Comparison of commutation methods

TI Precision Labs – Motor Drivers

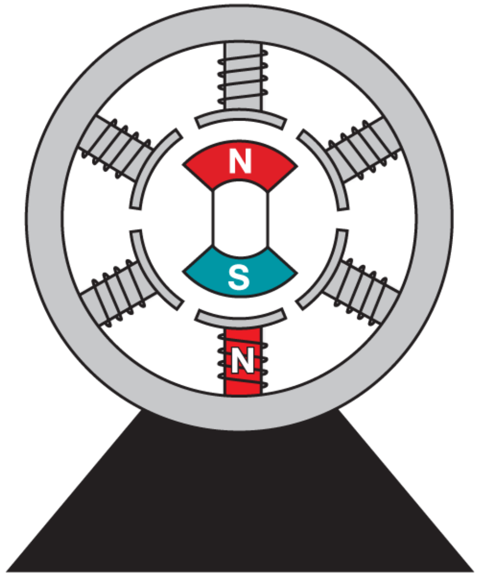
Presented and prepared by Aaron Barrera

Overview

- Types of commutation methods
- Trapezoidal (120°)
- Trapezoidal (150°)
- Sinusoidal (180°)
- Field-orientated control (FOC)

Types of commutation methods

- Many types of commutation methods can be used for spinning a BLDC motor, depending on the motor type, application, and solution



Motor Type

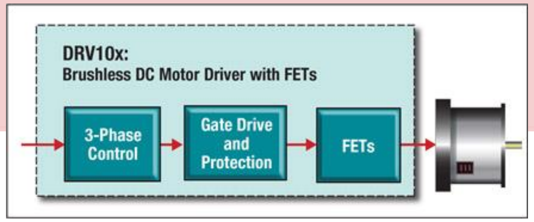
- Trapezoidal
- Sinusoidal

Application

- Torque
- Position
- Speed

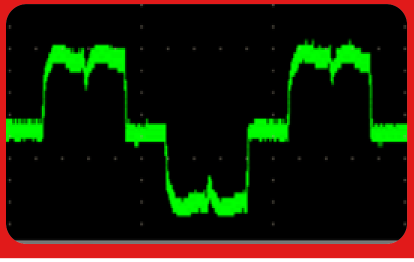
Solution

- Integrated Control and/or MOSFET
- Sensored vs. sensorless
- Acoustics, efficiency, etc.

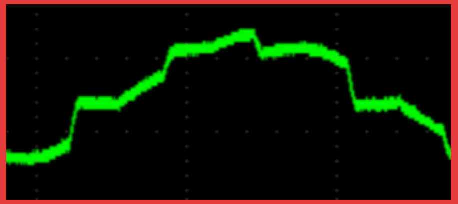


Types of commutation methods (cont.)

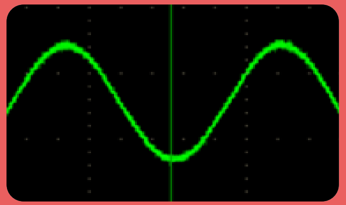
Trapezoidal (120°)



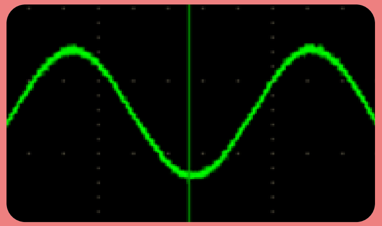
Trapezoidal (150°)



Sinusoidal (180°)



Field-oriented control (FOC)

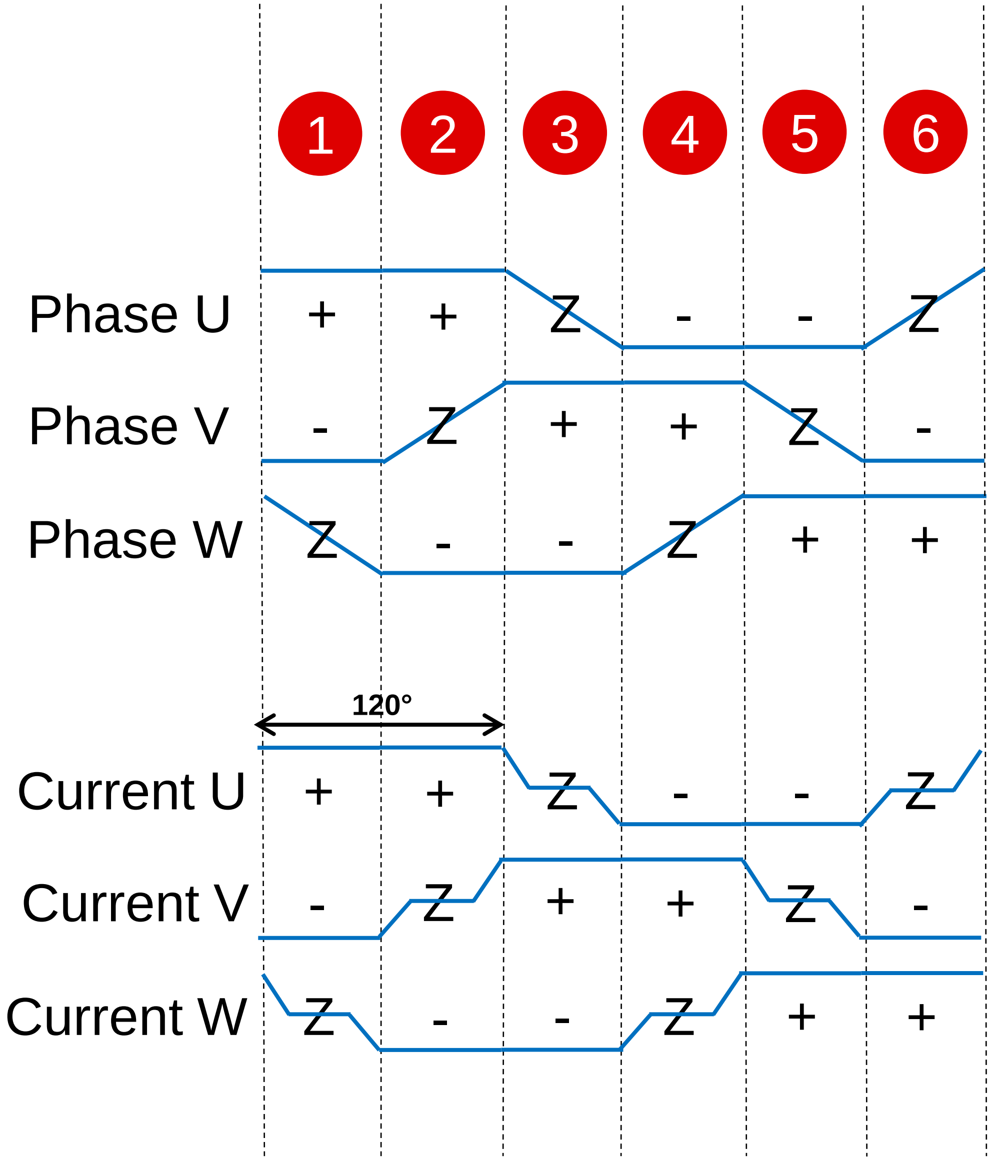


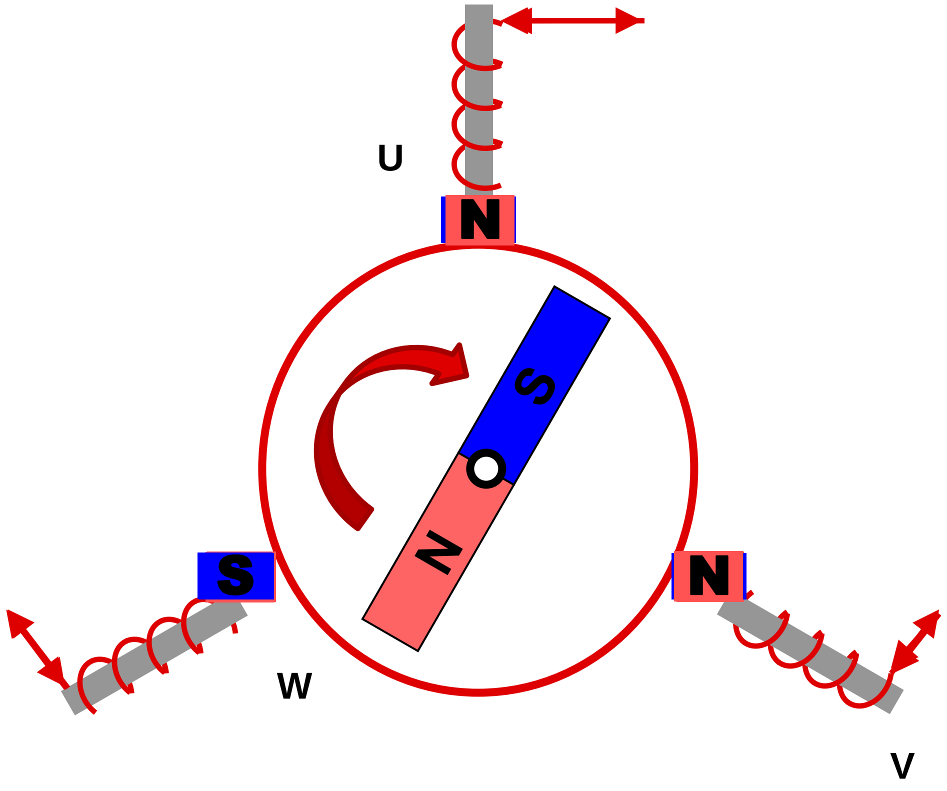
- Commutation methods range in complexity, cost, board space, and MCU needed

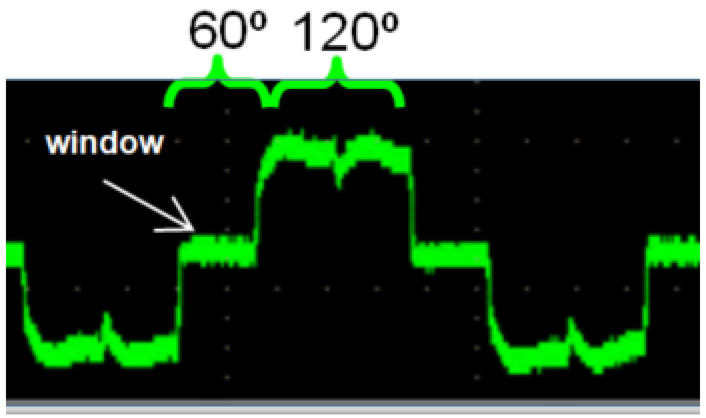
Trapezoidal control (120°)

- Most basic method of commutating a BLDC motor
- 6-step pattern
- States: 100% ON, OFF, or Hi-Z "window"
- Position must be known to efficiently commutate the motor

+ Low cost
+ Very simple to implement
+ Low processing power
+ High speed applications
- Torque ripple during current switching
- Electric and acoustic noise







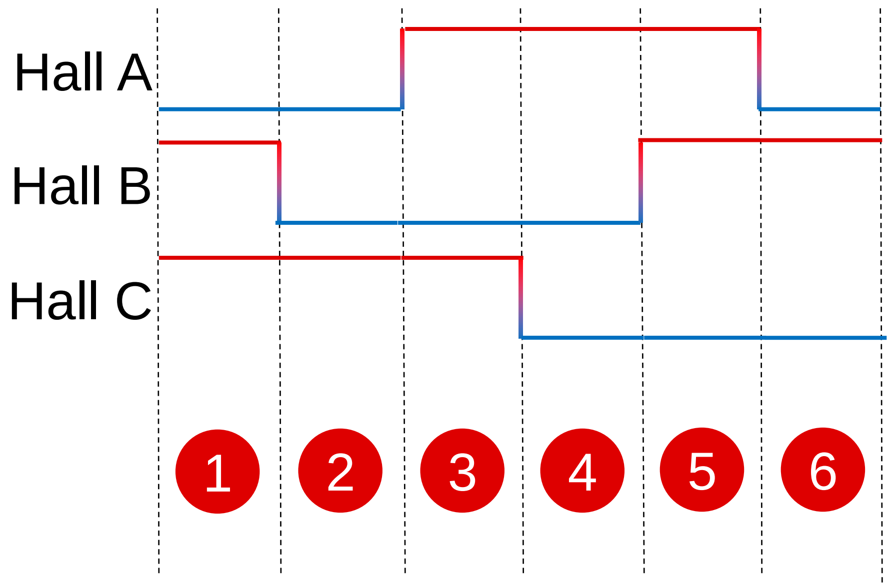
Sensored control

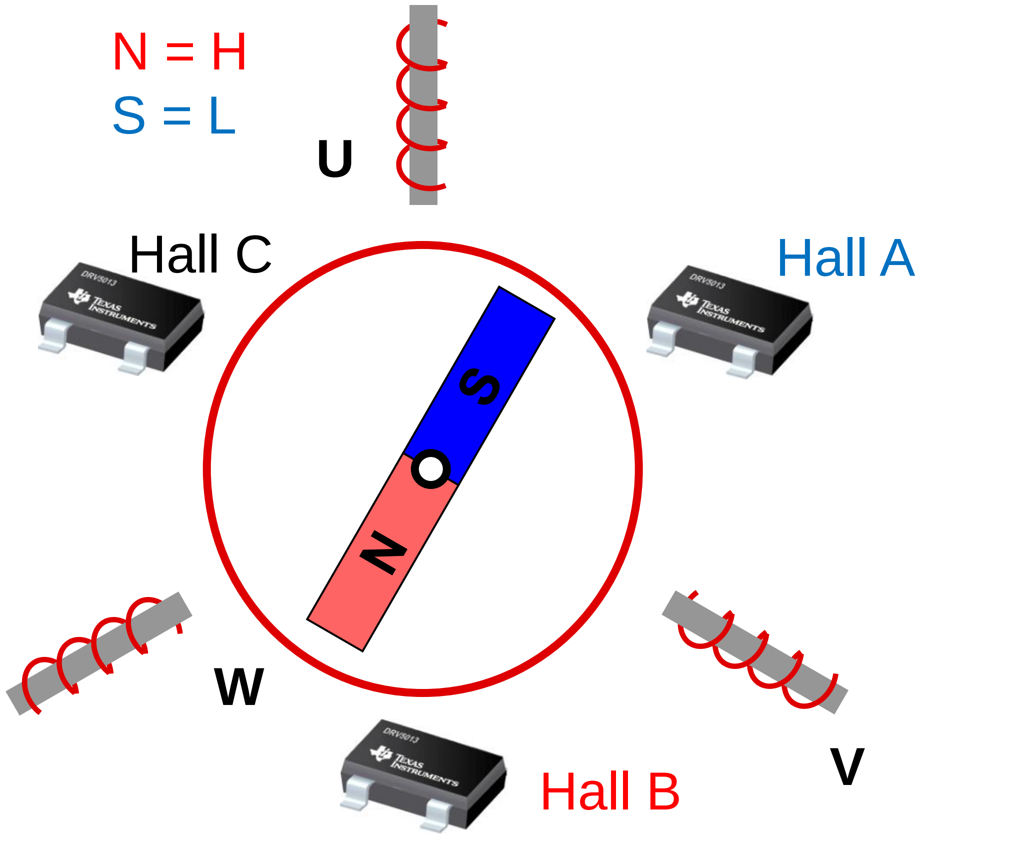
- Hall-effect sensors detect the position of the rotor
- Hall signals sent as logic-level inputs directly to MCU or gate driver

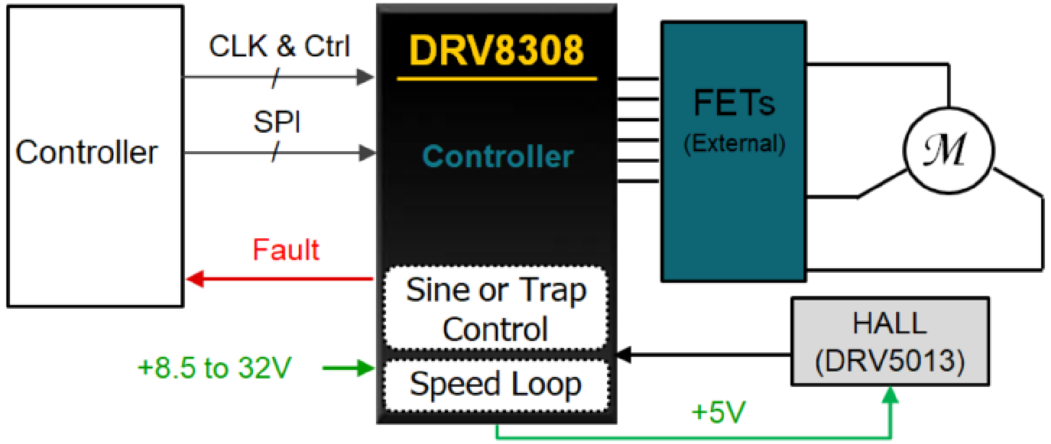
+ Low-cost solution
+ Position is known immediately, even during slow speeds or at rest

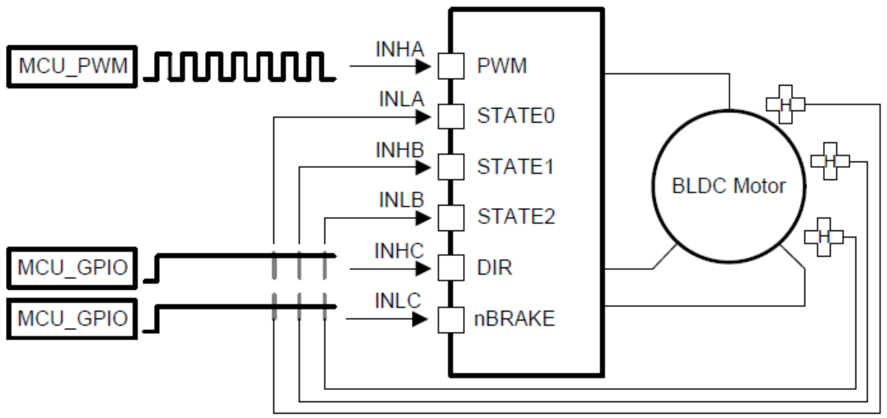
- Low-resolution
- Takes space on board

- Can be used for all torque, speed, or position applications









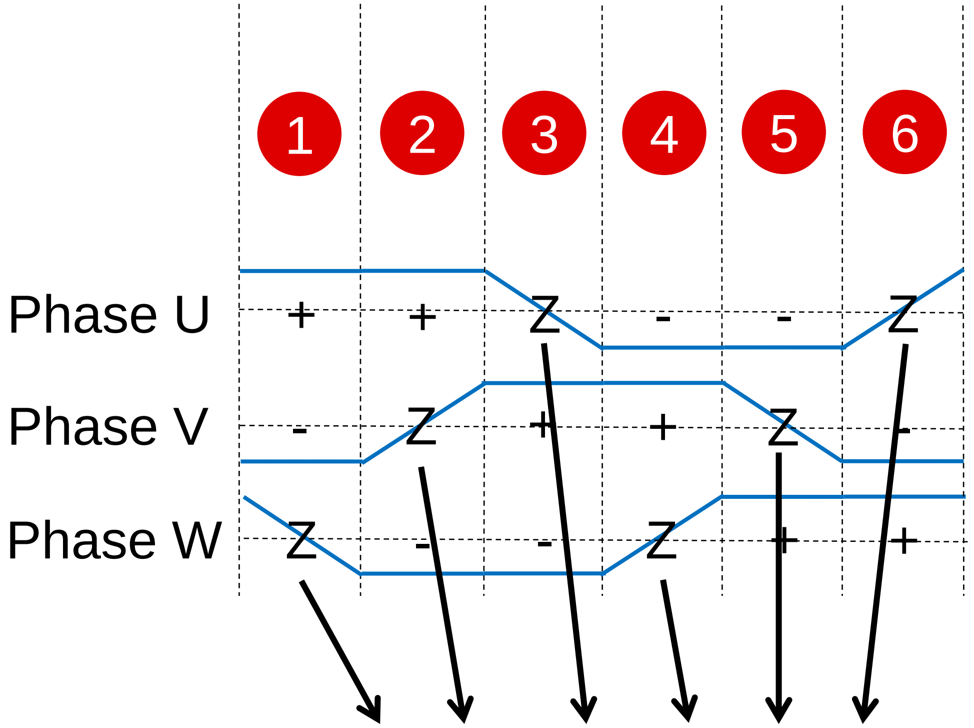
Sensorless control

- Undriven winding experiences a back-EMF (BEMF) voltage
- Measured with a BEMF comparator during a “window” or calculated

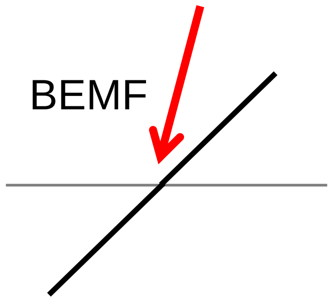
+ Eliminates need for sensors

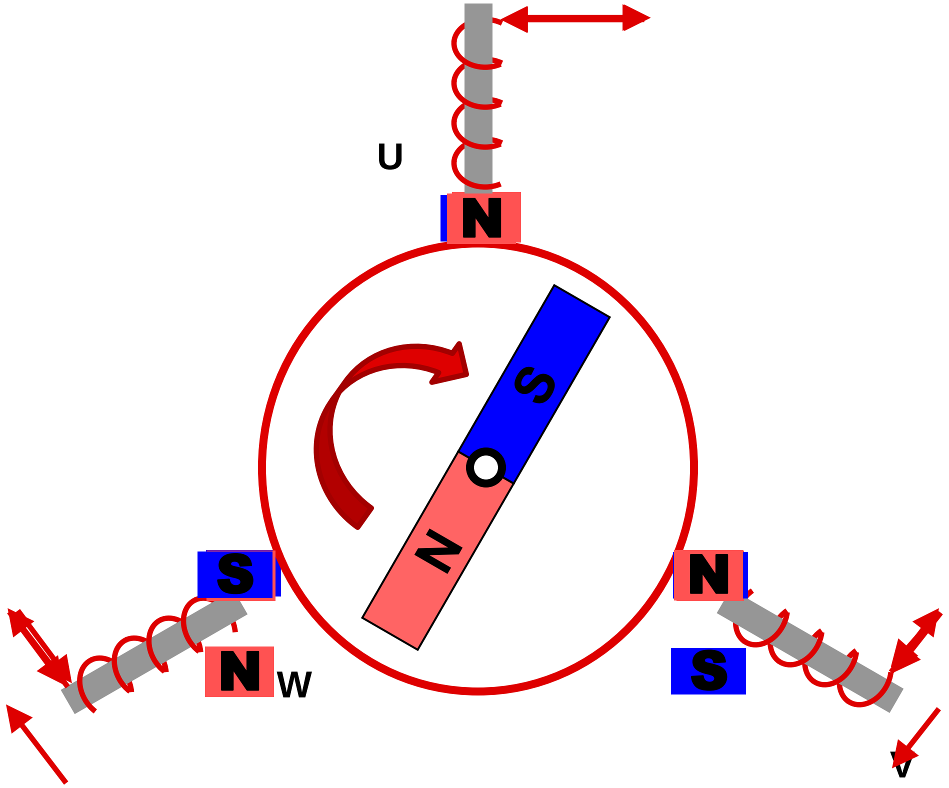
- Not operable at low speeds
- Additional signal chain and calculations required

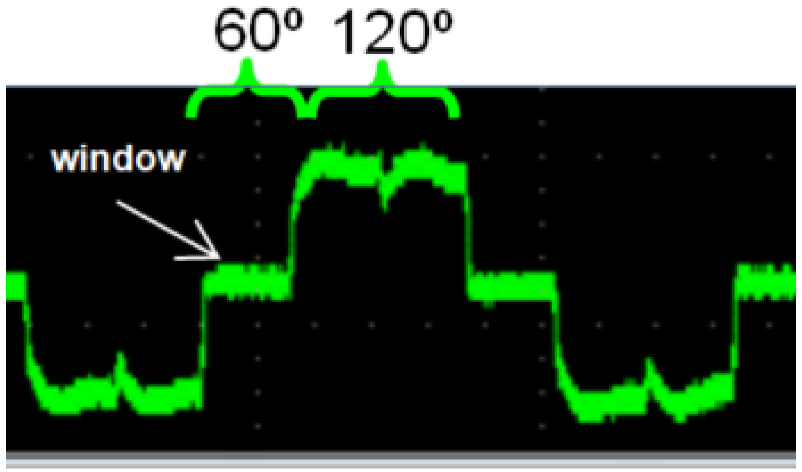
- Used mostly for speed applications



Back-EMF “zero crossing” on rising or falling Hi-Z windows can be used as a commutation signal







Trapezoidal control (150°)

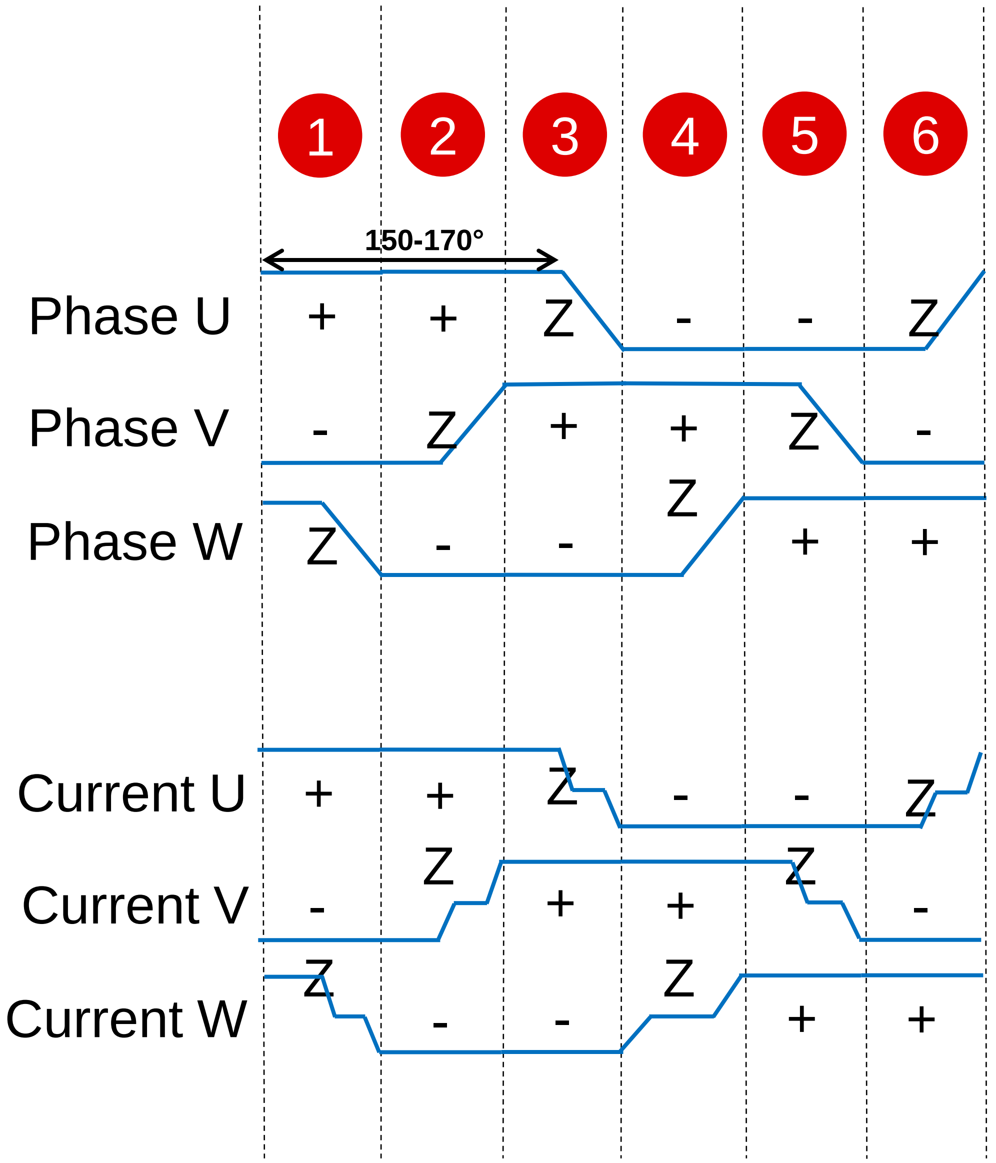
- "Pseudo-sinusoidal"
- Outputs are energized for 150 electrical degrees rather than 120
- Longer "ON" time, narrow Hi-Z window
- Used typically with sensorless control to measure BEMF crossings

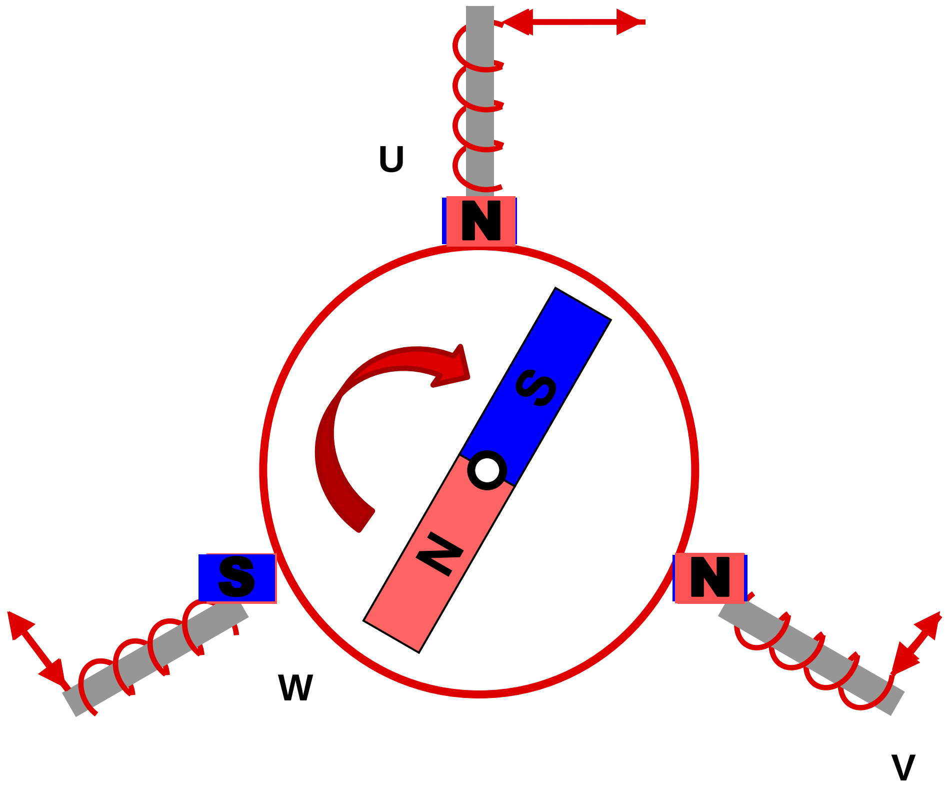
+ Low-cost
+ Better acoustics

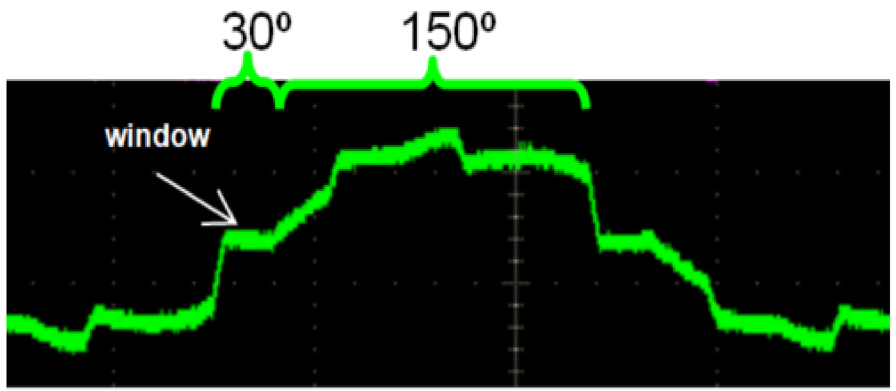
Compared to trapezoidal 120°

+ Higher power, speed, and torque

- Worse acoustics versus sinusoidal
- Torque ripple during current switching
- Tighter "window" to back EMF



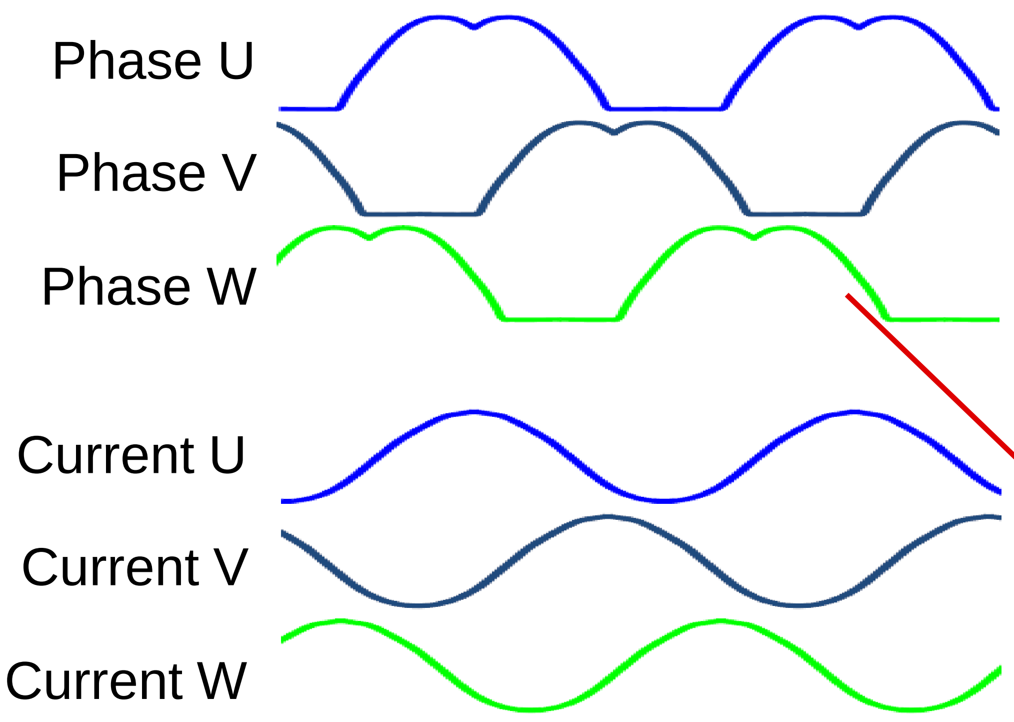


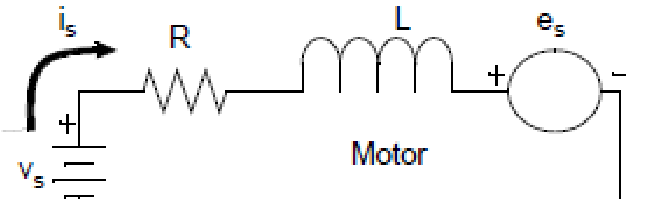


Sinusoidal control (180°)

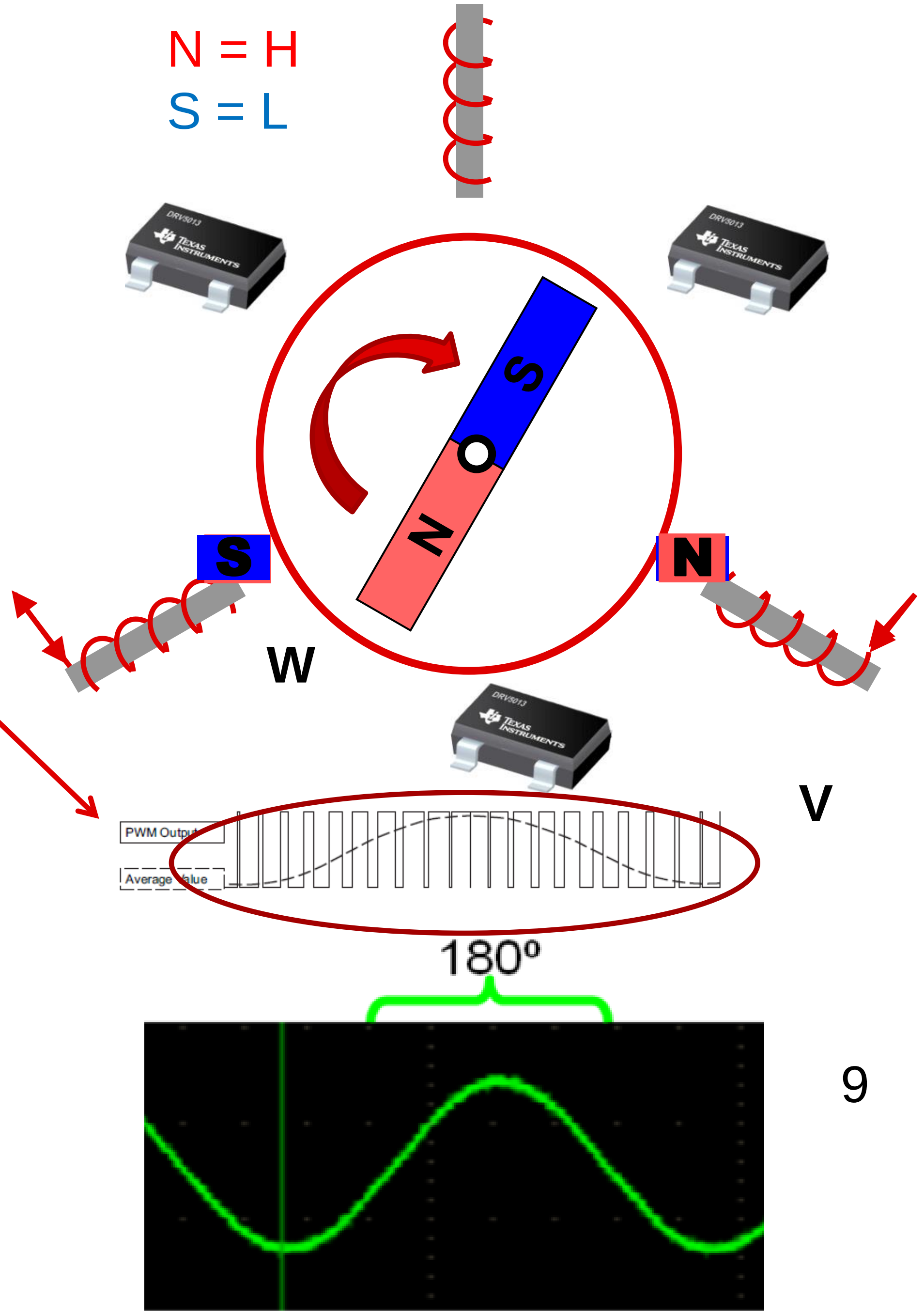
- Smoother, quiet commutation
- Sinusoidal current produced by using a PWM-varying profile for each phase
- Can be sensored (electrical frequency measurements) or sensorless (internal calculations)
- Speed applications

+ Ultra quiet
+ Highly efficient for sinusoidal motors
+ Small torque ripple
- Cannot directly measure BEMF due to no zero-crossing window
- More switching losses
- Increased complexity





$$v_s = Ri_s + L\frac{d}{dt}i_s + e_s$$



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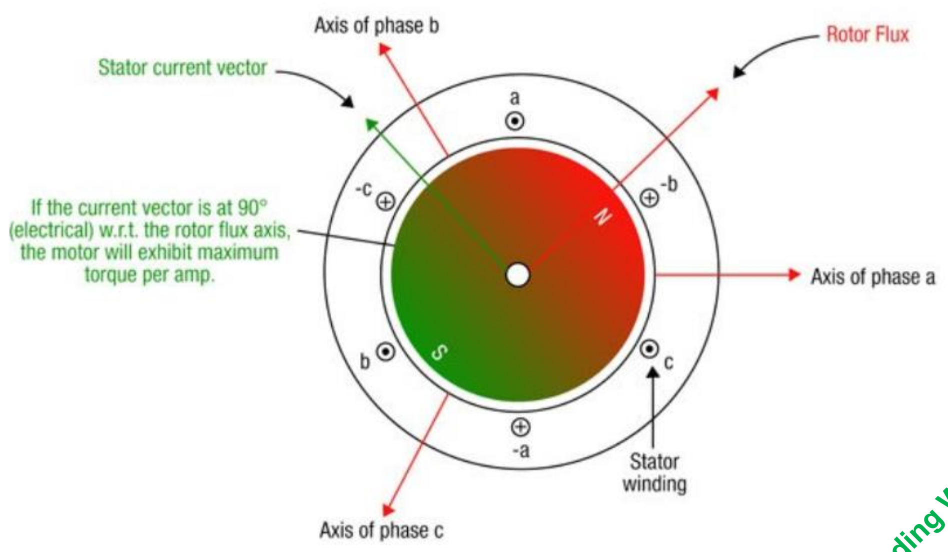
Field-oriented control (FOC)

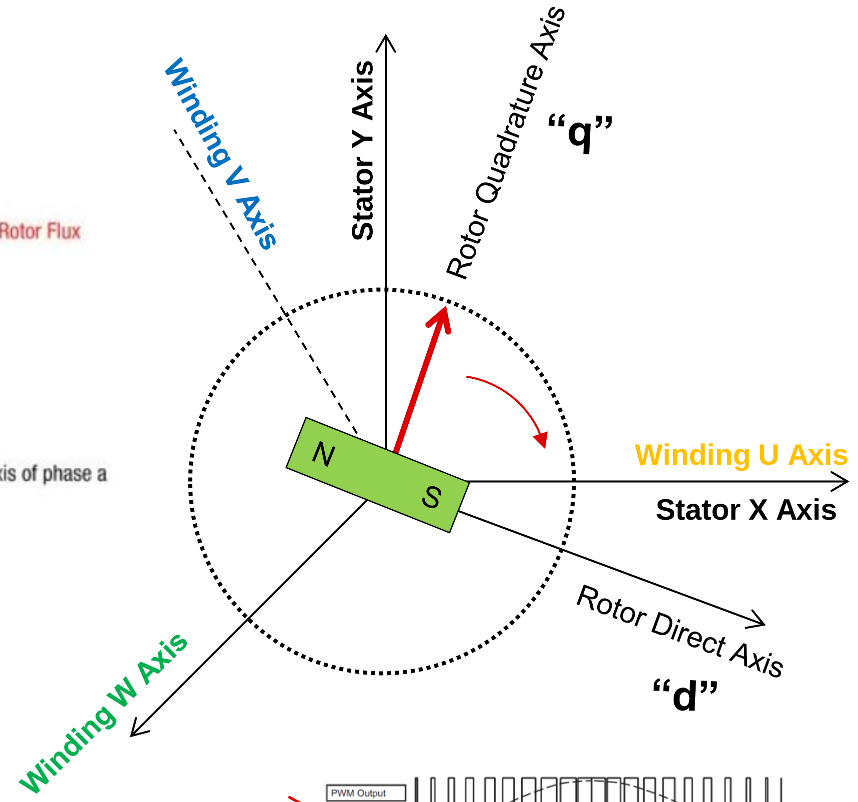
Maximizes torque by ensuring stator is perpendicular to the rotor

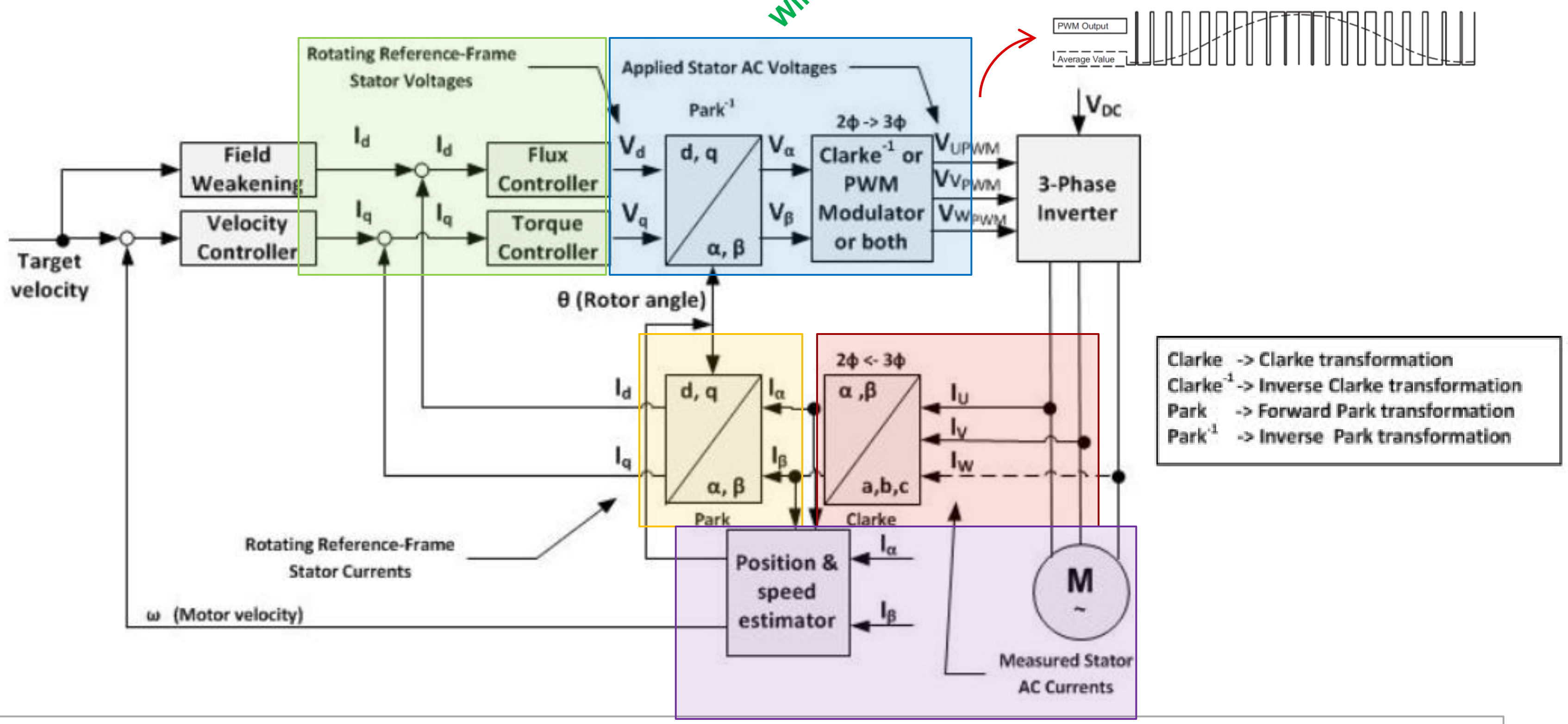
- Transformations used to convert phase current to in-phase and quadrature stator currents
  - 3-phase U,V, and W currents transformed to 2-phase stator currents (Clarke transform)
  - 2-phase stator currents transformed to in-phase and quadrature currents (Park transform)
- PI controller calculates error from perpendicular stator currents and rotor
- Inverse transforms determine PWM modulation needed for FOC
- **Used for speed, torque, or position**

+ Highest power output
+ Lowest noise
+ Low torque ripple
+ Maximum motor speed (field weakening)
+ Maximum motor efficiency

- Computation complexity (especially when sensorless)
- Switching losses
- Coding experience required







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