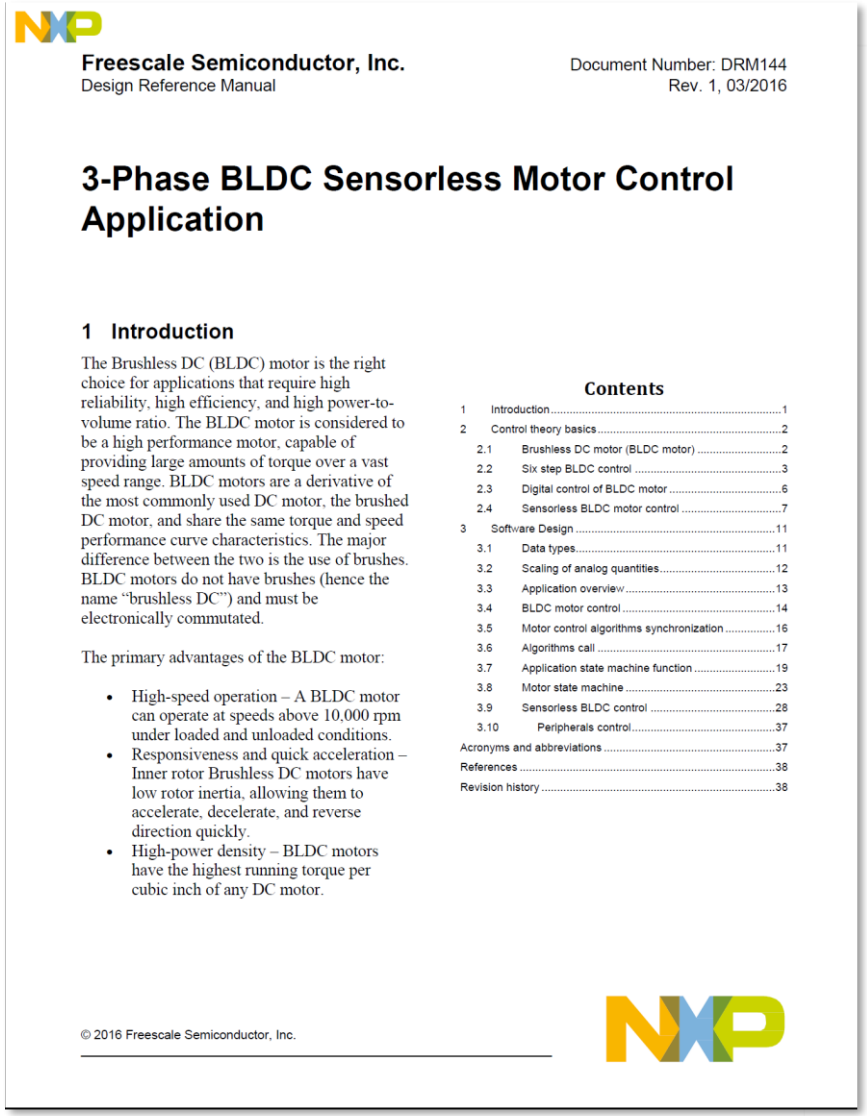
Sensorless Brushless DC (BLDC) Motor Control

Overview

- Derived from NXP/Freescale Reference Design documentation: DRM144 and AN5263
- Brushless DC motor benefits
  - High-speed operation
  - Responsive, quick operation due to low rotor inertia
  - High power density
  - High reliability due to lack of brushes



Freescale Semiconductor, Inc.
Design Reference Manual

Document Number: DRM144
Rev. 1, 03/2016

3-Phase BLDC Sensorless Motor Control Application

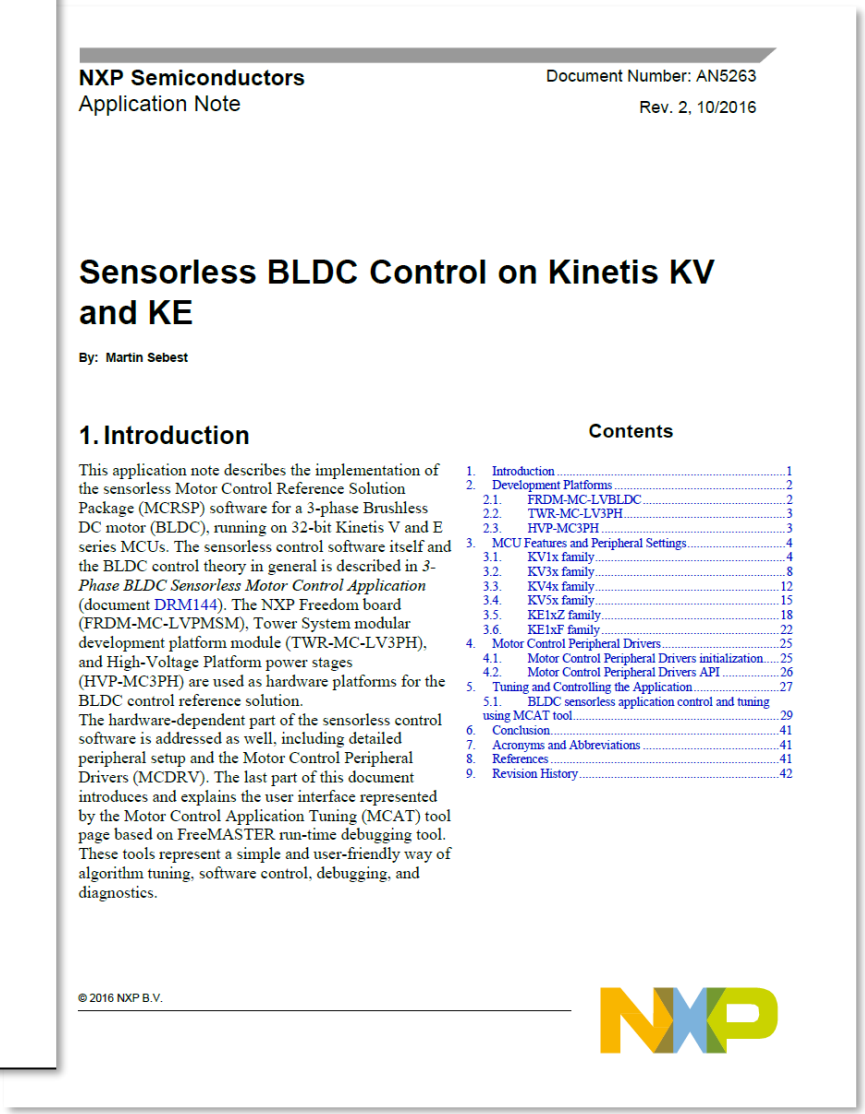
1 Introduction

The Brushless DC (BLDC) motor is the right choice for applications that require high reliability, high efficiency, and high power-to-volume ratio. The BLDC motor is considered to be a high performance motor, capable of providing large amounts of torque over a vast speed range. BLDC motors are a derivative of the most commonly used DC motor, the brushed DC motor, and share the same torque and speed performance curve characteristics. The major difference between the two is the use of brushes. BLDC motors do not have brushes (hence the name "brushless DC") and must be electronically commutated.

The primary advantages of the BLDC motor:

- High-speed operation – A BLDC motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions.
- Responsiveness and quick acceleration – Inner rotor Brushless DC motors have low rotor inertia, allowing them to accelerate, decelerate, and reverse direction quickly.
- High-power density – BLDC motors have the highest running torque per cubic inch of any DC motor.

Contents



NXP Semiconductors
Application Note

Document Number: AN5263
Rev. 2, 10/2016

Sensorless BLDC Control on Kinetis KV and KE

By: Martin Sebest

1. Introduction

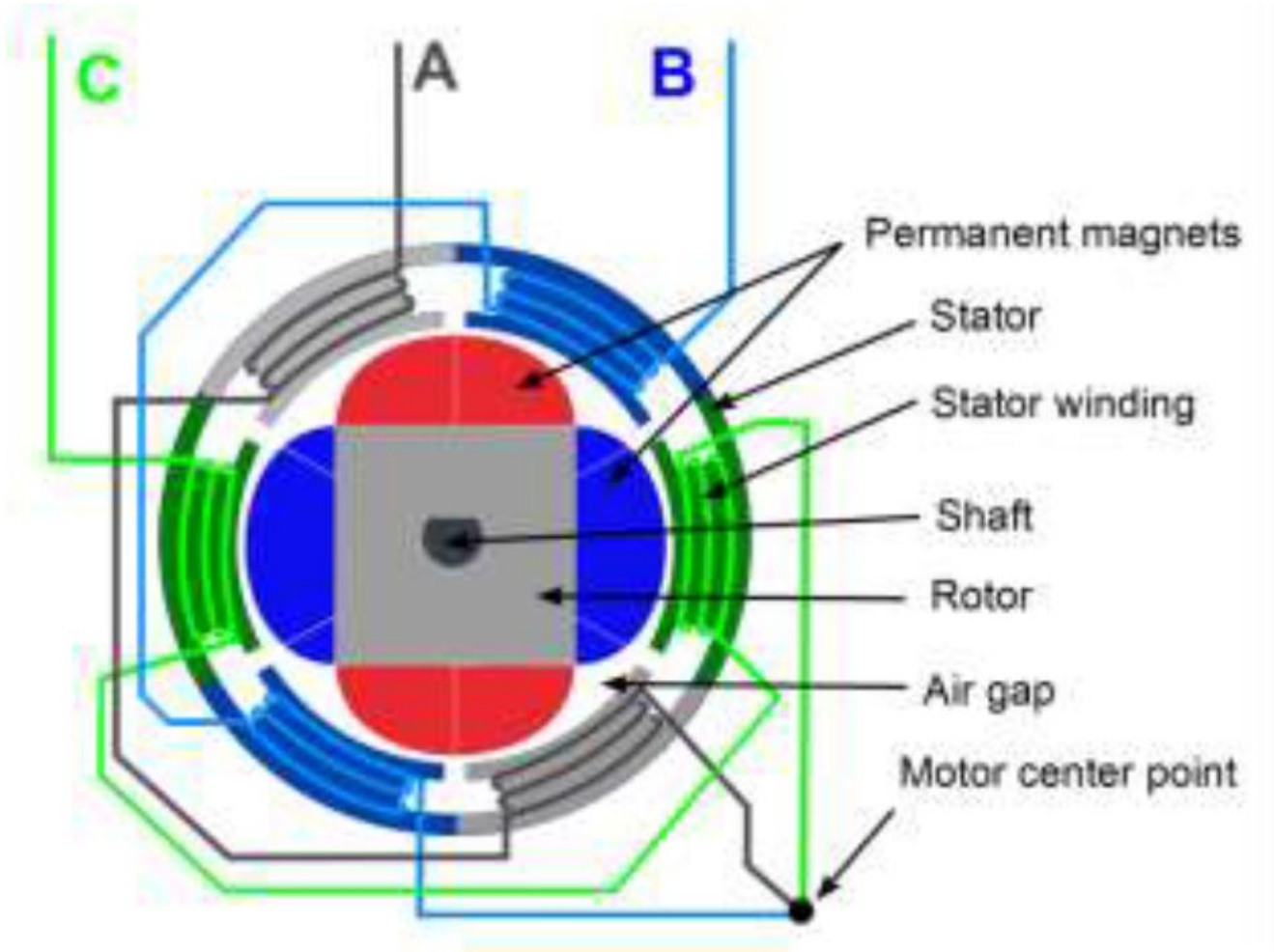
This application note describes the implementation of the sensorless Motor Control Reference Solution Package (MCRSP) software for a 3-phase Brushless DC motor (BLDC), running on 32-bit Kinetis V and E series MCUs. The sensorless control software itself and the BLDC control theory in general is described in *3-Phase BLDC Sensorless Motor Control Application* (document DRM144). The NXP Freedom board (FRDM-MC-LVPMSM), Tower System modular development platform module (TWR-MC-LV3PH), and High-Voltage Platform power stages (HVP-MC3PH) are used as hardware platforms for the BLDC control reference solution.
The hardware-dependent part of the sensorless control software is addressed as well, including detailed peripheral setup and the Motor Control Peripheral Drivers (MCDRV). The last part of this document introduces and explains the user interface represented by the Motor Control Application Tuning (MCAT) tool page based on FreeMASTER run-time debugging tool. These tools represent a simple and user-friendly way of algorithm tuning, software control, debugging, and diagnostics.

Contents

Motor Speed Control

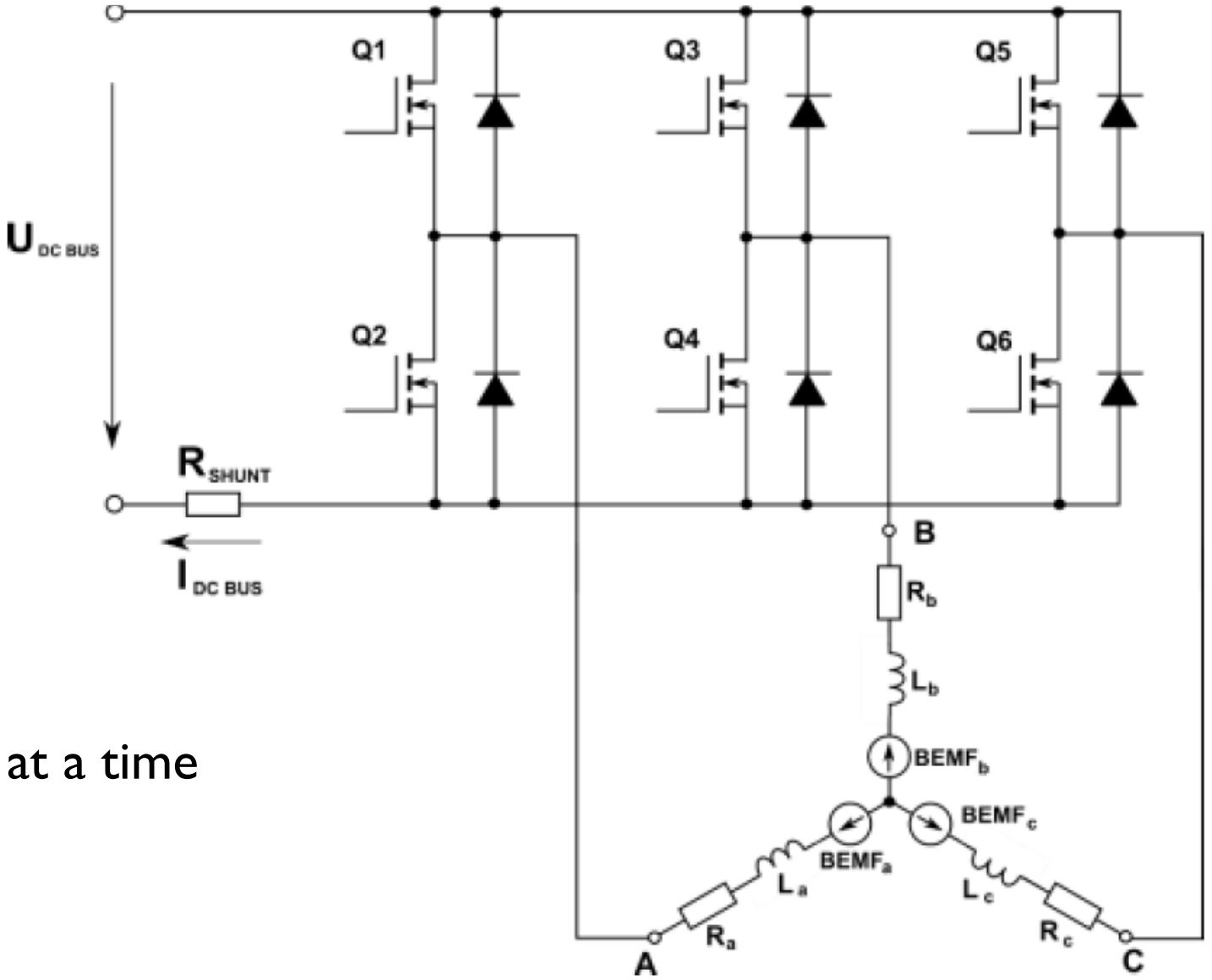
- Adjust voltage applied to windings
  - Higher voltage -> faster acceleration, faster rotation
- Need to measure speed to be able to control it
  - Shaft encoder? N pulses per revolution
    - Mechanical? Trouble-prone
    - Optical
    - Magnetic (Hall Effect sensor)

BLDC Motor



- Multiple stator windings
  - Three pairs: A, B, C
- Four permanent magnets on rotor
- **Commutation:** switch power to next set of windings to energize them, making rotor advance
  - Brushed motor relies on **mechanical** commutation by rotor
  - Brushless motor uses **electrical** commutation

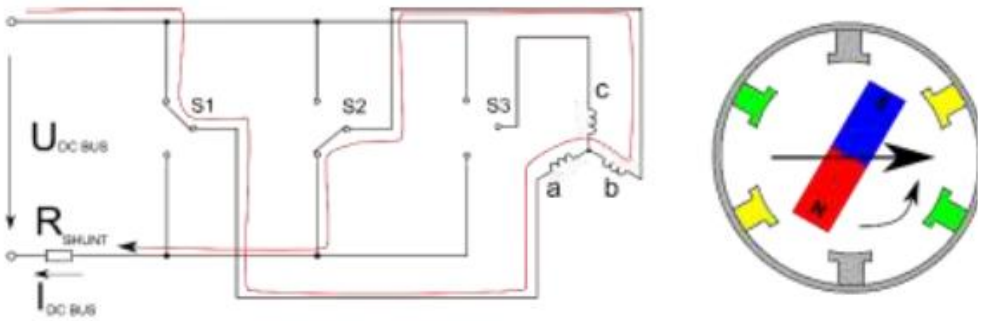
Power Stage for 3-Phase BLDC Motor



- Energize two coils at a time

Commutation Sequence

SECTOR I



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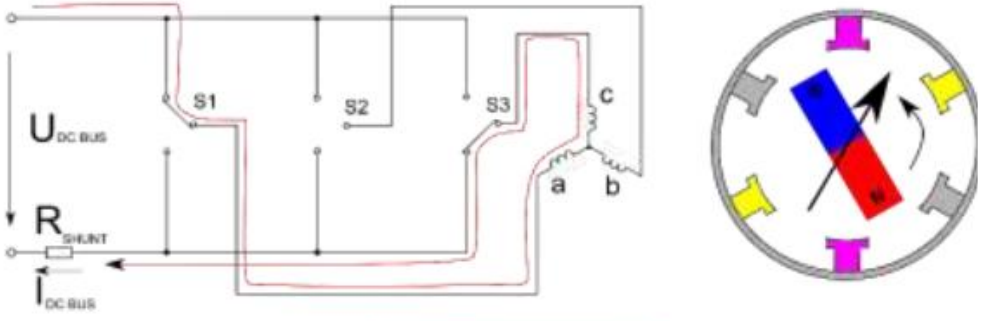

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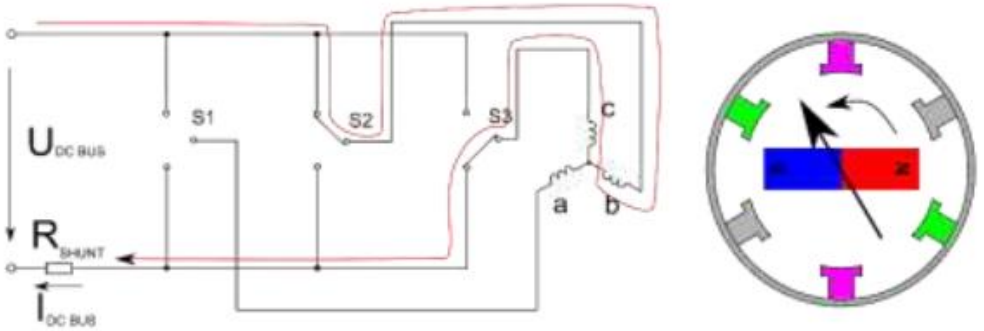

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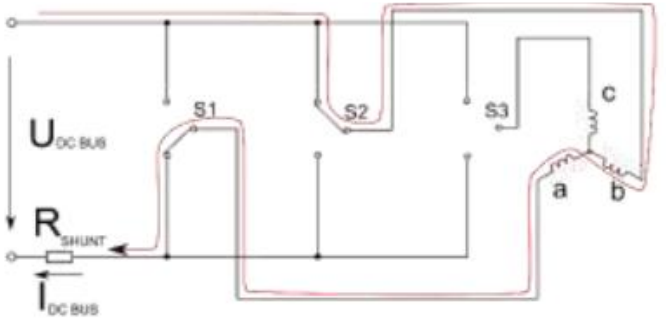

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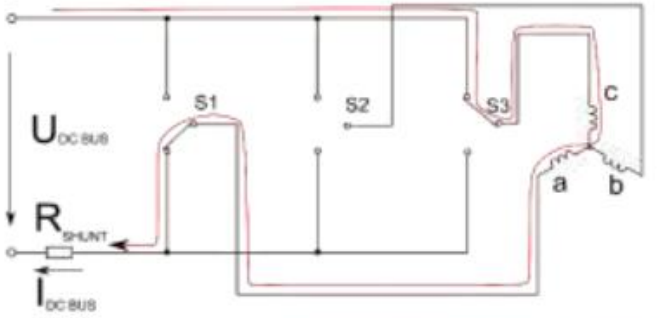

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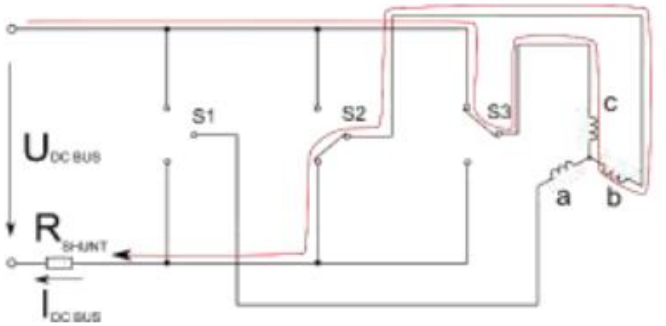
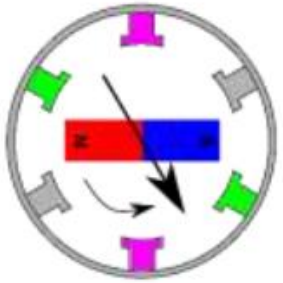
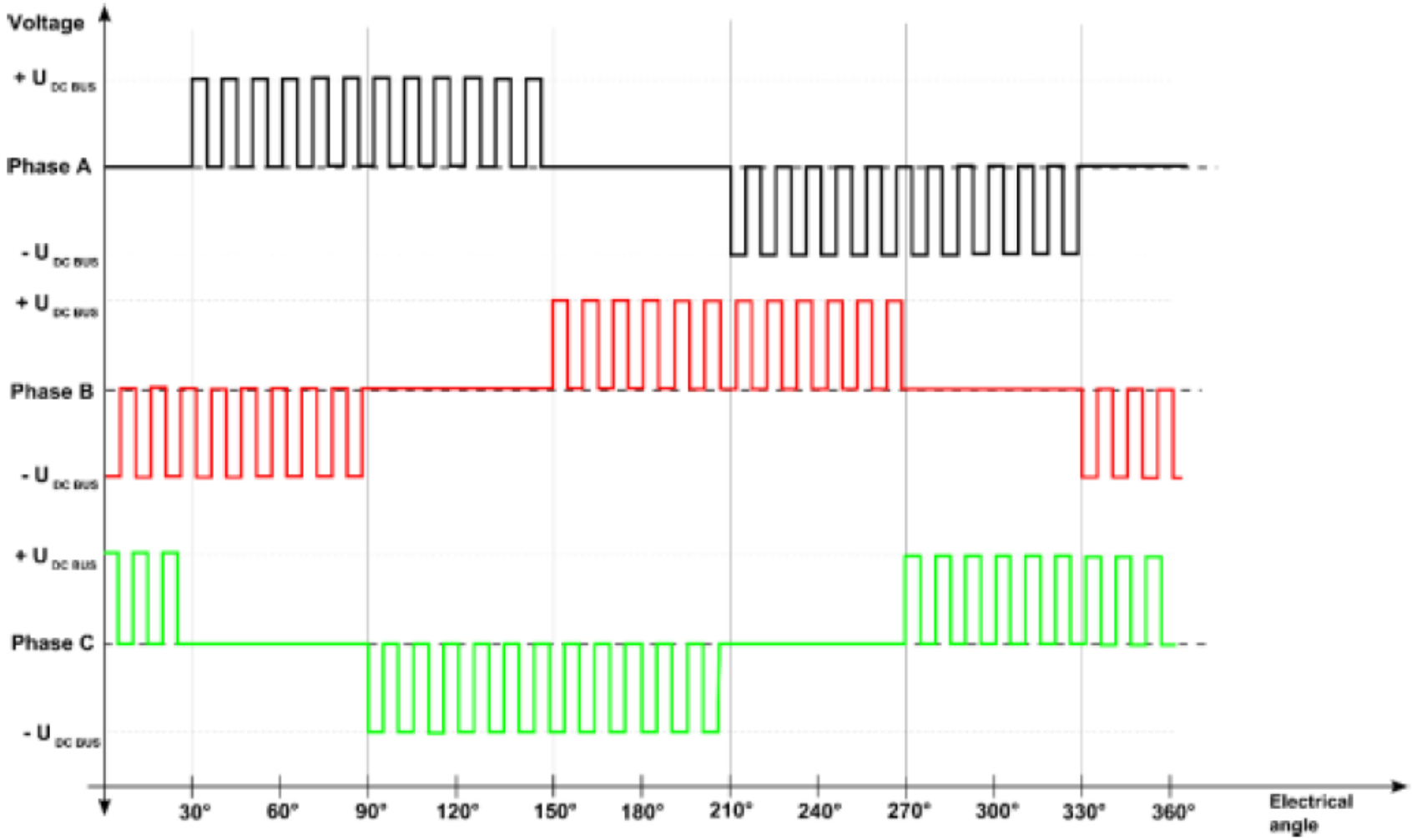




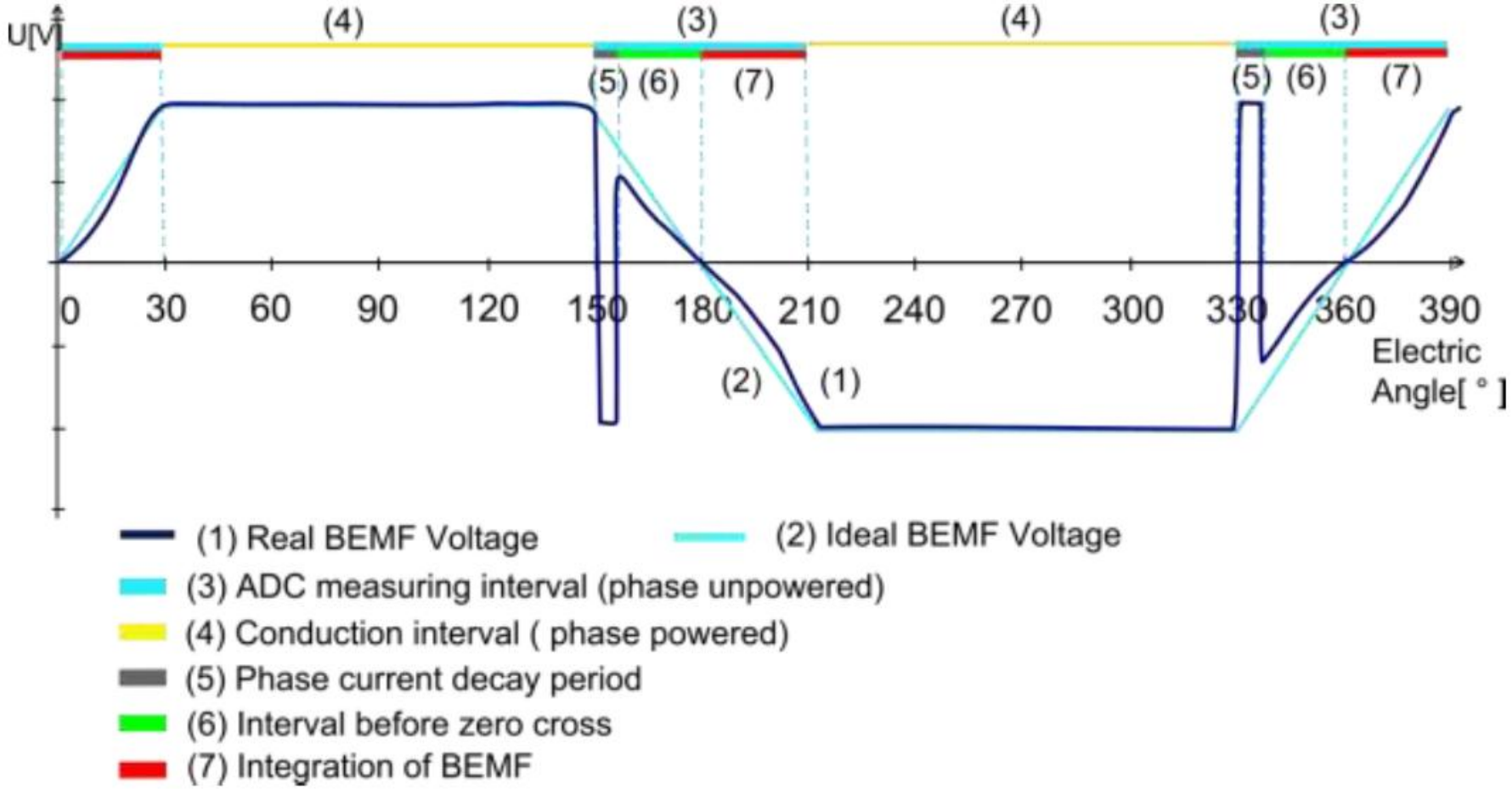
Waveforms for Phase Drive Voltages

- Voltage: U vs. V
- Drive two phases at a time, keeping 90° ahead of rotor
- Need to advance to next phase (pair of windings) to keep motor moving
  - Speed-dependent delay
- Adjust analog DC or PWM duty cycle to set how much flux is generated



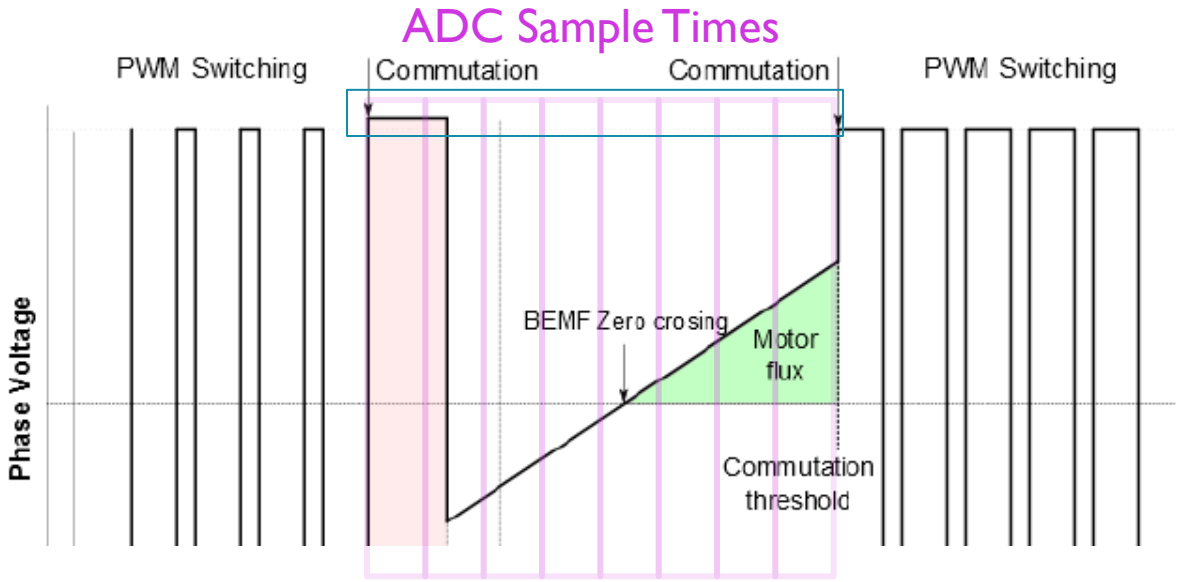
Rotor Position and Back EMF (BEMF)

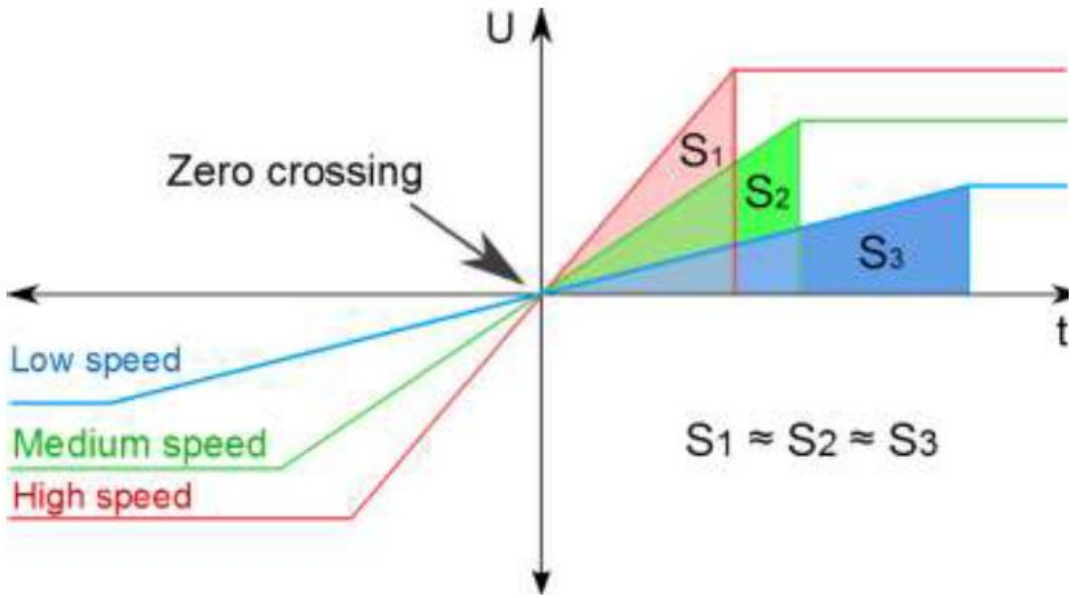
- Phase is powered during conduction intervals (4)
- During unpowered time (3) can measure BEMF
  - Not a straight line
  - Slope depends on motor speed
- Want to commutate this phase: on at 30°, off at 150°, on at 210°, off at 330°, etc.



Sensing Rotor Position with Back EMF (BEMF)

- Sample BEMF with ADC every PWM cycle when not driving this phase
- Detect zero crossing (180°)?
  - Good at high speeds
  - Vulnerable to noise at low speeds, since low voltages
- Integrate from zero crossing (180°) until threshold reached (indicating 210°)?
  - Area S under curve is mostly independent of motor speed
  - Error in detecting zero crossing has little impact on detection accuracy, since BEMF is low there
  - Good at low speeds
  - Not as effective at high speeds – too few samples





States Needed to Start Motor

- Alignment:
  - Don't know rotor position
  - Force rotor into known position by activating coils (A+, B+, C-)
- Start-up
  - Force commutations in open-loop mode based on desired acceleration and predefined parameters
  - Operate until back EMF large enough to measure
- Run
  - Closed-loop control with commutation controlled by back-EMF

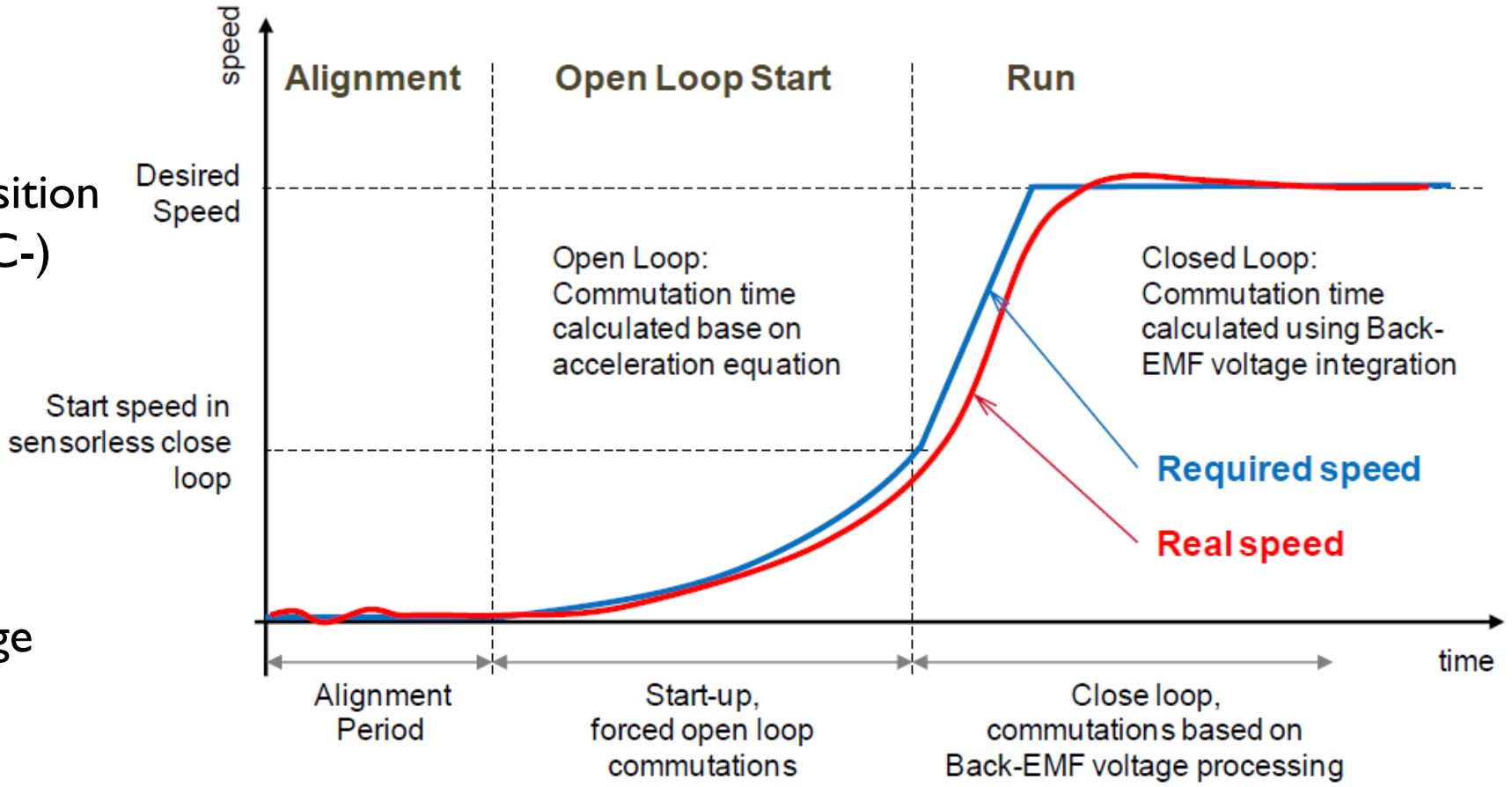


Figure 12. BLDC motor control states

Motor Run Sub-State

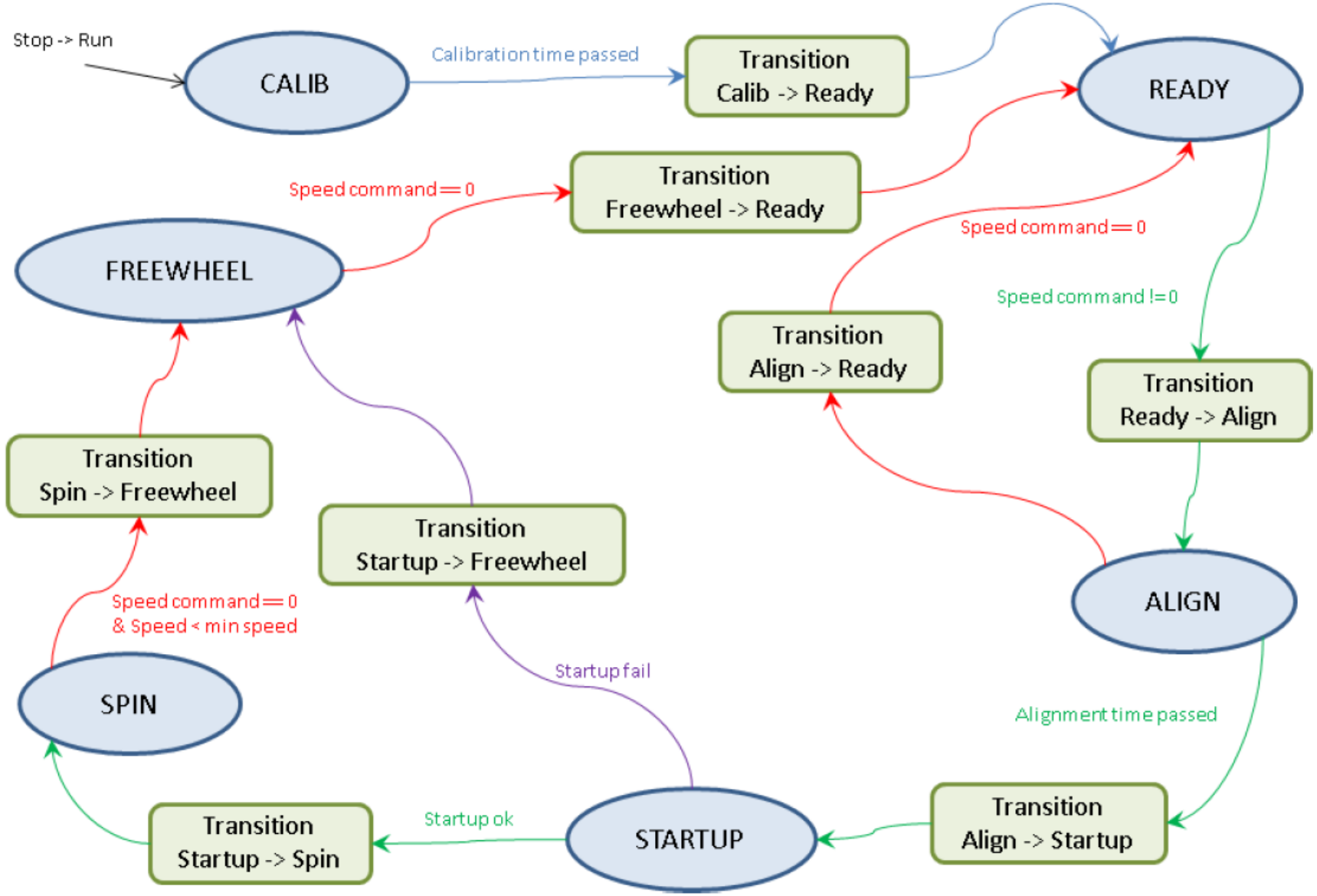
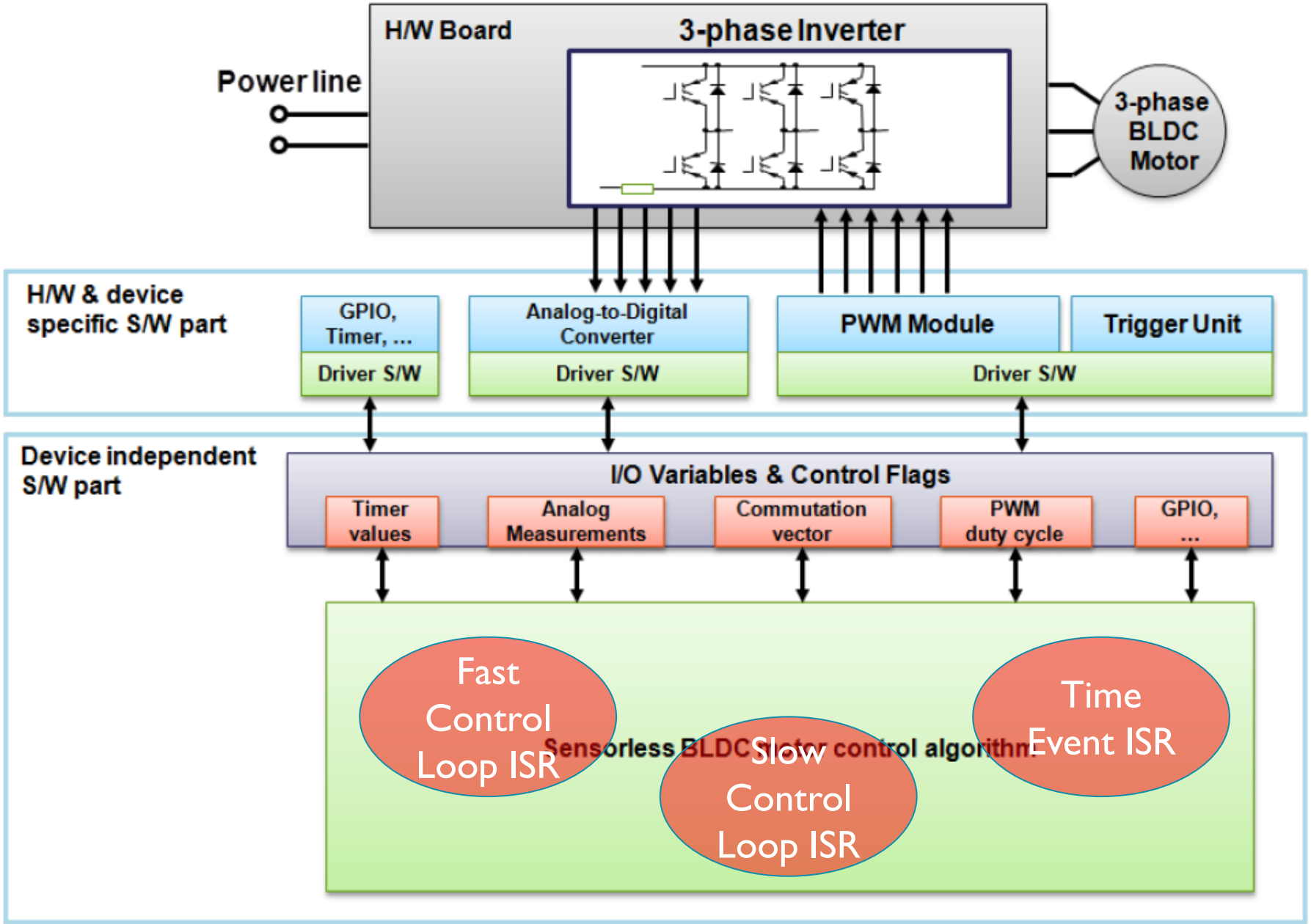
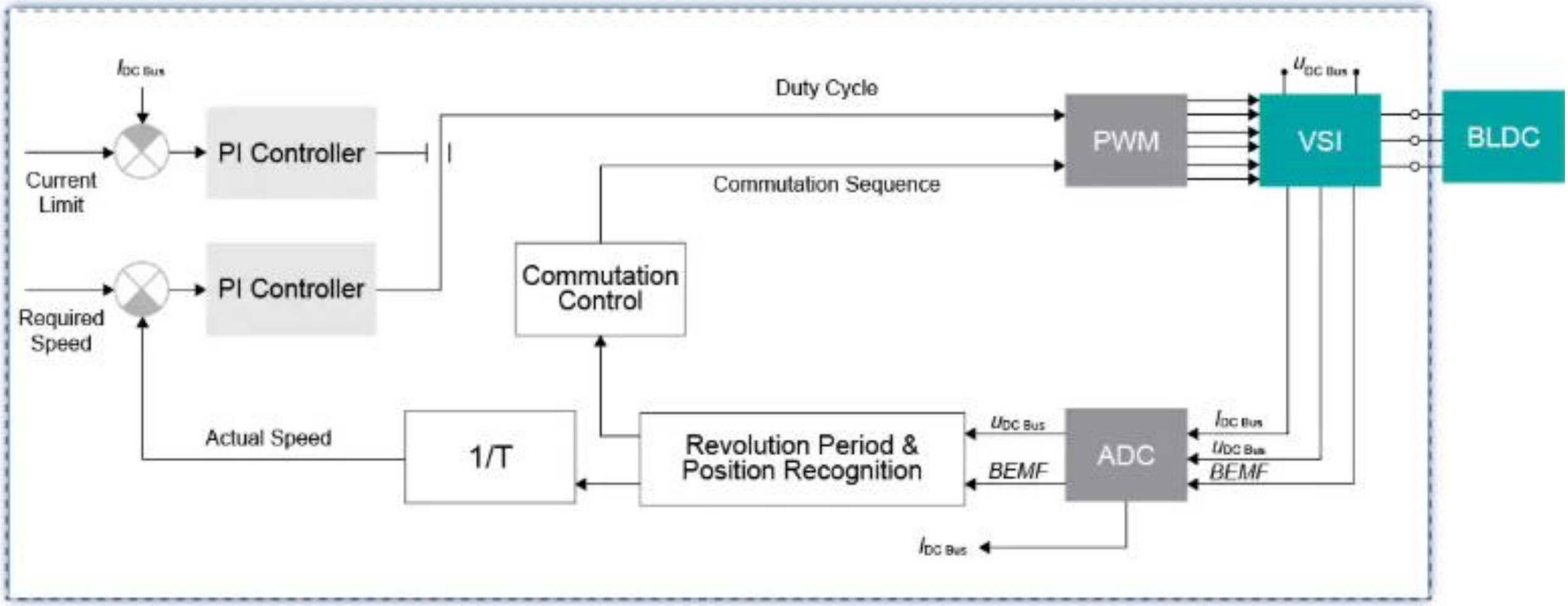


Figure 4. Motor Run sub-state diagram

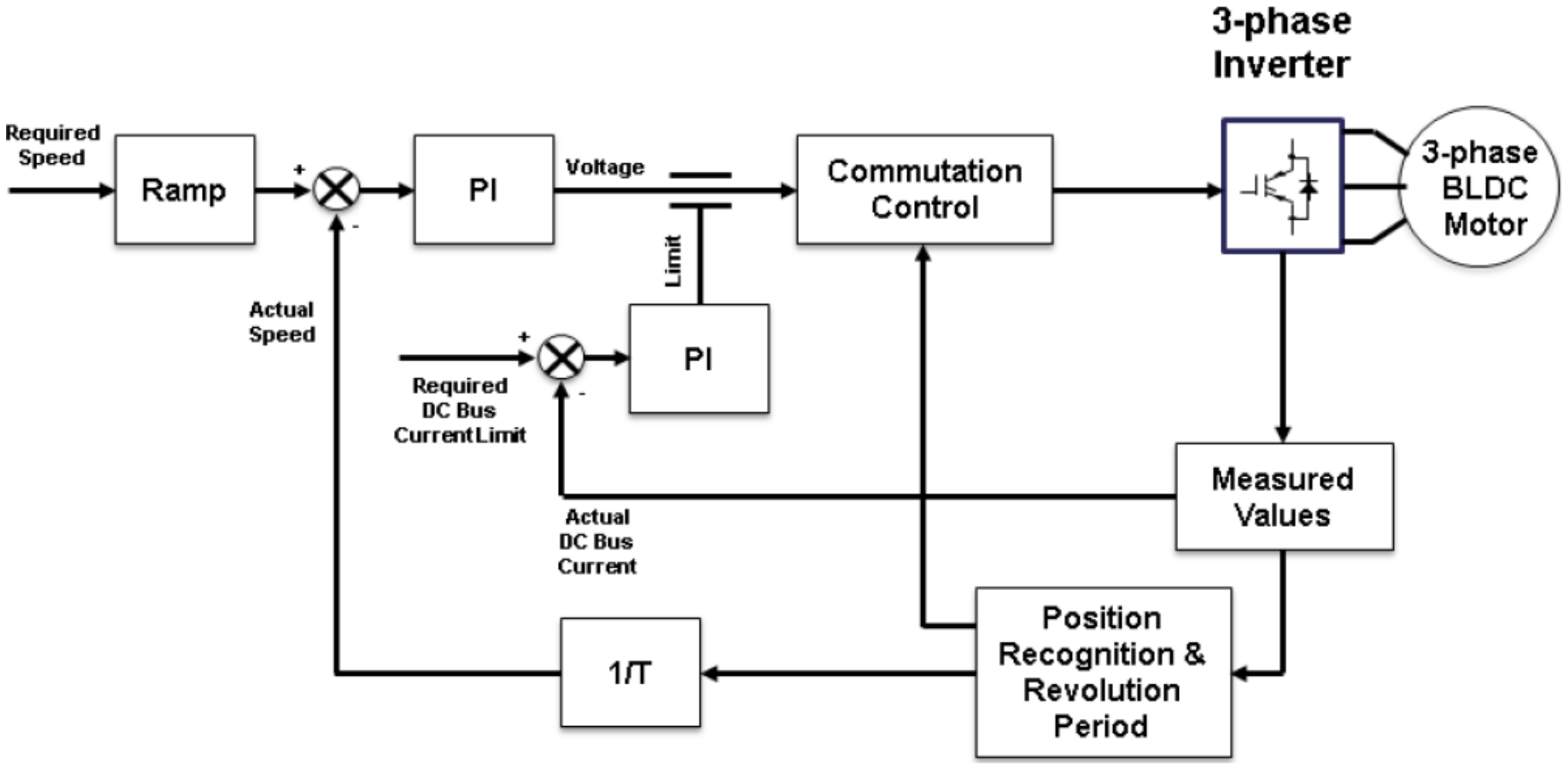
One View of the System



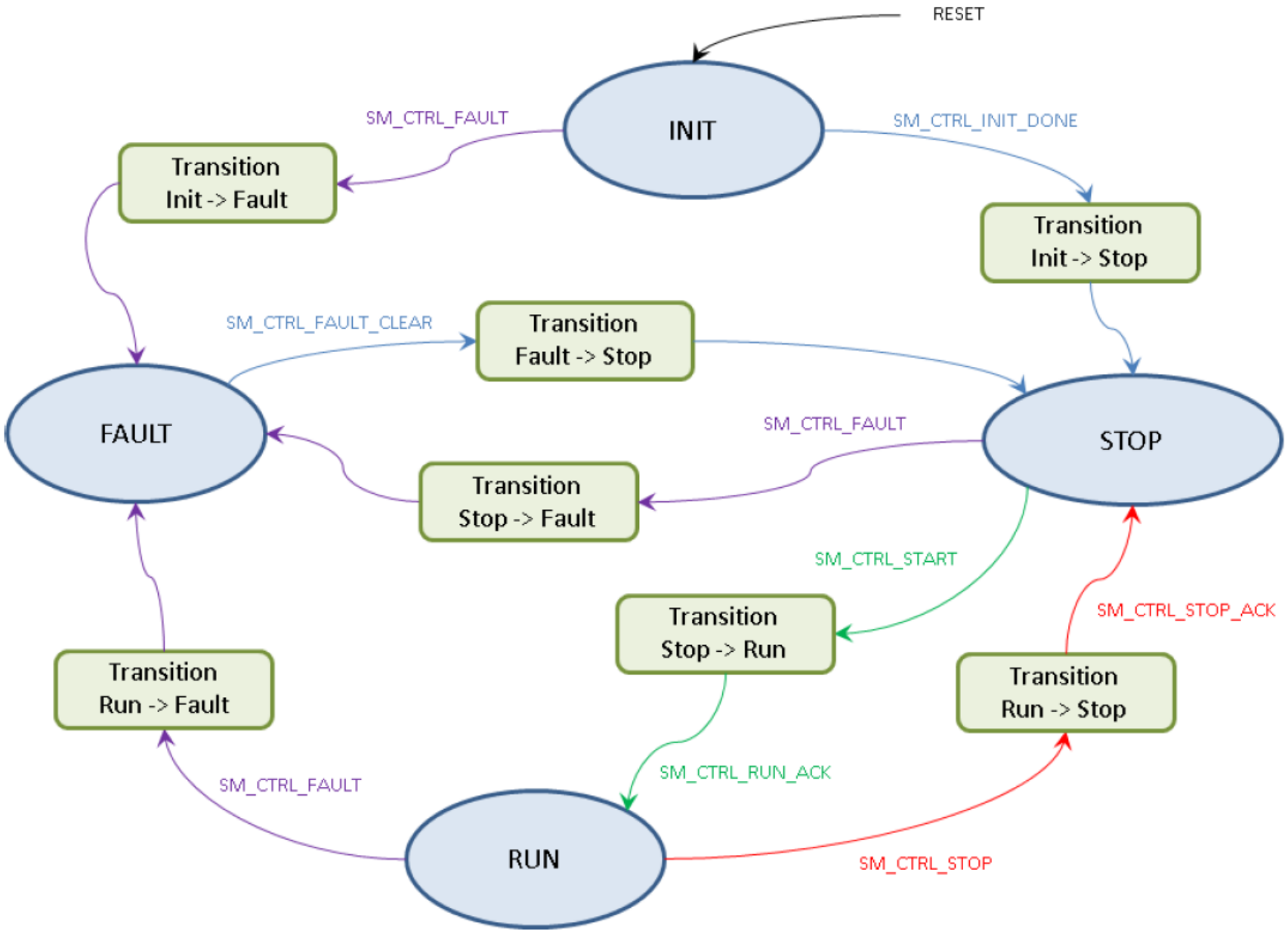
Another View of the System



Control System Diagram for Run State



Application State Machine



Example Timing

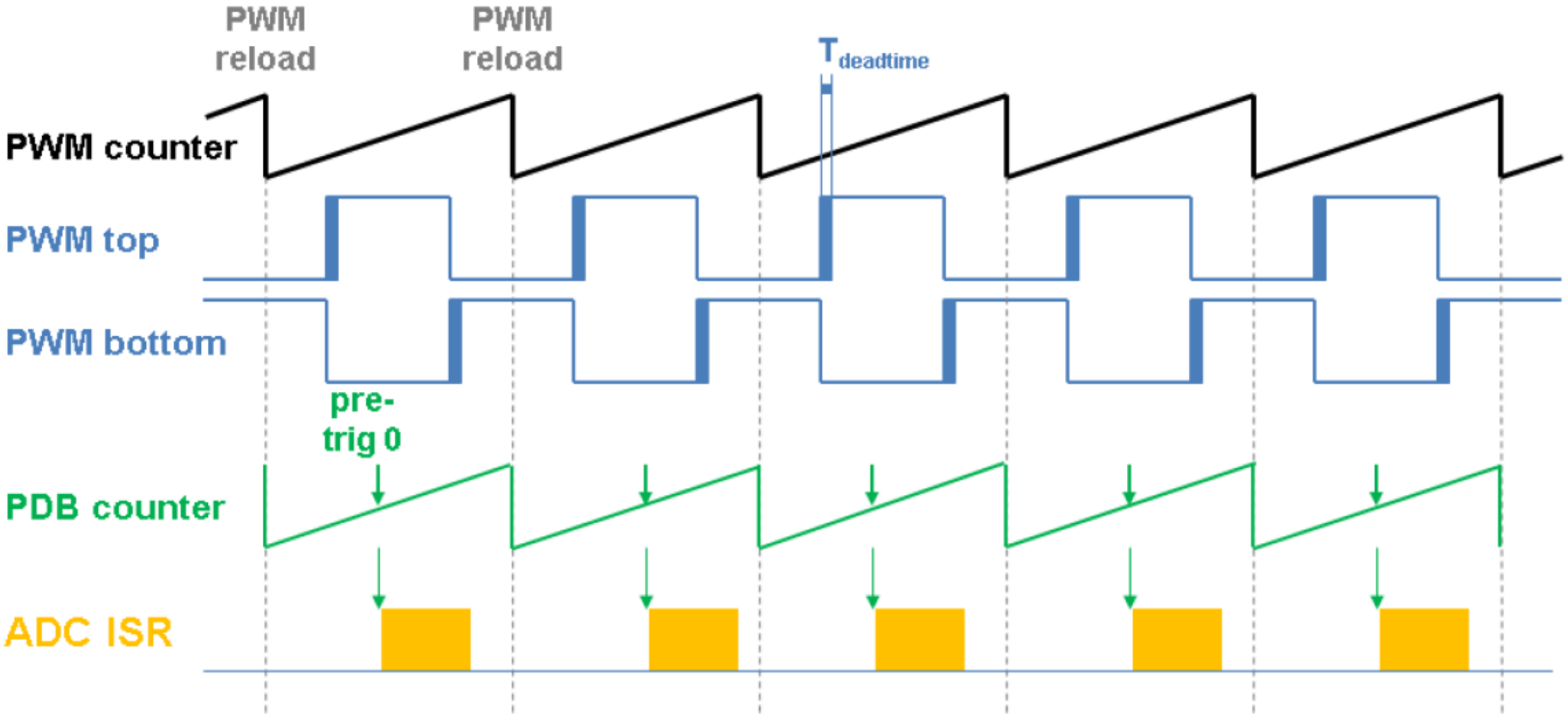


Figure 6. Hardware timing and synchronization on KV46F

Control Loop Function Flow Charts

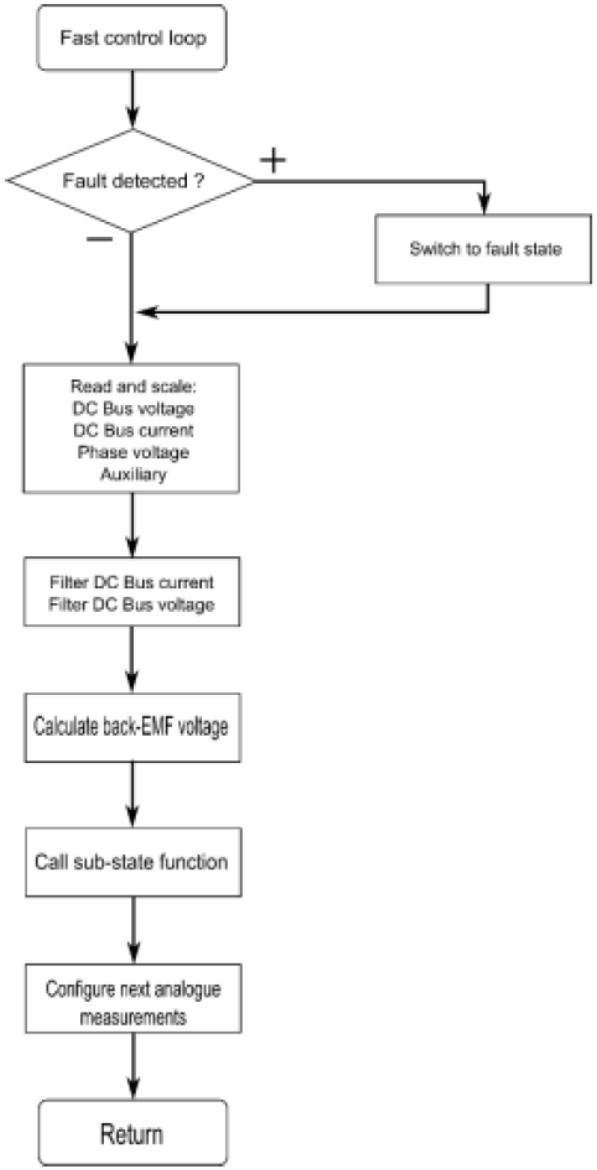


Figure 6. Fast control loop function

- Fast Control Loop
  - Runs once per PWM cycle
  - Tests for faults
  - Read voltages and currents, filter as needed
  - Calculate back EMF voltage
  - Do sub-state processing
- Slow Control Loop
  - Runs every 1 ms
  - Evaluate and control speed and torque

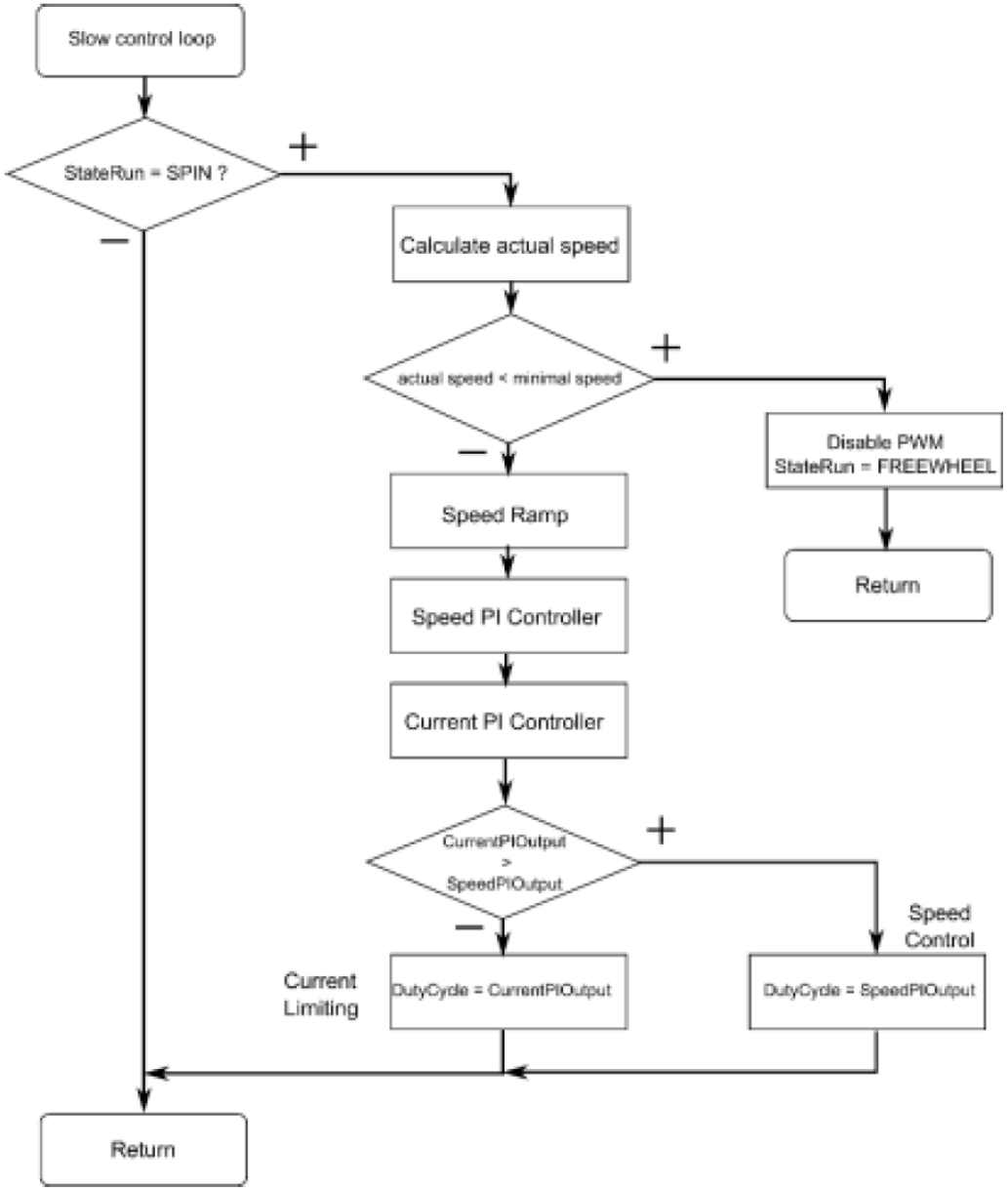
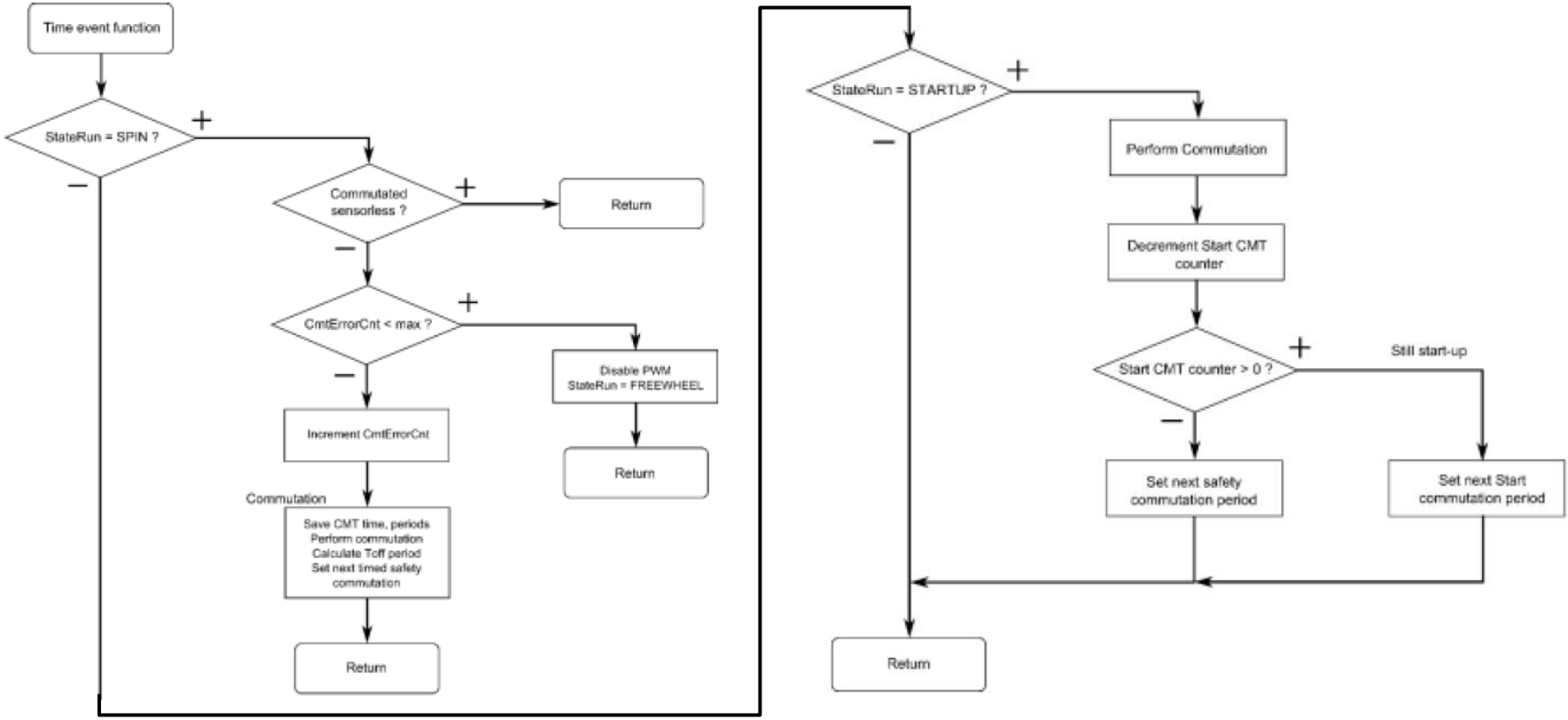


Figure 21. Slow control loop function

Time Event ISR

- Times application states
- Performs open-loop commutation in Startup state
- Protects motor from overcurrent in Spin state if position can't be determined

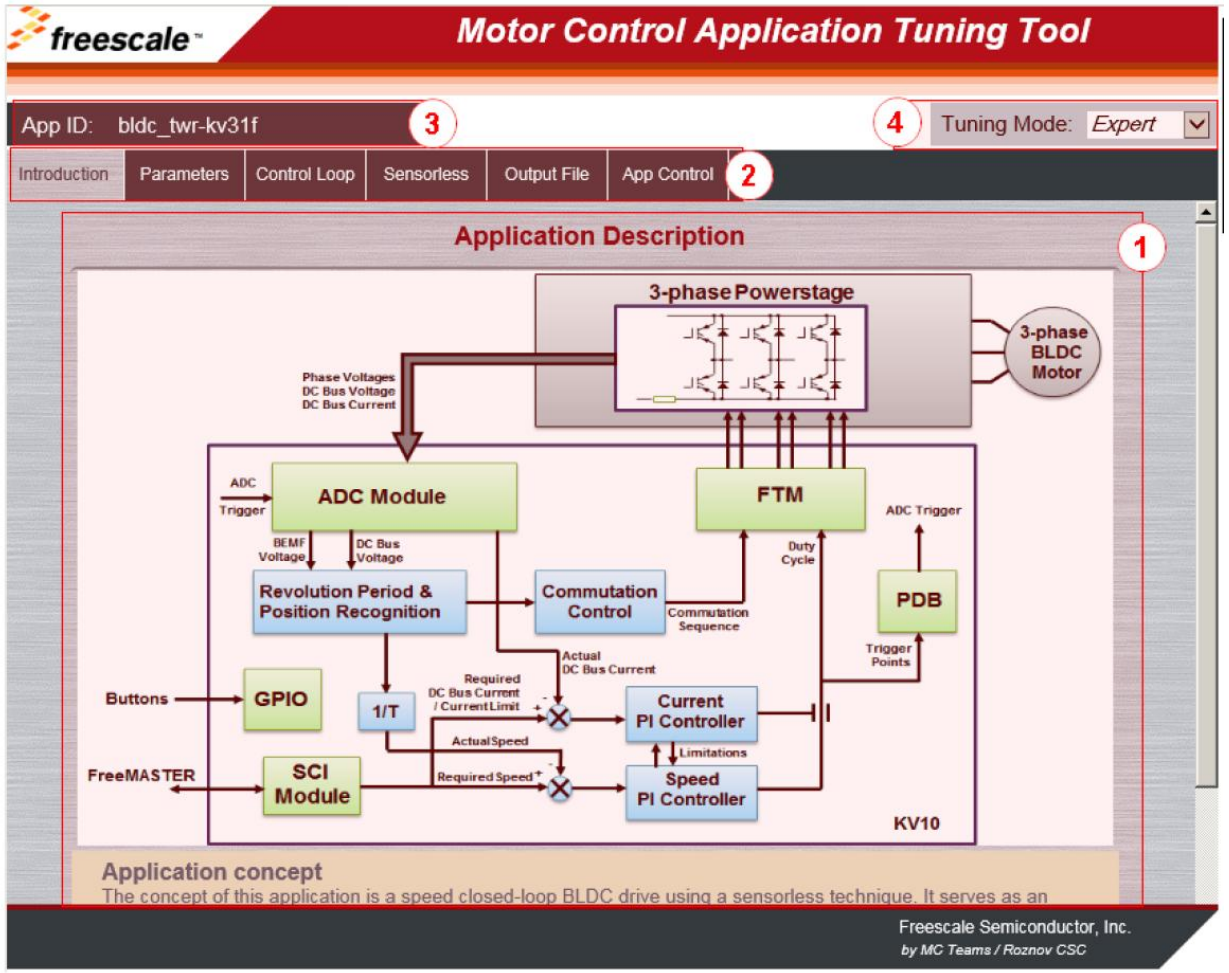


CPU Loading on Different MCUs

—	KE15Z	KV10	KV11
CPU clock [MHz]	72	75	75
Fast Control Loop [cycles] (%)	1298 (34.6 %)	1364 (36.4 %)	1171 (31.2 %)
Slow Control Loop [cycles] (%)	2563 (3.6 %)	2686 (3.6 %)	2217 (2.9 %)
Total CPU load [%]	38.2 %	40.0 %	34.1 %
Flash usage [B]	16 194	15 678	15 856
RAM usage [B]	3 397	3 393	3 401

—	KV31	KV46	KE18F	KV58
CPU clock [MHz]	120	148	168	237.5
Fast Control Loop [cycles] (%)	1189 (19.8 %)	826 (11.2 %)	769 (9.2 %)	564 (4.8 %)
Slow Control Loop [cycles] (%)	2105 (1.8 %)	1543 (1.0 %)	1216 (0.7 %)	1012 (0.4 %)
Total CPU load [%]	21.6 %	12.2 %	9.9 %	5.2 %
Flash usage [B]	15 904	15 884	16 056	15 892
RAM usage [B]	3 409	3 361	3 409	3 389

Development Support – MCDRV, MCAT



- See AN5263, Sections 4 and 5
- MCDRV: Motor Control Peripheral Drivers
  - Configuration, Functionality, API: Architecture
- System uses FreeMaster so PC-based tool can monitor and control code running on target MCU
- MCAT: described in section "Guidance on Tuning and Controlling the Application"