Field-Oriented Motor control

FINAL PRESENTATION

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Why is it necessary ?

1) FOC is the first technology to control the “real” motor control variables of torque and flux.

2) FOC provides an efficient way to control a motor in adjustable speed drive applications that have quickly changing loads.

2) The value FOC brings to these systems is reduced torque ripple, resulting in smoother motor performance and quieter operation.

Objectives

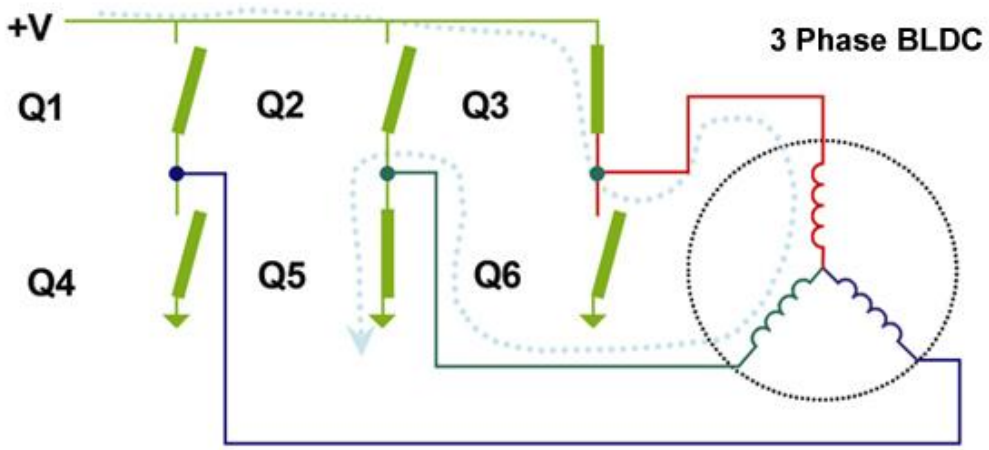
1) To learn basic working of BLDC motor.

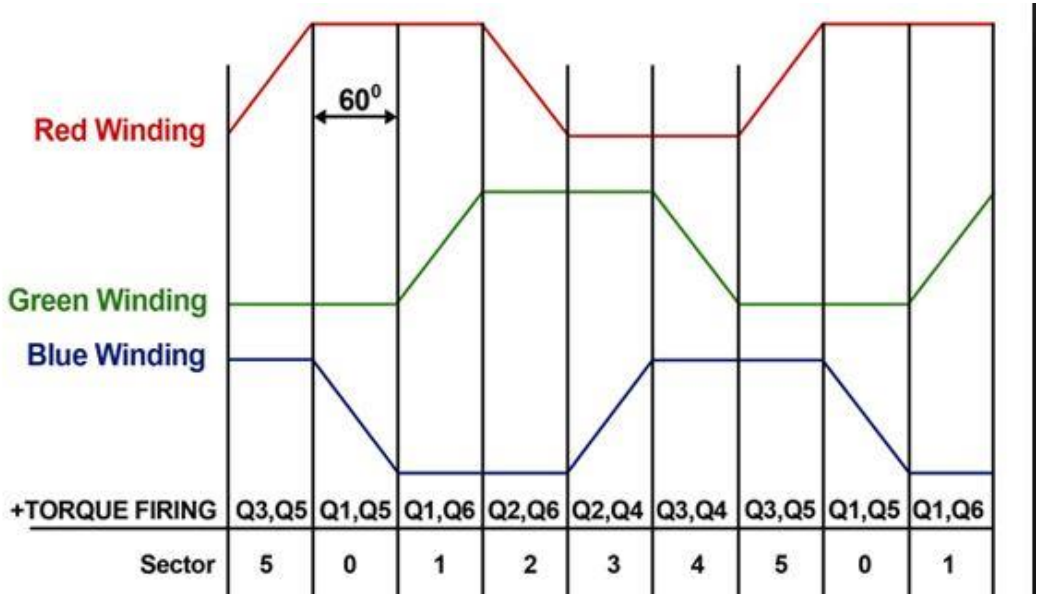
2) To learn different commutation strategies for BLDC motor (mainly Trapezoidal & FOC).

3) To get well oriented with FOC commutation scheme.

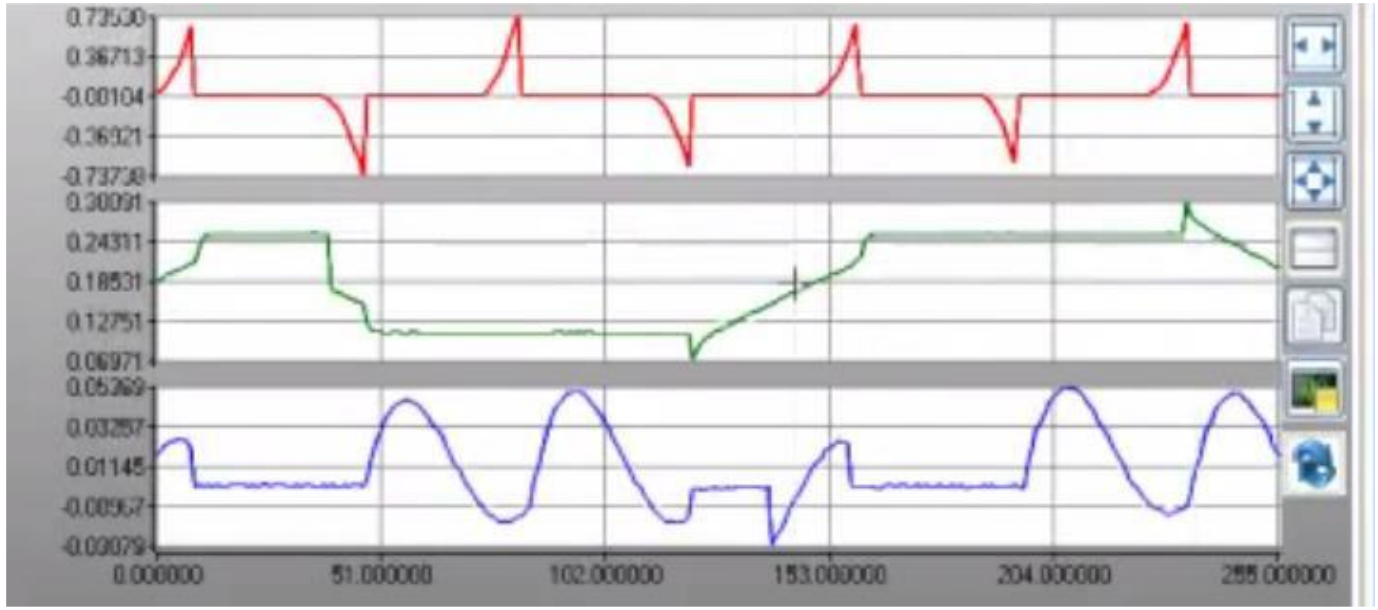
4) To determine and compare efficiency for the same.

Trapezoidal Commutation

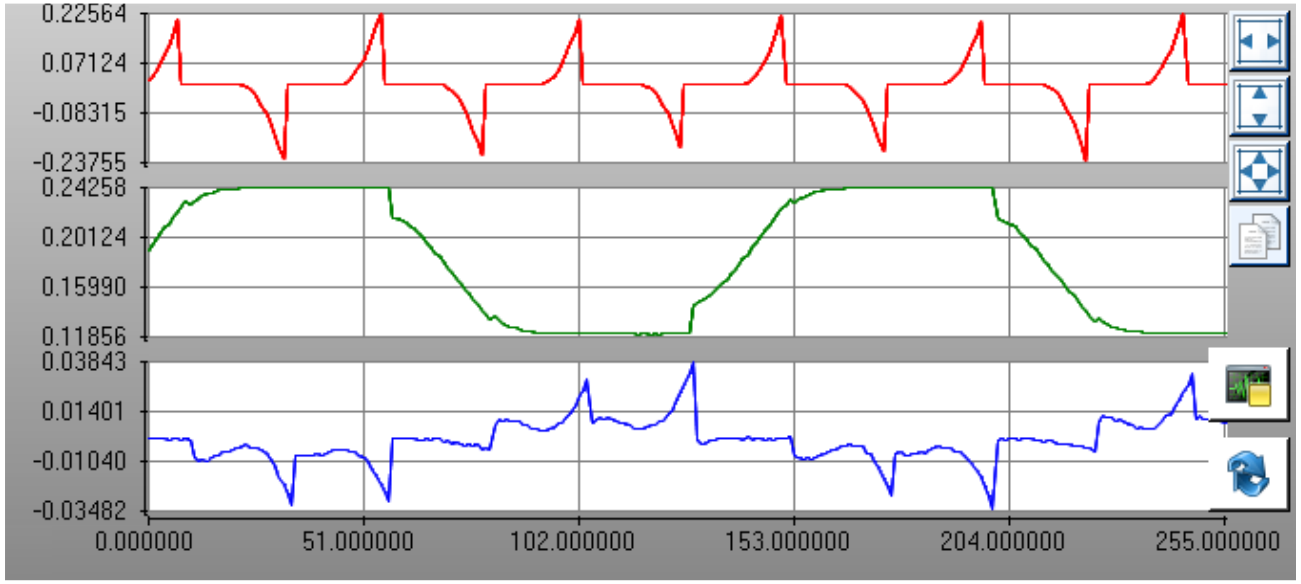




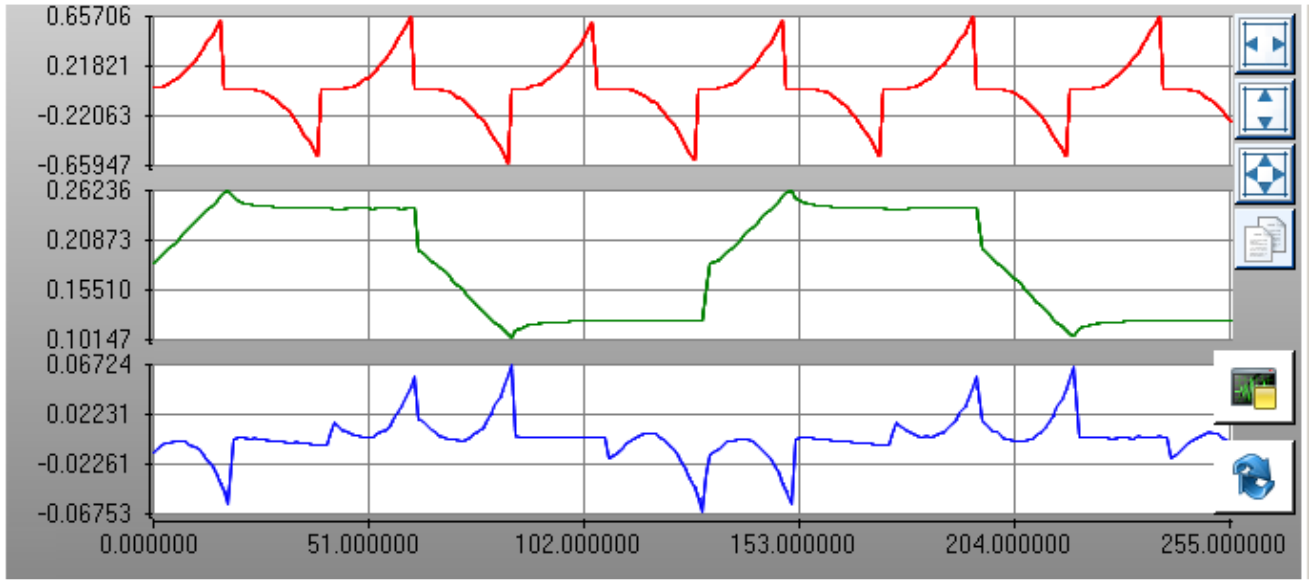
Commutation too early (flux threshold – 0.16pu)



Commutation at proper time (flux threshold – 0.30pu)



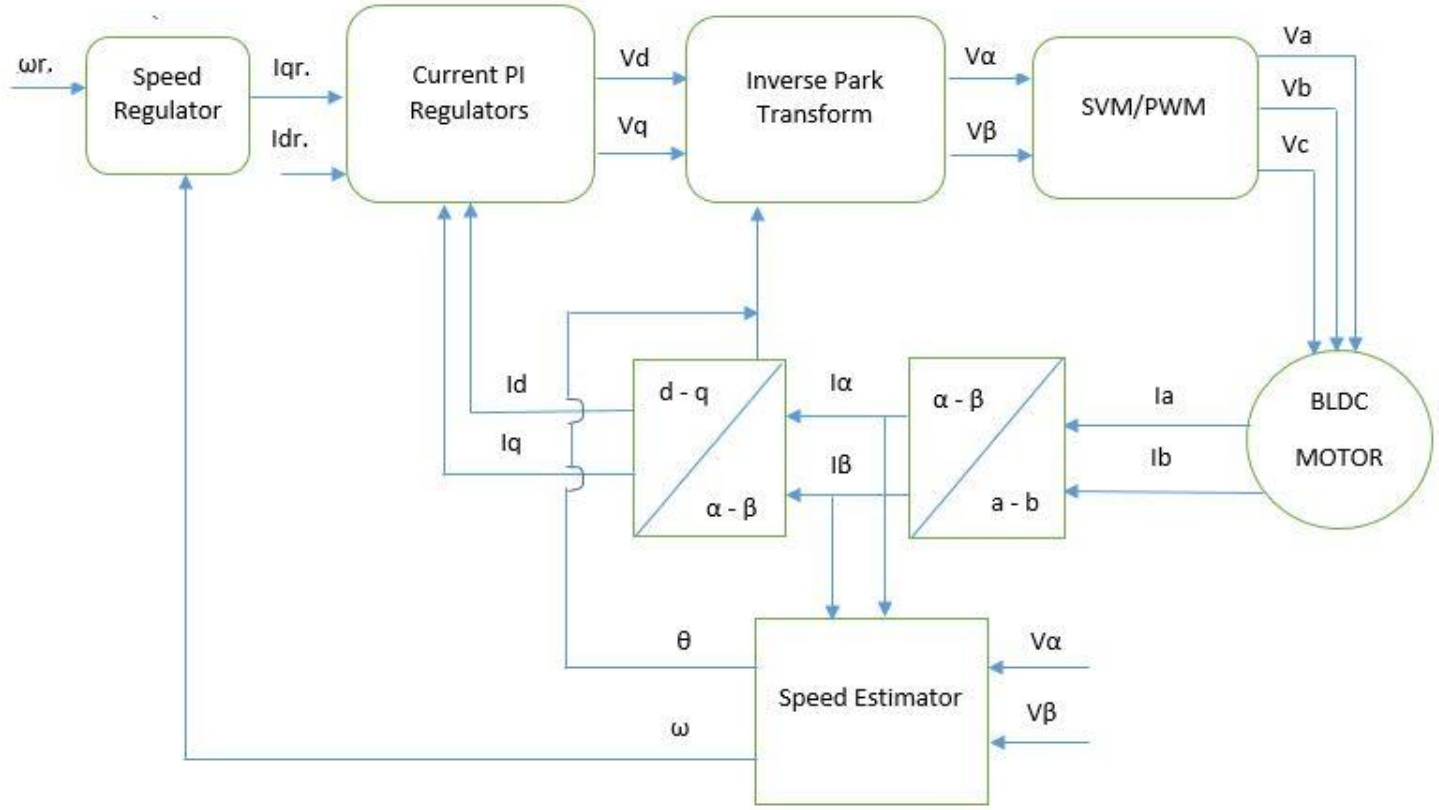
Commutation too late (flux threshold – 0.66pu)



Field Oriented Control (FOC)

- FOC describes the way in which the control of torque and speed are directly based on the electromagnetic state of the motor.
- It consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system.
- FOC machines need two constants as input references: the torque component (aligned with the **q coordinate**) and the flux component (aligned with **d coordinate**).

Block diagram of FOC



Steps involved in FOC

1) Taking i_a, i_b, i_c as instantaneous currents in the stator phases, then the stator current vector it defined as follow: $\vec{\imath}_s = i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3}$

2) (a,b,c) → (α, β) (the Clarke transformation), which outputs a two coordinate time variant system.

3) (a, β) → (d,q) (the Park transformation), which outputs a two coordinate time invariant system.

4) Out = $K_p * (In - Inref.) + K_i \int (In - Inref) . dt$

5) The corresponding outputs of the PI controllers are then passed through an inverse Park and Clarke transformation to convert them back to the 3-phase stator reference.

6) With the 3-phase reference signals generated, the PWM is modulated using Space Vector Modulation (SVM).

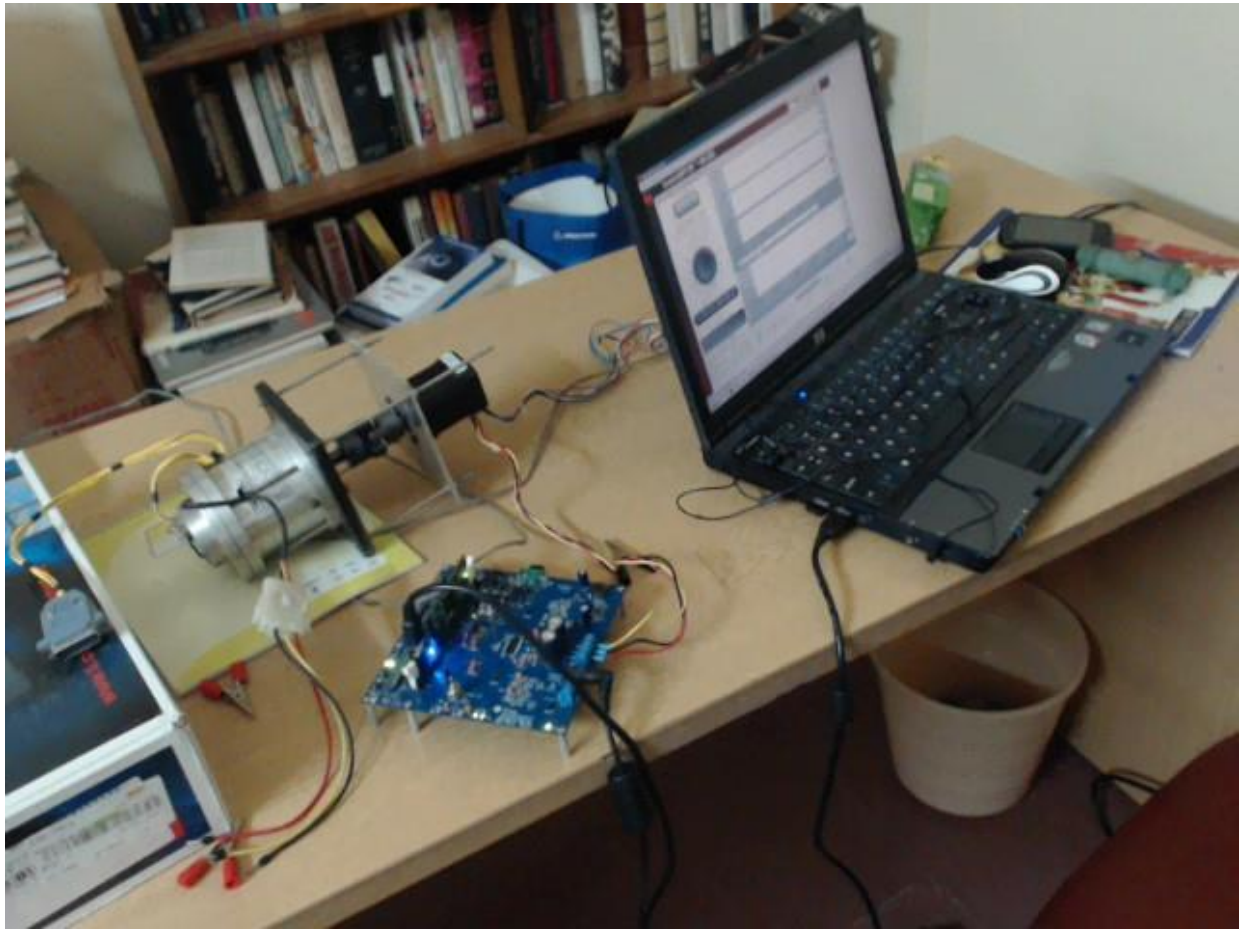
Why FOC is better?

1) FOC provides the smooth motion at slow speeds as well as efficient operation at high speeds.

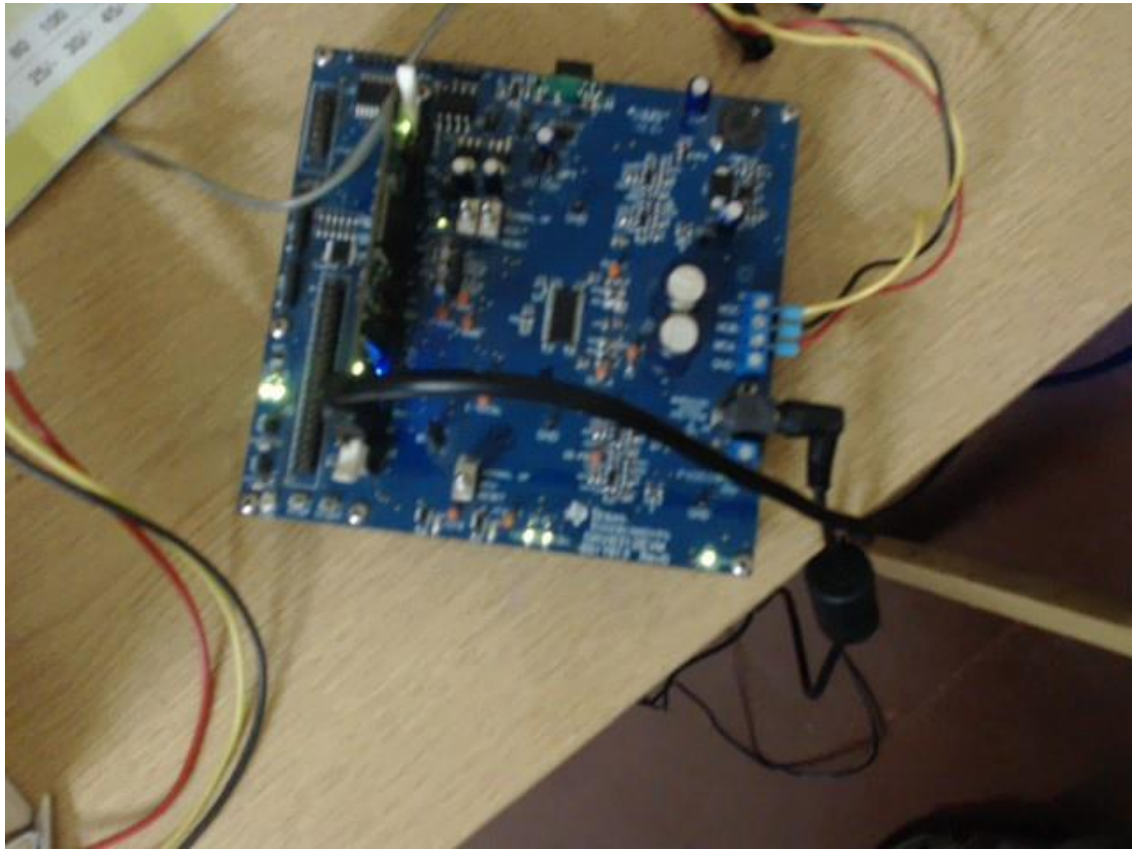
2) Trapezoidal commutation can be relatively efficient at high speeds, but causes torque ripple at slow speeds.

3) Benefits of FOC - improved efficiency, smoother operation, and lower noise.

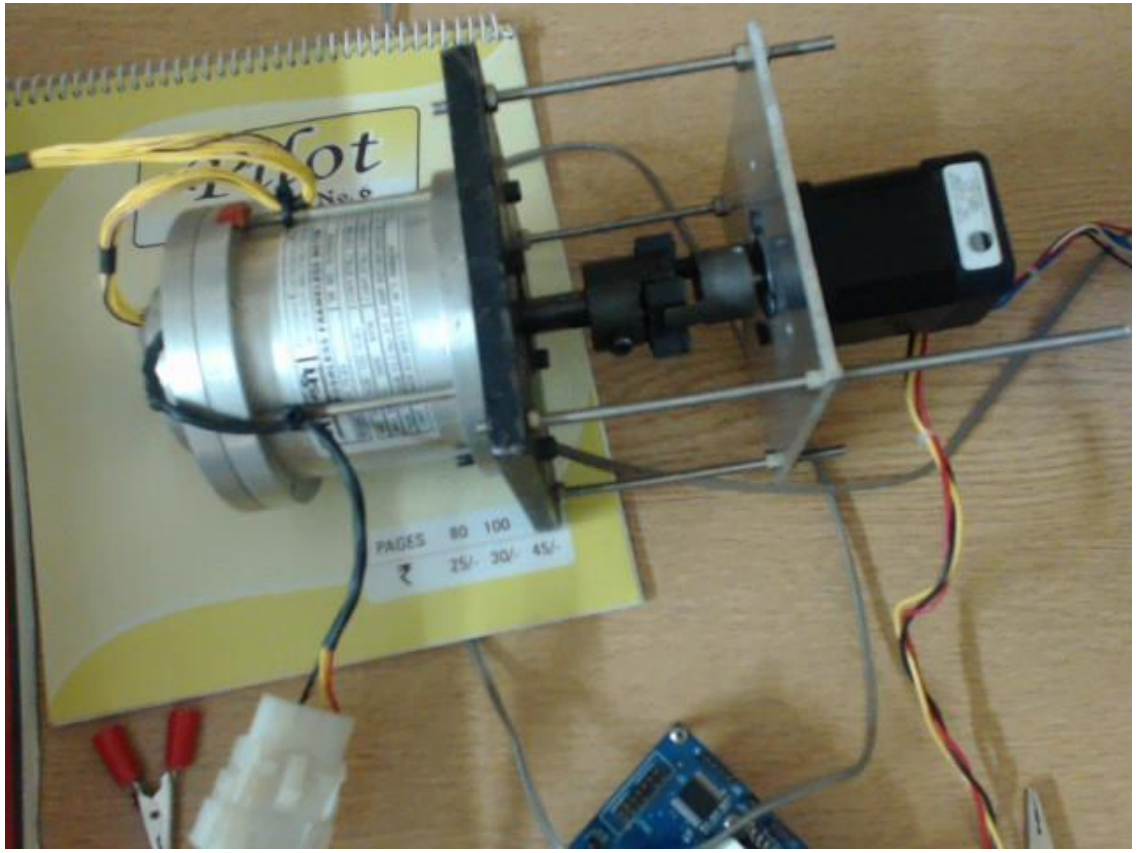
Experimental Setup



TI – EVM KIT



BLDC Motor



Calculation of B (damping friction coefficient)

$V_t = 12\ V$

No load speed (ω_o) = 4000 rpm

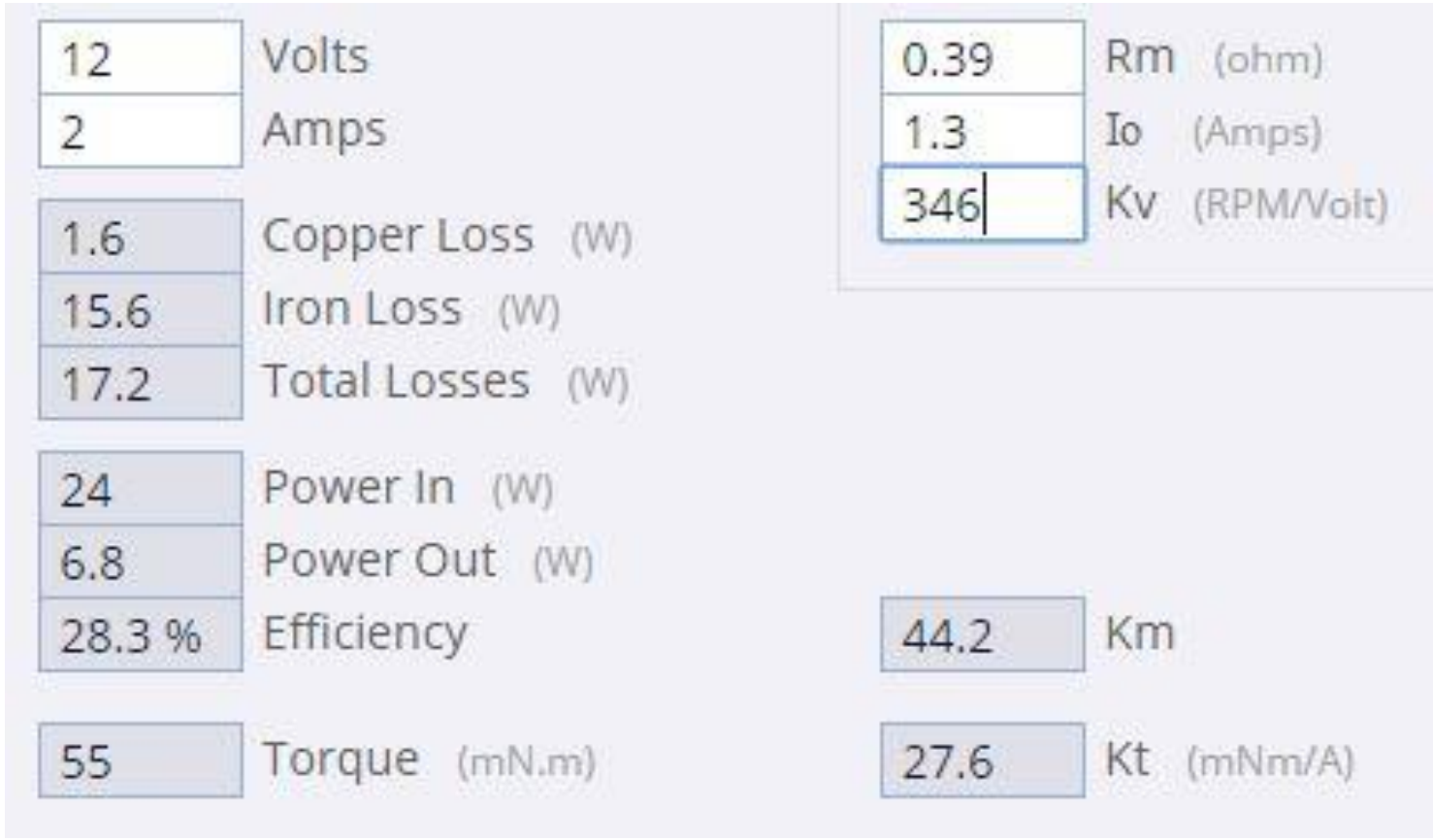
No load current (I_o) = 1.3 A

$R_m = 0.39\ \Omega$

Value of B (damping friction coefficient)

$$B = 0.024 \text{ Nm-s}$$

Efficiency of BLDC motor on no-load condition



Analysis

- Using the DRV8312-69m kit, able to run both sensor less trapezoidal and field oriented control on the motor.
- Due to switching losses in **trapezoidal commutation** it was expected that there would a greater heat dissipation in this case. This method has significant performance limitations in the form of torque ripple, which causes **vibration, noise, mechanical wear, and greatly reduced servo performance.**
- **FOC**, also known as vector control, improves upon this control by providing high efficiency at faster motor speeds. It delivers **the highest torque per watt** of power of all the control techniques.
- By adopting FOC, higher efficiencies of up to **96%** can be achieved in motor applications

Comparison Table

Commutation Methods	Speed Control	Torque Control		Algorithm Complexity
		Low Speed	High Speed	
Trapezoidal	Excellent	Torque Ripple	Efficient	Low
Sinusoidal	Excellent	Excellent	Inefficient	Medium
FOC	Excellent	Excellent	Excellent	High

Alternative analysis suggestions

1) Higher RPM running

2) Dynamic loading of the motors

3) Different motors

4) Observing the torque ripple effect of load on different control system using Oscilloscope.

Things I learned during this project

1) Learnt basic working of BLDC motor

2) Learnt different commutation schemes for BLDC motor

3) Studied mathematical models for the same

4) Explored TI – EVM KIT for BLDC motor

4) Learnt to use InstaSPIN GUI used for spinning the motor

5) Learnt presentation skills and importance of project planning

Thank You

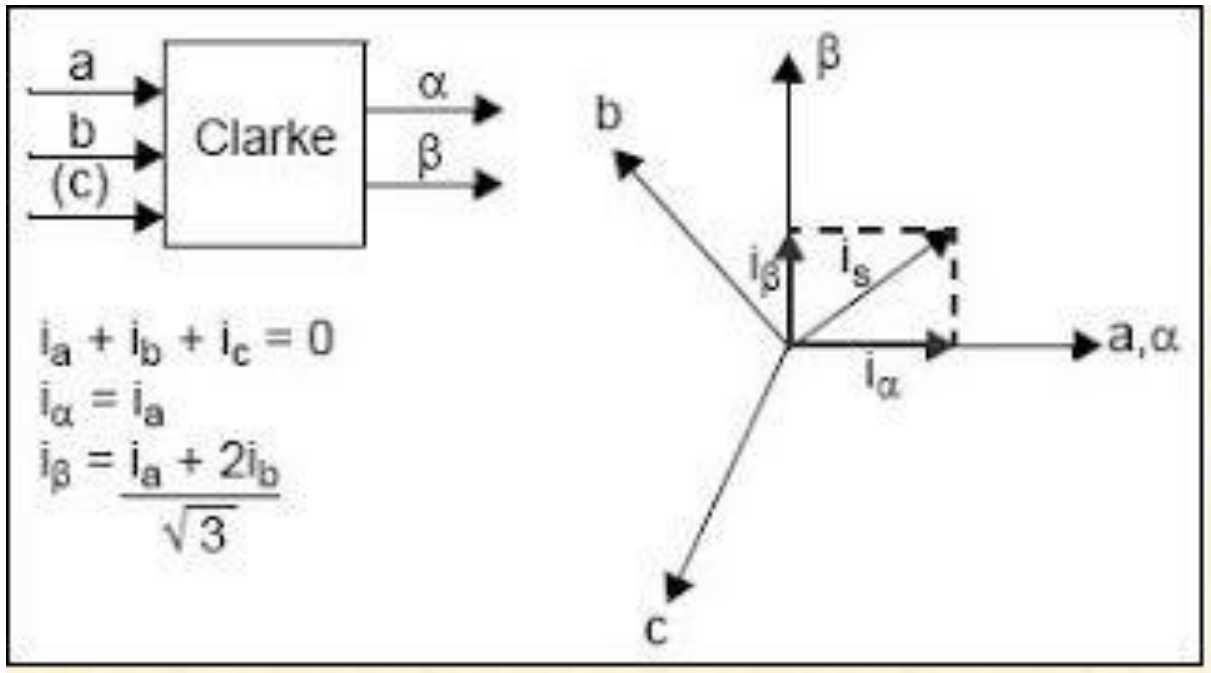
Appendix

Trapezoidal Commutation

- Current is controlled through motor terminals one pair at a time, with the third motor terminal always electrically disconnected from the source of power.
- The currents in two of the windings are equal in magnitude and the third is zero, this method can only produce current space vectors having one of six different directions.
- As the motor turns, the current to the motor terminals is electrically switched (commutated) every 60 degrees of rotation so that the current space vector is always within the nearest 30 degrees of the quadrature direction.

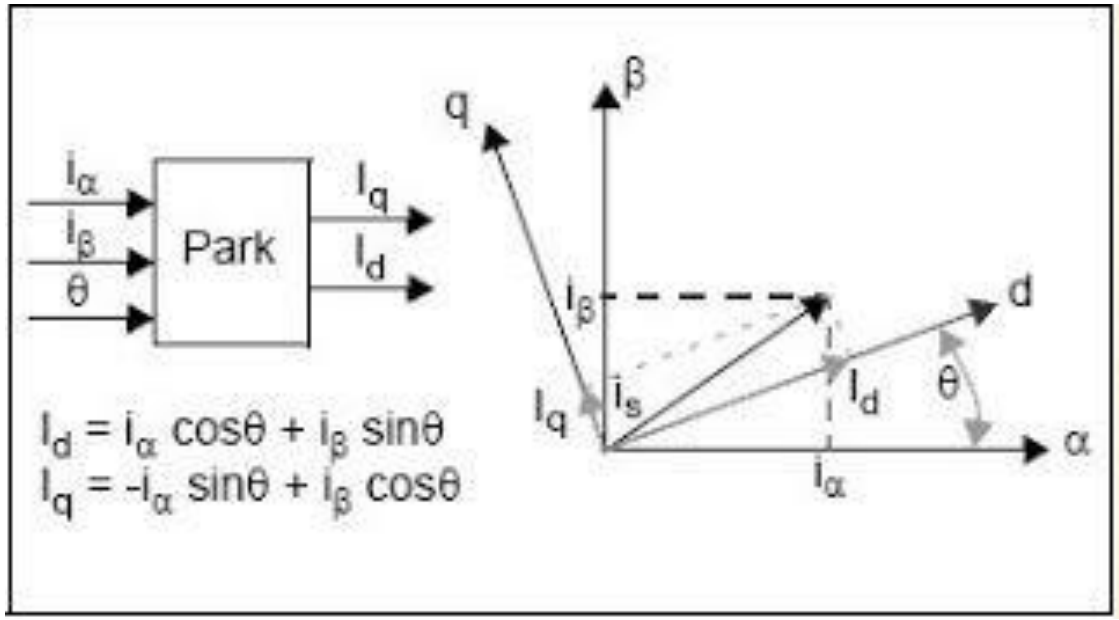
Clarke Transformation

3ϕ quantities are translated from 3phase reference frame to the two axis orthogonal stationary frame.

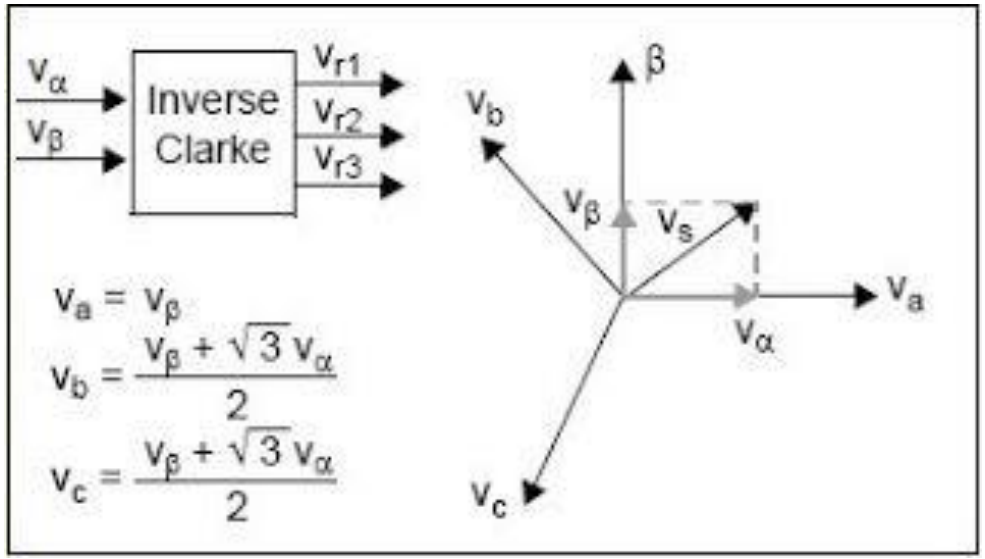


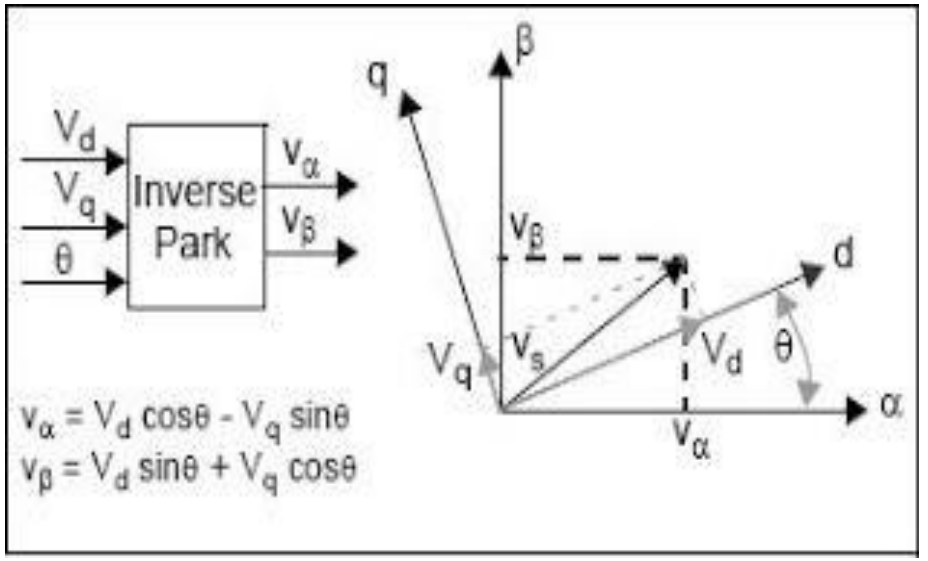
Park Transformation

Two axis orthogonal stationary reference frame quantities are transformed into rotating reference frame quantities.



Inverse Park & Clark Transformation





Calculation of B (damping friction) in BLDC motor

Vt = 12 V

No load speed (ωo) = 4000 rpm

No load current (Io) = 1.3 A

Rm = 0.39 Ω

$$Kb = \frac{(12 - 0.4*1.3)}{4000}$$

$$Kb = 0.00289 \ \frac{volt}{rpm} \text{ or } Kv = \frac{1}{Kb} = 346 \ \frac{rpm}{volt}$$

$$Kt = 17.34 \ \frac{mNm}{A}$$

$$Km = \frac{Kt}{\sqrt{Rm}} = 27.76 \ \frac{mNm}{\sqrt{watts}}$$

B = 0.024 Nm-s