DRV10983x, DRV10975x, and DRV10987 IPD Tuning Guide

The purpose of this document is to help the user to decide whether the motor under test can be used with Initial Position Detection (IPD) algorithm. This user's guide also provides guidance for tuning different IPD parameters. IPD is supported by DRV10983x, DRV10975x, and DRV10987.

Pre-Requirements

Before connecting your own motor, read the corresponding data sheet, EVM user's guide, and tuning guide, and watch the quick start video. Also, install the GUI software on your computer, and make sure the I^2C communication is working. If you have not done so, please refer to the Quick Start Guide.

Contents

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1 Introduction

The inductive sense method is used to determine the initial position of the motor when IPD is enabled. IPD can be enabled by setting IPDCurrThr[3:0] to any value other than 0000 or using the GUI (details in Section 3, Tuning Procedure). IPD can be used in applications where reverse rotation of the motor is not desirable. Once IPD function is properly configured, the align function is no longer required; hence the time needed by motor to align is saved. Time needed by IPD process is less as compared to align process; hence, the total motor startup time is smaller.

IPD is designed to detect inductance variation as a function of rotor position. IPD algorithm works by injecting a small duration of current pulse to the motor; hence there is no reverse rotation of motor during initial startup when IPD is used. IPD can generate acoustics which must be taken into account when determining the best start method for a particular application.

1.1 IPD Operation

IPD operates by sequentially applying voltage across two of the three motor phases according to the following sequence: VW WV UV VU WU UW (see Figure 1). When the current reaches the threshold configured in IPDCurrThr[3:0], the device stops applying voltage and moves on to the next sequence. The device measures the time it takes from when the voltage is applied until the current threshold is reached. The time varies as a function of the inductance in the motor windings. The state with the shortest time represents the state with the minimum inductance. The minimum inductance is because of the alignment of the north pole of the motor with this particular driving state. The example in Figure 1 indicates that the minimum time to reach current threshold was when phase V and phase U were driven, hence it represented minimum inductance and position of the north pole of motor determined.

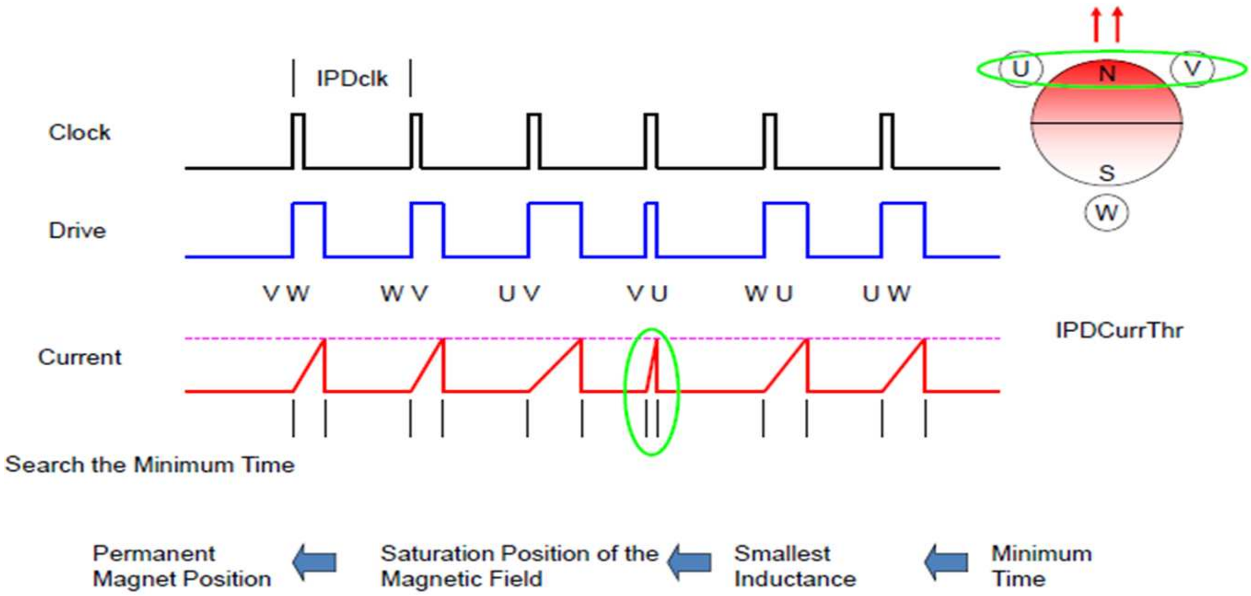

Figure 1. IPD Function

2 Preliminary Check for IPD Algorithm Based on Motor Inductance and Resistance

The motor inductance and resistance will give preliminary indication whether the motor is suitable for IPD or not. The values for motor resistance and inductances are available in the data sheet. If those values are not readily available, follow sections Section 2.1 and Section 2.2 to measure them.

2.1 Motor Resistance

Measure phase-to-phase resistance (R_{PH_PH}) across any two phases using a digital multimeter (see Figure 2). Note down this value, it is used in a later section

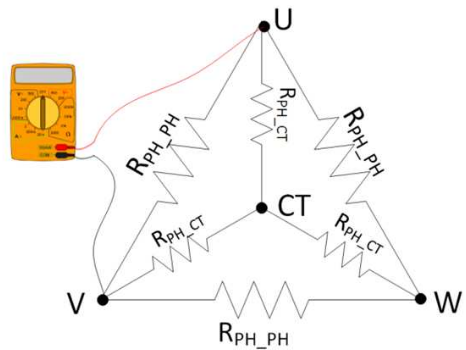

Figure 2. Motor Resistance Measurements

2.2 Motor Inductance

Motor inductance can be measured using many techniques. A precise value of motor inductances is not required here. For a simple and easy way to measure inductances, an LCR meter is recommended here.

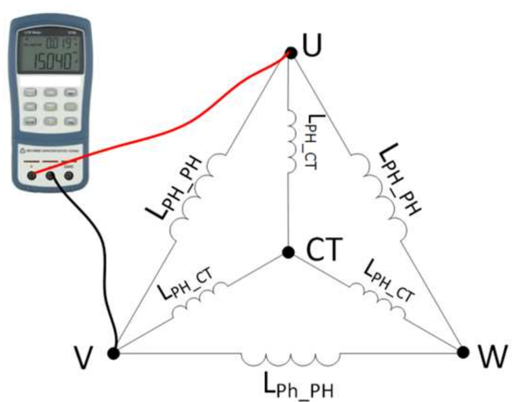

Figure 3. Motor Inductance Measurements

Measure phase-to-phase inductance (L_{PH_PH}) across any 2 phases using an LCR meter (see Figure 3). Note down this value, it is used in a later section.

2.3 Preliminary Check for IPD Algorithm

The following flow chart helps the user make sure that there is sufficient time for motor winding current to reach IPD threshold to reliably detect the rotor position. The minimum time required by the device is 100 µs, and Figure 4 ensures that a motor under test has adequate motor resistance and inductance to support IPD.

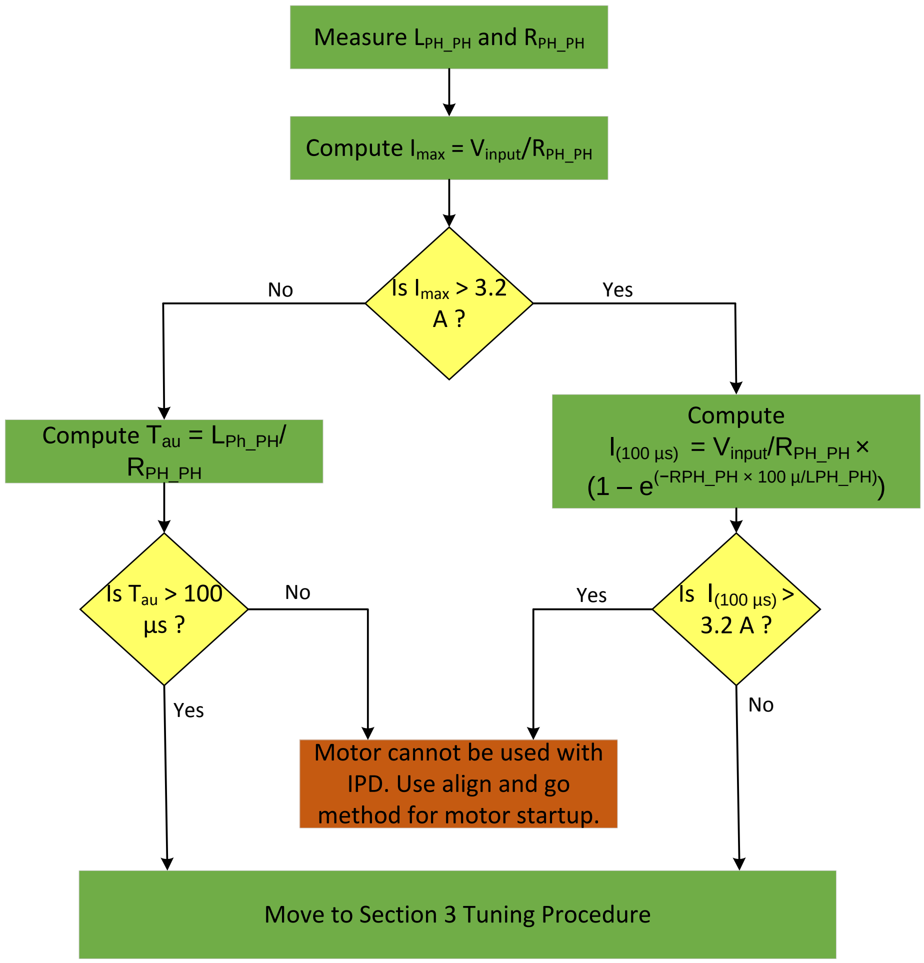

Figure 4. Flowchart for Preliminary Check of Motor for IPD Algorithm Suitability

- Compute max current using Equation 3:

$$I_{max} = V_{input}/R_{PH\_PH} \quad (1)$$

  where:
  - V_{input} is applied voltage in volts
  - R_{PH_PH} is phase-to-phase resistance from Section 2.1
- If I_{max} < 3.2 A, compute T_{au} using Equation 2:

$$T_{au} = L_{PH\_PH}/R_{PH\_PH} \quad (2)$$

  where:
  - T_{au} is electric time constant
  - L_{PH_PH} is phase-to-phase resistance from Section 2.2

  If T_{au} > 100 µs, then move on to the Tuning Procedure section.

  Otherwise, if T_{au} < 100 µs, then motor is not suitable for IPD algorithm (use Align and Go method for startup).

- If computed, I_{max} > 3.2 A, then solve the equation for instantaneous current across motor at time 100 µs ($I_{(100\ \mu s)}$) using Equation 3. See the Appendix for details on Equation 3.

$$I_{(100\ \mu s)} = V_{input} / R_{PH\_PH} \times \left(1 - e^{(-R_{PH\_PH} \times 100\ \mu s / L_{PH\_PH})}\right) \quad (3)$$

where:

- $I_{(100\ \mu s)}$ is instantaneous current flowing through motor winding at time 100 µs

If $I_{(100\ \mu s)}$ < 3.2 A, then move on to Section 3, Tuning Procedure.

Else, if $I_{(100\ \mu s)}$ > 3.2 A, then motor is not suitable for IPD algorithm (use Align and Go method for startup).

NOTE: If motor under test does not pass this criterion, then DRV10983x/75 will not be able to detect the initial position of the motor using IPD, use Align and Go method to drive the motor instead. Section 3, Tuning Procedure is only for motors which pass this criterion.

This check does not guarantee the device can detect initial position IPD, Refer to Section 3, Tuning Procedure for other criteria motor needs to satisfy for IPD algorithm to work. This criterion is used to determine whether resistance and inductance of motor under test is sufficient for IPD to work with DRV10983x/75.

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3 Tuning Procedure

The following steps guide the user to determine whether IPD is suitable for motor under test or not. It also provides guidance to optimize the various parameters used in IPD.

The pre-requirement for the next section is tuned to open loop parameters for motor under test. Refer to the device-specific tuning guide to tune open-loop parameters

Step 1. Move the rotor to a known position by connecting U-phase to DC input and V-phase to ground (see Figure 5). Use a lab power supply for this test and make sure the current amplitude is less than the motor rated current.

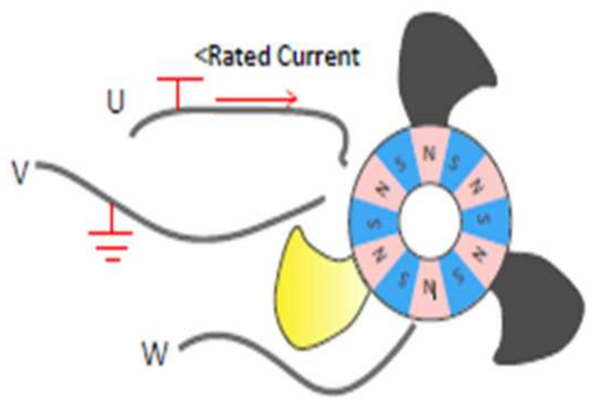

Figure 5. Injecting Current from Phase U to Phase V

Now that the rotor is aligned to a known sector (90 degrees), lock the shaft of motor to this known position either by using clamper or tape (see Figure 6).

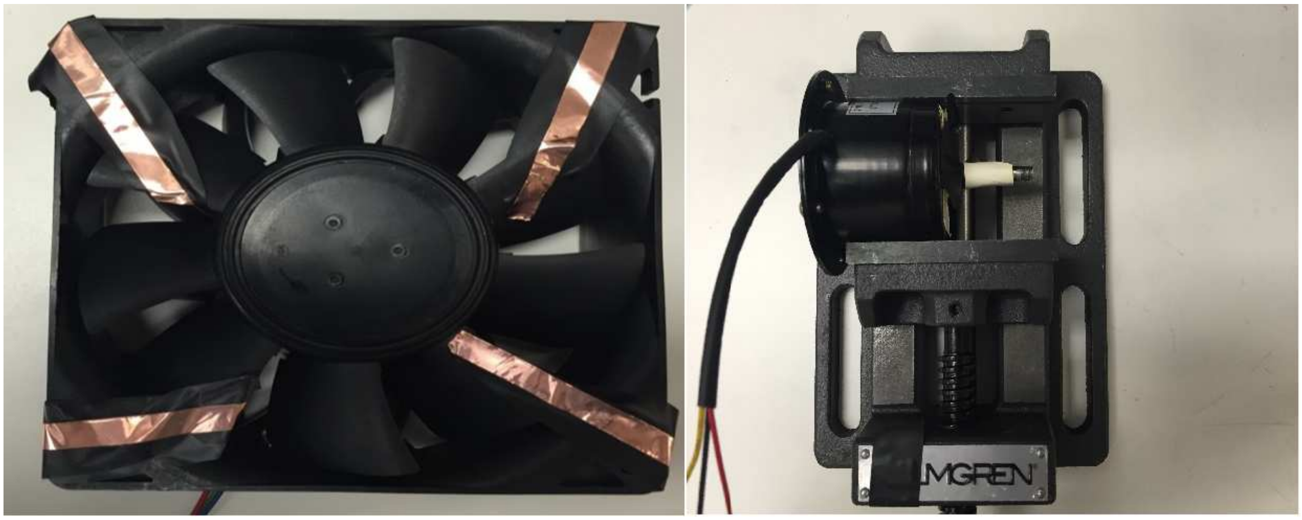

Figure 6. Rotor of Motor Locked to its Position Using Clamp and Insulation Tape

Step 2. Connect the motor to the motor terminal on the EVM. Connect phases U-V-W used during **Step 1 to terminal phase U-V-W on EVM** (U and V are the wires that are connected to power and ground in Figure 5).

Step 3. Turn ON the power to the EVM and launch the GUI. Check box 'Enable IPD' to use IPD (see Figure 7).

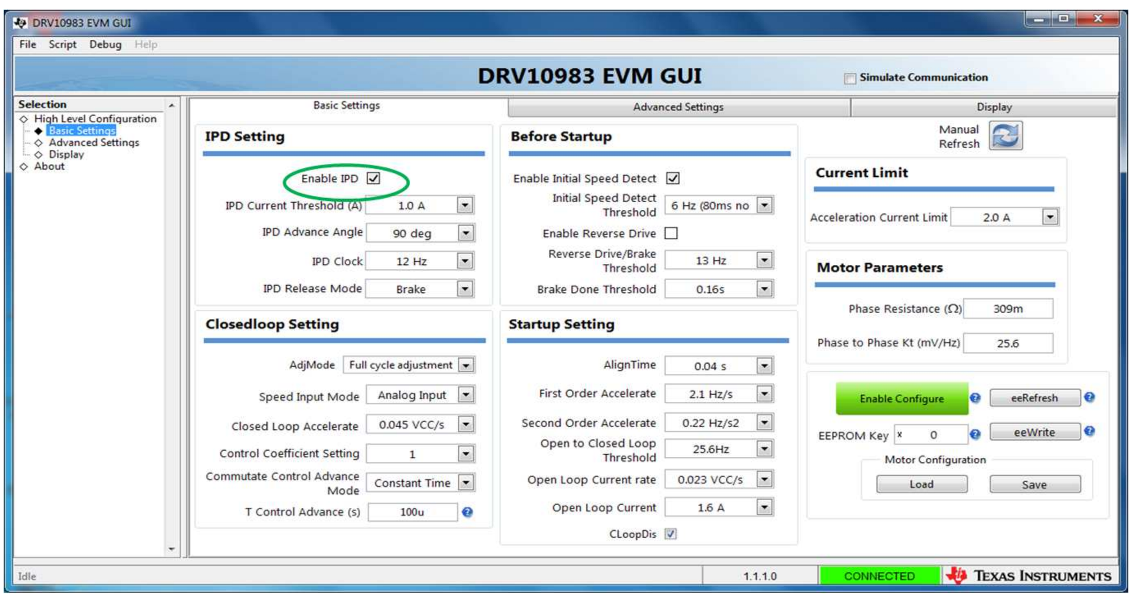

Figure 7. DRV10983x/75 EVM GUI Screenshot

Step 4. Set 'IPD Current Threshold (A)' parameter to rated motor current (see Figure 8). If the rated motor current is not known, then calculate IPD current threshold based on Equation 4.

$$IPD\_Current\_Threshold = 0.6 \times V_{input} / R_{PH\_PH} \quad (4)$$

where:

- R_{PH_PH} is resistance measured from Section 2.1
- V_{input} is input voltage

If Calculated IPD_Current_Threshold > 3.2 A, then select 'IPD Current Threshold' as 3.2 A from the drop-down menu.

NOTE: Guidance for selecting IPD current threshold is only for first iteration.

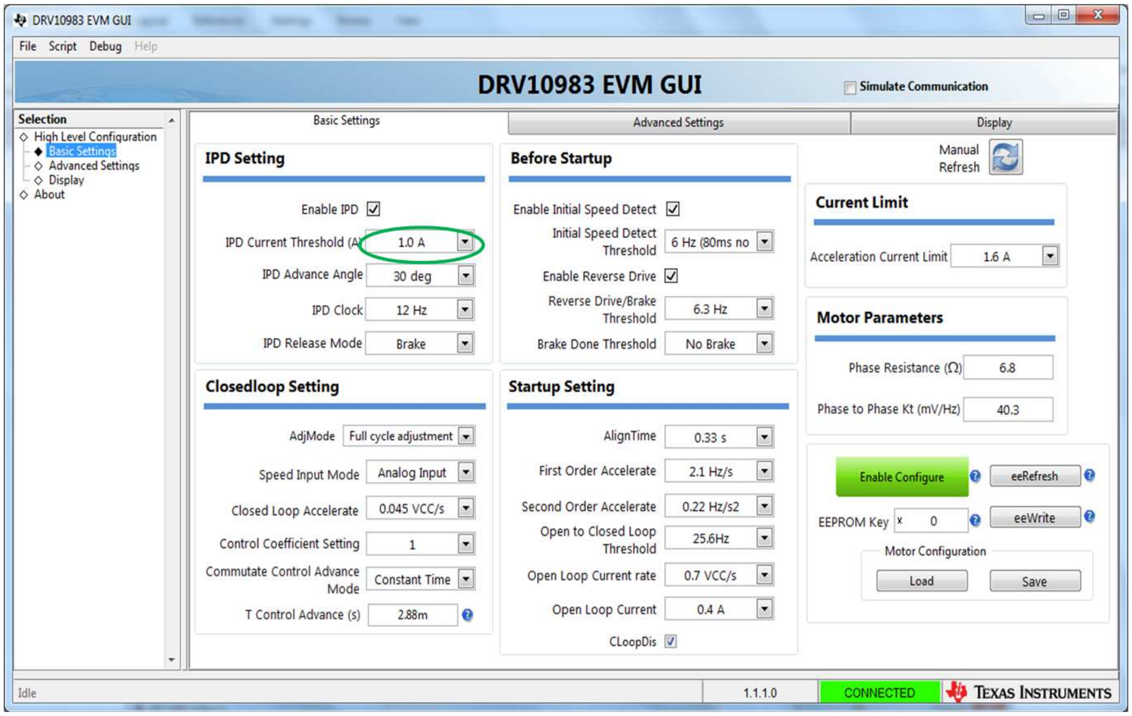

Figure 8. DRV10983x/75 EVM GUI Screenshot

Step 5. Set ‘IPD Advance Angle’ to 30 degrees, ‘IPD clock’ to 12 Hz, and ‘IPD Release Mode’ to brake (see Figure 9).

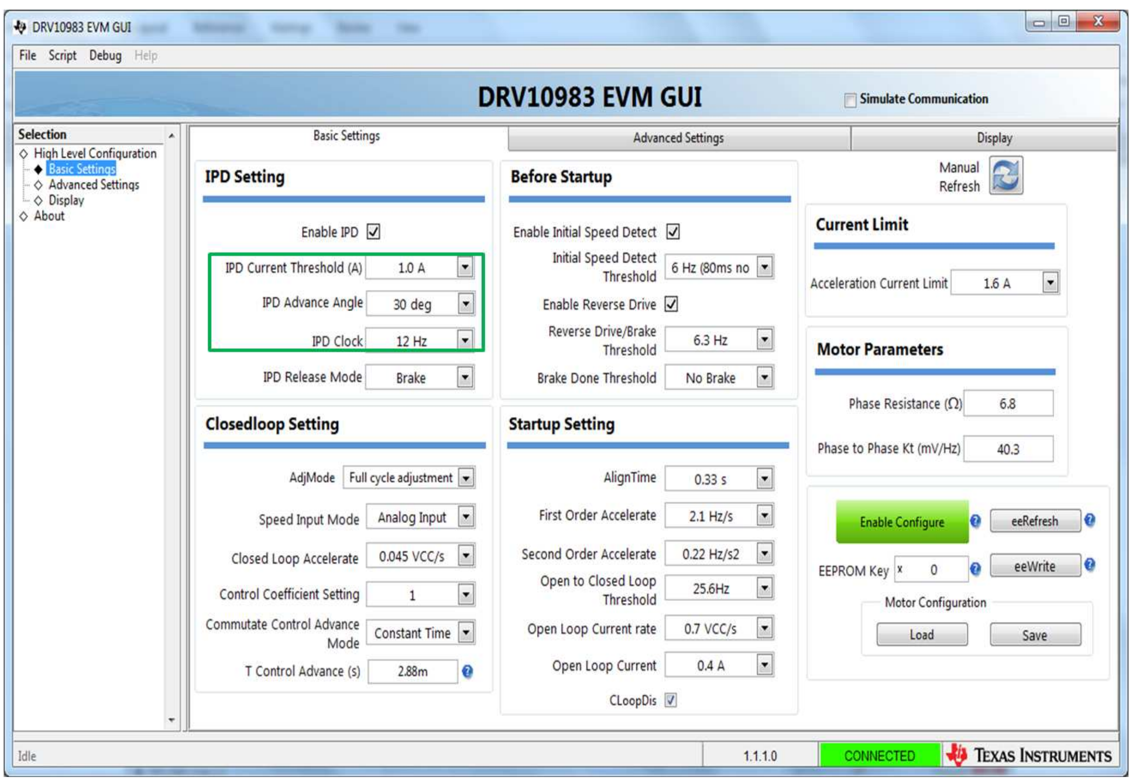

Figure 9. DRV10983x/75 EVM GUI Screenshot

6. During the evaluation of IPD, disable close loop operation of motor by checking box ‘CLoopDis’ (see Figure 10).

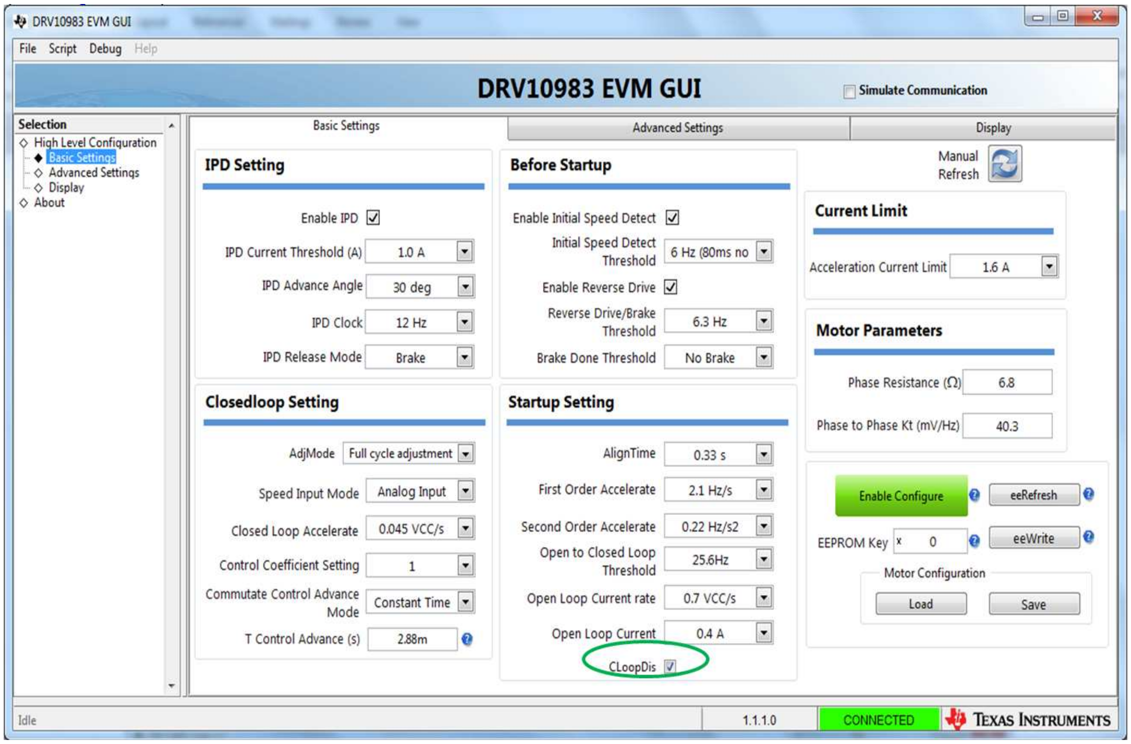

Figure 10. DRV10983x/75 EVM GUI Screenshot

Step 6. Turn ON the motor commutation (either analog or digital). Refer to the tuning guide and data sheet for more details on different methods to turn ON motor commutation. Make sure that motor is locked so that it is not moving or spinning. Monitor phase current on one of the phases and if the current waveform on any of the phases is clipped during IPD process, as shown in Figure 11, decrease ‘IPD Current Threshold’.

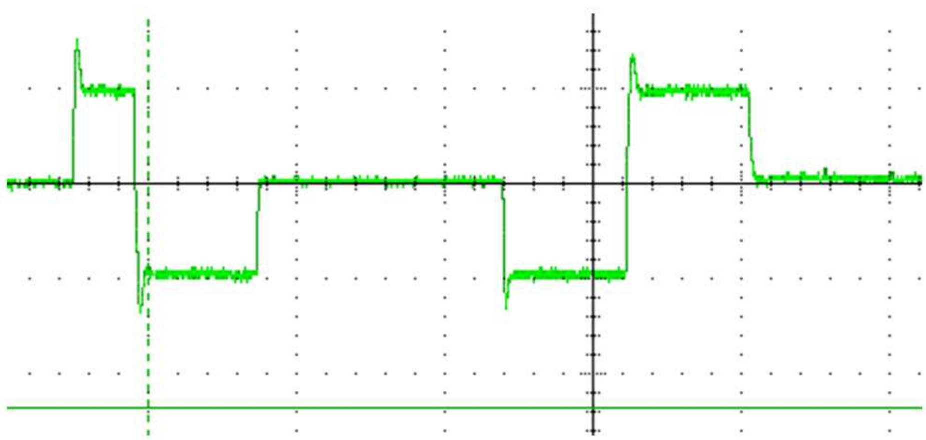

Figure 11. Current Clipping During IPD Process (not Desired)

8. Check IPD position on the 'Display' tab of the GUI (see Figure 12) by clicking the manual refresh button. It should display 60 or 120. If the GUI does not display 60 or 120, then the motor does not have enough inductance variance to be detected by IPD. In this case, the motor is not suitable to work with IPD. (Use Align and Go for initial startup.)

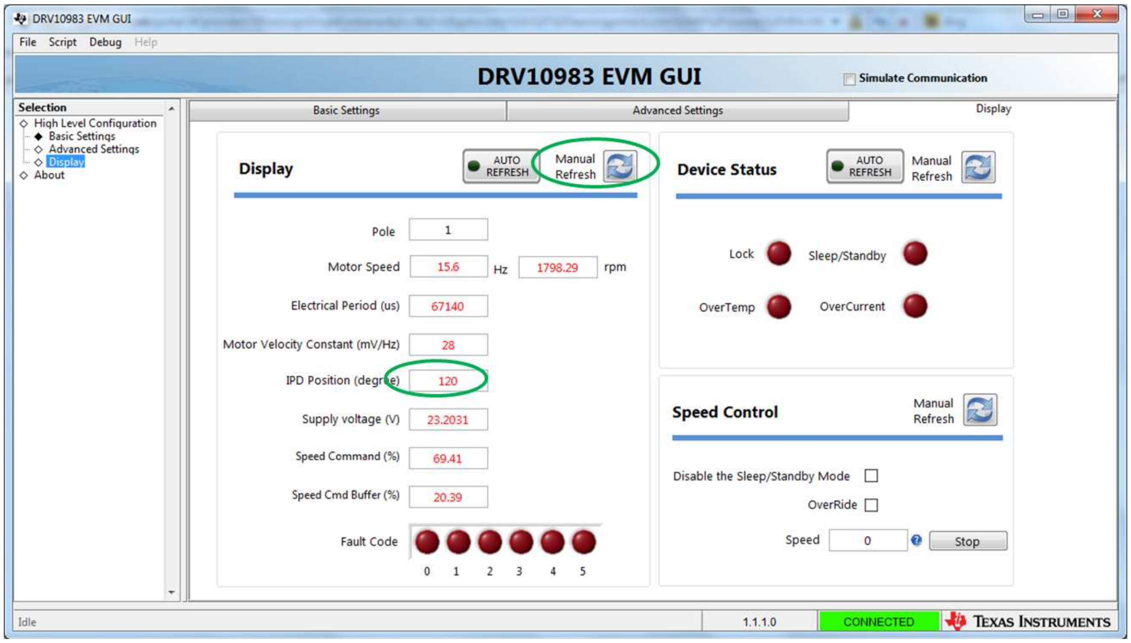

Figure 12. DRV10983x/75 EVM GUI Screenshot

Step 7. Repeat **Step 7** and **Step 8**, 3 to 4 times by turning motor commutation ON/OFF. Check whether IPD position displayed is same (either 60 or 120) every time. After every iteration, turn OFF motor commutation.

Step 8. Unlock the shaft of the motor and turn ON the motor commutation again. Visually check whether the motor is vibrating or has reverse spin during IPD process. If there is no vibration or reverse spin during initial IPD step and motor is spinning in open loop, go to the next step.

If there is unsatisfactory vibration of the motor or reverse spin during IPD stage, decrease 'IPD Current Threshold (A)' to a lower level and repeat **Step 1** through **Step 8**, except **Step 4**. (Since you are setting current threshold manually here onwards, do not follow guidance for calculating current threshold in **Step 4**.) If vibration or reverse spin is even present at a minimum current 0.4 A, then the motor is not suitable to be used with the IPD algorithm. (Use Align and Go for initial startup.)

Step 9. Selection of 'IPD release mode' - brake or tristate There are two options available to stop DRV10983x/75 from driving voltage applied to the motor when the current threshold is reached. If IPDRlsMd = 0, **Brake** mode is selected. The low-side (S6) MOSFET remains on to allow the current to recirculate between the MOSFET (S6) and body diode (S2) (see Figure 13). If IPDRlsMd = 1, the **tri-state** mode is selected. Both the high-side (S1) and low-side (S6) MOSFETs are turned OFF and the current flies back across the body diodes into the power supply (see Figure 14). The tri-state mode has a faster settle-down time, but could result in a surge on VCC. Manage this with appropriate selection of either a clamp circuit or by providing sufficient capacitance between VCC and GND. If the voltage surge cannot be contained and if it is unacceptable for the application, then select **Brake** mode.

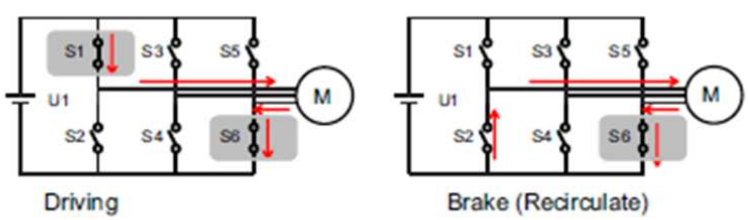

Figure 13. IPD Release Mode 0 – Brake Mode

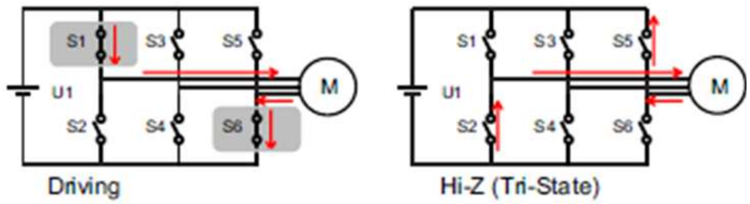

Figure 14. IPD Release Mode 1 – Tri-State Mode

Release mode for IPD can also be changed using 'IPD Release Mode' option in GUI (see Figure 15).

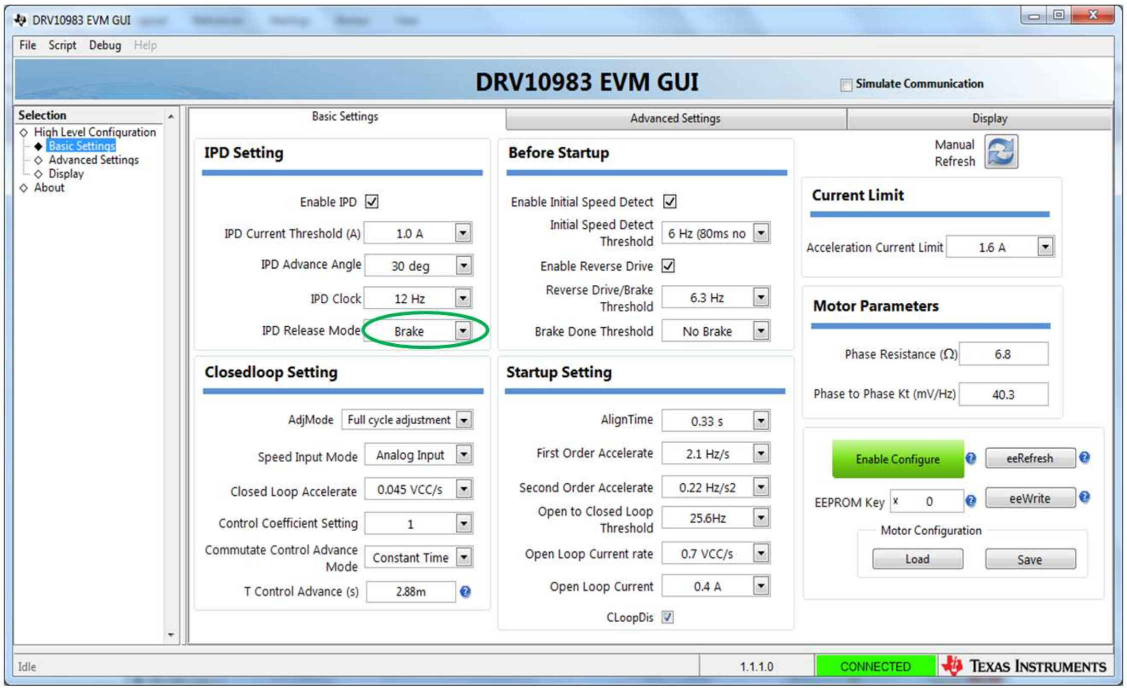

Figure 15. DRV10983x/75 EVM GUI Screenshot

The following waveform shows the difference between brake and tristate release mode in IPD. As seen in Figure 16, Tristate mode is faster compared to Brake mode. Figure 16 shows current waveform on one of the motor phases during IPD process.

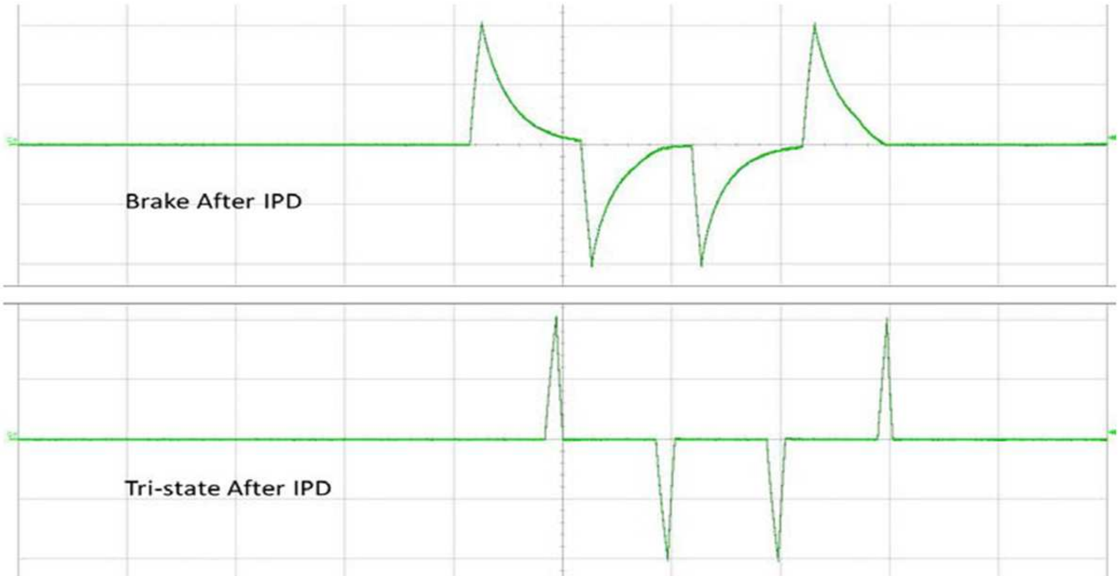

Figure 16. Brake Versus Tri-State After IPD

Step 10. Selection of IPD advance angle After the initial position is detected, the DRV10983x/75 begins driving the motor at an angle specified by IPDAdvcAgl[1:0]. Advancing the drive angle anywhere from 0° to 180° results in positive torque. IPD advance angle of 90° results in maximum initial torque. Applying maximum initial torque could result in uneven acceleration to the rotor. Select IPDAdvcAgl[1:0] to allow for smooth acceleration in the application (see Figure 17).

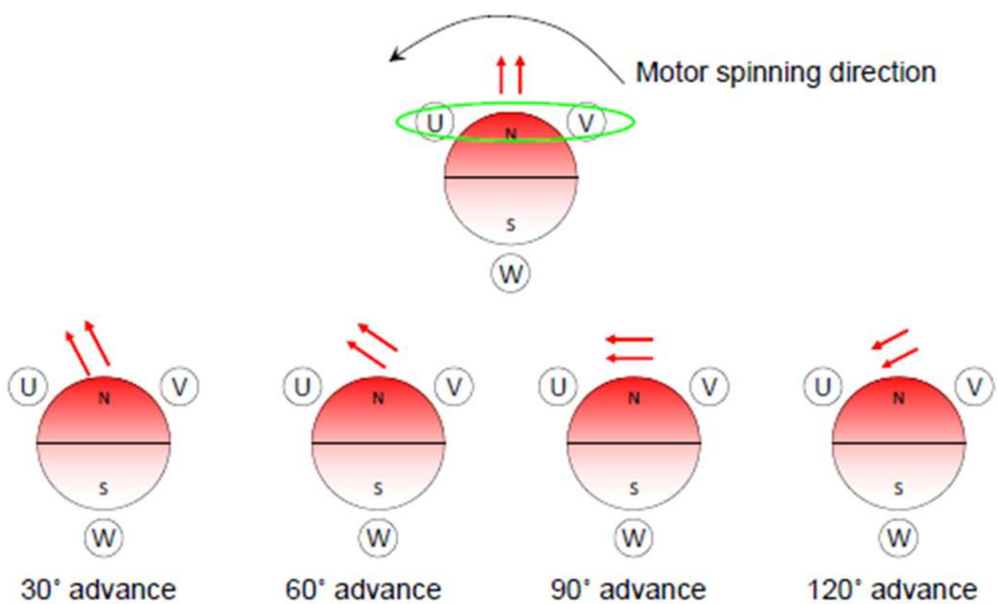

Figure 17. IPD Advance Angle

IPD Advance angle can be selected using ‘IPD Advance Angle’ option in GUI (see Figure 18).

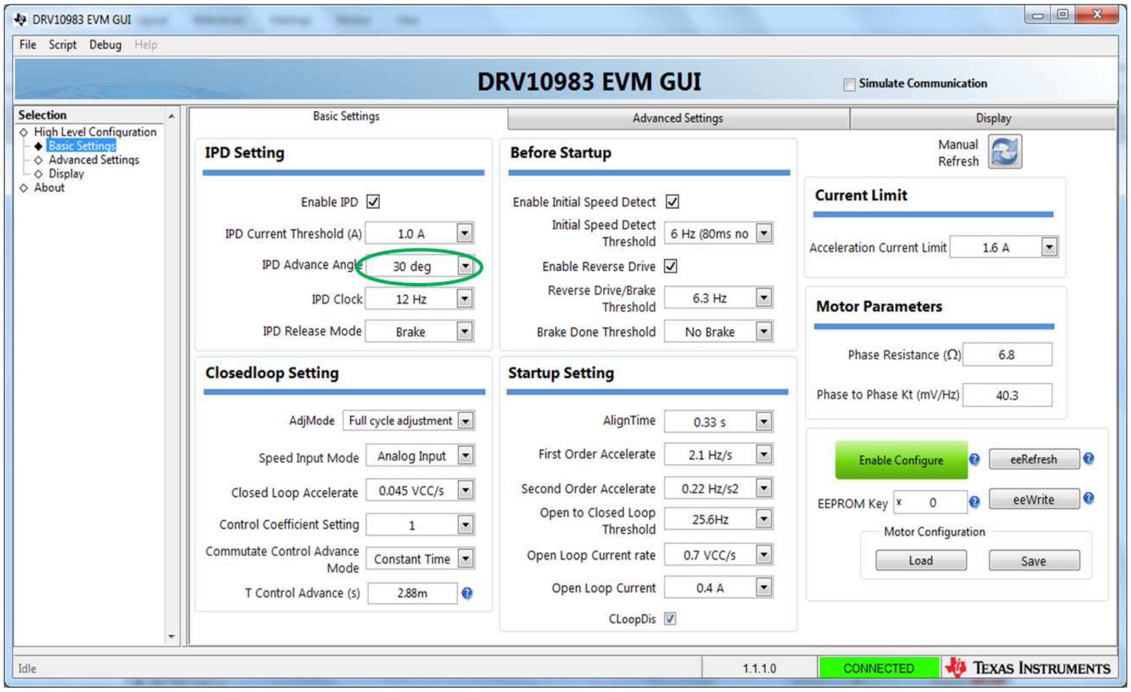

Figure 18. DRV10983x/75 EVM GUI Screenshot

Step 11. Optimization of parameter ‘IPD Clock’ IPD clock defines how fast the IPD pulses are applied. Motor with high inductance and high current thresholds need a longer time to settle the current down, so we need set the clock at a lower frequency. However, a slower clock makes IPD noise louder and current pulses lasts longer. We recommend setting the higher IPD clock frequency as long as IPD current is able to settle down completely. Also, When IPD clock is set to higher frequency, IPD will complete faster, and startup time will decrease.

Monitor current on one of the phases (U, V or W) using current probe and check current pulses on phase current during the IPD process. If there is large time gap between current pulses (see Figure 19), increase frequency of IPD clock. If current pulses overlap, decrease the IPD clock (see Figure 20). Figure 21 shows optimized current waveform during IPD process.

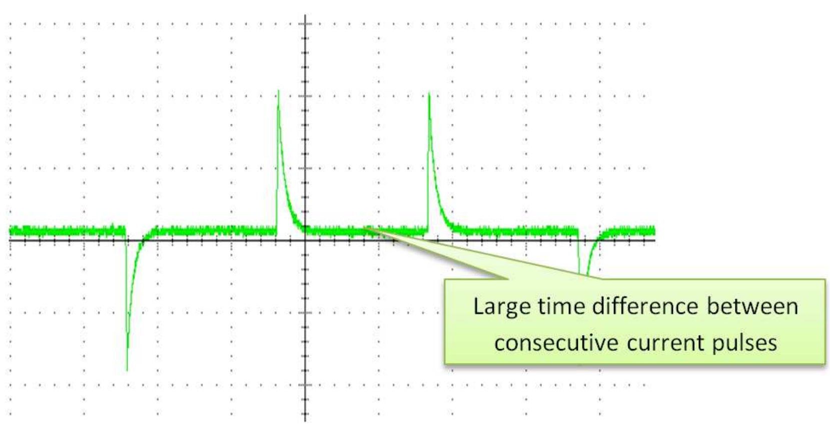

Figure 19. Current Waveform During IPD Process With Low ‘IPD Clock’ Frequency

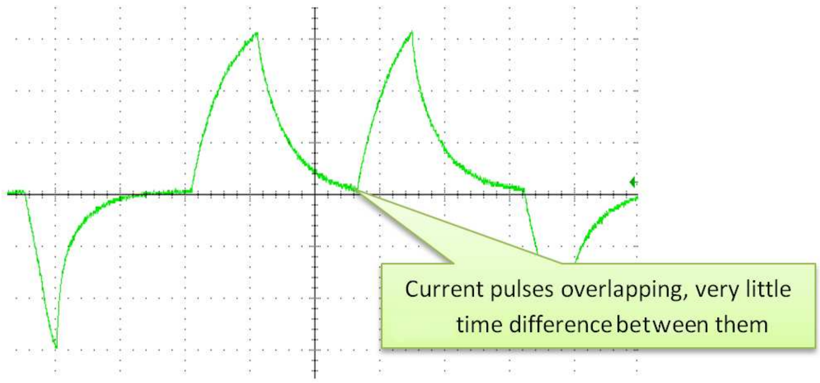

Figure 20. Current Waveform During IPD Process With High 'IPD Clock' Frequency

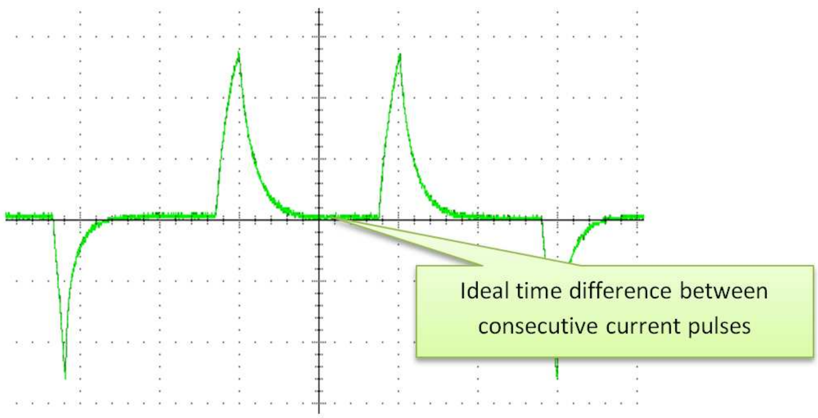

Figure 21. Current Waveform During IPD Process With Optimized 'IPD Clock' Frequency

IPD Clock can be changed using 'IPD Clock' option in GUI (see Figure 22).

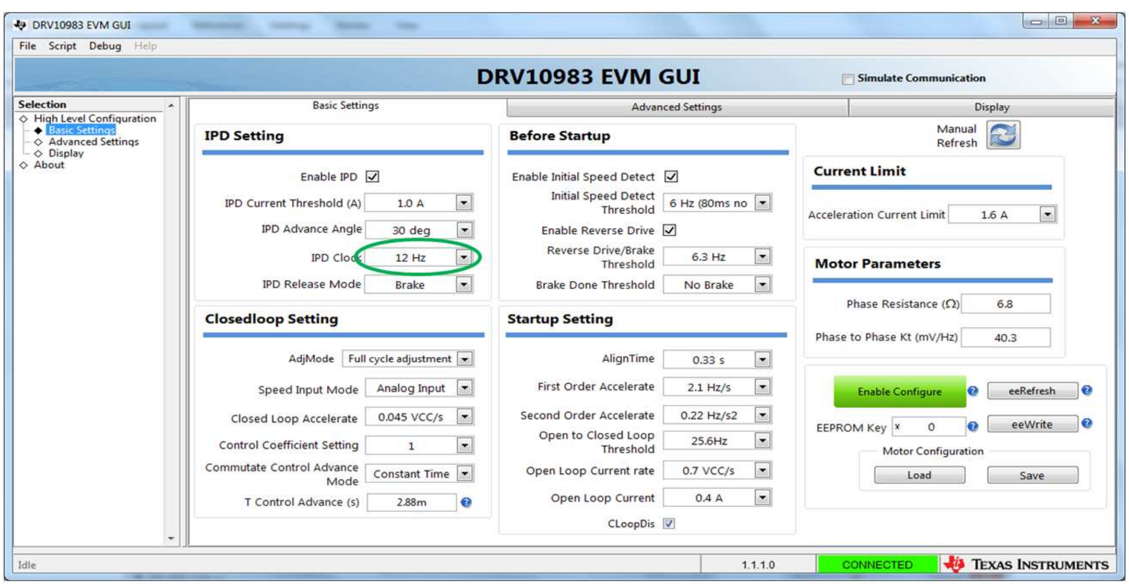

Figure 22. DRV10983x/75 EVM GUI Screenshot

A.1 Explanation for Equation 3

Motor has series inductance and resistance on each winding (see Figure 23). Hence, it forms series LR circuit. When step voltage is applied across series LR circuit, current rises as shown in Figure 24. The equation for instantaneous current for series LR circuit is given as $I = V / R \times \left(1 - e^{(-R_t/L)}\right)$.

Since minimum time required detecting inductance variation by DRV10983x/75 is 100 µs, instantaneous current across LR circuit at time 100 µs is calculated in Equation 3.

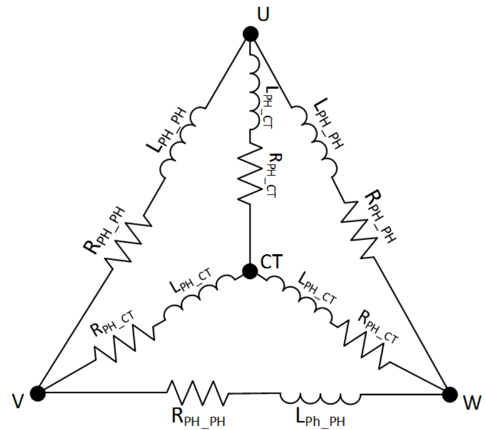

Figure 23. Motor Windings With Series Phase Resistance and Phase Inductance

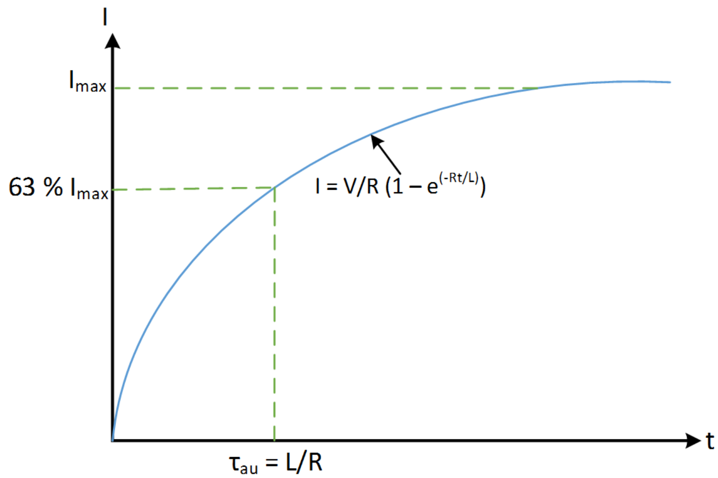

Figure 24. Step Response of Series LR Circuit

A.2 IPD Algorithm Validation for 2 Sample Motor

A.2.1 Example 1: Motor 1

Motor Resistance (Phase to Phase) R_{PH_PH}: 0.650 Ω

Motor Inductance (Phase to Phase) L_{PH_PH}: 200 µH

Applied Voltage V_{input} = 12 V

Using Equation 1:

Imax = V_{input}/R_{PH_PH}
Imax = 12/0.650 = 18.46 A
Imax > 3.2 A, so using Equation 3

$$I_{(100\ \mu s)} = V_{input} / R_{PH\_PH} \times \left(1 - e^{(-R_{PH\_PH} \times 100\ \mu s / L_{PH\_PH})}\right)$$

$$I_{(100\ \mu s)} = 12 / 0.65 \times \left(1 - e^{(-0.65 \times 100\ \mu s / 200\ \mu s)}\right)$$

I(100 µs) = 5.13 A,
I(100 µs) > 3.2 A; since motor 1 will reach maximum current of 3.2 A before 100 µs, DRV10983x does not have enough resolution to detect initial position using IPD. Therefore, motor 1 is not suitable for IPD algorithm.

A.2.2 Example 2: Calculation and Tuning example for Motor 2:

Motor Resistance (Phase to Phase) R_{PH_PH}: 13.5 Ω

Motor Inductance (Phase to Phase) L_{PH_PH}: 2 mH

Applied Voltage V_{input} = 24 V

Imax = V_{input}/R_{PH_PH}

Imax = 24/13.5 = 1.77 A

Imax < 3.2 A, so using Equation 2,

Tau = L_{PH_PH}/R_{PH_PH}
Tau = 2 m / 13.5 = 148 µs
Tau > 148 µs, so moving on to tuning procedure as described in Section 3, Tuning Procedure

Pre Requirement: Tune Motor according to tuning guide

1. Align motor by connecting external power supply to phase U (+ve terminal) and phase V (ground). Once the motor is aligned, lock it using tape (see Figure 25). Connect U-V-W phase of motor to U-V-W of EVM

Figure 25. Align and Lock Shaft of Motor

2. Set current threshold to 1 A, based on Equation 4 and other IPD related parameters as shown in Figure 26. Also disable close-loop operation.

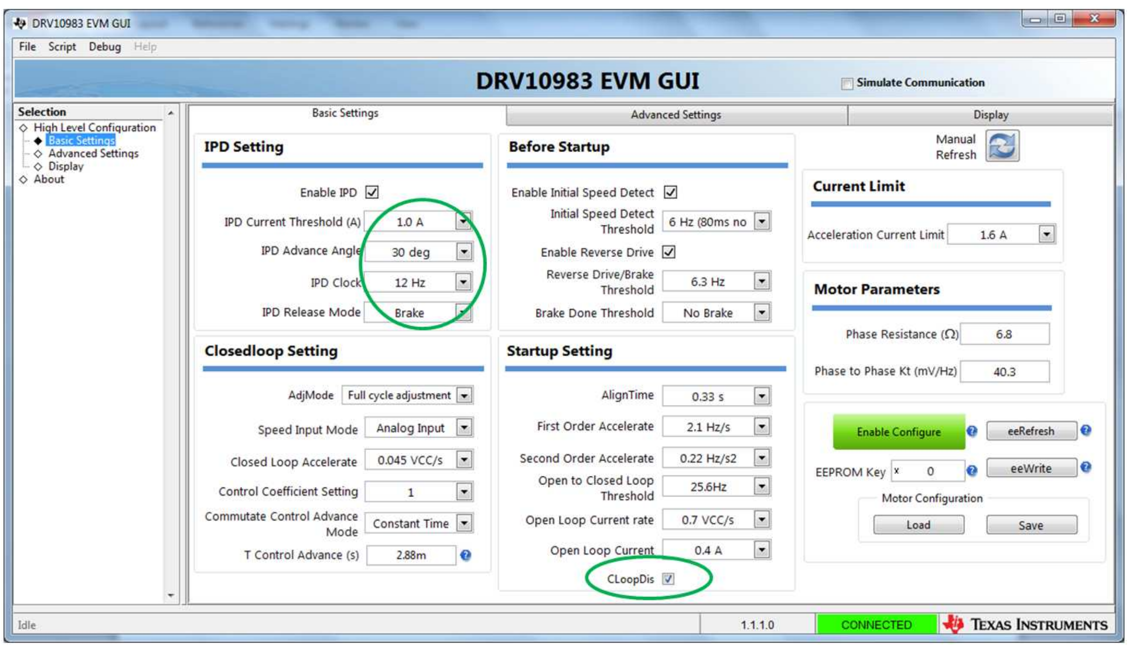

Figure 26. DRV10983x/75 EVM GUI Screenshot

3. Check current waveform and make sure it does not clip. As seen in Figure 27, current does not clip and it looks like pulses.

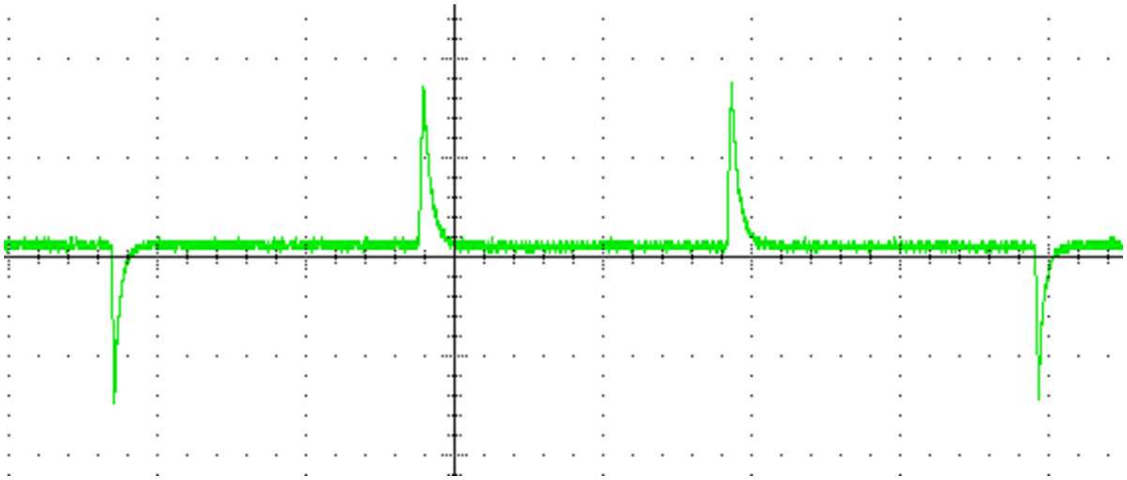

Figure 27. Motor Phase Current During IPD Process

4. Turn ON motor commutation and check IPD position in display tab by pressing manual refresh. 'IPD Position (degree)' shows 60 (see Figure 28). Now turn OFF commutation.

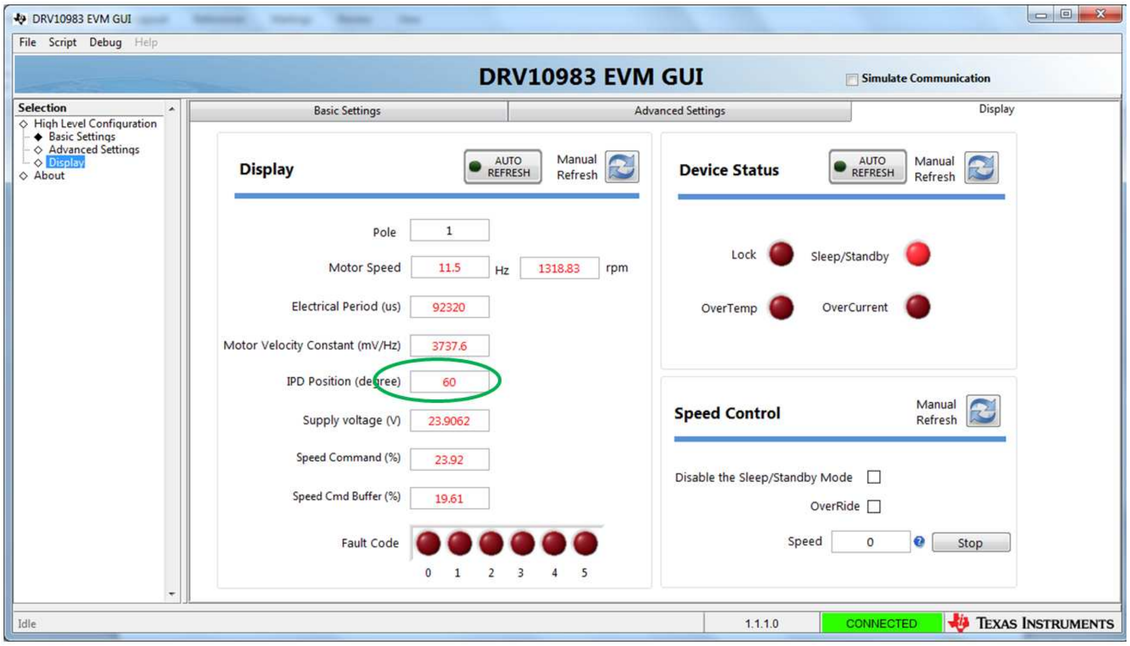

Figure 28. DRV10983x/75 EVM GUI Screenshot

5. Repeat previous step 3- 4 times, every time same value (either 60 or 120) for 'IPD Position (degree)' is displayed.

6. Unlock motor and turn ON motor commutation. When motor was going through IPD process during initial startup, visually there was little vibration, so IPD current threshold is reduce to 0.8 A (see Figure 29).

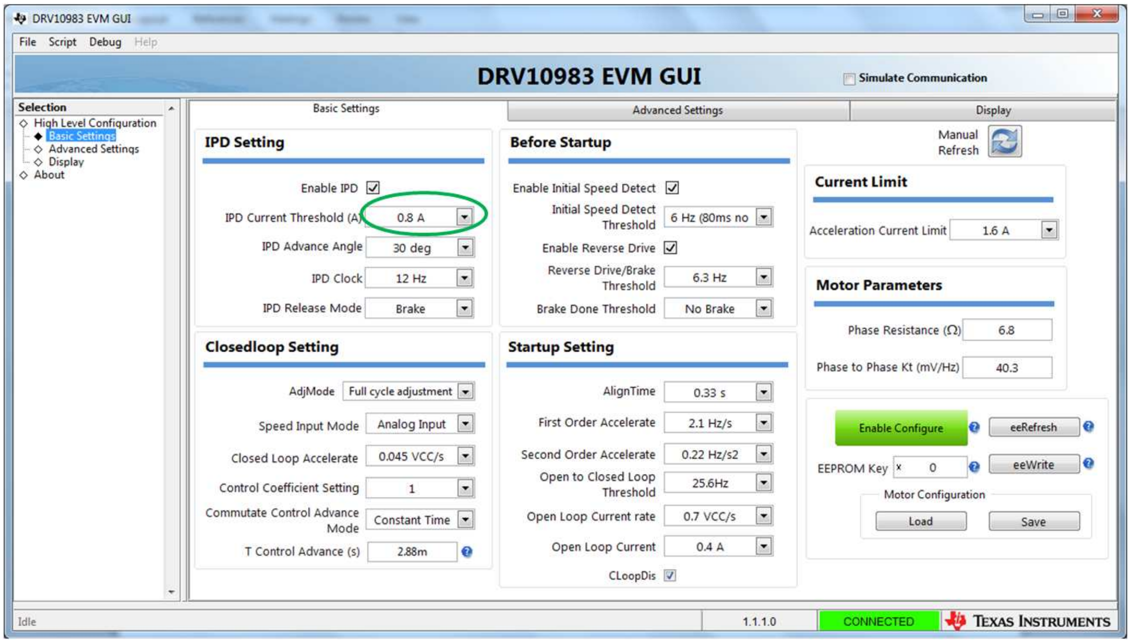

Figure 29. DRV10983x/75 EVM GUI Screenshot

7. Motor is aligned and locked again as described in 1. Motor commutation is turned ON while motor is locked. Check 'IPD position (degree)' in display tab and again it displays 60 or 120 (see Figure 30). After checking display, turn OFF motor commutation.

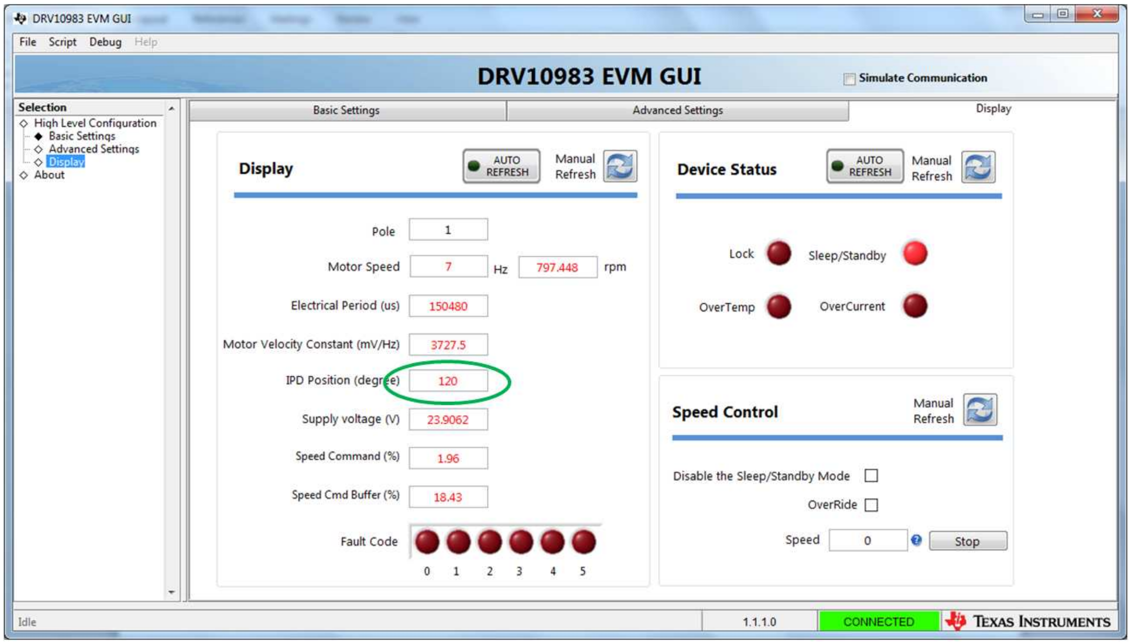

Figure 30. DRV10983x/75 EVM GUI Screenshot

8. Repeat previous step 3 to 4 times, every time same value (either 60 or 120) for ‘IPD Position (degree)’ is displayed.
9. Unlock motor and turn ON commutation again. Motor should be spinning in open loop now. Visually there was less vibration this time during the IPD process; therefore, move on to the next step.
10. IPD release mode - change IPD release mode using GUI (see Figure 31). Monitor phase current while evaluating Brake or Tristate mode. Turn ON motor in brake mode and capture phase current during IPD process, then turn OFF motor (see Figure 33). Change IPD release mode to tristate mode and repeat same process for this mode (see Figure 34).

    Since there is no protection against VCC surge in the hardware, Brake mode is selected for the application.

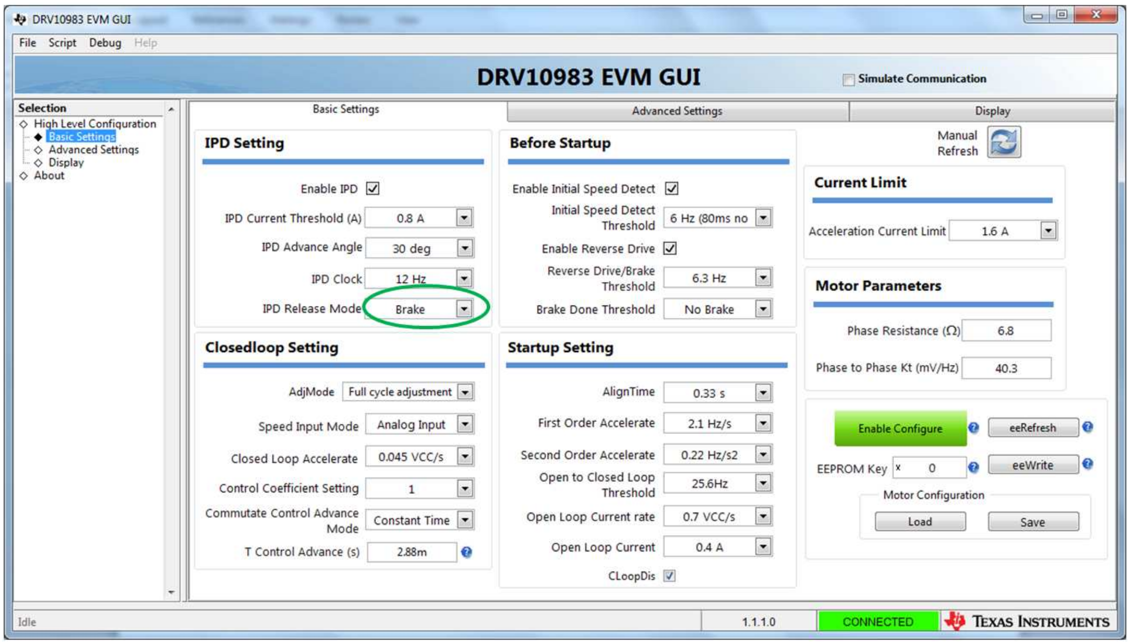

Figure 31. DRV10983x/75 EVM GUI Screenshot

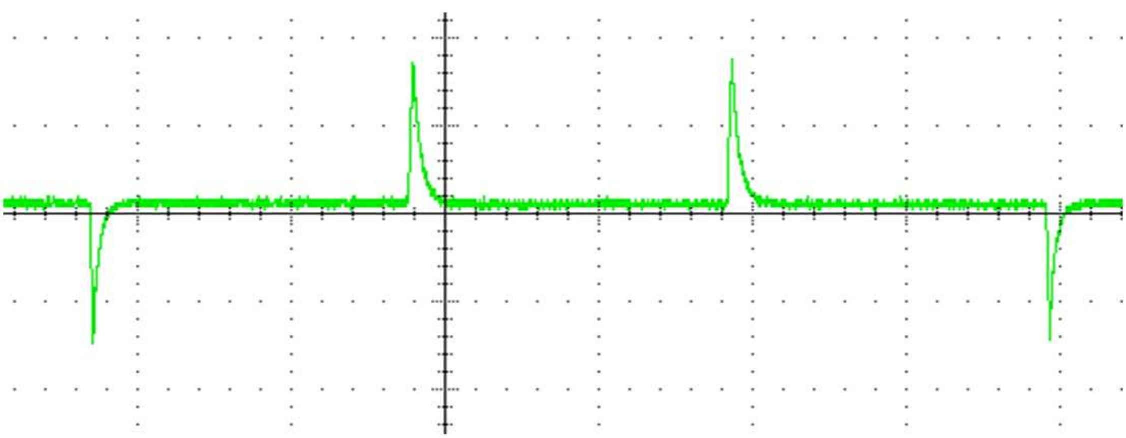

Figure 32. Motor Phase Current During Brake Mode

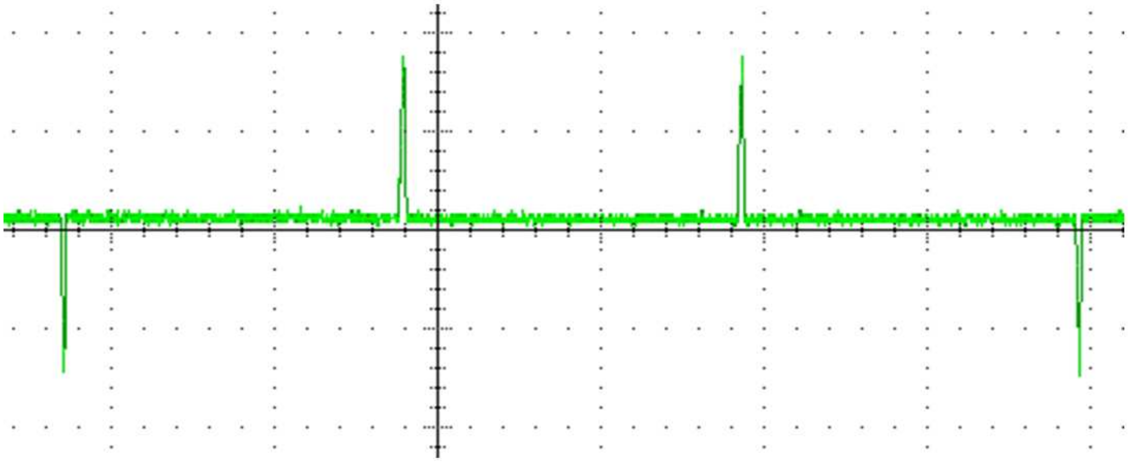

Figure 33. Motor Phase Current During Tristate Mode

11. IPD advance angle – selecting 90 degrees (see Figure 34) to achieve maximum torque during startup. Turn ON the motor commutation and spin motor in open loop. Visually make sure motor is spinning appropriately.

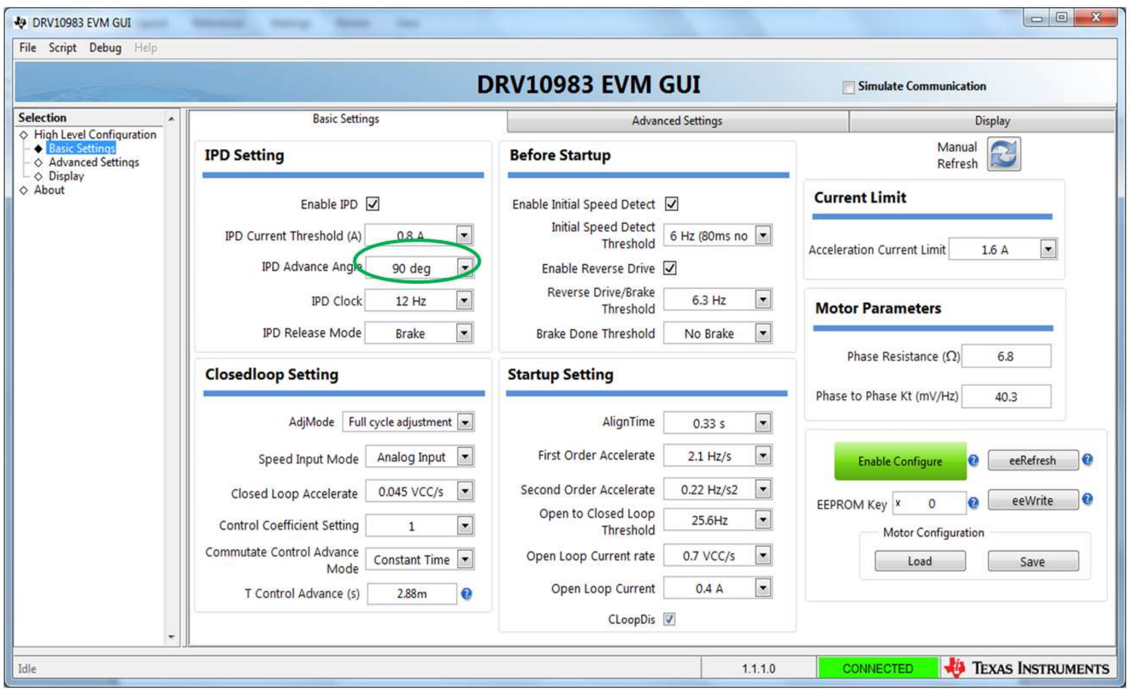

Figure 34. DRV10983x/75 EVM GUI Screenshot

12. IPD clock selection:

Turn ON motor commutation and capture phase current during IPD process for 12 Hz of IPD clock and then turn OFF motor (see Figure 35).

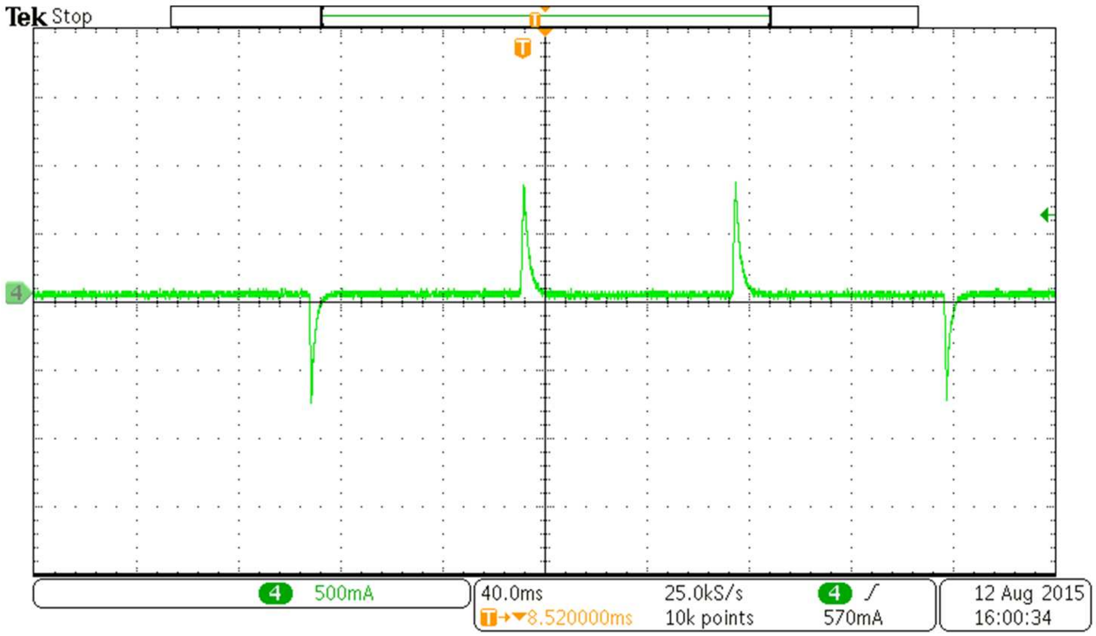

Figure 35. Motor Phase Current With 12-Hz IPD Clock

As seen in Figure 35 there is sufficient time difference between current pulses. Increase IPD clock frequency to next level – 24 Hz (see Figure 36). **Note: Time scale is different for** Figure 35, Figure 37, Figure 39, Figure 41.

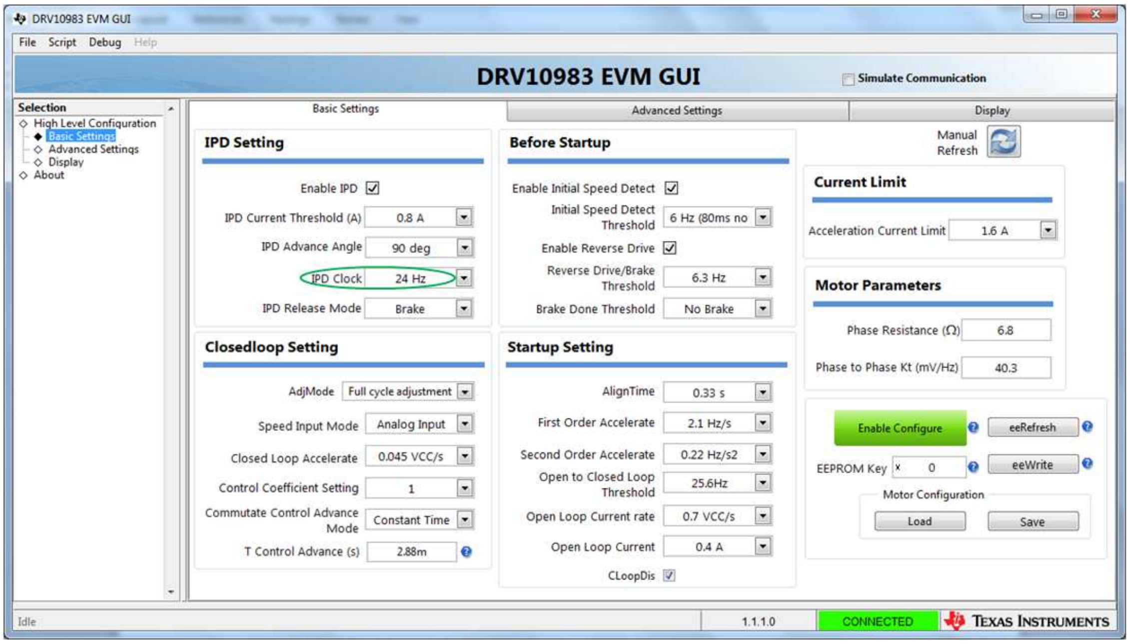

Figure 36. DRV10983x/75 EVM GUI Screenshot

Turn ON motor commutation and capture phase current during IPD process for 24 Hz of IPD clock and then turn OFF motor (see Figure 37).

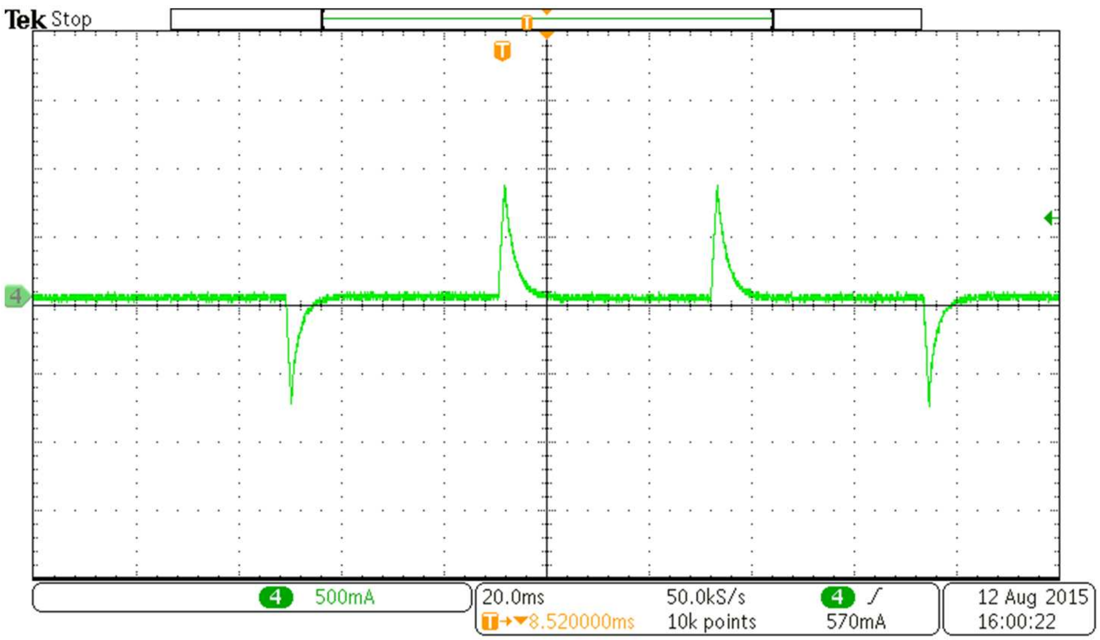

Figure 37. Motor Phase Current With 24-Hz IPD Clock

As seen in Figure 37 there is sufficient time difference between current pulses. Increase IPD clock frequency to the next level – 47 Hz (see Figure 38).

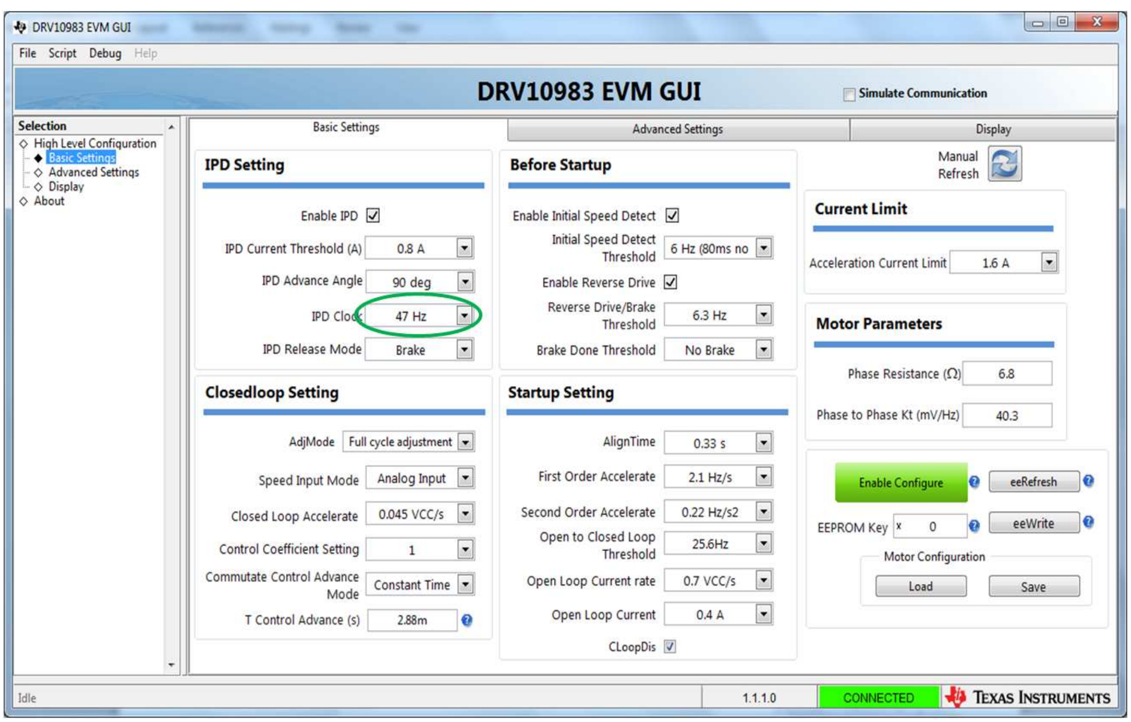

Figure 38. DRV10983x/75 EVM GUI Screenshot

Turn ON motor commutation and capture phase current during IPD process for 47 Hz of IPD clock and then turn OFF motor (see Figure 39).

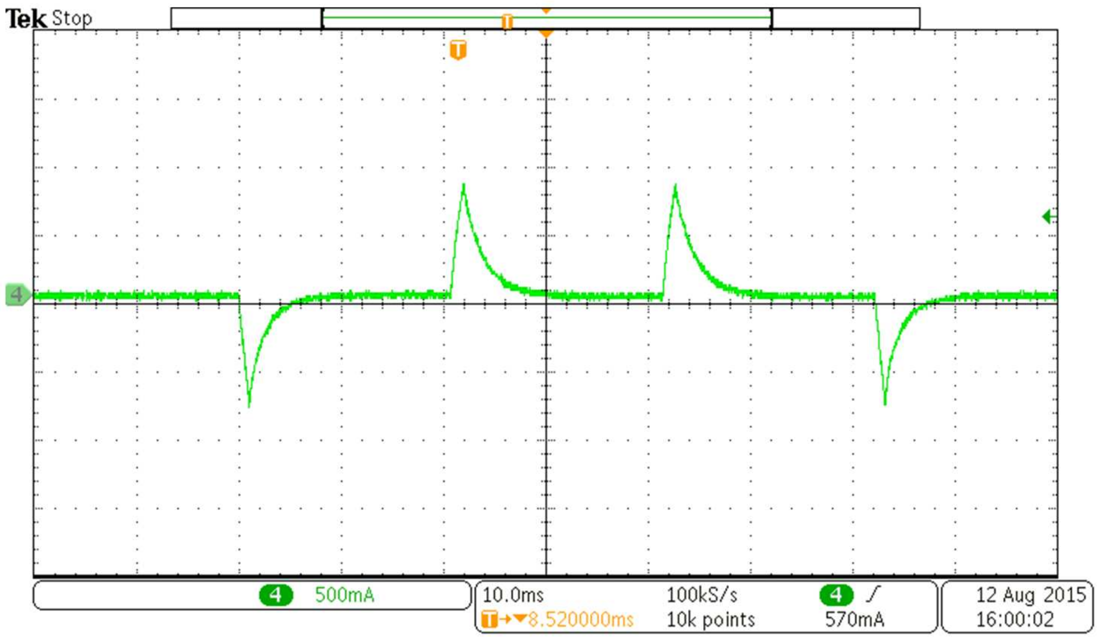

Figure 39. Motor Phase Current With 47-Hz IPD Clock

As seen in Figure 39 there is sufficient time difference between current pulses. Increase IPD clock frequency to next level – 95 Hz (see Figure 40).

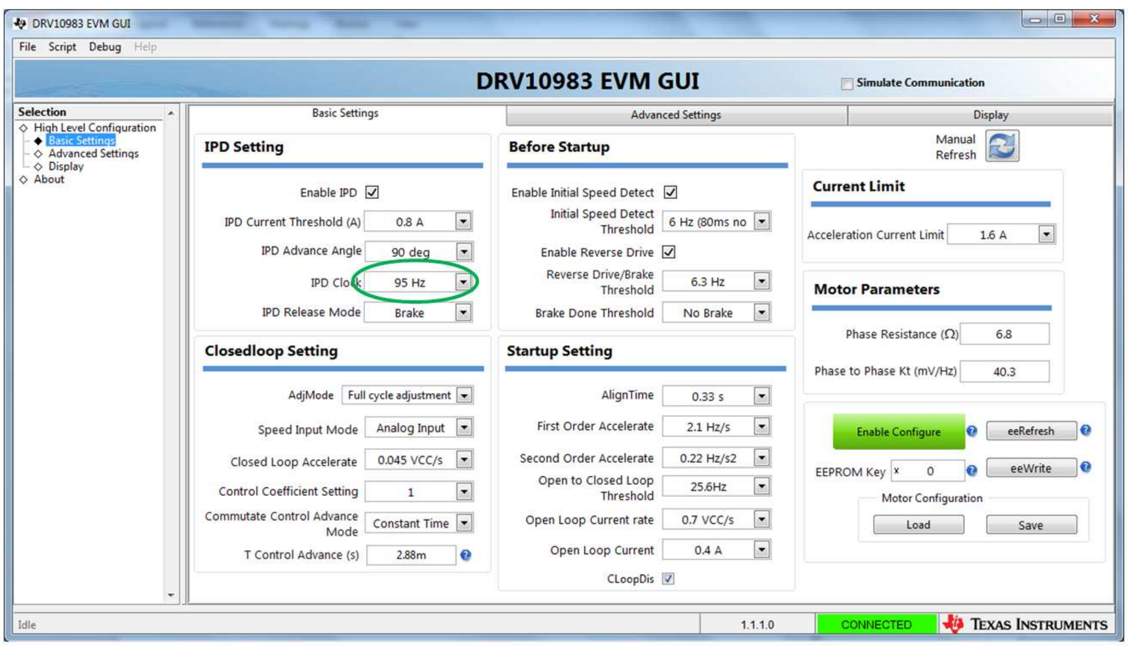

Figure 40. DRV10983x/75 EVM GUI Screenshot

Turn ON motor commutation and capture phase current during IPD process for 47 Hz of IPD clock and then turn OFF motor (see Figure 41).

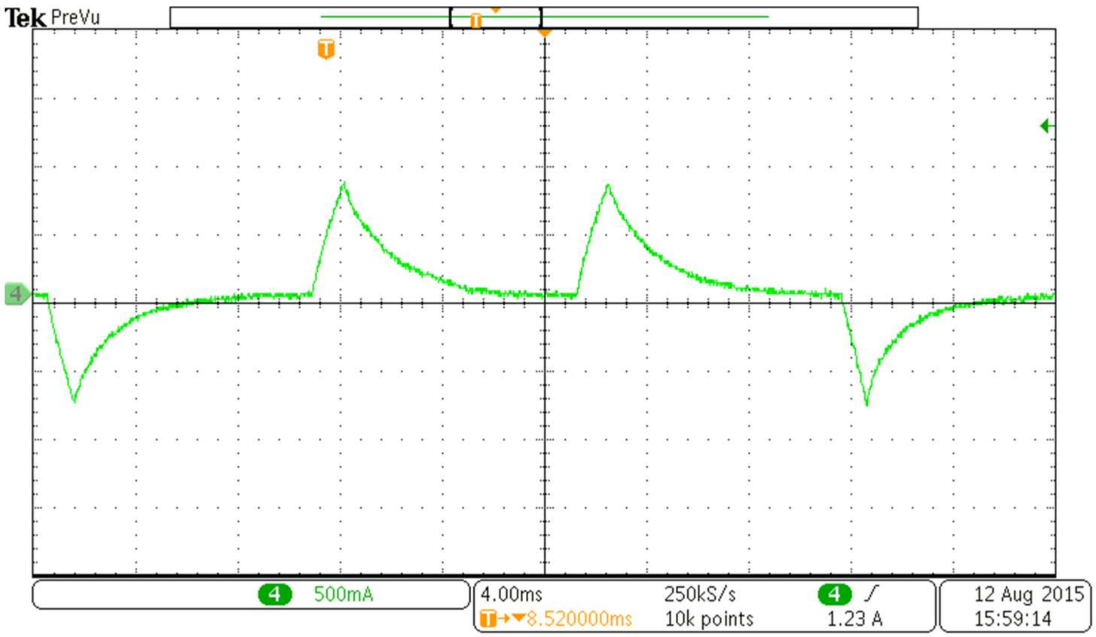

Figure 41. Motor Phase Current With 95-Hz IPD Clock

As seen in Figure 41, the time difference between consecutive current pulses is optimized and it will result in smallest open loop startup time.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (September 2015) to A Revision **Page**

- Changed title. 1
- Globally changed DRV10983 to DRV10983x, and added DRV10975x, and DRV10987.......... 1
- Added to the list of supported devices.......... 1
- Deleted bit 3 setting of the SysOpt1 register (0x23) from the first paragraph of the *Introduction*. 1
- Changed first sentence of the second paragraph of the *Introduction*. 1
- Changed first paragraph of *Preliminary Check for IPD Algorithm*.......... 4

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