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Application Note

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BLDC Sensorless Algorithm Tuning

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1 Introduction

BLDC motors are very popular in a wide application area. The BLDC motor lacks a commutator and is therefore more reliable and efficient than the DC motor.

To achieve the highest efficiency, highest torque, and a low motor noise, it is necessary to tune the commutation instance of the motors properly. Freescale offers the reference design DRM135, that targets Sensorless BLDC control using Back–EMF integration. The application targets the K60 device, however, it can be easily reused for FSL Kinetis processors.

This application note describes how to tune the BLDC Sensorless motor control application reference design software. The reference design software can be downloaded from the DRM135 page at freescale.com. (see References)

The hardware is built on the Freescale Tower rapid prototyping system and contains the following modules:

- TWR-Elevator
- TWR-K60N512
- TWR-MC-LV3PH + Linix 45ZWN24-40 motor
- TWR-SER

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2 Theory

2.1 Motor theory

A brushless DC (BLDC) motor is a rotating electric machine where the stator is a classic 3-phase stator like that of an induction motor, and the rotor has surface-mounted permanent magnets (see Figure 1). The same arrangement is used in the Linix 45ZWN24-40 motor that will be used for demonstration in this application note.

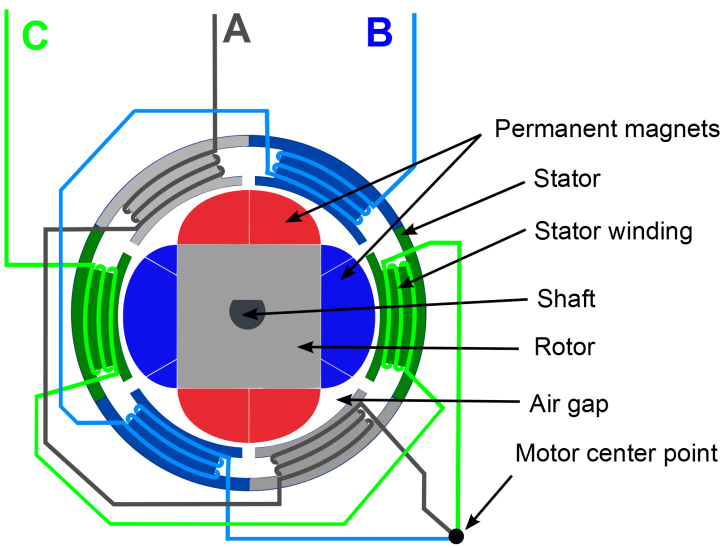

Figure 1. BLDC motor–cross section

2.2 Back-EMF sensing

Figure 2 shows branch and motor phase winding voltages during a 0–360° electrical interval. The yellow interval means a conduction interval of a phase. During this time, current flows through the winding and Back-EMF voltage is impossible to measure. After the commutation transient, there is a current recirculation and the fly-back diodes are conducting the decaying phase current. Blue lines determine the time when the Back-EMF voltage can be sensed during the designated intervals. Green lines determine the time when the zero-crossing detection can be enabled. The red line shows when the Back-EMF voltage is integrated, and at the end of the red interval there is the next commutation.

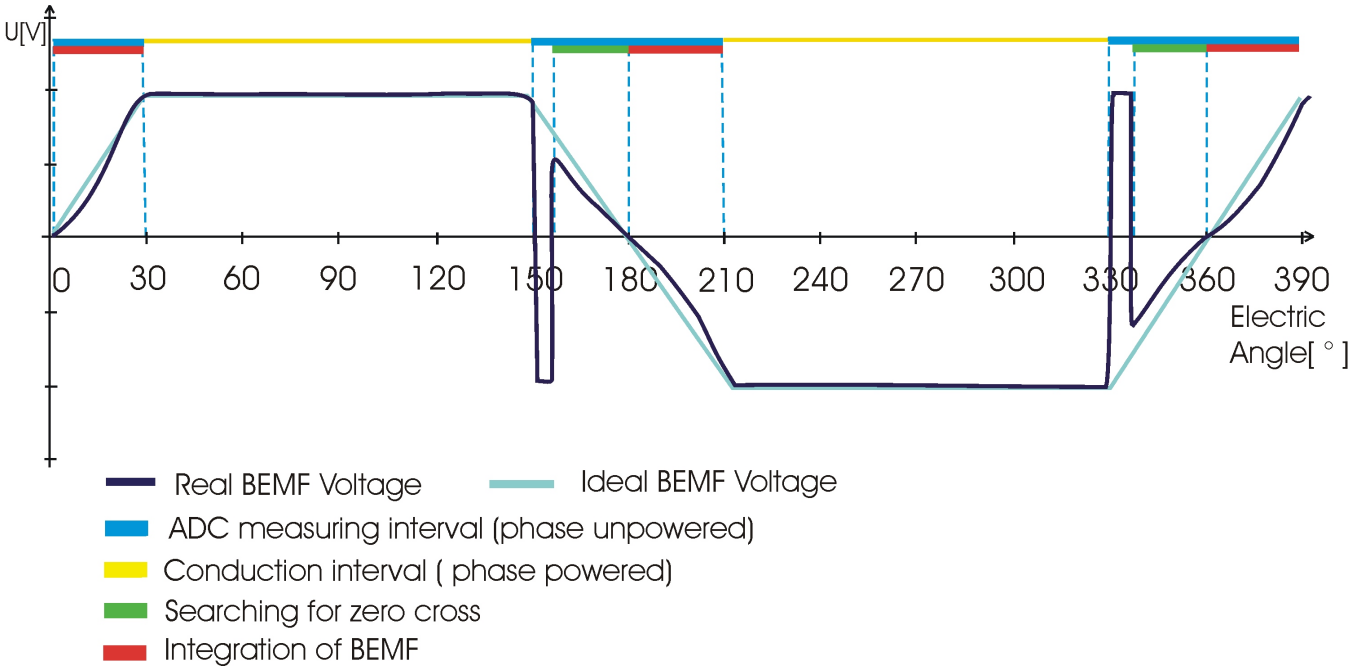

Figure 2. Single phase voltage waveform

For more information, see References.

2.3 Control theory

The reference design uses Back–EMF zero crossing integration for sensorless position determination.

The Back-EMF sensing technique is based on the fact that only two phases of a Brushless DC motor are energized at a time. The third phase is a non-fed phase that can be used to sense the Back-EMF voltage.

In this technique, the commutation instant is determined by integration of the non-fed phase's Back-EMF (that is, the unexcited phase's Back-EMF). The main characteristic is that the integrated area of the Back-EMFs, shown in Figure 3, is approximately the same at all speeds (S1=S2=S3). The integration starts when the non-fed phase's Back-EMF crosses zero. When the integrated value reaches a pre-defined threshold value, which corresponds to a commutation point, the phase is commutated.

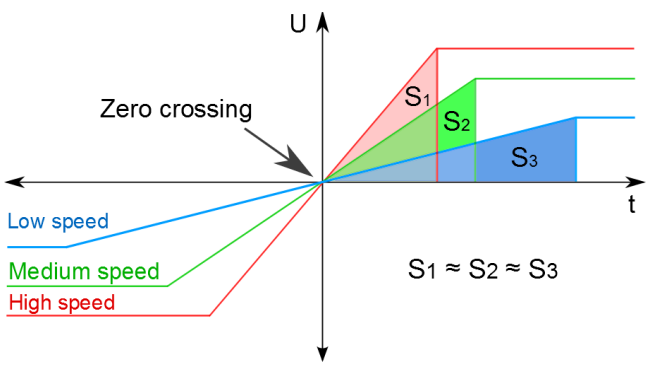

Figure 3. Back-EMF integration method

For more information, see References.

2.4 Tuning method

For a good commutation timing, one requirement has to be met. The two phases have to be switched when the same amplitude of Back-EMF voltage is on both phases. This can be achieved by the proper setup of the commutation threshold, which means that a voltage of an unconnected phase will be equal to the voltage of a phase that will be unconnected after commutation.

To get the right Back-EMF voltage, two assumptions have to be made:

- Top and bottom switches (in diagonal) are driven by the same PWM signal
- No current is going through the non-fed phase used to sense the Back-EMF

The second condition can be detected directly from the sensed Back-EMF voltage. Even after the phase is disconnected from the DC bus, current still flows through the freewheeling diode. The conduction time depends on the momentary load of the motor. The conduction freewheeling diode connects the released phase to either a positive or a negative DC bus voltage. The freewheeling diode interval is shown in Figure 4 and is drawn in a dark blue color. The recirculation time of the freewheeling diode must be shorter than a half commutation (till a zero crossing), otherwise the BEMF method cannot be used. The length of interval when the Back-EMF is not measured is constant in the reference design application. The first three samples after commutation are not considered for Back-EMF voltage detection due to the transient event. The freewheeling delay can be changed in the reference design S/W in the SKIP_PWM_CYCLE constant in the BLDC.h file.

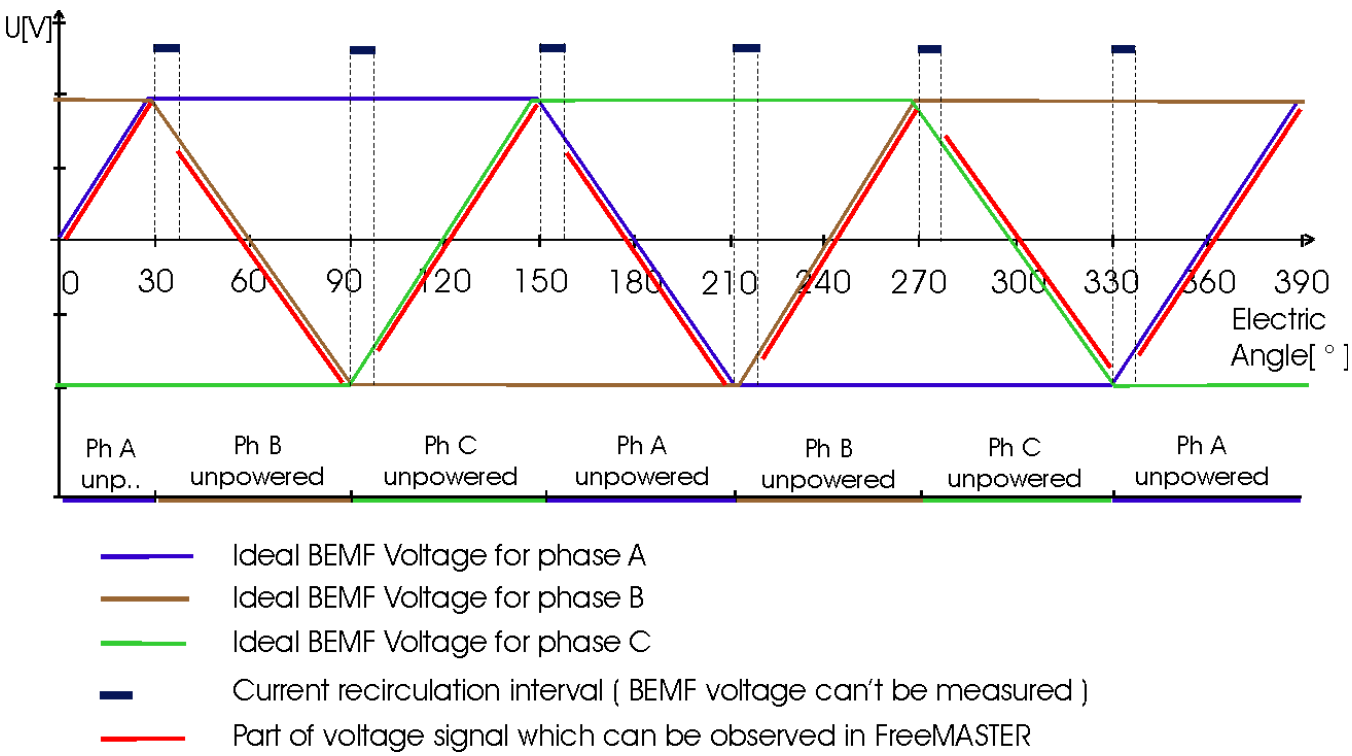

Figure 4. Three phase voltage waveform

3 Tuning the motor

The motor tuning incorporates the following steps:

1. Step 1: Hardware setup.
2. Step 2: Basic constants setup.
3. Step 3: Tuning mode setup.

4. Step 4: Commutation threshold setup.

3.1 Hardware setup

Always be sure that the hardware configuration is correct. In particular, the jumper setting of each tower part is very important in this application. Detailed information about the setup can be found in the reference design user guide available at freescale.com. (see References)

While tuning the motor, please use only a source with current limitation to protect against damage of the motor and power stage. Always ensure that the current limit is set up to about 50% of the motor nominal current. During the tuning, no load should be applied on the motor shaft.

3.2 Basic constants setup

Reference design software can be downloaded from the DRM135 page at freescale.com. (see References)

The first very important step is to set up a basic constant according to the motor used. The constant should be set in the BLDC_config.h file.

Number of motor pole pairs:	*PP*	*[1 … 48]*
Maximal motor speed:	*MAX_SCALED_SPEED*	*[500 … 30000]*
Required PWM frequency:	*PWM_FREQ*	*[5000 … 40000]*
Start-up duty cycle:	*START_DUTY_CYCLE*	*[0 … 100]*

When the changes are completed, it is necessary to reload the software.

3.3 Tuning mode setup

The tuning mode for the application is set up using FreeMASTER.

To configure the user interface to tuning mode, turn off the speed regulator and standstill detection, by disabling the setting “Standstill Detection” and “Closed Loop”. To enable PWM outputs, enter a value more than 400 rpm in the field “Speed Required”. After entering the speed command, a PWM output pins will be enabled. The motor does not rotate yet, because the zero voltage is applied. Changing the parameter “Duty cycle”, the output voltage can be easily changed. After the gradual increase of motor voltage, the motor should start to rotate. If not, the commutation threshold has probably been set up incorrectly. Change the “Commutation Threshold” to the range 100–65000, and turn the shaft by hand to start the motor spinning. The commutation threshold is usually smaller for a high-speed motor and bigger for low-speed motors. After a successful start, it is important to reach at least 30% of nominal speed to achieve a sufficient Back-emf voltage amplitude.

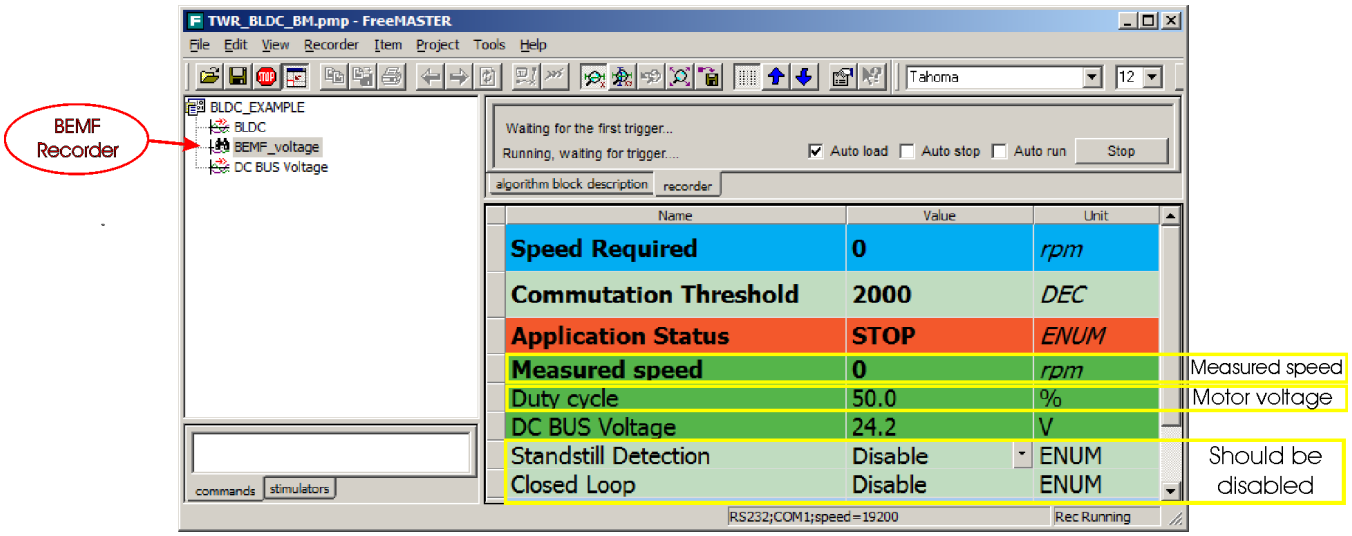

Figure 5. Tuning mode setup

3.4 Commutation threshold setup

During the tuning, the Back-EMF voltage signal will be observed. The shape of measured signal depends on the commutation threshold setup. Use the "BEMF_voltage" recorder to analyze the results. (see Figure 5)

During the motor tuning, the following cases can be observed:

1. **Case 1: Commutation comes too early.**

   Commutation threshold = 300.

   Behavior: Motor can deliver only a small torque, but is very silent. Voltage waveform is shown in Figure 6.

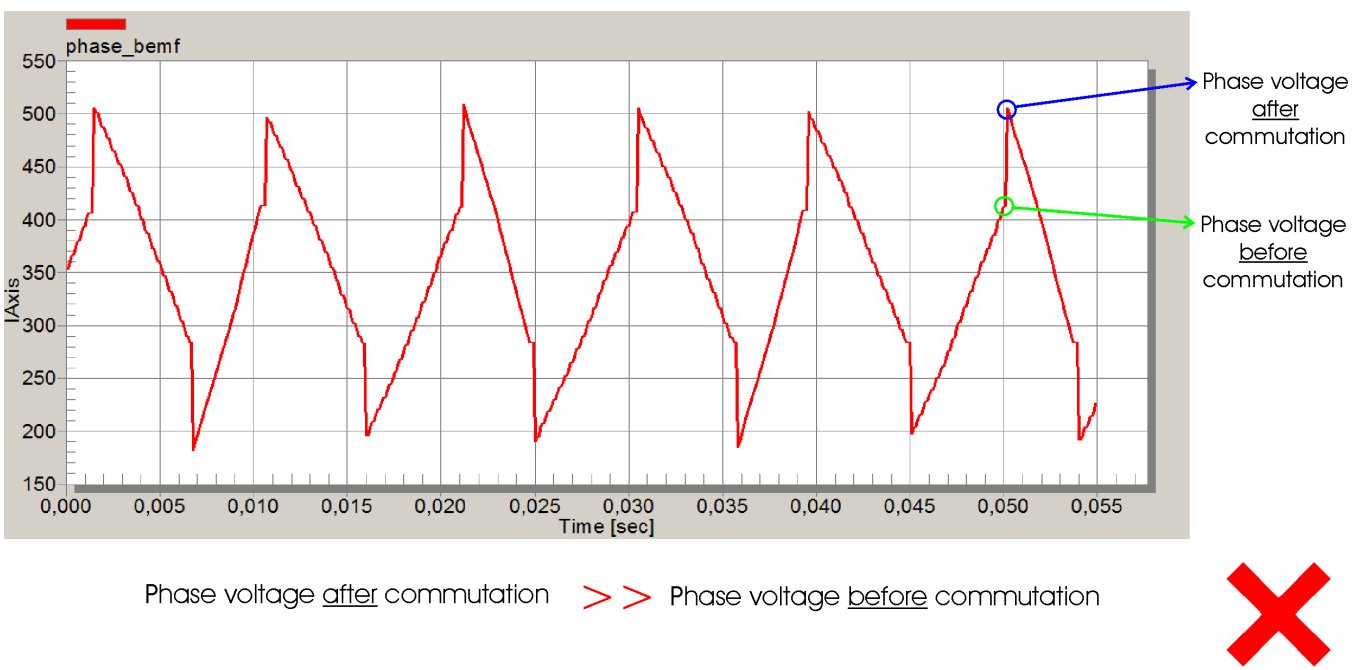

Figure 6. Early commutation timing

Solution: Increase the “Commutation Threshold” variable.

2. **Case 2: Commutation comes precisely**

   Commutation threshold = 1000.

   Behavior: Motor can deliver good torque and is very silent. For a bigger torque, it is better to commutate a bit later. For the best results, choose about 20% bigger commutation thresholds. In our case, it is 1200. This is also because the current recirculation interval is not included in the measurement. The motor is now a little bit noisier. Voltage waveform is shown in Figure 7. The voltages before and after the commutations are approximately equal. If the measured signal is asymmetric, the motor is not constructed precisely or the inductances of the phases are not equal.

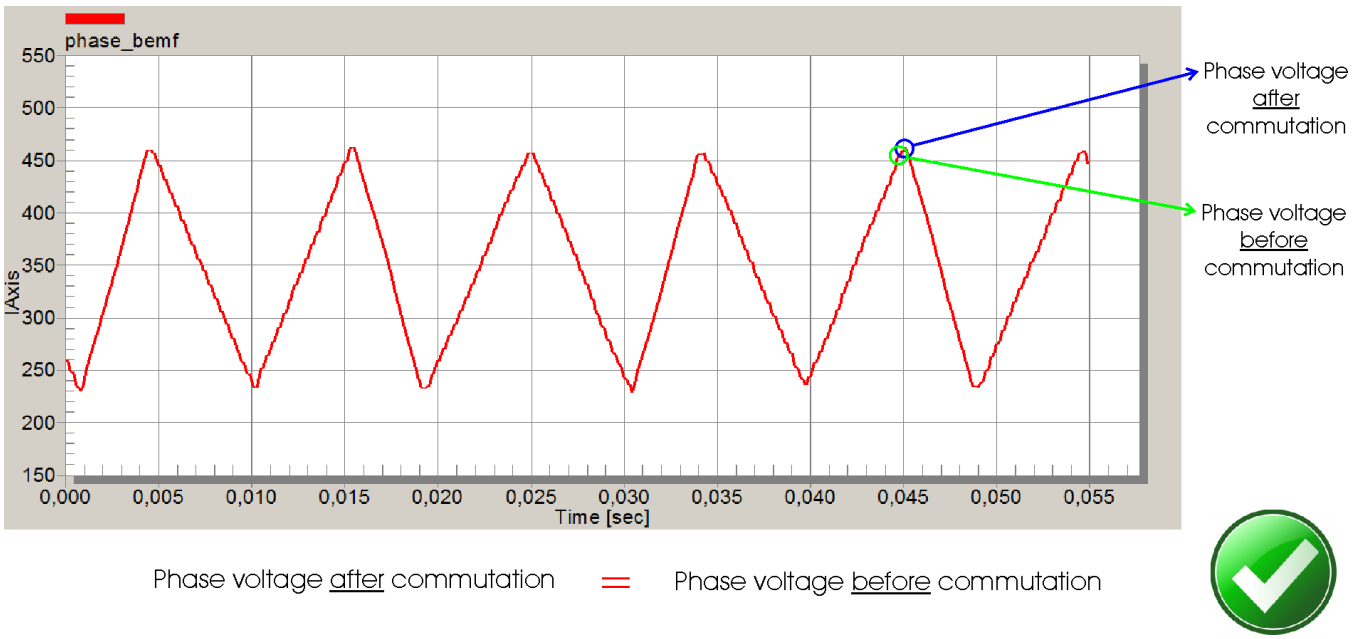

Figure 7. Precise commutation timing

3. **Case 3: Commutation comes too late.**

   Commutation threshold = 2200.

   Behavior: The motor is now significantly noisier. Also, the efficiency of the motor may be worse. Voltage waveform is shown in Figure 8.

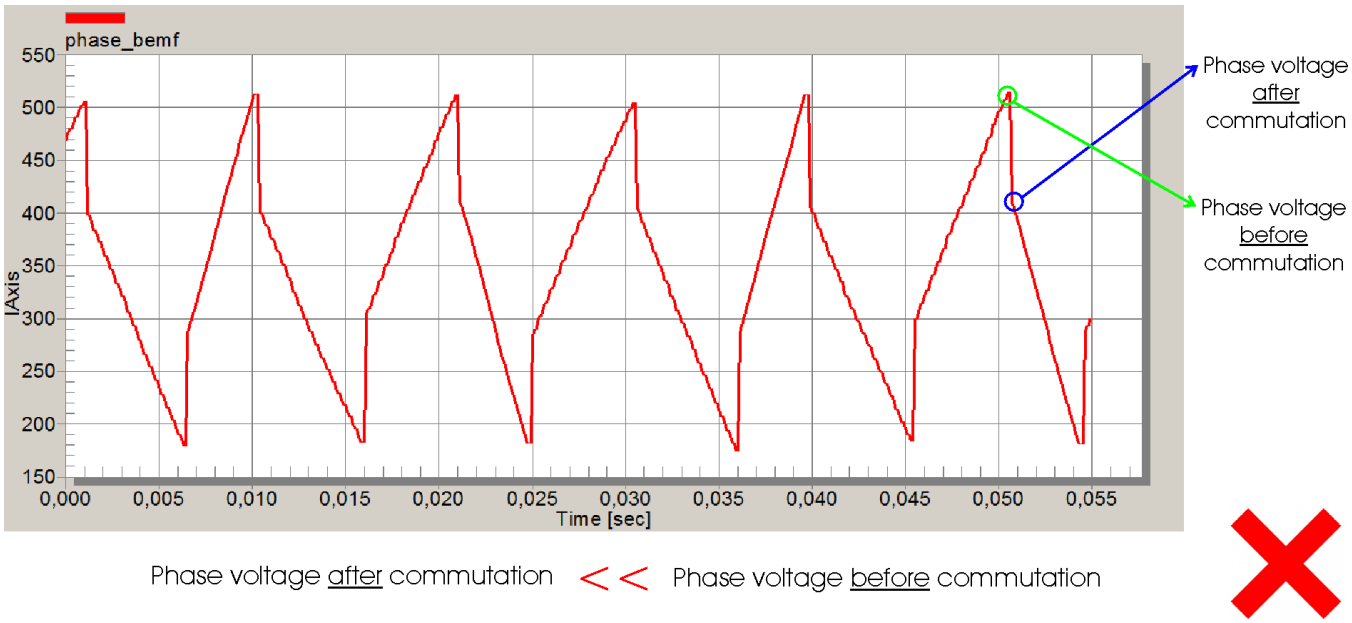

Figure 8. Late commutation timing

Solution: Decrease the “Commutation Threshold”.

4. **Case 4: Voltage spikes are observed.**

   Behavior: Voltage spikes are observed during commutations. Voltage waveform is shown in Figure 9.

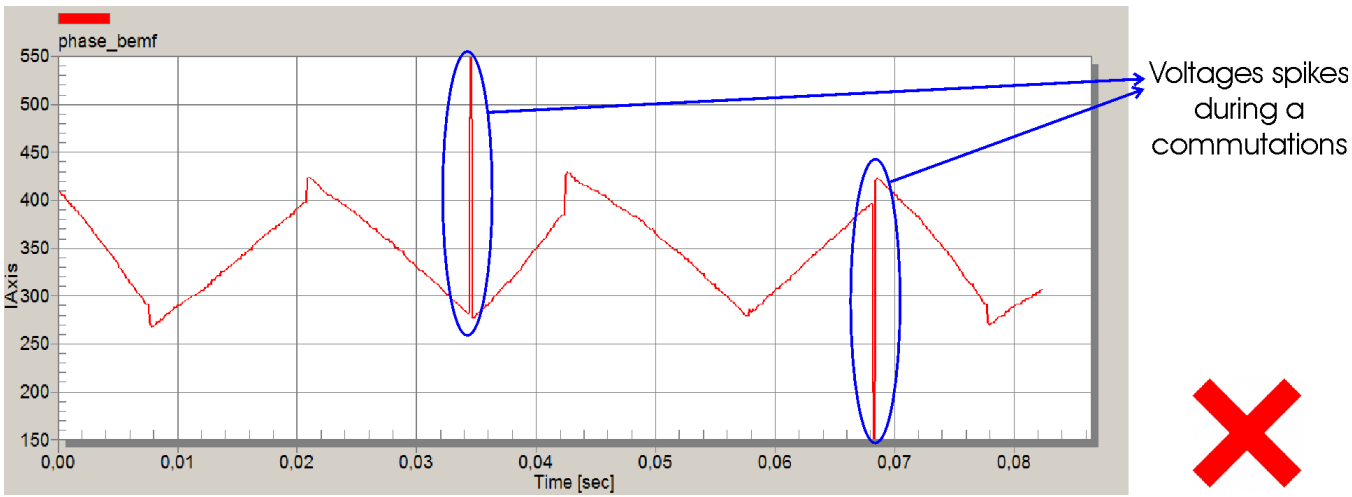

Figure 9. Voltage spikes during commutation

Solution: The current recirculation interval is too short. Increase the value of the freewheeling delay interval in the *SKIP_PWM_CYCLE* constant in the BLDC.h file. Voltage spike measurement is also good to apply during the nominal load of the motor, because a current recirculation interval depends on the motor current.

4 Conclusion

After the previous steps, the motor should run correctly with the best possible performance. This way, a wide range of motors can be tuned in a very short time.

5 References

1. 3-Phase BLDC Sensorless Motor Control on Kinetis User's Guide, BLDCSLK60UG available in freescale.com
2. 3-Phase BLDC Sensorless Control with MQX RTOS Using the K60N512, DRM135 available in freescale.com
3. 3-Phase BLDC Sensorless Control with MQX RTOS Using the K60N512, Software supplying DRM135 available in freescale.com

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