

How to Use iMOTION™ Script Language

About this document

Scope and purpose

This application note provides a guideline for using the iMOTION™ script language on Motion Control Engine (MCE) platform with typical script examples covering the implementation of Low-Pass Filter (LPF), 2-level speed selection interface, motor target speed shaping based on DC bus voltage with brown-out protection, and dynamic motor current limit customization.

Intended audience

This document is intended for customers who would like to understand how to use the iMOTION™ script language to realize customization of system start-up behavior, specific speed profile definition, as well as system specific fault handling definition.

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Script Language Overview

1 Script Language Overview

1.1 Introduction

The latest software release of iMOTION™ MCE includes a script engine, offering users the possibility to customize system level functionalities without affecting the motor and PFC control algorithm. The script engine is a light weight virtual machine that supports reading and writing all the motor control and PFC parameters and variables, allowing users to take advantage of the analog and digital resources that are not used by motor and / or PFC control, and is scalable for any functional extension in future. Typical script use cases include customization of system start-up behavior, specific speed profile definition and parameter configuration, as well as fault handling.

- The CPU resource is prioritized for the execution of the motor and PFC control algorithms. The spare CPU resource is used for the execution of background tasks as well as the script engine which is used to drive the execution of the script code. The priority of the execution of the script code is lower than that of the motor and PFC control algorithm execution, so that it won't affect the performance of the control algorithms. It is highly recommended to check actual CPU load during the run time to ensure the CPU resource is allocated appropriately.
- The script engine supports 2 independent tasks, namely, Task 0 and Task 1, running concurrently. The user script program runs repeatedly on a configurable interval within Task 0 or Task 1 loop. The shortest possible execution period is 1 ms for Task 0, and 10 ms for Task 1. The execution period for each task can be configured to the multiples of 1 ms for Task 0 or 10 ms for Task 1 in the script code. Task 0 has higher priority than Task 1.
- iMOTION™ script language is a type of interpreted language, for which its implementation compiles a script program into pseudo code (bytecode) first, and then executes instructions directly by a virtual machine running on MCE.

1.2 Script Development Workflow

The typical workflow of script program development starts from using MCEWizard [4] (or any other text editors) to write script code and save as script input file with '.mcs' suffix. MCEWizard is used to configure available Analog-to-Digital Converter (ADC) or General-Purpose-Input-Output (GPIO) pins if needed, and MCEWizard is also used to compile the script code to generate a script object file with '.ldf' suffix. The ldf file contains information about the total number of script instructions for Task 0 and Task 1, as well as a list of global variables defined in the script code. Then MCEDesigner [3] is used to download the ldf file to the target MCE, and it also supports monitoring the values of global variables used in the script program. More details about the script language and its development can be found in [2].

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2 Script Application Examples

2.1 2-Level Speed Selection Interface

2.1.1 Speed Selection Interface Requirement

A multi-level speed selection interface to support different speed levels selected by users is commonly seen in motor control applications such as hair-dryers. This example detailizes the requirement and script implementation of a 2-level speed selection interface using one of the available ADC pins on IMC101T [1] controller from iMOTION™ MCE series.

Some hardware circuits were designed to translate the position of the speed selection mechanical switch into a corresponding analog voltage level between 0 V and 5 V. Specifically, the voltage range from 0 V to 1 V was defined as OFF state, the voltage range from 1 V to 2 V was defined as LOW SPEED state, and the voltage range from 2 V and above was defined as HIGH SPEED. In order to eliminate potential oscillation when the voltage level is in the vicinity of the boundaries of different speed states, a hysteresis of 0.2 V was introduced.

This application requires an analog voltage sensing interface to sample and translate the analog voltage to the corresponding speed selection levels.

The following Figure 1 depicts the relationship between the speed selection and the analog voltage level. The blue line shows that when the speed selection is currently in OFF state, if the analog voltage rises above 1 V, then the speed selection shifts from OFF state to LOW SPEED state. When the current speed selection is in LOW SPEED state, if the analog voltage exceeds 2 V, then the speed selection shifts from LOW SPEED state to HIGH SPEED state. The red line shows that when the speed selection is currently in HIGH SPEED state, if the analog voltage falls below 1.8 V, then the speed selection shifts from HIGH SPEED state to LOW SPEED state. When the current speed selection is in LOW SPEED state, if the analog voltage falls below 0.8 V, then the speed selection shifts from LOW SPEED state to OFF state.

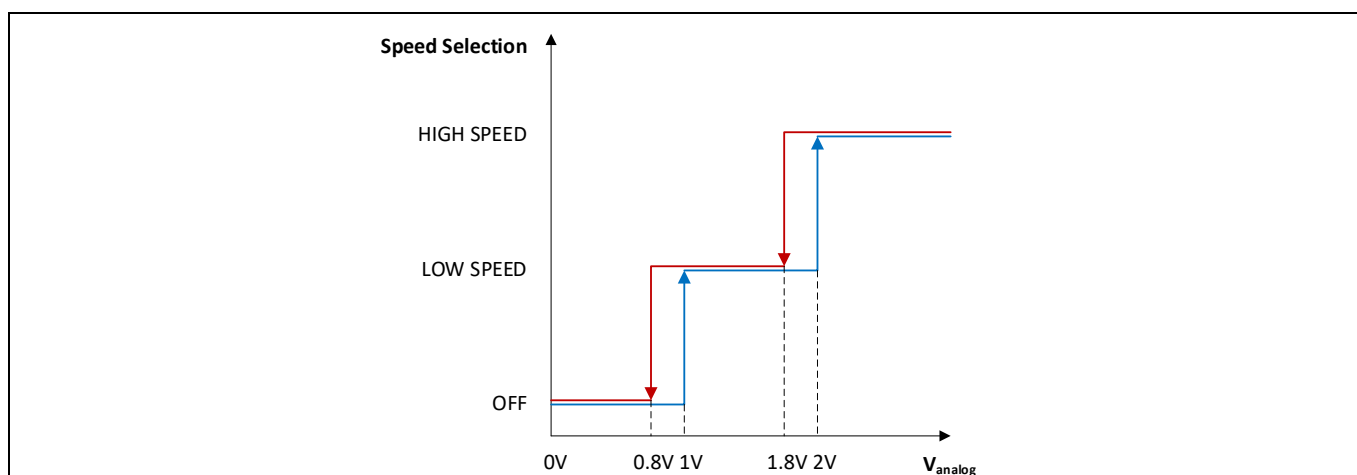


Figure 1 Speed Selection & Analog Voltage Relationship

2.1.2 Analog Input Pin for Speed Selection Interface

This application specific speed selection requirement described in Section 2.1.1 can be conveniently realized by enabling an analog input pin supported by the script engine. For this design, AIN0 pin was chosen to interface with speed selection hardware circuit. Once enabled, this analog input pin is sampled by MCE every 1 ms [2], and the ADC conversion results can be obtained by reading the variable named `ADC_Result0`.

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Given that the resolution of the ADC is 12 bit, the calculation from the voltage at AIN0 pin to the ADC conversion result follows this formula: $ADC_Result0 = INT(V_{AIN0} \cdot \frac{2^{12}-1}{V_{ref}} + 0.5)$, where V_{ref} is the reference voltage for the ADC. If we choose V_{ref} as 5 V, then those voltage thresholds associated with HIGH SPEED and LOW SPEED levels can be calculated using the abovementioned formula as summarized in the following Table 1.

Table 1 Speed Selection Interface Voltage Thresholds

Variable Name	Voltage Threshold	ADC Conversion Result
VLSStart	1V	819 (ADC Counts)
VLSStop	0.8V	655 (ADC Counts)
VHSStart	2V	1638 (ADC Counts)
VHSStop	1.8V	1474 (ADC Counts)

2.1.3 Speed Selection State Machine

The speed selection logic can be abstracted using a finite state machine (FSM) model. An FSM can change from one state to another in response to certain inputs. Figure 2 shows a state machine that was designed to interpret the speed selection inputs. It uses a state variable named `SpeedMode` to represent 3 possible states, namely, `Speed_Mode_OFF` (`SpeedMode = 0`), `Speed_Mode_LOW_SPEED` (`SpeedMode = 1`), and `Speed_Mode_HIGH_SPEED` (`SpeedMode = 2`). Starting off in `Speed_Mode_OFF` state, the target speed is reset to 0, and the motor is stopped. If VSP pin voltage is higher than `VLSStart`, then it shifts to `Speed_Mode_LOW_SPEED` state. While it is in `Speed_Mode_LOW_SPEED` state, if VSP pin voltage is lower than `VLSStop`, then it shifts to `Speed_Mode_OFF`; if VSP pin voltage is higher than `VHSStart`, then it shifts to `Speed_Mode_HIGH_SPEED` state. While it is in `Speed_Mode_HIGH_SPEED` state, if VSP pin voltage is lower than `VHSStop`, then it shifts to `Speed_Mode_LOW_SPEED` state. While it is in `Speed_Mode_HIGH_SPEED` or `Speed_Mode_LOW_SPEED` state, the target speed is set to the pre-defined `HighSpeedValue` or `LowSpeedValue` corresponding to the specific speed selection levels, and the motor is started. The start / stop motor operation can be realized by setting or resetting the motor variable named `Command`. Thanks to the accessibility of the motor parameters enabled by the script engine, `Command` parameter can be directly used in the script code without declaration.

Script Application Examples

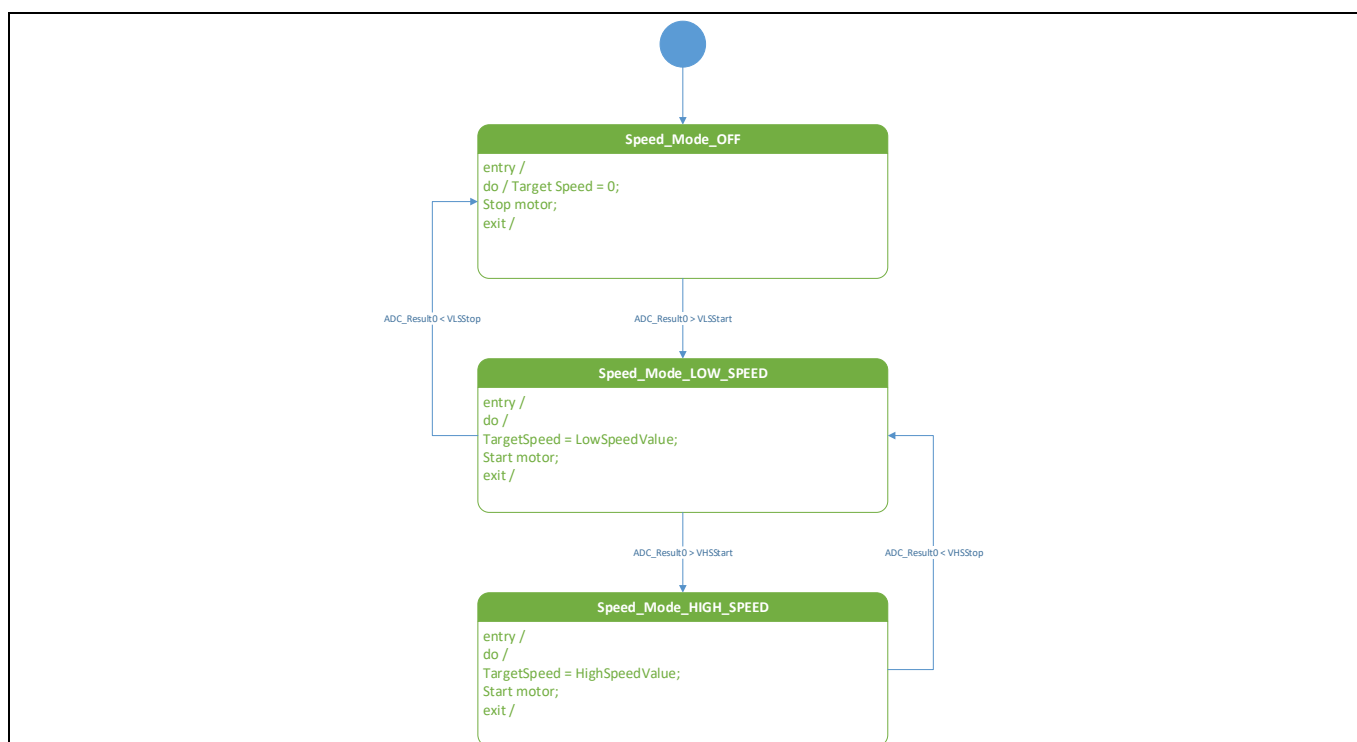


Figure 2 Speed Selection State Machine

2.1.4 Speed Selection Interface Script Implementation

The following Code Listing 1 shows the source code for the 2-level speed selection interface application implemented in Task 1. Since the user speed selection switch position doesn't change frequently, it is recommended to set the loop execution period of Task 1 to be 50 ms. The following Code Listing 2 shows a portion of the compiled script object file where it shows at line 009 that the number of instructions for Task 1 is 17. So, the execution step for Task 1 should be set to greater than 17 to ensure that the entire loop of Task 1 is completed during each execution period. In this example, the execution period for Task 1 (SCRIPT_TASK1_EXECUTION_PERIOD) was set to 5, and the execution step for Task 1 (SCRIPT_TASK1_EXECUTION_STEP) was chosen to be 20 to meet the desired timing requirement.

This example can also be implemented in Task 0, in which case the execution period for Task 0 (SCRIPT_TASK0_EXECUTION_PERIOD) should be set to 50 to achieve the same execution period of 50 ms.

Code Listing 1 Speed Selection Interface Script Code

```

001  /*****
002  /*Script user version value, should be 255.255*/
003  #SET SCRIPT_USER_VERSION (1.00)
004  #SET SCRIPT_TASK1_EXECUTION_PERIOD (5)
005  /*Defines number of lines to be executed every 10mS in Task1*/
006  #SET SCRIPT_TASK1_EXECUTION_STEP (20)
007  /*****
008  /* constant definition */
009  CONST int VLSSStart = 819; // 1V => 819 counts
010  CONST int VLSSStop = 655; // 0.8V => 655 counts
011  CONST int VHSStart = 1638; // 2V => 1638 counts
012  CONST int VHSStop = 1474; // 1.8V => 1474 counts
013  CONST int LowSpeedValue = 5000;

```

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Code Listing 1 Speed Selection Interface Script Code

```

014     CONST int HighSpeedValue = 10000;
015
016     /*Task1 init function*/
017     Script_Task1_init()
018     {
019         /* local variable definition */
020         int SpeedMode;
021
022         /*Initialize local variable*/
023         SpeedMode = 0;
024     }
025     /*Task1 script function*/
026     Script_Task1()
027     {
028         if (SpeedMode == 0)      // Speed selection is in OFF state.
029         {
030             TargetSpeed = 0;
031             Command = 0;    // Stop the motor.
032             if (ADC_Result0 > VLSStart)
033             {
034                 SpeedMode = 1;    // Shift to LOW_SPEED state.
035             }
036         }
037         if (SpeedMode == 1)      // Speed selection is in LOW_SPEED
state.
038         {
039             if (ADC_Result0 > VHSStart)
040             {
041                 SpeedMode = 2;    // Shift to HIGH_SPEED
state.
042             }
043             else
044             {
045                 if (ADC_Result0 < VLSStop)
046                 {
047                     SpeedMode = 0;    // Shift to OFF state.
048                 }
049                 else    //Stay in LOW_SPEED state.
050                 {
051                     TargetSpeed = LowSpeedValue;    // Update TargetSpeed.
052                     Command = 1;    // Start motor.
053                 }
054             }
055         }
056         if(SpeedMode == 2)      // Speed selection is in HIGH_SPEED
state.
057         {
058             if(ADC_Result0 < VHSStop)
059             {
060                 SpeedMode = 1;    // Shift to LOW_SPEED state.
061             }
062             else    // Stay in HIGH_SPEED state.
063             {

```

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Code Listing 1 Speed Selection Interface Script Code

```

064         TargetSpeed = HighSpeedValue;    // Update TargetSpeed.
065         Command = 1;
066     }
067 }
068 }
```

Code Listing 2 Portion of Compiled Script Object File for Speed Selection Interface Script Code

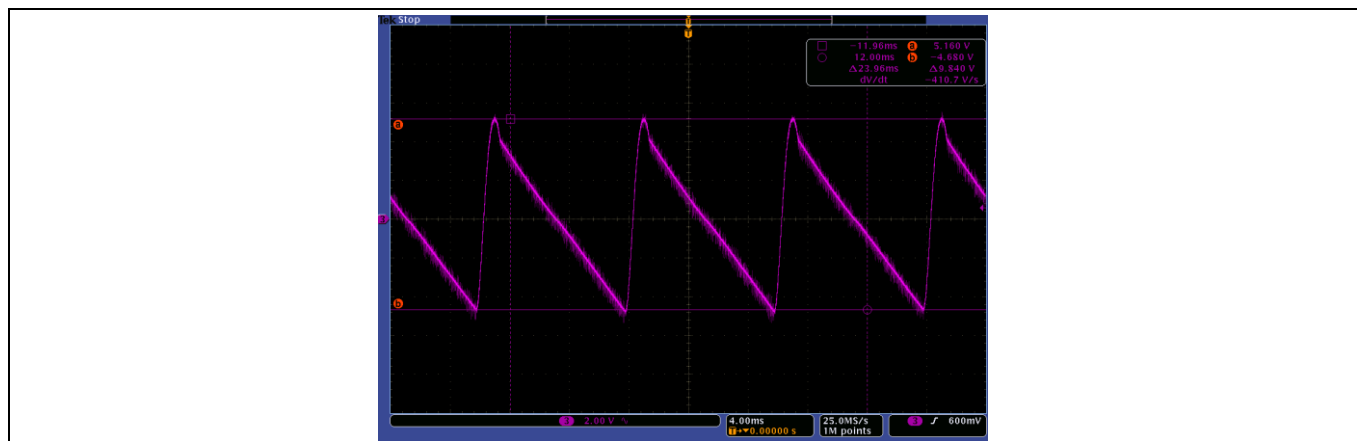
```

001  %-----
002  % Script Object File
003  %-----
004  % SCRIPT_USER_VERSION           : 001.000
005  % DATE & TIME                   : 05.06.2020   15:55:15
006  % SIZE                           : 297 Bytes
007  % Total Number of Lines         : 69
008  % Task0 - Number of Instructions : 0
009  % Task1 - Number of Instructions : 17
010  %-----
```

2.2 Low-Pass Filter for DC Bus Voltage

2.2.1 DC Bus Voltage Ripple

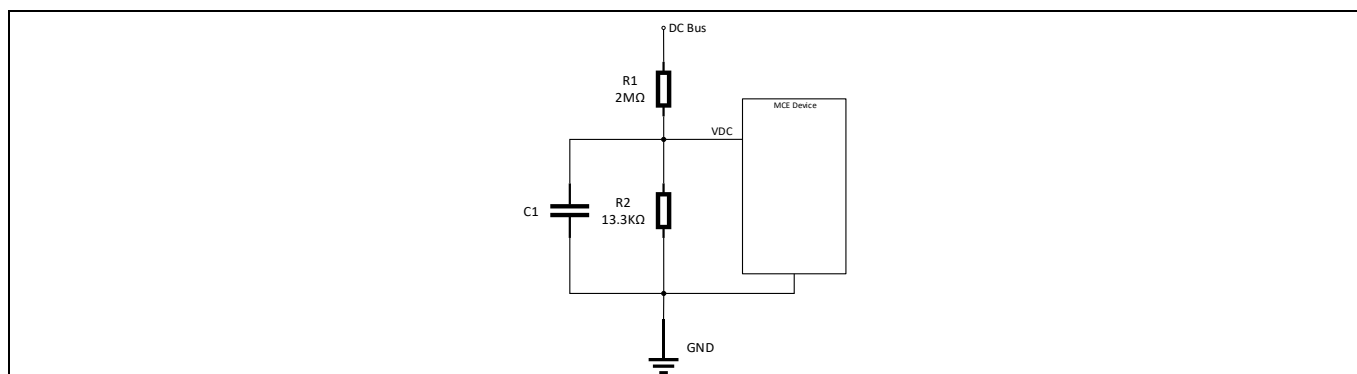
Typically, the AC input front-end stage consists of a bridge rectifier followed by a bulky DC bus capacitor to convert AC mains voltage to DC voltage whose amplitude tracks the peak of the AC input voltage. DC bus voltage refers to the voltage across the DC bus capacitor. When the motor is running, DC bus voltage waveform typically contains high frequency switching ripples as well as low frequency ripples due to bus capacitor charge and discharge operation at twice the mains frequency. Figure 3 is a screenshot of the AC portion of the actual DC bus voltage waveform with IMC101T controller driving a Permanent Magnet Synchronous Motor (PMSM) running at a speed = 19400 RPM and $V_{in} = 125 \text{ VAC} / 50\text{Hz}$. It could be seen that the amplitude of the DC bus voltage ripples was around 9.84 V.



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CH3: DC Bus Voltage (AC coupling); V_{pp_CH3} : 9.84 V**Figure 3 DC Bus Voltage Waveform Screenshot****2.2.2 DC Bus Voltage Sensing**

The valid input voltage for the ADC of MCE ranges from 0 V to 5 V thanks to the selection of 5 V as the ADC reference voltage ($V_{ref} = 5V$). Accordingly, the DC bus voltage is scaled down by a voltage divider composed of R1 and R2 as shown in the following Figure 4 and then connected to VDC pin of MCE. With $R_1 = 2M\Omega$ and $R_2 = 13.3K\Omega$, the DC Bus sensing gain $G_{DCBus_sensing} = \frac{R_2}{R_1 + R_2} = \frac{13.3K\Omega}{2M\Omega + 13.3K\Omega} = 0.00661$, and the maximum DC voltage that the VDC pin can sense is up to 757 V.

**Figure 4 DC Bus Voltage Sensing Interface Circuit Diagram**

The DC bus voltage is being sampled by MCE every motor Pulse Width Modulation (PWM) cycle and is represented by the motor parameter `VdcRaw` whose unit is ADC count [2]. A typical motor PWM cycle value is 50 μs . `VdcRaw` goes through an internal digital LPF stage and the result is stored in `VdcFilt` [2].

Given that the resolution of the ADC is 12 bit, the conversion from DC bus voltage to ADC sampling result follows this formula: $V_{DCBus_ADC} = INT(V_{DCBus} \cdot G_{DCBus_sensing} \cdot \frac{2^{12}-1}{V_{ref}} + 0.5)$, where the *INT* operator means taking the integer portion of a given number.

Thanks to the accessibility of the motor parameters enabled by the script engine, `VdcRaw` and `VdcFilt` parameters can be directly used in the script code without declaration. Figure 5 shows the `VdcRaw` and `VdcFilt` waveforms under the same input / output conditions as in the case of Figure 3 using the tracing window of MCEDesigner [3]. With 9.84 V of DC bus voltage ripple amplitude, `VdcRaw` ripple amplitude should be 53 ADC counts following the abovementioned conversion formula. From Figure 5 it can be seen that the amplitude of `VdcRaw` ripple was about 53 ADC counts. Comparing `VdcFilt` waveform with that of `VdcRaw`, it can be observed that although most of the high frequency ripples seen in `VdcRaw` was attenuated, `VdcFilt` still presented a good amount of low frequency ripples whose amplitude was as high as 30 ADC counts.

In order to obtain an averaged value of DC bus voltage when the system is in steady state, there is a need to implement an additional stage of LPF in the script to attenuate the ripple of `VdcFilt` to no more than 1 ADC count.

Script Application Examples

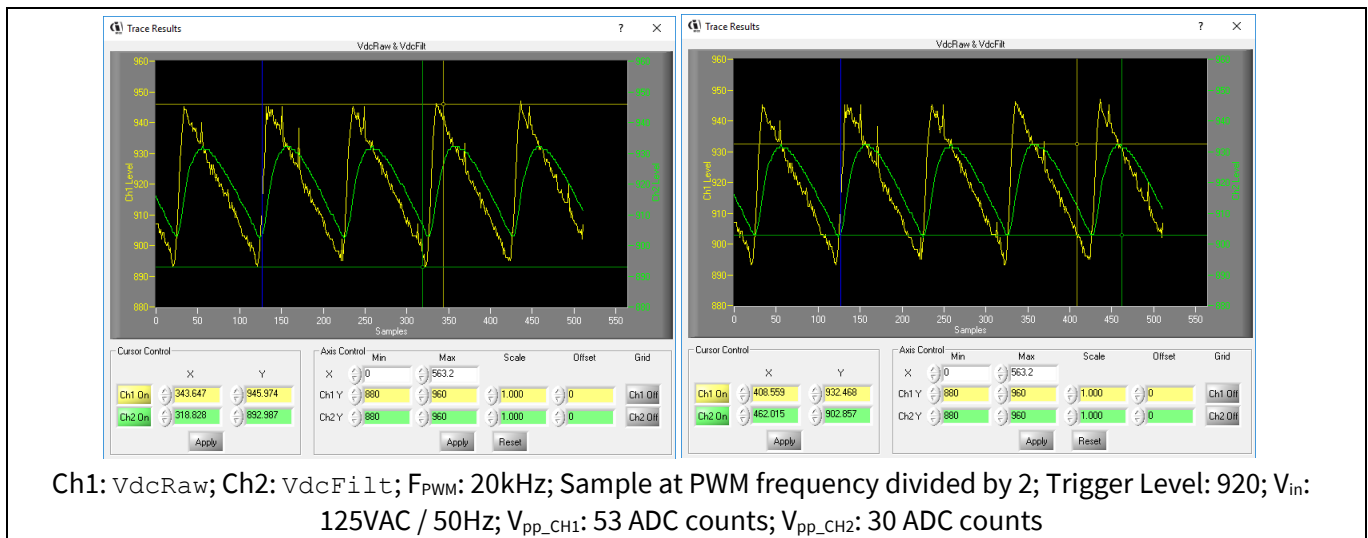


Figure 5 VdcRaw & VdcFilt Waveform Screenshot

2.2.3 LPF Design & Implementation

Considering the limited resources supported by the script engine, a 1st order Infinite Impulse Response (IIR) low-pass digital filter algorithm was chosen for this application. Its difference equation is shown as follows: $y(n) = \alpha \cdot y(n-1) + (1-\alpha) \cdot x(n)$, where α is a constant between 0 and 1, $x(n)$ is the current input value, $y(n)$ is the current output value, and $y(n-1)$ is the last output value. This filter's z domain transfer function is as follows: $H_{LPF}(z) = \frac{1-\alpha}{1-\alpha \cdot z^{-1}}$. Assuming that the sampling period is represented by T_s , and using $z = e^{s \cdot T_s}$ to replace z , we could obtain the filter's transfer function in s domain: $H_{LPF}(s) = \frac{1-\alpha}{1-\alpha \cdot e^{-sT_s}}$.

The dominant portion of the `VdcFilt` ripples was the twice-of-mains-frequency component at 100 Hz or 120 Hz. According to Nyquist theorem, the sampling frequency needs to be at least higher than twice of the frequency of interest to realize effective attenuation. Task 1 can support down to 10 ms execution period, which in this case is not enough. Task 0 was chosen to implement this LPF algorithm thanks to its support for down to 1 ms execution period. The higher the sampling frequency is, the higher the frequency of interest that can be attenuated goes. Accordingly, we chose the sampling period $T_s = 1 \text{ ms}$ so that the LPF would be effective for the frequency ranging up to 500 Hz.

Taking 100Hz as the worst case example, attenuation of $\frac{1}{30}$ corresponds to $20 \cdot \log_{10}\left(\frac{1}{30}\right) = -29.5\text{dB}$. In order to achieve at least -29.5dB at 100 Hz, the desired α needs to be 0.98 based on the calculation of the magnitude of $H_{LPF}(s)$. Unfortunately, the script engine only supports 32 bit signed integer type of variables [2], so that the floating point number 0.98 has to be represented in fractional format. If we define $\alpha = \frac{\alpha_{NUM}}{\alpha_{DEN}}$, then the LPF can be implemented by using the following pseudo code in Code Listing 3.

Code Listing 3 LPF Pseudo Code

```
011      Y1 (n) = Y1 (n-1) + (αDEN-αNUM) * (X (n) - Y (n-1)) ;
012      Y (n) = Y1 (n) / αDEN;
```

It is recommended to choose α_{DEN} to be equal to the power of 2, so that the division operation can be realized efficiently by right shift operation. If we choose $\alpha_{DEN} = 64$, then the best integer value with minimum error for $\alpha_{NUM} = 63$, which results in an equivalent $\alpha = 0.984$ with an error of 0.5%. The division by 64 can be replaced by right shifting 6 bits. The following Code Listing 4 shows the script code implementation for the LPF.

Code Listing 4 LPF Script Code

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```

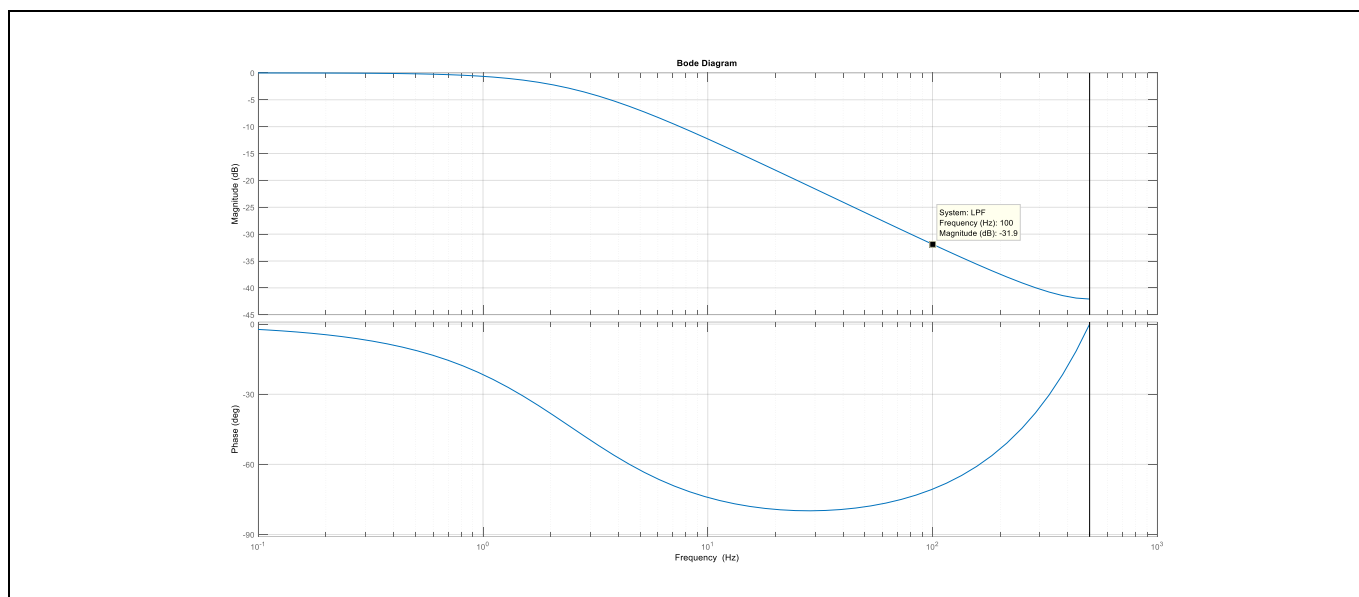
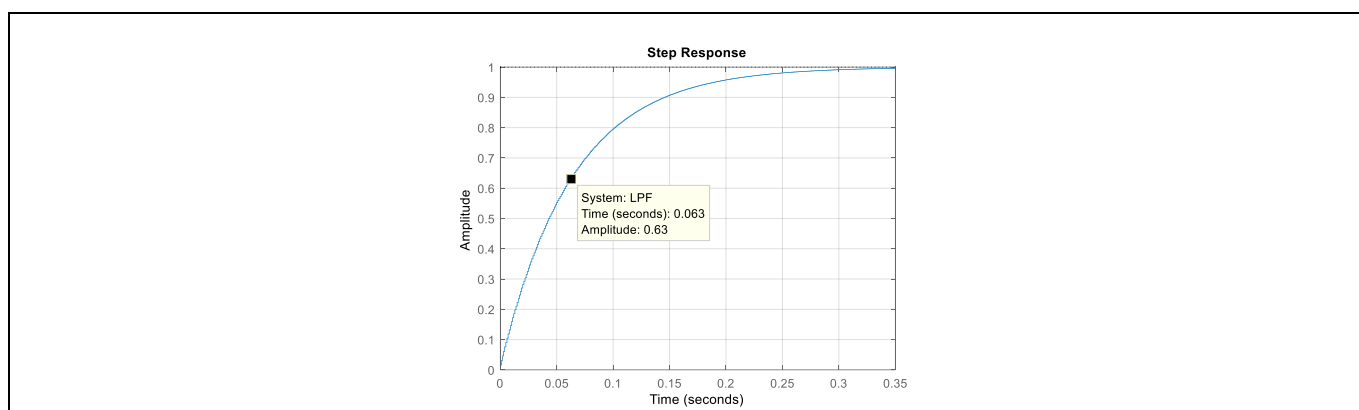
001      /*****
002      /*Script execution time for Task0 in ms, maximum value 65535*/
003      #SET SCRIPT_TASK0_EXECUTION_PERIOD (1)
004      /*Defines number of lines to be executed every 1ms in Task0*/
005      #SET SCRIPT_TASK0_EXECUTION_STEP (2)
006      /*****
007      /* Global variable definition */
008      int VDCBusLPF;
009      /*****
010      /*Task0 init function*/
011      Script_Task0_init()
012      {
013          /*Initialize global variable*/
014          VDCBusLPF = 0;
015          /* local variable definition */
016          int VDCBusMultiplyDEN;
017          /*Initialize local variable*/
018          VDCBusMultiplyDEN = 0;
019      }
020
021      /*Task0 script function*/
022      Script_Task0()
023      {
024          // Vdcbus filtering
025          VDCBusMultiplyDEN = VDCBusMultiplyDEN + (VdcFilt -
VDCBusLPF);
026          VDCBusLPF = VDCBusMultiplyDEN >> 6;
}

```

As can be seen from the code, since there are 2 effective instructions (line 025 and 026) in the LPF implementation, the number of instructions to be executed every 1 ms by Task 0 needs to be set to 2 accordingly (line 005), so that Task 0 loop execution period becomes 1 ms. Thus, 1kHz sampling frequency for `VdcFilt` is ensured. The effective number of instructions for each Task can be found out in the relevant script object file with a suffix of '.ldf'.

With this implementation, the filter's time constant $\tau = -\frac{T_s}{\ln(\alpha)} = -\frac{1ms}{\ln(0.984)} = 63ms$; the cut-off frequency $f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi \cdot 63ms} = 2.51Hz$; the gain at 100 Hz is -31.9 dB. Using MATLAB, the Bode plot and step response of the implemented LPF were calculated and shown in the following Figure 6 and Figure 7.

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Figure 6 Calculated 1st Order IIR LPF Frequency ResponseFigure 7 Calculated 1st Order IIR LPF Step Response

2.2.4 LPF Test Results

Figure 8 shows the waveforms of the filter input represented by `VdcFilt` and the filter output represented by `VDCBusLPF_L` (lower 16 bit of `VDCBusLPF`). It can be seen that the filtered result, `VDCBusLPF_L`, fluctuates by no more than 1 ADC count. With the amplitude of `VdcFilt` being 30 ADC counts, the degree of attenuation achieved was about -30 dB.

Figure 9 shows the measured step response of the implemented LPF, where V_{in} was increased from 70 VAC to 125 VAC. The initial value of `VdcFilt` was 500 ADC counts, and the steady state value of `VdcFilt` was 919 ADC counts, resulting in a step change of 419 ADC counts. The time it took for `VdcFilt` to step up by 265 ADC counts ($419 \cdot (1 - e^{-1}) = 419 \cdot 0.6321 = 265$) was 63.374 sample counts. Since the motor PWM cycle was 50 μ s, and this tracing window screenshot was obtained with a sample rate that was equal to motor PWM frequency divided by 20, the equivalent sample cycle was 1 ms. Accordingly, the measured time constant $\tau_{measured} = 63.374 \text{ sample counts} \cdot 1 \text{ ms} = 63.374 \text{ ms}$. This result matches the theoretical value very well.

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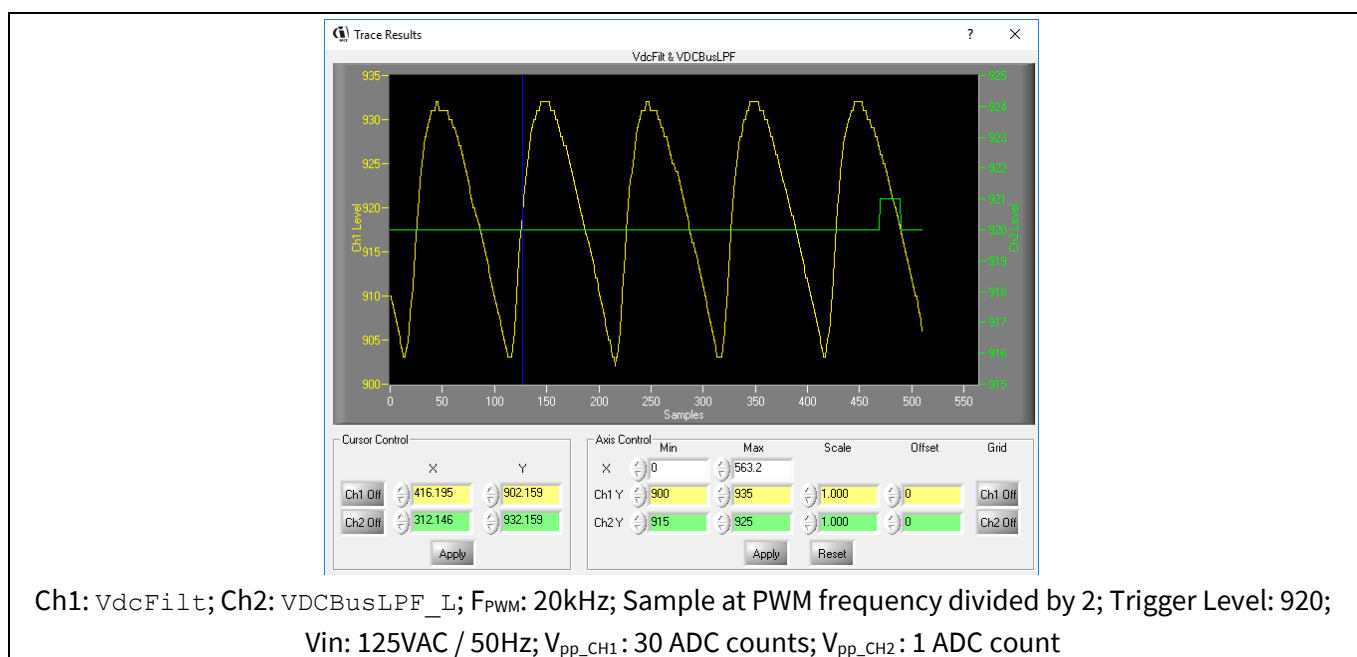
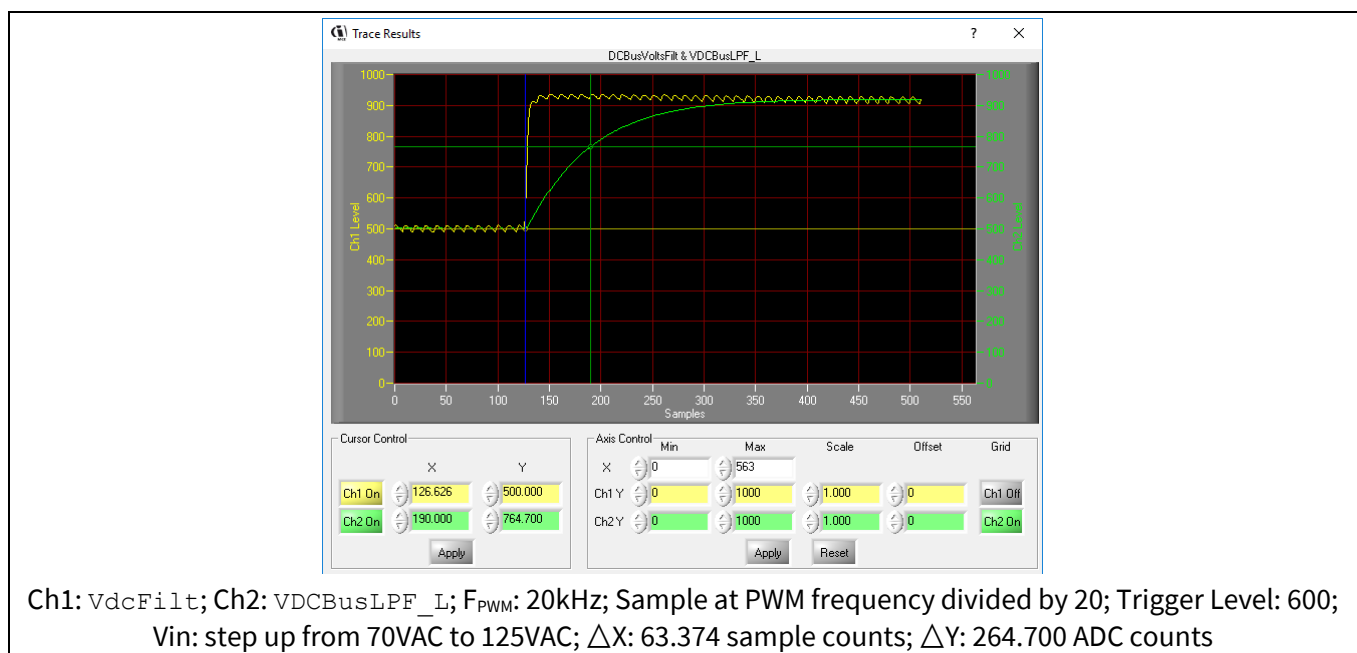


Figure 8 VdcFilt & VDCBusLPF_L Waveform Screenshot

Figure 9 Measured 1st Order IIR LPF Step Response Screenshot

2.3 Target Speed Shaping & Brown-out Protection

In this example, it is shown that the motor target speed can be tailored as a function of DC bus voltage. Additionally, if the DC bus voltage brown-out occurs, then the motor is stopped. Since both of the requirements are based on DC bus voltage, these two functions are implemented together in this example.

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2.3.1 Target Speed Requirements

Some applications such as hair-dryers require setting the motor target speed dynamically based on instantaneous DC bus voltage level. Take an application that uses a 6 pole PMSM type motor whose maximum speed is 20K RPM as an example, given the 2-level speed selection interface described in Section 2.1, the relationship between the target speed and DC bus voltage is defined by a quadratic function with 2 different sets of coefficients for HIGH SPEED and LOW SPEED levels respectively as shown below.

$$TargetSpeed_{HS} = A_h \cdot V_{DCBus}^2 + B_h \cdot V_{DCBus} + C_h;$$

$$TargetSpeed_{LS} = A_l \cdot V_{DCBus}^2 + B_l \cdot V_{DCBus} + C_l.$$

The unit of *TargetSpeed* is RPM, and the unit of V_{DCBus} is Volt. The coefficients of the quadratic function are listed in the following Table 2.

Table 2 Coefficients of the Quadratic Function for Target Speed & DC Bus Voltage Relationships

HIGH SPEED		LOW SPEED	
A_h	-0.159	A_l	-0.572
B_h	132.585	B_l	228.480
C_h	1494.450	C_l	-6153.675

The calculated target speed using the abovementioned quadratic function needs to be within its corresponding maximum and minimum limits. Table 3 below lists the speed limit requirements for HIGH SPEED and LOW SPEED levels.

Table 3 Max. & Min. Target Speed Limit Definitions

	HIGH SPEED	LOW SPEED
Max. Target Speed Limit	16200 RPM	19400 RPM
Min. Target Speed Limit	11625 RPM	13537 RPM

In addition, DC bus brown-out protection is required to prevent the motor from continuing to operate when the DC bus voltage decreases below certain threshold. In order to eliminate potential oscillation when the DC bus voltage is around the brown-out level, a hysteresis of 5V was introduced. The following Table 4 lists the DC bus brown-in and brown-out voltage levels.

Table 4 DC Bus Brown-In & Brown-Out Voltage Levels

DC Bus Brown-In Voltage	90 V
DC Bus Brown-Out Voltage	85 V

The overall relationships between the target speed and the DC bus voltage for HIGH SPEED and LOW SPEED levels are shown in the following Figure 10 and Figure 11. The solid blue line shows that if the DC bus voltage rises from 0 V, the motor won't start to run until the DC bus voltage exceeds 90 V. The dashed red line shows that if the motor is currently running, then it doesn't stop running until the DC bus voltage falls below 85 V.

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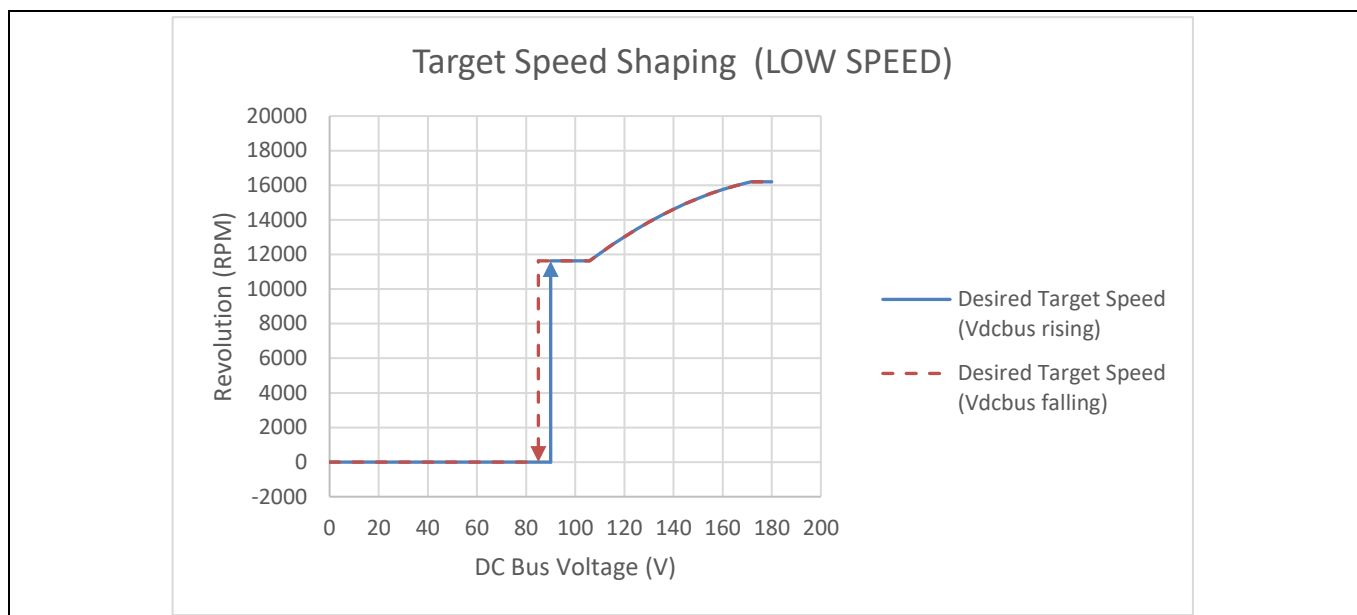


Figure 10 Target Speed Shaping (LOW SPEED)

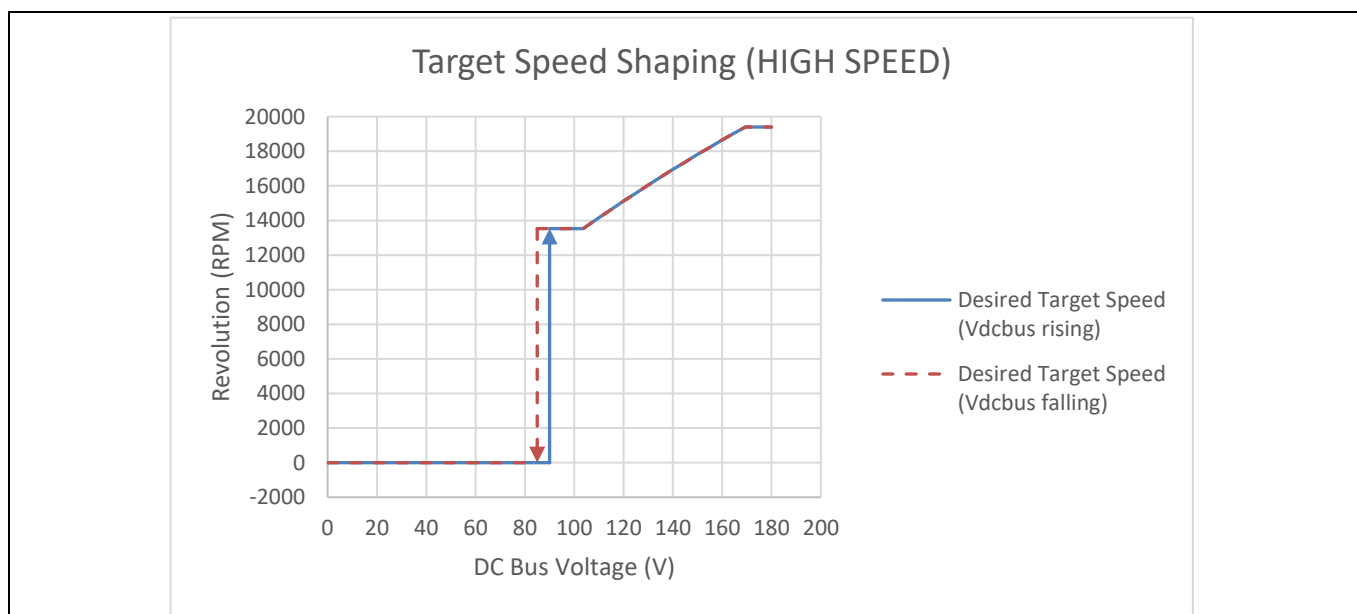


Figure 11 Target Speed Shaping (HIGH SPEED)

2.3.2 DC Bus Status State Machine

A dedicated state machine can be designed to keep track of DC Bus brown-in / brown-out status as shown in the following Figure 12. The DC bus status state machine uses a state variable `DCBusState` to represent 2 possible states, namely, `DC_Bus_State_Abnormal` (`DCBusState = 0`), and `DC_Bus_State_Normal` (`DCBusState = 1`). The input signal to this state machine needs to be an averaged DC bus voltage ADC conversion result to minimize potential oscillation. The LPF described in Section 2.2 can be used to generate the required input signal `VDCBusLPF`. Starting off in `DC_Bus_State_Abnormal` state, if `VDCBusLPF` is greater than the value of `VDCBusBrownIn`, then the DC bus status state machine shifts to `DC_Bus_State_Normal` state. While it is in `DC_Bus_State_Normal` state, if `VDCBusLPF` becomes less than the value of `VDCBusBrownOut`, then the state machine shifts back to `DC_Bus_State_Abnormal` state.

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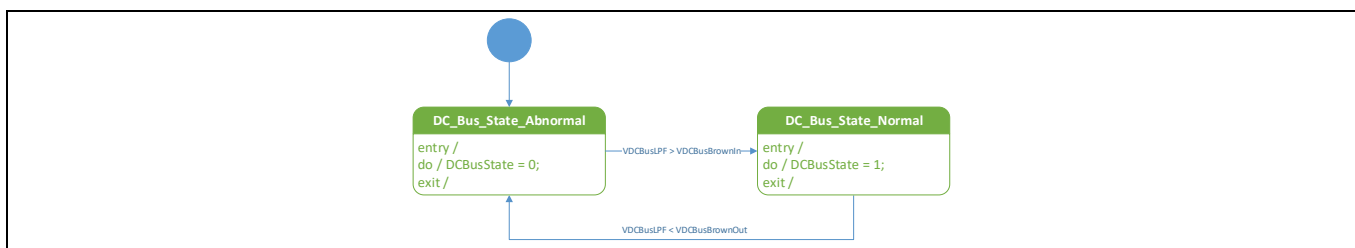


Figure 12 DC Bus Status State Machine Diagram

The calculation of the value of $V_{DCBusBrownIn}$ and $V_{DCBusBrownOut}$ follows the conversion formula described in Section 2.2.2, and the voltage levels specified in Table 4. The results are shown in Table 5 below.

Table 5

DC Bus Brown-In Voltage	90 V	$V_{DCBusBrownIn}$	487 (ADC counts)
DC Bus Brown-Out Voltage	85 V	$V_{DCBusBrownOut}$	460 (ADC counts)

2.3.3 Scaling for Target Speed Shaping Calculation

Section 2.3.1 defined the relationship between $TargetSpeed$ and V_{DCBus} for different speed selection levels, where the unit of $TargetSpeed$ was RPM, and the unit of V_{DCBus} was Volt. However, in MCE software, the target speed is represented by a signed 16 bit integer, where 16383 corresponds to the motor's maximum speed. For this application, $TargetSpeed = 16383$ corresponds to the maximum motor speed of 20K RPM. The DC bus voltage in MCE software is presented by its corresponding ADC sampling result in ADC counts, following the conversion formula described in Section 2.2.2. Thus, the formulas defined in Section 2.3.1 cannot be used directly in script code. In order to obtain the correct calculation result of target speed in script code, those scaling factors need to be taken into consideration as shown in the following formula.

$$TargetSpeed_{script} = \left[A \cdot (V_{DCBus_{ADC}} \cdot \frac{V_{ref}}{2^{12}-1} \cdot \frac{1}{G_{DCBus_{sensing}}})^2 + B \cdot (V_{DCBus_{ADC}} \cdot \frac{V_{ref}}{2^{12}-1} \cdot \frac{1}{G_{DCBus_{sensing}}}) + C \right] \cdot \frac{16383}{Speed_{max}}, \text{ where}$$

$V_{ref} = 5V$, $G_{DCBus_{sensing}} = 0.00661$ (described in Section 2.2.2), $Speed_{max} = 20000$, A , B , and C are the 3 coefficients in the original quadratic function that defines the relationship between the target speed and DC bus voltage for different speed selection levels.

If we define $T_{spd_factor} = \frac{16383}{Speed_{max}} = 0.819$, and $V_{DCBus_factor} = \frac{V_{ref}}{2^{12}-1} \cdot \frac{1}{G_{DCBus_{sensing}}} = 0.185$, then we can obtain the following formula:

$$TargetSpeed_{script} = (A \cdot T_{spd_factor} \cdot V_{DCBus_factor}^2) \cdot V_{DCBus_{ADC}}^2 + (B \cdot T_{spd_factor} \cdot V_{DCBus_factor}) \cdot V_{DCBus_{ADC}} + (C \cdot T_{spd_factor})$$

If we define $A_{script} = A \cdot T_{spd_factor} \cdot V_{DCBus_factor}^2$, $B_{script} = B \cdot T_{spd_factor} \cdot V_{DCBus_factor}$, and $C_{script} = C \cdot T_{spd_factor}$, then the above formula can be simplified as follows.

$$TargetSpeed_{script} = A_{script} \cdot V_{DCBus_{ADC}}^2 + B_{script} \cdot V_{DCBus_{ADC}} + C_{script}$$

Using this formula, the relevant coefficients with the inclusion of the scaling factors can be calculated for different speed selection levels as shown in the following Table 6.

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Table 6 Coefficients in Floating Point Format for the Quadratic Function for Target Speed & DC Bus Voltage Relationships with Scaling Factors

HIGH SPEED		LOW SPEED	
A_{h_script}	-0.004	A_{l_script}	-0.016
B_{h_script}	20.074	B_{l_script}	34.593
C_{h_script}	1224.179	C_{l_script}	-5040.783

The script engine only supports 32 bit signed integer type of variables [2], so these floating point numbers have to be represented in fractional format in the script code. For instance, if we choose a common denominator DEN, then the target speed shaping calculation in script can be realized by using the following pseudo code in Code Listing 5.

Code Listing 5 Target Speed Shaping Calculation Pseudo Code

```

001      Speed_Value = A_NUM * VDCBus * VDCBus + B_NUM * VDCBus +
      C_NUM;
002      TargetSpeed = Speed_Value / DEN;

```

Considering the accuracy requirement and overflow limit, we chose a common denominator of 65536 (Q15.16 format), with which the division operation can be replaced by efficient right shifting 16 bits. With that, the numerator value for each coefficient can be calculated accordingly as shown in the following Table 7.

Table 7 Coefficients in Q15.16 Format for the Quadratic Function for Target Speed & DC Bus Voltage Relationships with Scaling Factors

Denominator		65536	
HIGH SPEED		LOW SPEED	
A_{h_NUM}	-291	A_{l_NUM}	-1049
B_{h_NUM}	1315558	B_{l_NUM}	2267069
C_{h_NUM}	80227767	C_{l_NUM}	-330352746

2.3.4 Target Speed Shaping & Brown-out Protection Script Implementation

The following Code Listing 6 shows the source code for the target speed shaping with brown-out protection application implemented in Task 1. Since the target speed doesn't need to be updated too frequently, it is recommended to set the loop execution period of Task 1 to be 50 ms. The compiled script object file shows that the number of instructions for Task 1 is 42. So, the execution step for Task 1 should be set to greater than 42 to ensure that the entire loop of Task 1 is completed during each execution period. In this example, the execution period for Task 1 (SCRIPT_TASK1_EXECUTION_PERIOD) was set to 5, and the execution step for Task 1 (SCRIPT_TASK1_EXECUTION_STEP) was chosen to be 50 to meet the desired timing requirement.

This example can also be implemented in Task 0, in which case the execution period for Task 0 (SCRIPT_TASK0_EXECUTION_PERIOD) should be set to 50 to achieve the same execution period of 50 ms.

Code Listing 6 Target Speed Shaping & Brown-out Protection Script Code

```

001      /*****
      */
002      /*Script user version value, should be 255.255*/
003      #SET SCRIPT_USER_VERSION (1.00)
004      /*Script execution time for Task0 in mS, maximum value 65535*/

```

Script Application Examples

Code Listing 6 Target Speed Shaping & Brown-out Protection Script Code

```

005      #SET SCRIPT_TASK0_EXECUTION_PERIOD (1)
006      /*Defines number of lines to be executed every 1mS in Task0*/
007      #SET SCRIPT_TASK0_EXECUTION_STEP (2)
008      /*Script execution time for Task1 in 10mS, maximum value
        65535*/
009      #SET SCRIPT_TASK1_EXECUTION_PERIOD (5)
010      /*Defines number of lines to be executed every 10mS in Task1*/
011      #SET SCRIPT_TASK1_EXECUTION_STEP (50)
012      /******
013      /* constant definition */
014      CONST int VDCBusBrownIn = 487; // Vdcbus_brown_in = 90V =>
        487 counts
015      CONST int VDCBusBrownOut = 460; // Vdcbus_brown_out = 85V =>
        460 counts
016
017      CONST int VLSSstart = 819; // Vsp_low_spd_start = 1V => 819
        counts
018      CONST int VLSSstop = 655; // Vsp_low_spd_stop = 0.8V => 655
        counts
019      CONST int VHSSstart = 1638; // Vsp_high_spd_start = 2V => 1638
        counts
020      CONST int VHSSstop = 1474; // Vsp_high_spd_stop = 1.8V =>
        1474 counts
021
022      CONST int AlNum = -1049;
023      CONST int BlNum = 2267069;
024      CONST int ClNum = -330352770;
025      CONST int AhNum = -291;
026      CONST int BhNum = 1315558;
027      CONST int ChNum = 80227700;
028      CONST int DenShiftBit = 16; // Denominator = 2^16 = 65536
029
030      CONST int TspdLSMin = 9523; // In LOW_SPEED mode, Target Speed
        min = 11625 rpm => 9523 counts.
031      CONST int TspdLSMax = 13270; // In LOW_SPEED mode, Target
        Speed max = 16200 rpm => 13270 counts.
032      CONST int TspdHSMin = 11089; // In HIGH_SPEED mode, Target
        Speed min = 13537 rpm => 11089 counts.
033      CONST int TspdHSMax = 15892; // In HIGH_SPEED mode, Target
        Speed max = 19400 rpm => 15892 counts.
034
035      /* Global variable definition */
036      int VDCBusLPF;
037      int DCBusState;
038      int SpeedMode;
039      int SpeedValue;
040
041      /*Task0 init function*/
042      Script_Task0_init()
043      {
044          /*Initialize global variable*/
045          VDCBusLPF = 0;
046          /* local variable definition */

```

Script Application Examples

Code Listing 6 Target Speed Shaping & Brown-out Protection Script Code

```
047      int VDCBusMultiplyDEN;
048      /*Initialize local variable*/
049      VDCBusMultiplyDEN = 0;
050  }
051
052  /*Task0 script function*/
053  Script_Task0()
054  {
055      // Vdcbus filtering
056      VDCBusMultiplyDEN = VDCBusMultiplyDEN + (VdcFilt -
VDCBusLPF);
057      VDCBusLPF = VDCBusMultiplyDEN >> 6;
058  }
059
060  /*Task1 init function*/
061  Script_Task1_init()
062  {
063      /*Initialize global variable*/
064      DCBusState = 0;
065      SpeedMode = 0;
066      SpeedValue = 0;
067
068      /*local variable definition*/
069
070      /*Initialize local variable*/
071  }
072
073  /*Task1 script function*/
074  Script_Task1()
075  {
076      // DC bus state machine
077      if (DCBusState == 0) // DCBus is abnormal.
078      {
079          if (VDCBusLPF > VDCBusBrownIn)
080          {
081              DCBusState = 1; // Shift to DCBus normal state.
082          }
083      }
084
085      if (DCBusState == 1) // DCBus is normal.
086      {
087          if (VDCBusLPF < VDCBusBrownOut)
088          {
089              DCBusState = 0; // Shift to DCBus abnormal state.
090          }
091      }
092
093      // Speed selection state machine
094      if (SpeedMode == 0) // Speed selection is in OFF state.
095      {
096          TargetSpeed = 0;
097          Command = 0; // Stop the motor.
098      }
```

Script Application Examples

Code Listing 6 Target Speed Shaping & Brown-out Protection Script Code

```

099         if (ADC_Result0 > VLSStart)
100         {
101             SpeedMode = 1;  // Shift to LOW_SPEED state.
102         }
103     }
104
105     if (SpeedMode == 1) // Speed selection is in LOW_SPEED
state.
106     {
107         if (ADC_Result0 > VHSStart)
108         {
109             SpeedMode = 2;  // Shift to HIGH_SPEED state.
110         }
111         else
112         {
113             if (ADC_Result0 < VLSStop)
114             {
115                 SpeedMode = 0;  // Shift to OFF state.
116             }
117             else //Stay in LOW_SPEED state.
118             {
119                 if (DCBusState == 1)  // DC bus voltage is normal.
120                 {
121                     // Calculate target speed. Target speed follows 2nd
order polynomial curve for LS.
122                     SpeedValue = A1Num * VDCBusLPF * VDCBusLPF + B1Num *
VDCBusLPF + C1Num;
123                     SpeedValue = SpeedValue >> DenShiftBit;
124                     if (SpeedValue > TspdLSMax) // Upper limit check
125                     {
126                         SpeedValue = TspdLSMax;
127                     }
128                     if (SpeedValue < TspdLSMin) // Lower limit check
129                     {
130                         SpeedValue = TspdLSMin;
131                     }
132                     TargetSpeed = SpeedValue; // Update TargetSpeed.
133                     Command = 1;  // Start motor.
134                 }
135                 else // DC bus voltage is abnormal.
136                 {
137                     TargetSpeed = 0;  // Reset TargetSpeed.
138                     Command = 0;  // Stop motor.
139                 }
140             }
141         }
142     }
143
144     if(SpeedMode == 2)  // Speed selection is in HIGH_SPEED
state.
145     {
146         if(ADC_Result0 < VHSStop)
147         {

```

Script Application Examples

Code Listing 6 Target Speed Shaping & Brown-out Protection Script Code

```

148         SpeedMode = 1; // Shift to LOW_SPEED state.
149     }
150     else // Stay in HIGH_SPEED state.
151     {
152         if (DCBusState == 1) // DC bus voltage is normal.
153         {
154             // Target speed follows 2nd order polynomial curve for
HS.
155             SpeedValue = AhNum * VDCBusLPF * VDCBusLPF + BhNum *
VDCBusLPF + ChNum;
156             SpeedValue = SpeedValue >> DenShiftBit;
157             if (SpeedValue > TspdHSMax) // Upper limit check
158             {
159                 SpeedValue = TspdHSMax;
160             }
161             if (SpeedValue < TspdHSMin) // Lower limit check
162             {
163                 SpeedValue = TspdHSMin;
164             }
165             TargetSpeed = SpeedValue; // Update TargetSpeed.
166             Command = 1; // Start motor.
167         }
168     else // DC bus voltage is abnormal.
169     {
170         TargetSpeed = 0; // Reset TargetSpeed.
171         Command = 0; // Stop motor.
172     }
173 }
174 }
175 }

```

2.3.5 Target Speed Shaping Measurement Results

The actual motor speed was measured by calculating the frequency of the motor phase current waveforms while the input voltage was swept from 65 VAC to 130 VAC at different speed selection levels. The measurement data for LOW SPEED level was shown in the following Table 8 and plotted against the desired target speed shaping curves in Figure 13. As can be seen from the measurement data, the actual motor speed followed the desired target speed calculated as a quadratic function of DC bus voltage with tolerance of no more than 1%. The calculated speed was limited by either the pre-defined minimum or maximum motor speed for LOW SPEED level.

Table 8 Measurement Data of Target Speed & DC Bus Voltage (LOW SPEED)

V _{in} (Vrms)	V _{DCbus} (Vdc)	Measured Motor Speed (rpm)	Calculated Target Speed (rpm)	Target Speed Error (%)
64	85.8	11680	11625	0.5%
67	89.6	11740	11625	1.0%
78	105.6	11680	11590	0.8%
80	108.4	11900	11890	0.1%
90	122.0	13216	13204	0.1%
100	135.9	14380	14329	0.4%

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V_{in} (Vrms)	V_{DCbus} (Vdc)	Measured Motor Speed (rpm)	Calculated Target Speed (rpm)	Target Speed Error (%)
64	85.8	11680	11625	0.5%
67	89.6	11740	11625	1.0%
110	149.9	15300	15238	0.4%
120	164.0	15980	15926	0.3%
125	171.1	16260	16188	0.4%
126	172.6	16264	16200	0.4%
130	178.3	16264	16200	0.4%

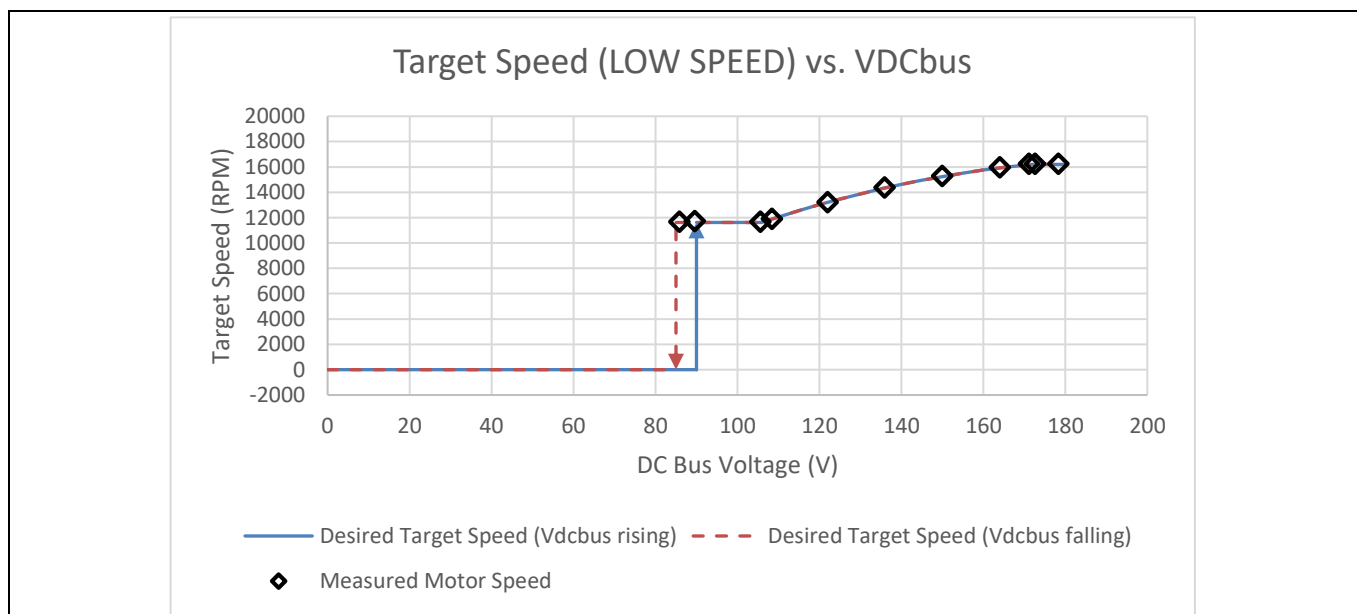


Figure 13 Measurement of Target Speed vs. DC Bus Voltage (LOW SPEED)

Table 9 and Figure 14 show the measurement data for HIGH SPEED level. It can be seen consistently that the actual motor speed followed the desired target speed calculated as a quadratic function of DC bus voltage with tolerance of no more than 1%. The calculated speed was limited by either the pre-defined minimum or maximum motor speed for HIGH SPEED level.

Table 9 Measurement Data of Target Speed & DC Bus Voltage (HIGH SPEED)

V_{in} (Vrms)	V_{DCbus} (Vdc)	Measured Motor Speed (rpm)	Calculated Target Speed (rpm)	Target Speed Error (%)
65	86.3	13100	13537	-3.2%
66	87.9	13260	13537	-2.0%
77	103.7	13600	13537	0.5%
78	105.0	13628	13667	-0.3%
90	121.4	15280	15254	0.2%
100	135.2	16560	16519	0.2%
110	149.0	17762	17728	0.2%
120	162.8	18944	18875	0.4%
124	168.5	19454	19331	0.6%
125	170.0	19458	19400	0.3%

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V_{in} (Vrms)	V_{DCbus} (Vdc)	Measured Motor Speed (rpm)	Calculated Target Speed (rpm)	Target Speed Error (%)
65	86.3	13100	13537	-3.2%
66	87.9	13260	13537	-2.0%
130	177.2	19466	19400	0.3%

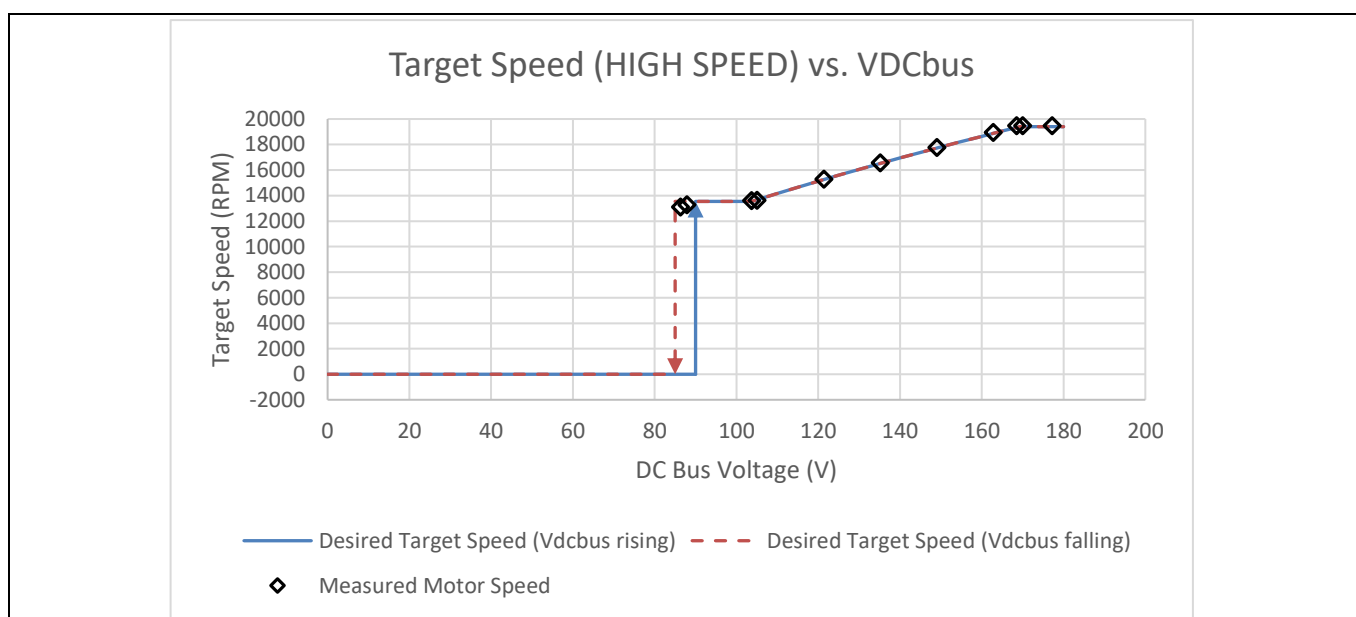


Figure 14 Measurements of Target Speed vs. DC Bus Voltage (HIGH SPEED)

2.4 Dynamic Motor Current Limit Customization

2.4.1 Motor Current Limit Requirement

By default, the motor current limit is set to 100% of its rated current. Some applications require implementing customized motor current limit based on the speed selection input to enable tighter torque control. Besides, during the motor speed ramp-up or ramp-down period, the motor current limit needs to be loosened up to its original setting (100% of the rated current) momentarily to allow for quicker response to speed change request. When the motor is stopped, the motor current limit also needs to be restored to its original setting. The detailed motor current limit requirements are listed in the following Table 10.

Table 10 Motor Current Limit Requirements

	Rated Current	Speed Ramp-up / Ramp-down Period	Speed Selection = OFF	Speed Selection = HIGH SPEED	Speed Selection = LOW SPEED
Motor Current Limit	3 A	3 A	3 A	0.6 A	0.38 A

2.4.2 Dynamic Motor Current Limit Algorithm Design & Implementation

The following Figure 15 shows the detailed flowchart for dynamic motor current limit calculation algorithm. During the initialization, the original motor current limit value ($MotorLim$) is stored in a variable named `CurrentLimitOriginal`. The customized motor current limit during steady state at a given speed selection level is updated by speed selection state machine and is maintained by the variable named

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`CurrentLimitTarget`. The instantaneous motor current limit (`CurrentLimitValue`) is calculated based on the absolute difference between the `TargetSpeed` and `SpdRef`. The rate of change for `CurrentLimitValue` is set by the variable named `CurrentLimitIncrement` which was set to 100 (counts / 10 ms) in the script code. Since the rate of change for `SpdRef` is relatively slower than that for `TargetSpeed`, if the absolute difference between `TargetSpeed` and `SpdRef` is greater than the value of `SpeedDiffThresh` (100 counts), then it is determined that the speed transient period is started during which the motor current limit is required to increment gradually all the way up to its original value. If the absolute difference between `TargetSpeed` and `SpdRef` is less than 100 counts, then it implies that the speed steady state is started during which the motor current limit is required to decrement gradually down to its customized value represented by `CurrentLimitTarget` for a given speed selection level. The `CurrentLimitValue` calculation is updated every loop execution period (10 ms), and then `MotorLim` value is synchronized to that of `CurrentLimitValue`.

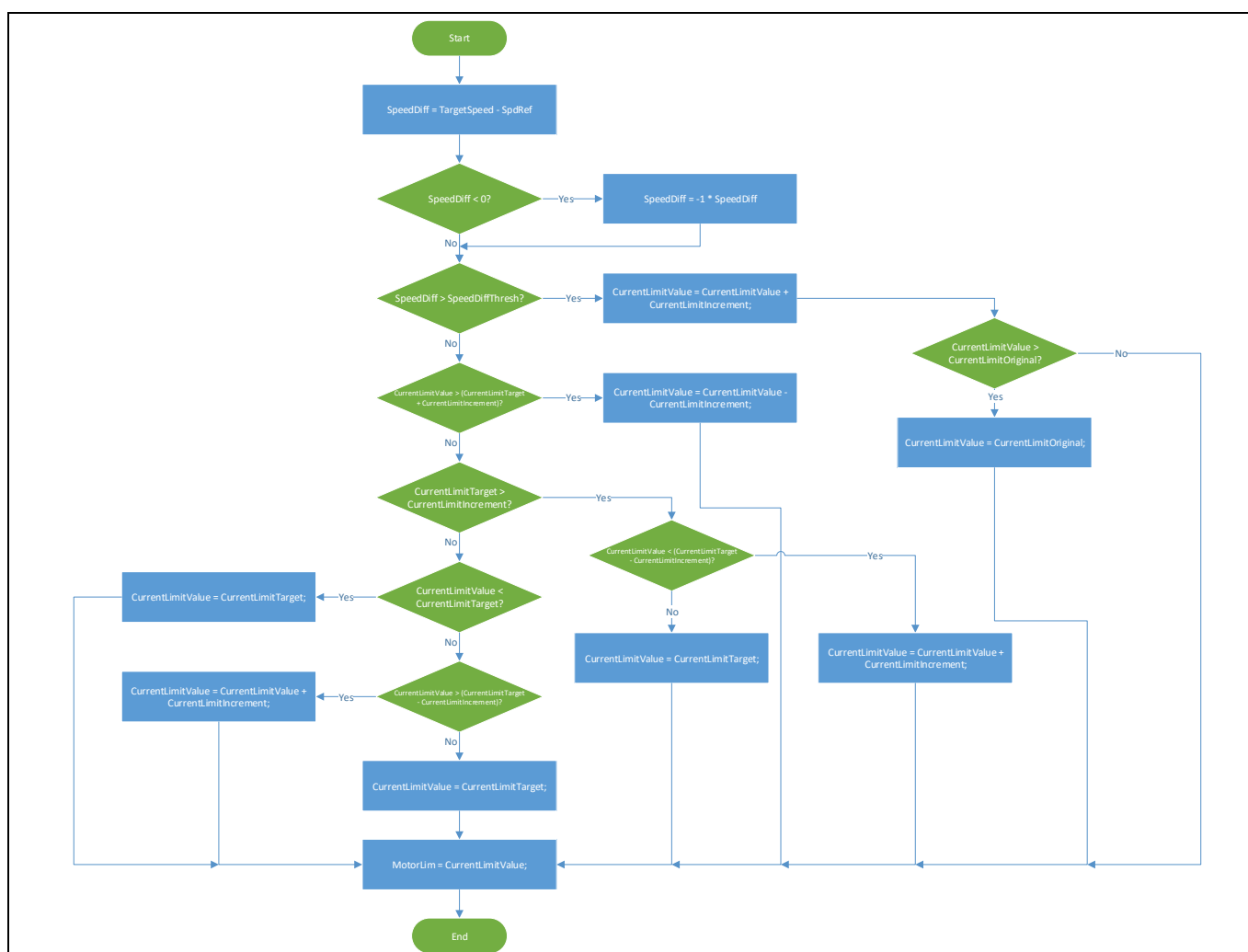


Figure 15 Flowchart of Dynamic Motor Current Limit Algorithm

The following Code Listing 7 shows the source code for the dynamic motor current limit customization application implemented in Task 1. Since the rate of change for the motor current limit is defined as 100 counts / 10 ms, it is recommended to set the loop execution period of Task 1 to be 10 ms. The compiled script object file shows that the number of instructions for Task 1 is 56. So, the execution step for Task 1 should be set to greater than 56 to ensure that the entire loop of Task 1 is completed during each execution period. In this example, the execution period for Task 1 (`SCRIPT_TASK1_EXECUTION_PERIOD`) was set to 1, and the execution

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step for Task 1 (SCRIPT_TASK1_EXECUTION_STEP) was chosen to be 60 to meet the desired timing requirement.

This example can also be implemented in Task 0, in which case the execution period for Task 0 (SCRIPT_TASK0_EXECUTION_PERIOD) should be set to 10 to achieve the same execution period of 10 ms.

Code Listing 7 Dynamic Motor Current Limit Script Code

```

001  /*****
002  /*Script user version value, should be 255.255*/
003  #SET SCRIPT_USER_VERSION (1.00)
004  /*Script execution time for Task0 in mS, maximum value 65535*/
005  #SET SCRIPT_TASK0_EXECUTION_PERIOD (1)
006  /*Defines number of lines to be executed every 1mS in Task0*/
007  #SET SCRIPT_TASK0_EXECUTION_STEP (2)
008  /*Script execution time for Task1 in 10mS, maximum value
    65535*/
009  #SET SCRIPT_TASK1_EXECUTION_PERIOD (1)
010  /*Defines number of lines to be executed every 10mS in Task1*/
011  #SET SCRIPT_TASK1_EXECUTION_STEP (60)
012  /*****
013  /* constant definition */
014  CONST int VDCBusBrownIn = 487; // Vdcbus_brown_in = 90V =>
    487 counts
015  CONST int VDCBusBrownOut = 460; // Vdcbus_brown_out = 85V =>
    460 counts
016
017  CONST int SpeedDiffThresh = 100; // Set the speed difference
    threshold to 100 counts.
018  CONST int CurrentLimitIncrement = 100; // Motor current limit
    ramp rate = 100 counts / update interval (10 ms).
019  CONST int CurrentLimitLS = 519; // low speed motor current
    limit = 0.38A => 519 counts
020  CONST int CurrentLimitHS = 819; // high speed motor current
    limit = 0.6A => 819 counts
021
022  CONST int VLSSstart = 819; // Vsp_low_spd_start = 1V => 819
    counts
023  CONST int VLSSstop = 655; // Vsp_low_spd_stop = 0.8V => 655
    counts
024  CONST int VHSSstart = 1638; // Vsp_high_spd_start = 2V => 1638
    counts
025  CONST int VHSSstop = 1474; // Vsp_high_spd_stop = 1.8V =>
    1474 counts
026
027  CONST int LowSpeedValue = 5000;
028  CONST int HighSpeedValue = 10000;
029
030  /* Global variable definition */
031  int VDCBusLPF;
032  int DCBusState;
033  int SpeedDiff;
034  int CurrentLimitOriginal;
035  int CurrentLimitValue;
036  int CurrentLimitTarget;

```

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Code Listing 7 Dynamic Motor Current Limit Script Code

```

037     int SpeedMode;
038
039     /*******/
040     /*Task0 init function*/
041     Script_Task0_init()
042     {
043         /*Initialize global variable*/
044         VDCBusLPF = 0;
045         /* local variable definition */
046         int VDCBusMultiplyDEN;
047         /*Initialize local variable*/
048         VDCBusMultiplyDEN = 0;
049     }
050
051     /*Task0 script function*/
052     Script_Task0()
053     {
054         // Vdcbus filtering
055         VDCBusMultiplyDEN = VDCBusMultiplyDEN + (VdcFilt -
VDCBusLPF);
056         VDCBusLPF = VDCBusMultiplyDEN >> 6;
057     }
058
059     /*Task1 init function*/
060     Script_Task1_init()
061     {
062         /*Initialize global variable*/
063         DCBusState = 0;
064         SpeedDiff = 0;
065         CurrentLimitOriginal = MotorLim; // Save the original motor
current limit set in MCEWizard.
066         CurrentLimitValue = CurrentLimitOriginal; // The initial
value needs to be synced with the original motor current limit set in
MCEWizard.
067         CurrentLimitTarget = CurrentLimitOriginal; // The initial
value needs to be synced with the original motor current limit set in
MCEWizard.
068         SpeedMode = 0;
069
070         /*local variable definition*/
071
072         /*Initialize local variable*/
073     }
074
075     /*Task1 script function*/
076     Script_Task1()
077     {
078         // DC bus state machine
079         if (DCBusState == 0) // DCBus is abnormal.
080         {
081             if (VDCBusLPF > VDCBusBrownIn)
082             {
083                 DCBusState = 1; // Shift to DCBus normal state.

```

Script Application Examples

Code Listing 7 Dynamic Motor Current Limit Script Code

```
084         }
085     }
086
087     if (DCBusState == 1)  // DCBus is normal.
088     {
089         if (VDCBusLPF < VDCBusBrownOut)
090         {
091             DCBusState = 0; // Shift to DCBus abnormal state.
092         }
093     }
094     // Calculate the difference between the target speed and the
    speed reference in preparation for motor current limit calculation.
095     SpeedDiff = TargetSpeed - SpdRef; // Find out the difference
    between the speed reference and the target speed.
096     if(SpeedDiff < 0) // The target speed is lower than the
    speed reference.
097     {
098         SpeedDiff = -1 * SpeedDiff; // Takes the absolute value of
    SpeedDiff.
099     }
100     // Calculate motor current limit based on speed reference
    and target speed.
101     if(SpeedDiff > SpeedDiffThresh) // The speed reference is
    more than SpeedDiffThresh counts different from the target speed. We
    need to increase the motor current limit to its original value
    temporarily.
102     {
103         CurrentLimitValue = CurrentLimitValue +
    CurrentLimitIncrement; // Increase the motor current limit by
    CurrentLimitIncrement until it reaches CurrentLimOriginal.
104         if (CurrentLimitValue > CurrentLimitOriginal) // Upper
    boundary check for CurrentLimitValue.
105         {
106             CurrentLimitValue = CurrentLimitOriginal;
107         }
108     }
109     else // The speed reference is no more than 100 counts
    different from the target speed. We need to decrease the motor current
    limit to CurrentLimitTarget.
110     {
111         if(CurrentLimitValue > (CurrentLimitTarget +
    CurrentLimitIncrement)) // The motor current limit value at this
    moment is greater than the specified motor current limit by more than
    CurrentLimitIncrement.
112         {
113             CurrentLimitValue = CurrentLimitValue -
    CurrentLimitIncrement; // Decrease the motor current limit target by
    CurrentLimitIncrement.
114         }
115         else // The motor current limit target is no more than
    the specified motor current limit by more than CurrentLimitIncrement.
116         {
```

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Code Listing 7 Dynamic Motor Current Limit Script Code

```
117         if (CurrentLimitTarget > CurrentLimitIncrement) //
            CurrentLimitTarget is greater than CurrentLimitIncrement. Boundary
            check needed for the following minus operation.
118         {
119             if (CurrentLimitValue < (CurrentLimitTarget -
            CurrentLimitIncrement)) // The motor current limit value at this
            moment is less than the specified motor current limit by more than
            CurrentLimitIncrement.
120             {
121                 CurrentLimitValue = CurrentLimitValue +
            CurrentLimitIncrement; // Increase the motor current limit target by
            CurrentLimitIncrement.
122             }
123             else // The motor current limit target falls between
            CurrentLimitTarget - CurrentLimitIncrement and CurrentLimitTarget +
            CurrentLimitIncrement.
124             {
125                 CurrentLimitValue = CurrentLimitTarget; // Set the
            motor current limit target to the specified motor current limit.
126             }
127         }
128         else // CurrentLimitTarget is no more than
            CurrentLimitIncrement.
129         {
130             if (CurrentLimitValue < CurrentLimitTarget)
131             {
132                 CurrentLimitValue = CurrentLimitTarget; // Set the
            motor current limit target to the specified LOW_SPEED motor current
            limit.
133             }
134             else // CurrentLimitValue is greater than
            CurrentLimitTarget
135             {
136                 if (CurrentLimitValue > (CurrentLimitTarget -
            CurrentLimitIncrement)) // The motor current limit value at this
            moment is less than the specified LOW_SPEED motor current limit by
            more than CurrentLimitIncrement.
137             {
138                 CurrentLimitValue = CurrentLimitValue +
            CurrentLimitIncrement; // Increase the motor current limit target by
            CurrentLimitIncrement.
140             }
141             else //The motor current limit value is within the
            range of CurrentLimitTarget and CurrentTarget - CurrentLimitIncrement.
142             {
143                 CurrentLimitValue = CurrentLimitTarget; // Set the
            motor current limit target to the specified motor current limit.
144             }
145             }
146         }
147     }
148 }
```

Script Application Examples

Code Listing 7 Dynamic Motor Current Limit Script Code

```

149      MotorLim = CurrentLimitValue; // Update MotorLim.
150
151      // Speed selection state machine
152      if (SpeedMode == 0) // Speed selection is in OFF state.
153      {
154          TargetSpeed = 0;
155          CurrentLimitTarget = CurrentLimitOriginal;
156          Command = 0; // Stop the motor.
157
158          if (ADC_Result0 > VLSStart)
159          {
160              SpeedMode = 1; // Shift to LOW_SPEED state.
161          }
162      }
163
164      if (SpeedMode == 1) // Speed selection is in LOW_SPEED
state.
165      {
166          if (ADC_Result0 > VHSStart)
167          {
168              SpeedMode = 2; // Shift to HIGH_SPEED state.
169          }
170          else
171          {
172              if (ADC_Result0 < VLSStop)
173              {
174                  SpeedMode = 0; // Shift to OFF state.
175              }
176              else //Stay in LOW_SPEED state.
177              {
178                  if (DCBusState == 1) // DC bus voltage is normal.
179                  {
180                      TargetSpeed = LowSpeedValue; // Update TargetSpeed.
181                      CurrentLimitTarget = CurrentLimitLS;
182                      Command = 1; // Start motor.
183                  }
184                  else // DC bus voltage is abnormal.
185                  {
186                      TargetSpeed = 0; // Reset TargetSpeed.
187                      CurrentLimitTarget = CurrentLimitOriginal; // When
the target speed is zero, motor current limit is restored back to the
original limit.
188                      Command = 0; // Stop motor.
189                  }
190              }
191          }
192      }
193
194      if(SpeedMode == 2) // Speed selection is in HIGH_SPEED
state.
195      {
196          if(ADC_Result0 < VHSStop)
197          {

```

Script Application Examples

Code Listing 7 Dynamic Motor Current Limit Script Code

```

198         SpeedMode = 1; // Shift to LOW_SPEED state.
199     }
200     else // Stay in HIGH_SPEED state.
201     {
202         if (DCBusState == 1) // DC bus voltage is normal.
203         {
204             // Target speed follows 2nd order polynomial curve for
HS.
205             TargetSpeed = HighSpeedValue; // Update TargetSpeed.
206             CurrentLimitTarget = CurrentLimitHS;
207             Command = 1; // Start motor.
208         }
209         else // DC bus voltage is abnormal.
210         {
211             TargetSpeed = 0; // Reset TargetSpeed.
212             CurrentLimitTarget = CurrentLimitOriginal; // When
the target speed is zero, motor current limit is restored back to the
original limit.
213             Command = 0; // Stop motor.
214         }
215     }
216 }
217 }

```

2.4.3 Dynamic Motor Current Limit Measurement Results

The following Figure 166 shows how the motor current limit was dynamically changed when the speed selection changed between OFF state and HIGH SPEED state. When the speed selection changed from OFF to HIGH SPEED state, the motor started to spin with its current limit `MotorLim` set to its original value saved in `CurrentLimitOriginal`. As the motor speed reference `SpdRef` approached its HIGH SPEED steady state target speed, the motor current limit `MotorLim` started to decrease with a rate of 100 counts / 10 ms. After about 330 ms, it reached its customized limit for HIGH SPEED level (`CurrentLimitHS = 819`). When the speed selection changed from HIGH SPEED to OFF state, the motor speed reference `SpdRef` was instantly reset, while the motor limit `MotorLim` started to ramp up with a rate of 100 counts / 10 ms, and stabilized at its original value saved in `CurrentLimitOriginal` after about 330 ms.

The following Figure 17 shows how the motor current limit was dynamically changed when the speed selection changed between OFF state and LOW SPEED state. When the speed selection changed from OFF to LOW SPEED state, the motor started to spin with its current limit `MotorLim` set to its original value saved in `CurrentLimitOriginal`. As the motor speed reference `SpdRef` approached its LOW SPEED steady state target speed, the motor current limit `MotorLim` started to decrease with a rate of 100 counts / 10 ms. After about 360 ms, it reached its customized limit for LOW SPEED level (`CurrentLimitLS = 519`). When the speed selection changed from LOW SPEED to OFF state, the motor speed reference `SpdRef` was instantly reset, while the motor limit `MotorLim` started to ramp up with a rate of 100 counts / 10 ms, and stabilized at its original value saved in `CurrentLimitOriginal` after about 360 ms.

The following Figure 18 shows how the motor current limit was dynamically changed when the speed selection changed between LOW SPEED state and HIGH SPEED state. When the speed selection changed from LOW SPEED to HIGH SPEED state, the motor speed reference `SpdRef` started to ramp up, while the motor current

Script Application Examples

limitMotorLim started to ramp up with a rate of 100 counts / 10 ms from its customized limit for LOW SPEED level (CurrentLimitLS = 519). It finally reached its original value saved in CurrentLimitOriginal. As soon as SpdRef approached its steady state HIGH SPEED target speed, the motor current limit MotorLim started to decrease with the same ramp rate, and eventually it was stabilized at its customized limit for HIGH SPEED level (CurrentLimitHS = 819). When the speed selection changed from HIGH SPEED to LOW SPEED state, the motor speed reference SpdRef started to ramp down, while the motor current limit MotorLim started to ramp up with a rate of 100 counts / 10 ms from its customized limit for HIGH SPEED level (CurrentLimitHS = 819). It finally reached its original value saved in CurrentLimitOriginal. As soon as SpdRef approached its steady state LOW SPEED target speed, the motor current limit MotorLim started to decrease with the same ramp rate, and eventually it was stabilized at its customized limit for LOW SPEED level (CurrentLimitLS = 519).

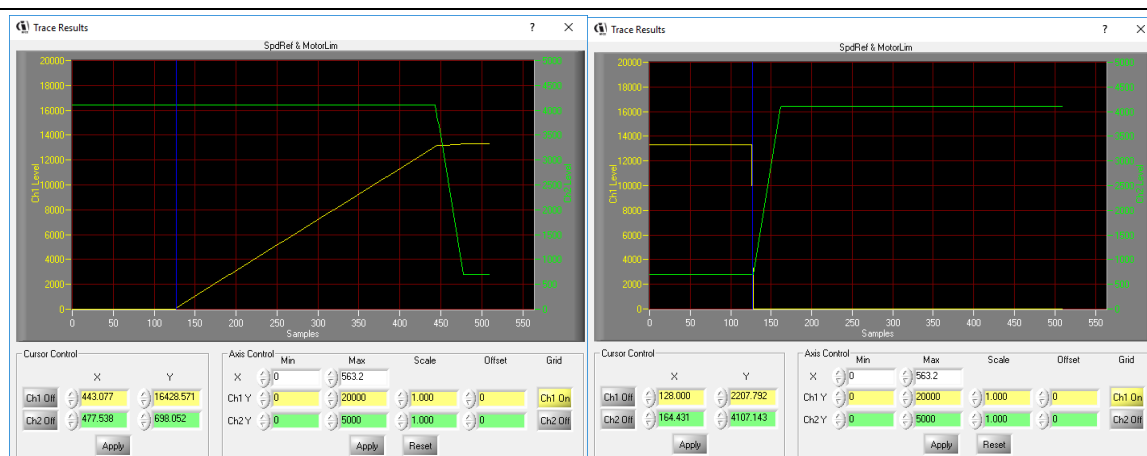


Figure 16 Motor Current Limit Screenshots (OFF <-> HIGH SPEED)

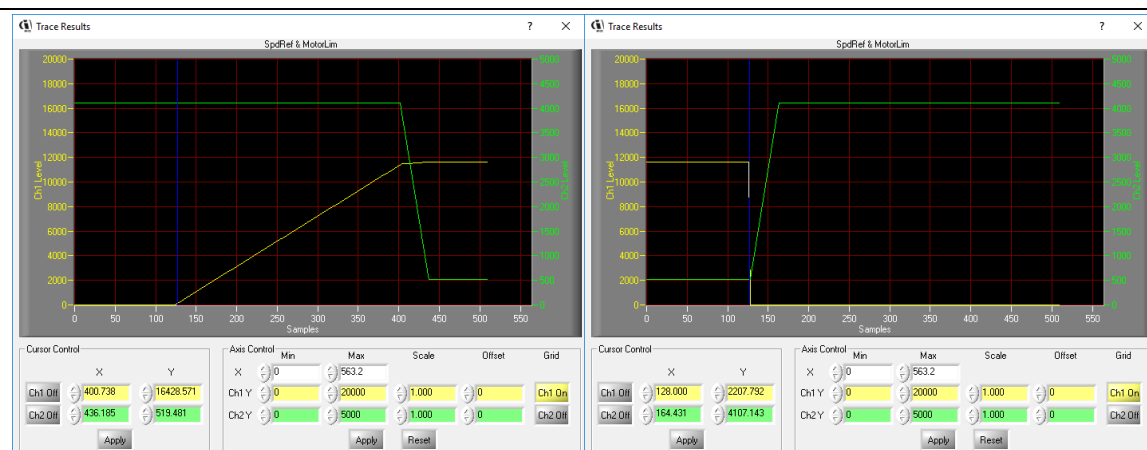


Figure 17 Motor Current Limit Screenshots (OFF <-> LOW SPEED)

Script Application Examples

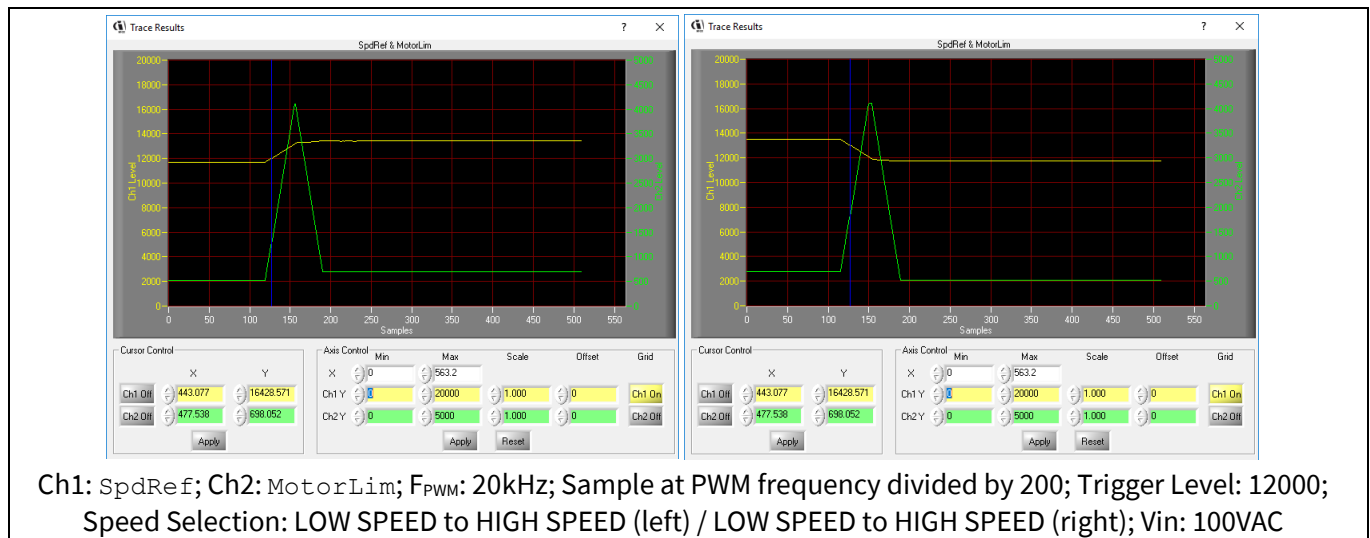


Figure 18 Motor Current Limit Screenshots (LOW SPEED <-> HIGH SPEED)

Script Performance Evaluation

3 Script Performance Evaluation

3.1 CPU Load Evaluation

The CPU resource is prioritized for the implementation of the motor and PFC control algorithm. The script engine is designed to take advantage of the spare CPU resource for the execution of the script program. The priority of the execution of the script program is lower than that of the motor and PFC control algorithm, so that it won't affect the performance of the control algorithm. However, CPU usage needs to be carefully evaluated before enabling the script function.

The estimated CPU usage varies depending on the configuration of the motor or PFC PWM frequency as well as the safety functions. MCEWizard can be used to estimate the CPU usage. If the CPU usage estimation is higher than 90% as shown in the left screenshot of the following Figure 19, then enabling script function is likely to overload the CPU. It is highly recommended to keep the CPU usage estimation to no more than 90% when the users intend to enable the script function.

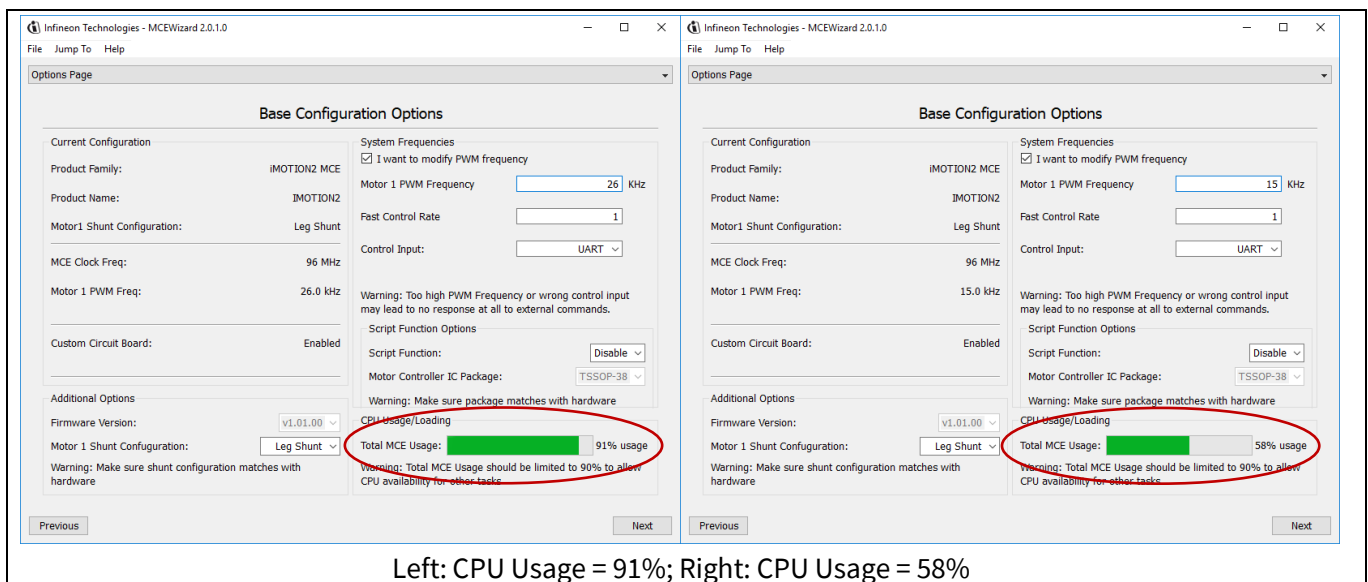


Figure 19 CPU Usage Estimation Using MCEWizard

The execution of the script program, depending on the complexity of the code and the configuration of the execution period and the execution step for each task, would have an impact on the CPU loading. It is recommended to evaluate the CPU load during run time with the script program enabled to ensure that the MCE is not overloaded.

The CPU load status can be obtained by reading the system parameter 'CPU Load' [2] using MCEDesigner [3]. The CPU load is represented in 0.1% [2]. The following Figure 20 shows that CPU load was 68.2% with the script described in Section 2.3 enabled while the motor was running with speed selection set to LOW SPEED level. The more complicated the script code becomes, the higher CPU load it would demand.

Script Performance Evaluation

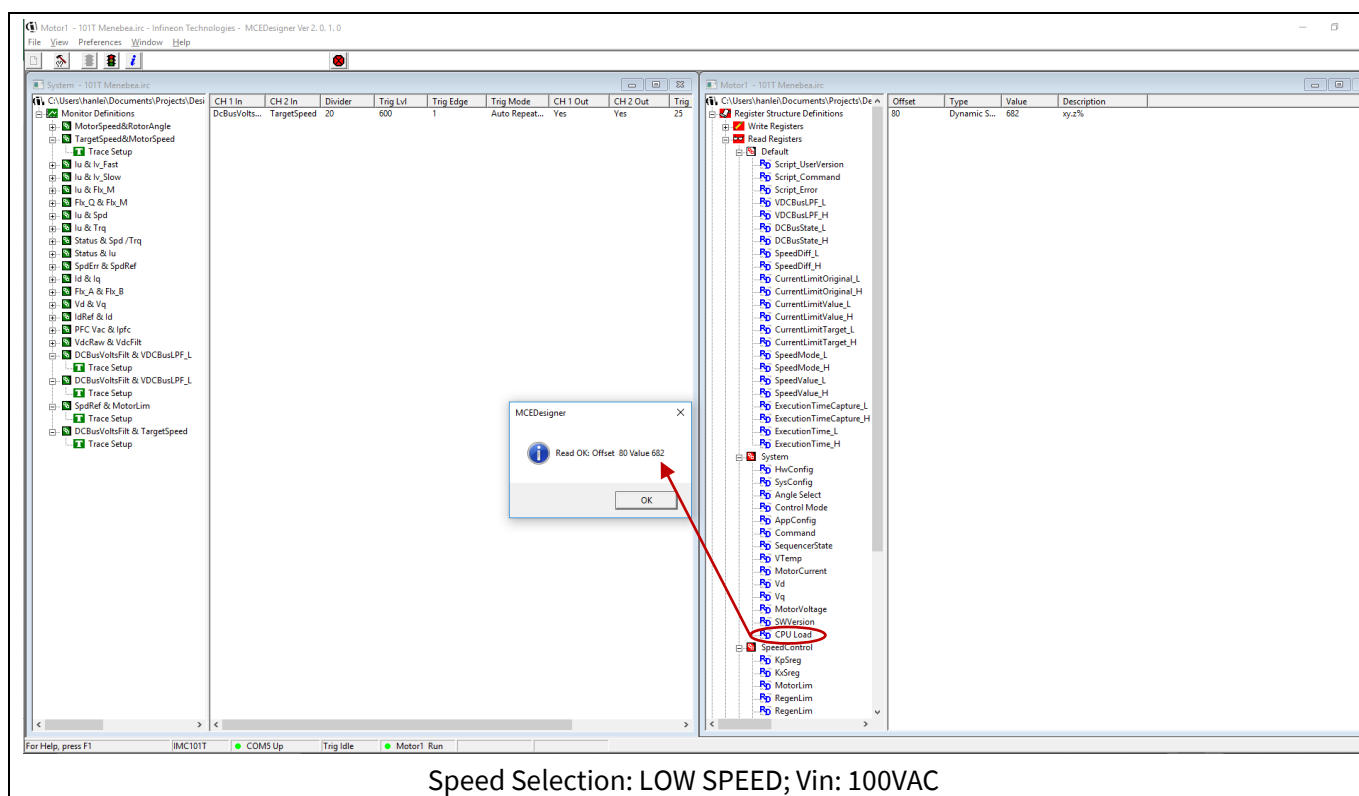


Figure 20 Reading 'CPU Load' Parameter Using MCEDesigner When Script Is Running

3.2 Script Task Timing

3.2.1 Script Task Timing Setup

The script engine supports 2 independent tasks, namely, Task 0 and Task 1, running concurrently. Task 0 is scheduled to be executed in the system tick interrupt which typically occurs every 1 ms. Task 1 is scheduled to be executed in the background loop task. Task 0 has higher priority than Task 1.

The user script program runs repeatedly on a configurable interval within Task 0 or Task 1 loop. The execution period of Task 0 is configurable in the script code by setting the parameter named `SCRIPT_TASK0_EXECUTION_PERIOD`. The granularity of the configurable execution period for Task 0 is 1 ms. For example, setting `SCRIPT_TASK0_EXECUTION_PERIOD` to 5 results in an execution period of $5 \cdot 1\text{ms} = 5\text{ms}$ for Task 0. The execution period of Task 1 is also configurable in the script code by setting the parameter named `SCRIPT_TASK1_EXECUTION_PERIOD`. The granularity of the configurable execution period for Task 1 is 10 ms. For example, setting `SCRIPT_TASK1_EXECUTION_PERIOD` to 5 results in an execution period of $5 \cdot 10\text{ms} = 50\text{ms}$ for Task 1.

The number of script instructions that gets executed by each task during every execution period can be configured in the script code by setting the parameter named `SCRIPT_TASK0_EXECUTION_STEP` for Task 0 or `SCRIPT_TASK1_EXECUTION_STEP` for Task 1 accordingly [2].

The actual timing setup for each script task needs to be adjusted according to the specific application requirements.

Script Performance Evaluation

3.2.2 Script Task Execution Time Evaluation

The execution time of Task 0 or Task 1 can be measured by taking advantage of the variable named `RunTimeCounter` provided by the MCE software. `RunTimeCounter` is a free running timer with 1 ms resolution that is accessible from within the script code. As an example shown in the following Code Listing 8, one can capture the value of `RunTimeCounter` at the beginning of Task 1 and save it in a variable named `ExecutionTimeCapture`. At the end of Task 1, the value of `RunTimeCounter` gets captured again and then subtracted with the value of `ExecutionTimeCapture` to obtain the execution time for Task 1 which is saved in the variable named `ExecutionTime`. As a global variable, the value of `ExecutionTime` can be read using MCEDesigner during run time.

The script program described in Section 2.4 was used as an example to evaluate execution time for Task 1, whose execution period was set to 10 ms. The following Figure 21 shows the value of `ExecutionTime_L` (lower 16 bit of `ExecutionTime`) was 4 with the script enabled while the motor was running with speed selection set to LOW SPEED level. This shows the loop execution time of Task 1 was about 4 ms while the motor was running. Since the actual execution time for Task 1 was shorter than the specified execution period, it indicates that Task 1 didn't overrun.

The more complicated the script code in each task becomes, the longer loop execution time it would result in. As long as the loop execution time for a script task doesn't exceed the specified loop execution period, the script task wouldn't overrun and the timing requirements can always be guaranteed. If the loop execution time for a script task exceeds the specified loop execution period, then the desired timing for this script task cannot be guaranteed. In that case, the script task will continue to finish up the on-going loop execution and then immediately start a new loop execution, in which case the actual loop execution period for this script task is determined by the loop execution time.

If the execution period of Task 0 is set to 1 ms, then it is not possible to use `RunTimeCounter` to estimate the execution time of Task 0 due to the resolution limit. In that case, the CPU load can be checked to indirectly estimate the execution status of Task 0. As long as the actual CPU load doesn't exceed 95%, the specified number of instructions for Task 0 can be guaranteed to be executed within 1 ms period without over-run situation. If Task 0 hasn't finished up executing the specified number of instructions by the end of the 1 ms period, then it would overload the CPU. In that case, an execution fault would be registered by asserting the 10th bit of the variable `FaultFlags` [2], and cause the system to go into fault state when the safety functions are disabled, or going into failsafe mode when the safety functions are enabled.

Code Listing 8 Execution Time Measurement for Task 1 Using `RunTimeCounter` in Script Code

```

001      /*****/
002      /* Global variable definition */
003      int ExecutionTimeCapture;
004      int ExecutionTime;
005      /*****/
006      /*Task1 script function*/
007      Script_Task1()
008      {
009          ExecutionTimeCapture = RunTimeCounter;
010      ...
011      ...
012      ...
013          ExecutionTime = RunTimeCounter - ExecutionTimeCapture;
014      }
```

Script Performance Evaluation

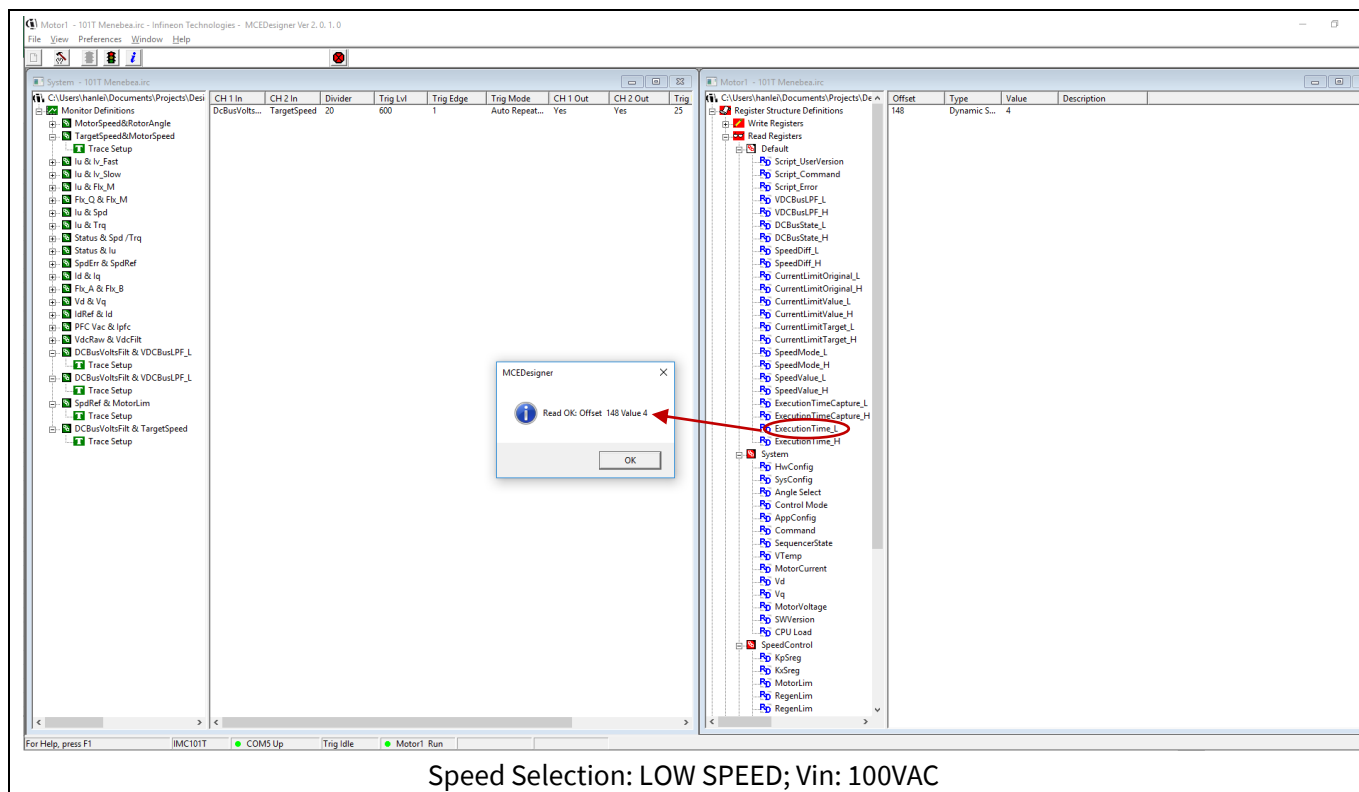


Figure 21 Reading 'ExecutionTime_L' Variable Used in Script Code Using MCEDesigner

3.2.3 Script Task Execution Period Evaluation

The variable `RunTimeCounter` can also be used to measure the loop execution period of Task 0 or Task 1. `RunTimeCounter` is a free running timer with 1 ms resolution that is accessible from within the script code. The following Code Listing 9 shows an example of using `RunTimeCounter` to measure the loop execution period of Task 1.

Code Listing 9 Loop Execution Period Measurement for Task 1 Using `RunTimeCounter` in Script Code

```

001  /*****
002  /* Global variable definition */
003  int LoopExecutionPeriodCapture;
004  int LoopExecutionPeriod;
005  /*****
006  /*Task1 script function*/
007  Script_Task1()
008  {
009      LoopExecutionPeriod = RunTimeCounter -
LoopExecutionPeriodCapture;
010      LoopExecutionPeriodCapture = RunTimeCounter;
011      ...
012      ...
013      ...
014  }
```

Script Guidelines & Limitations

4 Script Guidelines & Limitations

- The maximum number of global variables supported by the script engine is 30. The maximum number of local variables for each task is 24. The intercommunication between Task 0 and Task 1 can be realized by using global variables. Only global variables are accessible from MCEDesigner or user UART interface. It is recommended to define a variable as the global type if users intend to read its value during run time using MCEDesigner [3].
- The maximum allowed script code size is 16kB. This is equivalent to approximately 1500 lines of script code. The actual object code size is reported in the compiled script object file. An example is shown at line 008 and line 009 in Code Listing 2.
- The script engine only supports 32 bit signed integer type of variables, so that the floating point type of variables or constants need to be converted to Q format for proper processing in the script code. An example of Q format conversion can be found in Section 2.3.3.
- The script engine supports 2 independent tasks, namely, Task 0 and Task 1, running concurrently. The user script program runs repeatedly on a configurable interval within Task 0 or Task 1 loop. The shortest possible execution period is 1 ms for Task 0, and 10 ms for Task 1. The execution period for each task can be configured to the multiples of 1 ms for Task 0 or 10 ms for Task 1 in the script code. Task 0 has higher priority than Task 1. The actual timing setup for each script task needs to be adjusted according to the specific application requirements.
- The analog input pins are sampled by MCE every 1 ms. According to Nyquist theorem, if the input analog signal frequency is higher than 500 Hz, then it cannot be properly represented by the sampling method of MCE script engine. It is highly recommended that an analog LPF should be used to attenuate the input analog signal frequency that is higher than 500 Hz to minimize the aliasing effect.
- The GPIO pins are sampled and updated by MCE every 1 ms. Any GPIO input changes that occur faster than 1 ms will not be properly captured by the sampling method of MCE script engine. Similarly, any GPIO output changes that happen faster than 1 ms cannot be realized by using the script program. The fastest possible frequency generated by toggling an GPIO pin using script is 500 Hz.
- It is recommended to change a specific GPIO pin value only once within the Task 0 or Task 1's loop. If there are more than one instances of GPIO manipulation within Task 0 or Task 1's loop, only the last operation would take effect due to the unique GPIO update mechanism in MCE software. For example, given that a specific GPIO pin is originally reset to logic low level, if this GPIO pin is set to logic high level at the beginning of Task 0, and then it gets reset at the end of Task 0, the actual GPIO will not toggle as expected. Instead, it will remain in reset state after the execution of Task 0 loop.
- For those time critical functions, it is recommended to be implemented in Task 0, whose minimum execution period can be set to 1 ms. For those functions that are not time critical, either Task 0 or Task 1 can be used. In that case, it is recommended to set the execution period of the script task to 50 ms typically.
- Digital filter implementation using the script can be realized in Task 0 with sampling frequency up to 1 kHz due to the minimum execution period limit of Task 0. As a result, signal frequency higher than 500 Hz cannot be properly sampled and processed.
- The script language doesn't support the implementation of infra-red communication.
- The script language can support Programmable Logic Controller (PLC) as long as the minimum timing requirement is no less than 1 ms.
- The script language doesn't support the implementation of digital Hall Effect sensors.

References

5 References

- [1] iMOTION™ IMC100 High Performance Motor Control IC Series Datasheet (REV 1.5).
- [2] iMOTION™ Motor Control Engine Software Reference Manual (REV 1.3).
- [3] MCEDesigner User Guide (REV 2.0.1.1).
- [4] MCEWizard 2.0 User Guide (REV 2.0.1.1).

Revision history

Document version	Date of release	Description of changes
1.0	9/5/2018	Initial release.
1.1	6/5/2020	Analog input sampling rate and GPIO update rate are revised. Example code in Section 2.1.4, 2.3.4, and 2.4.2 revised to use CONST keyword to define constants.

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