Sensorless Drive for Single-Phase BLDC Motor Using dsPIC33CK

AN5419

Introduction

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This application note describes a sensorless method of driving the single-phase Brushless DC (BLDC) motor using the dsPIC33CK Digital Signal Controller (DSC). This DSC features the high-performance Digital Signal Processor (DSP) and its enhanced peripherals such as ADC, PWM, timers and comparators to contribute to the time-critical sensorless control of the motor. By opting for sensorless control, the necessity of position sensors and related components may be disregarded for less complexity in hardware assembly and a reduced bill of materials.

For an in-depth reference for the construction and mechanism of single-phase BLDC motors, turn to AN5423 for “Sensored Single Phase BLDC Motor Control Using dsPIC33CK.”

Features

- Variable Speed Control through X2CScope
- Motor Speed Correction
- Clockwise and Counterclockwise Directional Control
- Motor Parameter Monitoring using Microchip’s MPLAB® X IDE X2CScope
- Simplified Code Generation using MPLAB® Code Configurator (MCC)

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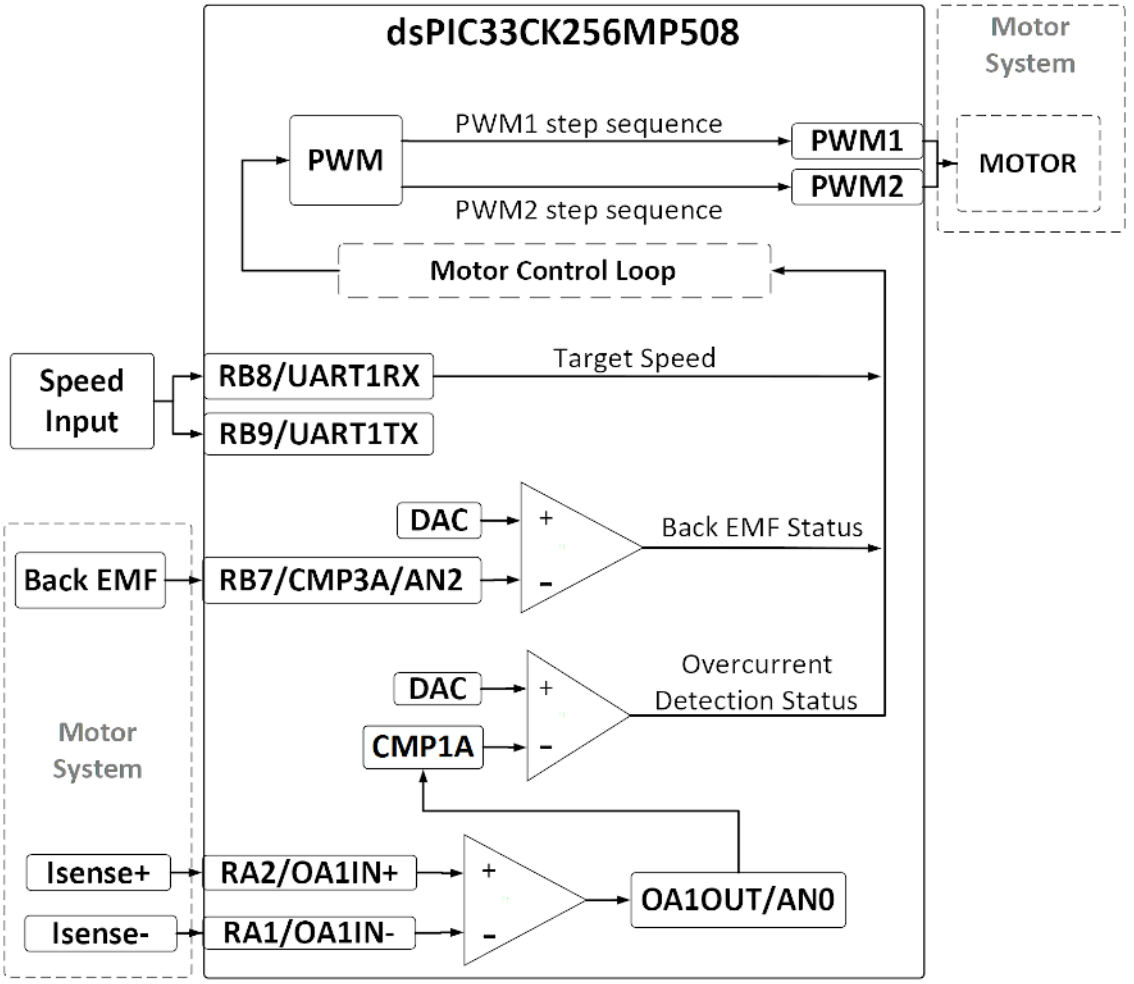
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1. dsPIC Block Diagram

The dsPIC peripheral configuration and execution for this solution is illustrated in 1. dsPIC Block Diagram. The dsPIC33CK256MP508 Digital Signal Controller (DSC) is used in the implementation.

Figure 1-1. dsPIC Block Diagram



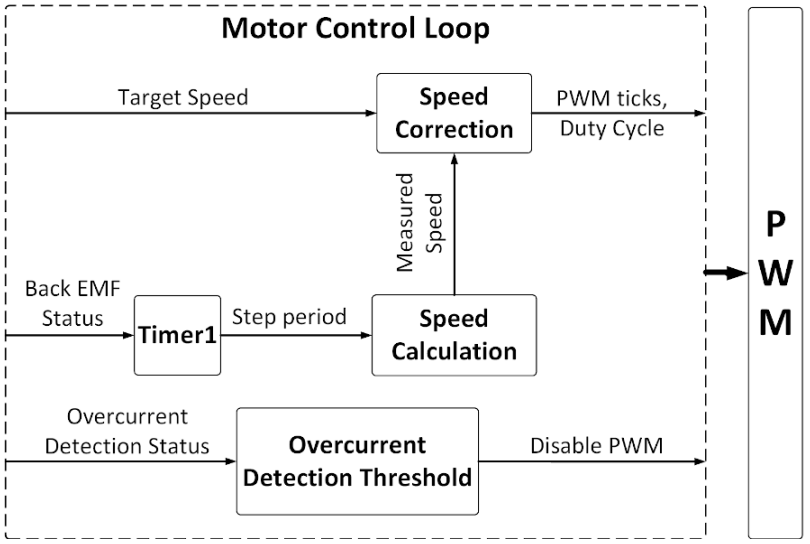
As illustrated in Figure 1-1, there are several dsPIC33CK peripherals used to drive a single-phase BLDC motor in sensorless control.

The speed input is the user-defined speed for the motor, which is read through UART communication. X2CScope, a virtual oscilloscope tool in MPLAB X IDE, is used in the implementation to enter and update the speed input, which is defined as target speed in the firmware. X2CScope also allows data monitoring of drive parameters during run-time without halting the CPU.

The analog comparator with DAC monitors the generated back EMF feedback from the running motor. The comparator identifies the rising and falling edge of the back EMF for the calculation of the motor's estimated speed. A second comparator tracks the current sense level based on the output of the built-in operational amplifier.

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Figure 1-2. Motor Control Loop



In Figure 1-2, the motor control loop executes the pre-commutation calculations for the timing and control of the PWM using the input parameters target speed, back EMF status and overcurrent detection status.

Speed correction updates the PWM drive parameters to increase or decrease the speed of the motor based on the comparison of the target and measured speed. Measured speed is the estimated motor speed in the output. Speed calculation for measured speed uses Timer1 to capture the step period, which is based on the elapsed time between back EMF rising and falling edge status.

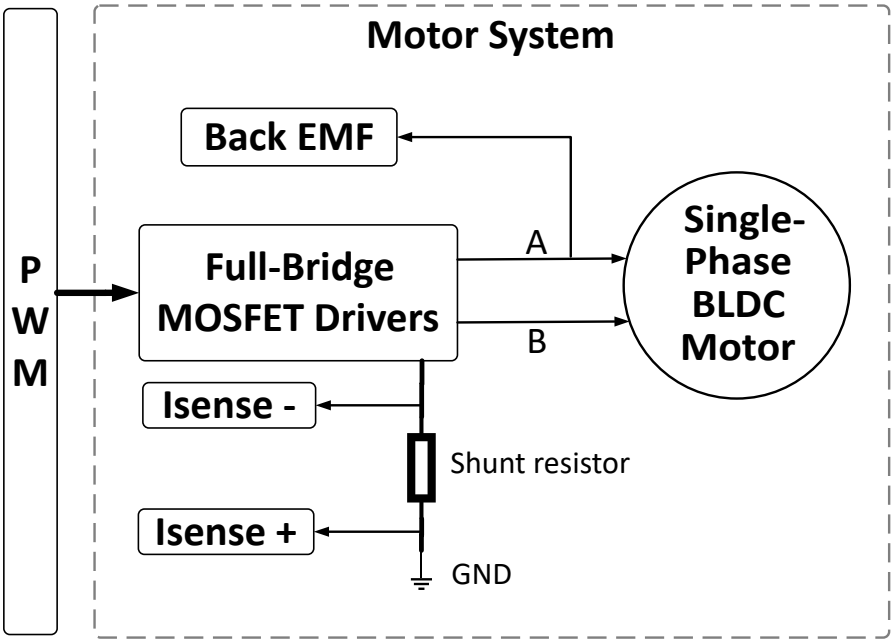
The overcurrent detection threshold observes the current sense level when it increases over the set threshold in the firmware for a certain period. This is to avoid false triggering due to current spikes. When the threshold is exceeded over the set period, the PWM is disabled.

The PWM drives the motor by switching the MOSFET full-bridge driver. The motor is commutated through the timed execution of the two-step commutation sequence that is configured in the PWM.

The motor system is illustrated in Figure 1-3, where it shows the back EMF is monitored across one of the motor windings while the motor is in active drive. The low-side current-sensing shunt resistor is connected to the full-bridge MOSFET inverter. It converts the current to proportional voltage, which is then amplified by the internal operational amplifier of dsPIC.

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Figure 1-3. Motor System

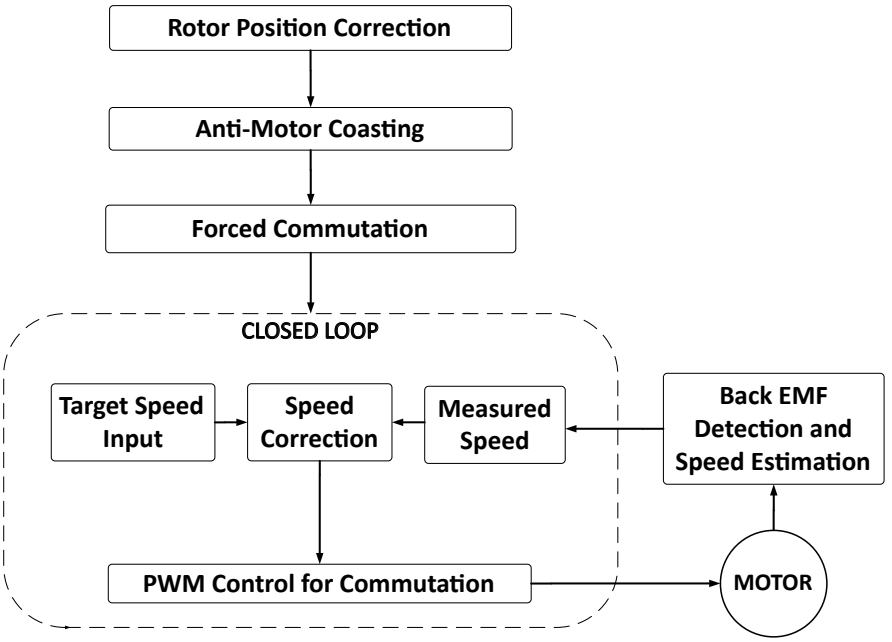


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2. Sensorless Drive Control Loop

Figure 2-1 describes the firmware execution of the sensorless drive of a single-phase BLDC motor. Each function block is described in the following sections.

Figure 2-1. Control Loop Diagram



2.1 Rotor Position Correction

It is important that a correct rotor position is established before the start-up procedure to ensure a consistent directional rotation of the motor. It also prevents the rotor from spinning in a different erratic direction which causes the motor to stall.

Without Hall sensors to detect the present rotor position, the drive depends on the rotor position correction to set up the motor prior to start-up. This function generates one step of the two-step PWM sequence to correct the rotor to one predetermined position set in the firmware. The duration of the PWM sequence is dependent on motor load and cogging torque. In the implementation, the PWM during rotor position correction is active for 300ms. For reference, the two-step PWM sequence is discussed in the section for PWM control for commutation.

If the rotor is initially situated in the wrong starting position, it will be corrected. Otherwise, the rotor will stay in place and, at worst, experience vibrations due to the executed PWM sequence.

2.2 Anti Motor-Coasting

This function enables a firmware-enabled brake to prevent the motor from coasting. When the rotor is turned during position correction, the motor may coast or spin due to momentum. The brake function is implemented by enabling the low-side MOSFETs. When the low-side MOSFETs are enabled, the current circulating in the full-bridge MOSFET is dissipated through the motor's winding and MOSFET's on-state resistance.

A rest period is inserted to overcome the consequences caused by high cogging torque. Cogging torque intensity depends on the motor's construction, such as air gap and the number of stators. This torque can be observed when the rotor wobbles after being turned. However, this slight back and forth motion can disrupt the motor's rotational direction if the motor is immediately started up without a delay to stabilize it. In the implementation, the delay is set to 1.5 seconds.

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2.3 Forced Commutation

The motor start-up procedure is done via forced commutation where the PWM switches the full-bridge MOSFETs to control the motor in an open-loop sequence. The duty cycle is tuned to fit the voltage rating of the motor. It starts from a set minimum open-loop duty cycle up to the set maximum open-loop duty cycle. The speed is also estimated to start from a minimum open-loop speed to a maximum open-loop speed. When the maximum open-loop speed is reached, the firmware transitions to closed-loop control.

2.4 Closed Loop

Closed-loop control is an internal feedback process used to control the speed of the motor during operation. It performs speed correction to update the drive parameters that maintain the accuracy of the motor speed to the target speed set in the input. The following sections are function blocks in the closed-loop control.

2.4.1 Speed Correction

Speed correction is a function under closed-loop control that compares the target speed and measured speed of the motor. When determined unequal, this function corrects the motor speed by tuning the parameters that control the drive, such as period and duty cycle.

Drive tuning is done by linear response correction. Linear response uses an incremental or decremental approach to meet the target speed using a fixed sensitivity parameter. This creates a straightforward and linear change in speed. Since the changes in speed and duty cycle are constant, the motor can maintain its stability as it operates, in exchange for a slower speed response.

2.4.2 Target Speed

The target speed input is set via X2CScope by entering the desired speed in the global variable target speed. X2CScope version used in the implementation is version 1.6.6. The target speed ranges from the minimum closed-loop speed to the maximum closed-loop speed. If the user inputs a target speed below the minimum or above the maximum, it is corrected to the minimum and maximum, respectively.

2.4.3 Measured Speed

Measured speed is the speed estimated from the back EMF feedback of the motor. This estimation is guided by Equation 2-1.

Equation 2-1. Measured Speed

$$Measured\ Speed = \frac{60 \times Timer1\ Clock}{Poles \times Timer1\ Prescaler \times TMR1}$$

Timer1 is a 16-bit timer configured with a clock source and prescaler. In the implementation, Timer1 has 100MHz input frequency and a prescaler of 256 to have a period of 5us to 167ms. This prescaler is required to cover the minimum closed-loop speed of 300RPM. In frequency, that is 100Hz and in period, that is 100ms.

TMR1 represents the Timer1 buffer, which is set to 0 and increases up to the set period (167ms). In the implementation, the Timer1 interrupt is called whenever the comparator finds the rising edge or falling edge in the back EMF feedback. When interrupted, Timer1 buffer records the period between two edges. Then, Timer1 buffer is reset to zero and the interrupt flag is cleared to wait for the next interrupt at rising edge.

2.4.3.1 Back EMF monitoring

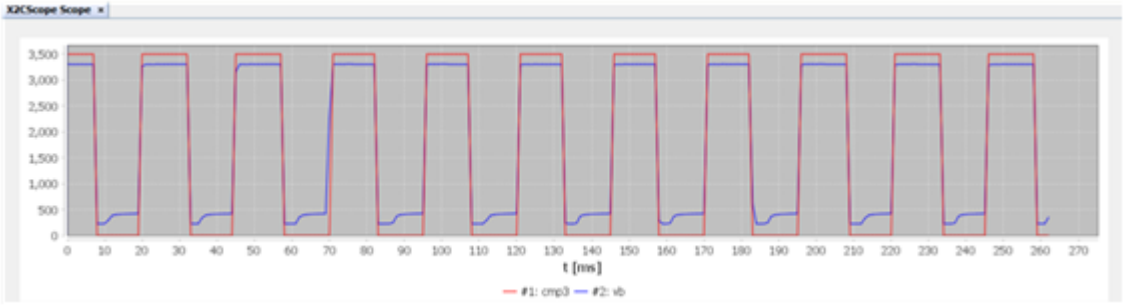
The high-speed analog comparator with DAC monitors the back EMF feedback signal from the motor. The back EMF of a single-phase BLDC motor using this solution's drive is trapezoidal. The comparator's DACOUT is set at a certain level that must be within the range of the back EMF to

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distinguish a new pulse period. This is demonstrated by sampling the back EMF via ADC and using the comparator to compare the measured voltage to the reference voltage. The ADC reading of the back EMF is shown as an example using X2CScope in Figure 2-2. When the back EMF crosses over DACOUT, the comparator updates the status bit. In Figure 2-2, cmp3 is the CMP3 output status bit, multiplied by 3500 for visualization, and vb is the back EMF signal from motor winding B.

The comparator interrupts every status bit update. The function for commutation requires an interrupt every status update and Timer1 is specified to interrupt at every rising edge (comparator output status = 1).

Figure 2-2. X2CScope Capture of Back EMF vs. Comparator Origin Status with DACOUT = 3000



2.5 PWM Control for Commutation

The peripheral implementation of the motor commutation in sensorless control uses the dsPIC33CK's PWM module. The firmware execution of the PWM for one motor revolution is illustrated in Figure 2-3.

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Figure 2-3. Drive Timing Diagram

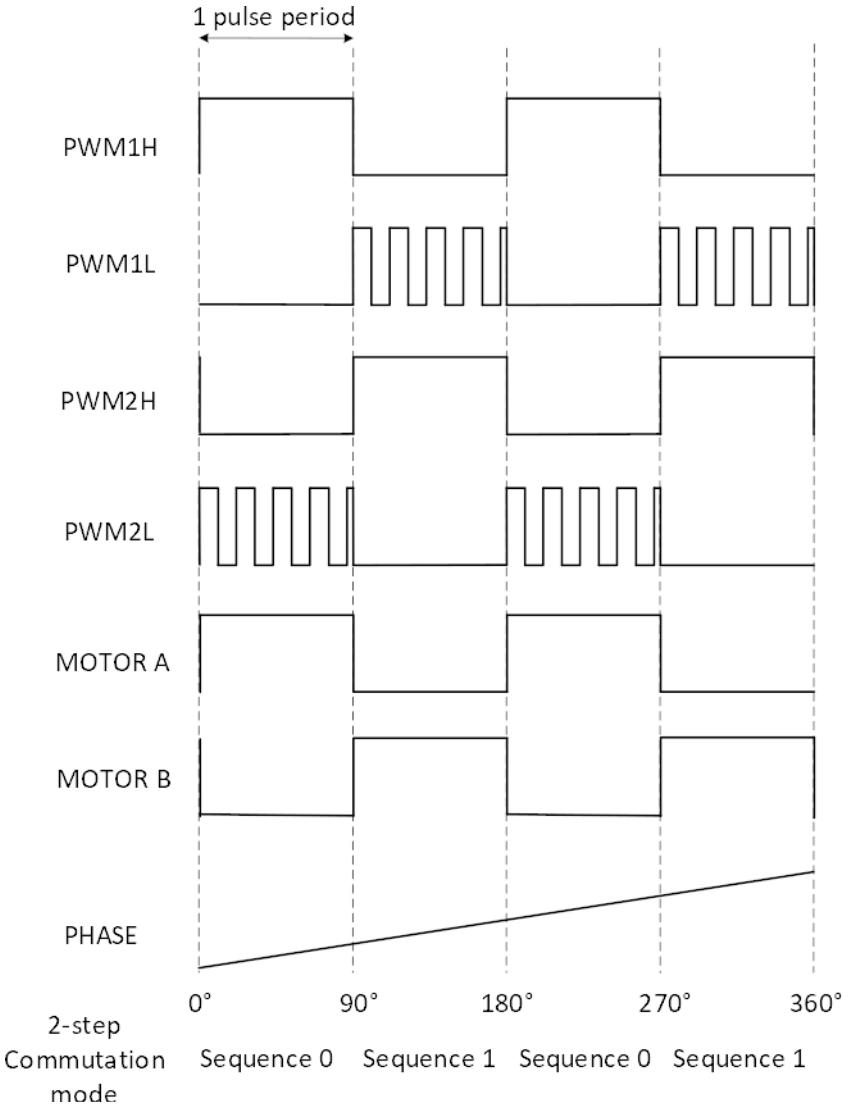


Figure 2-3 shows the two-step commutation sequence that the PWM generates to rotate the motor in one revolution. Each step happens in one pulse period. However, without position sensors, the timing of each step cannot be determined. In sensorless drive, it can be derived from the target speed using Equation 2-2.

Equation 2-2. PWM Timing Period

$$Target\ PWM\ Ticks = \frac{60}{4 \times ADC\ interrupt\ time \times Target\ Speed}$$

Target PWM ticks represent the total ticks of PWM cycles needed to make one step in the two-step commutation sequence. In the implementation, the ADC interrupt triggers functions that update the drive parameters. ADC interrupt time is used because the trigger source is the PWM trigger. The ADC interrupt service is called every 50us.

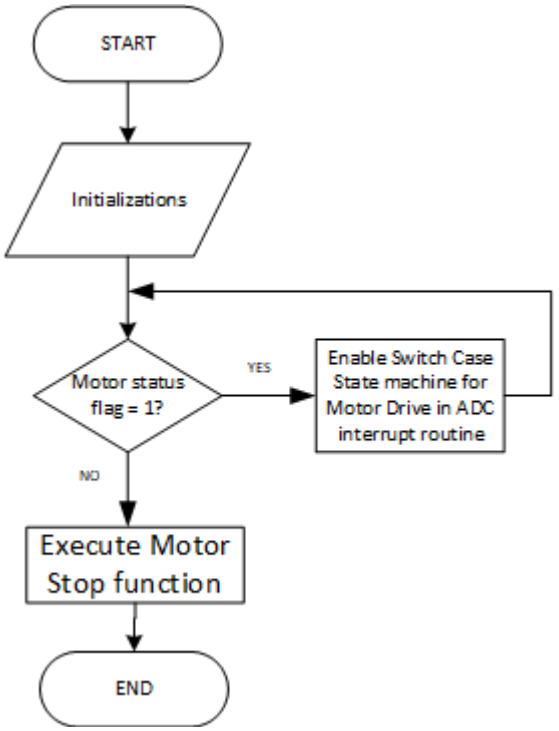
When the target speed is updated, the PWM ticks are calculated. Every 50us, a counter is incremented until it reaches the number of PWM ticks, and the PWM drive changes to the next step commutation sequence.

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3. Firmware Flowchart

The firmware flowchart provides illustrations of the overall program flow of the firmware design and the step-by-step arrangement of the input/output declarations, function processes, decisions and control loops involved to drive the single-phase BLDC motor.

Figure 3-1. Main Loop Flowchart

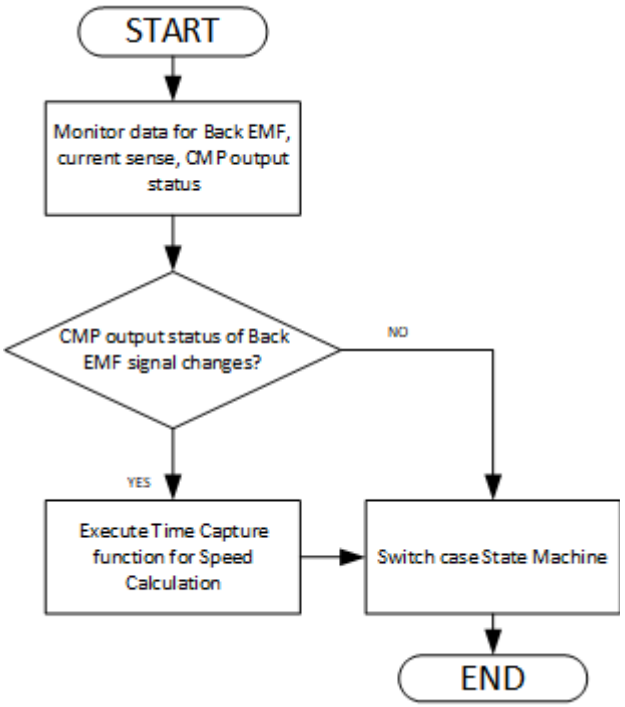


The routine in the main while loop is illustrated in the flowchart in Figure 3-1. The initialization in the input declares configurations for system clock, pin manager, global interrupts, Timer1, UART communication, PWM, comparators, ADCs and X2CScope.

The flag for the motor status can be controlled via push button to enable or disable the drive functions in the ADC Interrupt Service Routine (ISR).

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Figure 3-2. ADC Interrupt Service Routine Flowchart

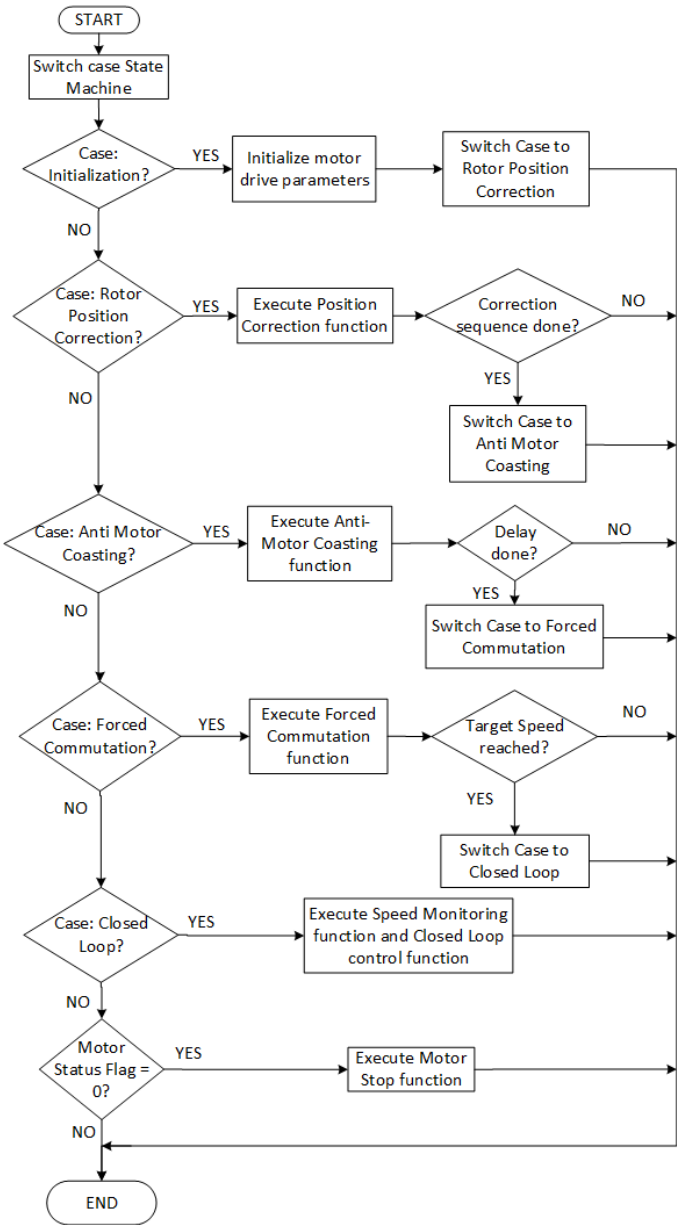


The functions inside the ADC ISR are illustrated in Figure 3-2. This ISR is integral to driving the motor as one of the channels monitors the back EMF signal. The back EMF is the feedback signal where the measured speed is derived from. This measured speed is one of the parameters needed for error correction in the closed-loop control. This ADC channel is set with a PWM trigger as the trigger source (interrupts every 50us).

Another important part in the ADC ISR is the state machine and the flow chart is illustrated in Figure 3-3. The state machine houses the number of states that the driven motor undergoes during the motor driver procedure.

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Figure 3-3. State Machine Flowchart



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4. Conclusion

The dsPIC33CK family of Digital Signal Controllers used in this solution provides agile execution of high-speed control loop instructions for real-time sensorless control of single-phase BLDC motors. It covers the time sensitivity of parameter acquisition from speed input, duty cycle and timing period calculations and PWM switching and sequence generation. In addition to the device's practical features, the cost-effectiveness of the solution using this device is proven with a reduced bill of materials and breaking down the complexity of component assembly.

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