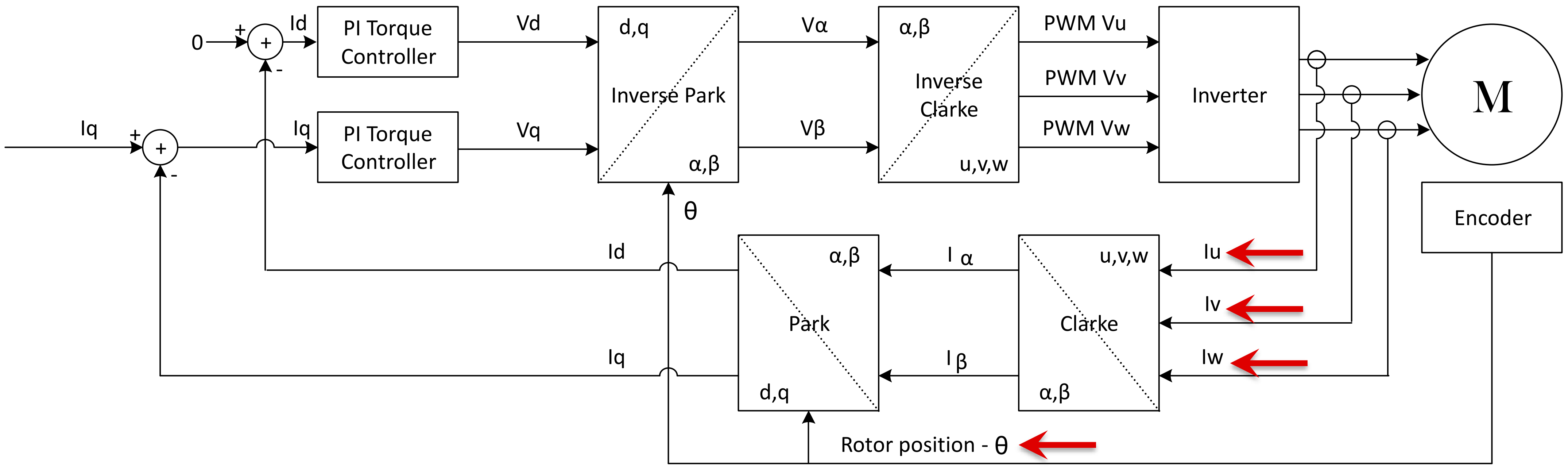
Direct and Quadrature torque vectors:

$$I_d, I_q$$

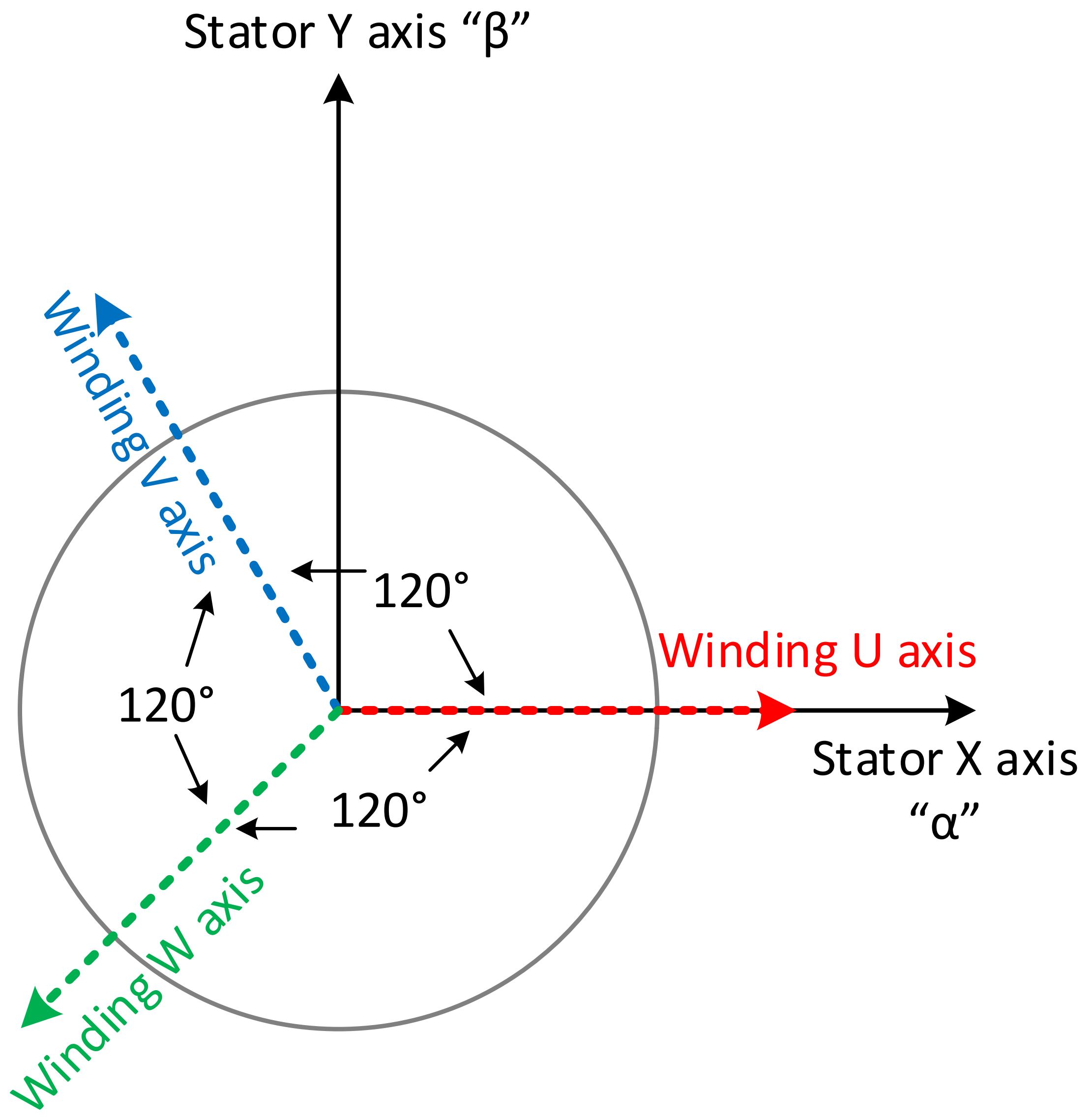
Control block diagram



Control block diagram - FOC



Math – Clarke transform



Variables:

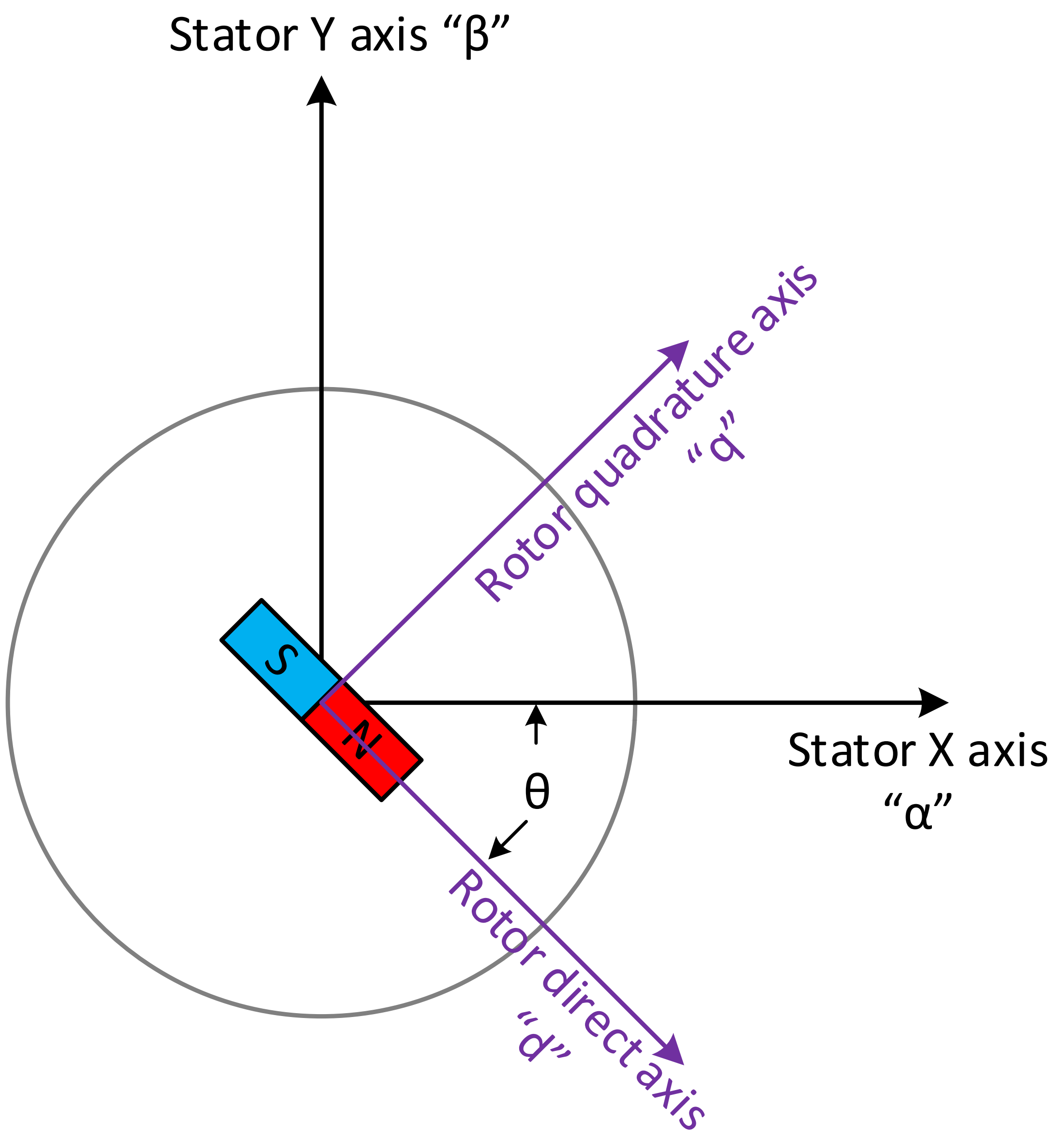
$$I_U, I_V, I_W \rightarrow \mathrm{I}_\alpha, I_\beta$$

Clarke transform equations:

$$\alpha = U_\alpha + V_\alpha + W_\alpha$$
$$\alpha = U + V\cos(120°) + W\cos(240°)$$
$$\alpha = U - \frac{1}{2}V - \frac{1}{2}W$$

$$\beta = U_\beta + V_\beta + W_\beta$$
$$\beta = Vsin(120°) + Wsin(240°)$$
$$\beta = \frac{\sqrt{3}}{2}V - \frac{\sqrt{3}}{2}W$$

Math – Park transform



Variables:

$\mathrm{I}_{\alpha}, I_{\beta} \rightarrow I_d, I_q$ Rotor Angle: θ

Park transform equations:

$$d = \alpha_d + \beta_d$$
$$d = \alpha \cos(\theta) + \beta \sin(\theta)$$

$$q = \alpha_q + \beta_q$$
$$q = \alpha\, sin(\theta) + \beta\, sin(\theta)$$

FOC applications

Method	Control Implementation	Noise	Motor efficiency	Switching Loss	Comments
Trap	Look-up table (simple)	High	Low	Low	Best for high-torque or high-speed applications
Sine	Look-up table (complex)	Low	High	High	Not the best for dynamic torque
FOC	Real-time calculation (complex)	Lowest	Highest	High	Highest torque and efficiency, best torque ripple

- Torque ripple
  - Quiet operation (fans, air purifiers)
  - Smooth dynamic operation in full speed range (robotic servos, washing machines)
- Motor efficiency
  - Longer battery life
  - Lower power consumption (cost savings)
- Motor speed
  - Increased speed performance through field-weakening technique (robot vacuums)

Additional Resources

- TIPL video series:
  - https://training.ti.com/ti-precision-labs-motor-drives-commutation-trapezoidal
  - https://training.ti.com/ti-precision-labs-motor-drivers-sinusoidal-control
  - https://training.ti.com/ti-precision-labs-motor-drivers-sensored-vs-sensorless-control
- C2000 motor control:
  - https://training.ti.com/c2000-motorcontrol-training-series

To find more motor driver technical resources and search products, visit ti.com/motordrivers