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Continuous Variable PWM Frequency Manual

Revision 0.3

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Table of Contents

1. Introduction

The Gen 5 and CMxxx inverters support variable Pulse Width Modulation (PWM) frequency. This feature is not available in Gen 3 (PMxxx) or Gen 4 (RMxxx) inverters. PWM frequency is the rate at which the inverter switches the DC bus voltage to produce AC voltage waveforms for the motor. It can be advantageous to adjust the PWM frequency depending on motor characteristics and/or inverter operating characteristics.

This document describes setup and operation of continuously variable PWM frequency for the CMxxx inverters. The variable PWM frequency features described in this manual are only applicable to the CMxxx inverters. These inverters run a firmware version with a release version of 65XX. This feature was introduced in 6526 and present in all firmware's released after. The table below lists the supported inverters and respective PWM limitations:

Inverter	Allowed Continuous Variable PWM Range [kHz]*	Allowed Stall PWM Range [kHz]*
CM200DX	6 – 24	2 – 24
CM200DZ	6 – 24	2 – 24
CM350DZ	6 – 24	2 – 24
CM350SiC	6 – 16	6 – 16

* The above PWM frequency ranges are the maximum allowed. Not all inverter/motor combinations may work well at all frequencies. Most motor/inverter combinations work well in the 8 – 12 kHz range. If it is desired to operate outside this range consulting with Cascadia Motion technical support would be advised.

The Continuous Variable PWM functionality takes in user inputs of a minimum, maximum, and nominal PWM frequency and runs an internal routine to apply the optimal PWM for the given operating point within those constraints.

2. Continuous Variable PWM Method

The current capability of the inverter depends on several factors:

- Current rating of the power module
- PWM Frequency, higher frequency will reduce maximum current rating
- DC Bus Voltage, higher DC bus voltage will reduce maximum current rating
- Motoring vs Regeneration may affect current rating
- Inverter Coolant Temperature, higher temperature will reduce maximum current rating

The Gen 5 software will adjust the current limit based on these factors. The Continuous Variable PWM functionality takes all these factors into account to apply the optimal PWM that provides the highest current rating while maintaining a PMW frequency adequate for control of the motor.

With Continuous Variable PWM Method the PWM frequency only changes in increments of 1 [kHz]. The only instance that may result in a transition greater than 1 [kHz] is in or out of stall. The minimum time the Continuously Variable PWM Method will stay at a given PWM frequency before transitioning is controlled by the dwell time parameter PWM_Var_Dwell_Rate_EEPROM_(x3ms).

The following sections present a conceptual view of what the Continuous Variable PWM Method would look like if mapped over the full operating space for an iM-375DZ-D. This is purely for reference. The actual map is calculated real time. Stall is not present in these plots, just for visual clarity.

2.1 Nominal PWM

Continuous Variable PWM Method will prioritize running at the nominal PWM defined by PWM_Nominal_Freq_EEPROM_(kHz) unless some other condition is commanded that would require a different PWM to best attain that commanded condition. This can be simply summarized as a starting point of a constant PWM across all operating conditions, as seen in Figure 1.

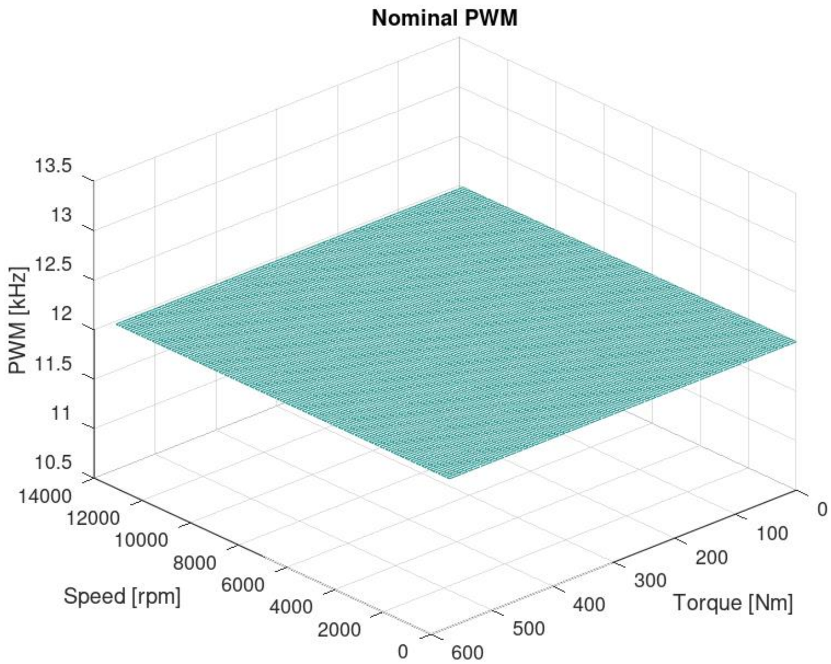

Figure 1: Example Nominal PWM Frequency Application

The nominal PWM frequency acts as the reference point for the desired PWM frequency over a majority of the operating space. This value is generally chosen on criteria of sound, drivability, and noise reduction in the system.

2.2 Speed Limitations

Electric motors have an inherent minimum PWM frequency to maintain control at a certain speed. The general metric is that at least 10 switching instances should be present per electrical rotation. There are other factors that go into this when determining drivability and control bandwidth, but this simple metric effectively states that at higher speed a higher PWM frequency is required. The Continuous Variable PWM Method will chose the minimum PWM frequency that can run at a given speed without going below the (Minimum PWM Frequency Parameter) or above the (Maximum PWM Frequency Parameter). Looking purely at speed for the metric of minimum PWM required the Continuous Variable PWM map would look like the example in Figure 2 (for 10 pole motor used in iM-375DZ-D).

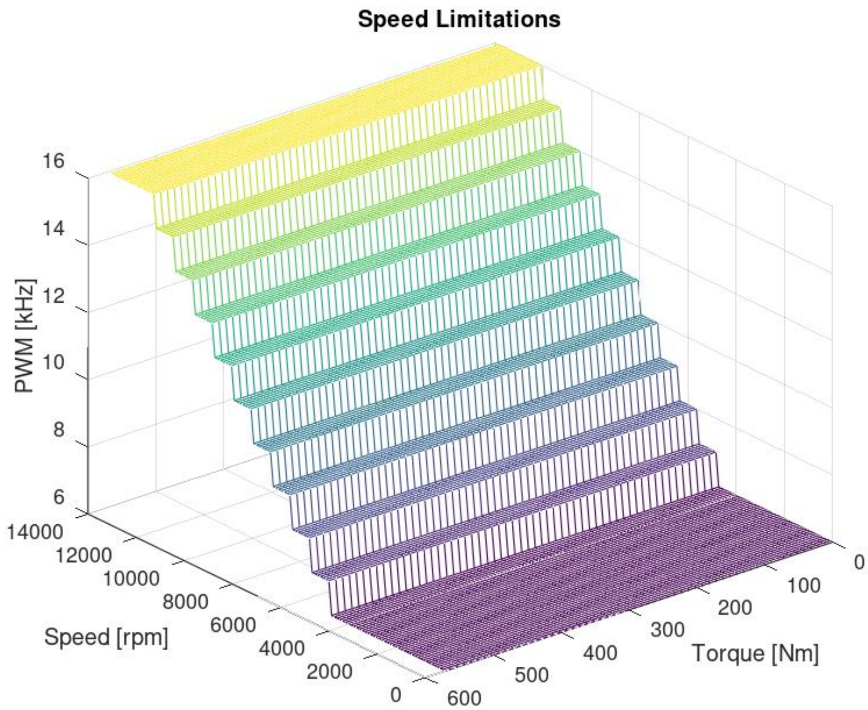

Figure 2. Example of Speed Limitation for Continuous Variable PWM Method

There is some inherent safety built into the selection of the maximum PWM frequency. Selecting a PWM frequency that violates an electric fundamental frequency of less than 10x the EEPROM parameter Motor_Overspeed_EEPROM_(RPM) will reset the parameter to the minimum PWM frequency as calculated by:

PWM frequency = Motor_Overspeed_EEPROM_(RPM)*Poles/120*10 rounded up.

2.3 Current Limitations

The most complex relationship with determining the appropriate PWM revolves around the current limitations of the inverter power module. All the factors listed on Page 3 change what the capability of the inverter is. Continuous Variable PWM Method considers all these factors to provide a maximum current rating for the inverter. It then optimizes which PWM frequency is the lowest possible frequency that will achieve the intended operating point, but will not chose a PWM above the nominal PWM_Nominal_Freq_EEPROM_(kHz) or below the minimum PWM PWM_Minimum_Variable_Freq_EEPROM_(kHz). For example, looking solely at attaining the current request the Continuous Variable PWM frequency map would look like Figure 3 (for iM-375DZ-D).

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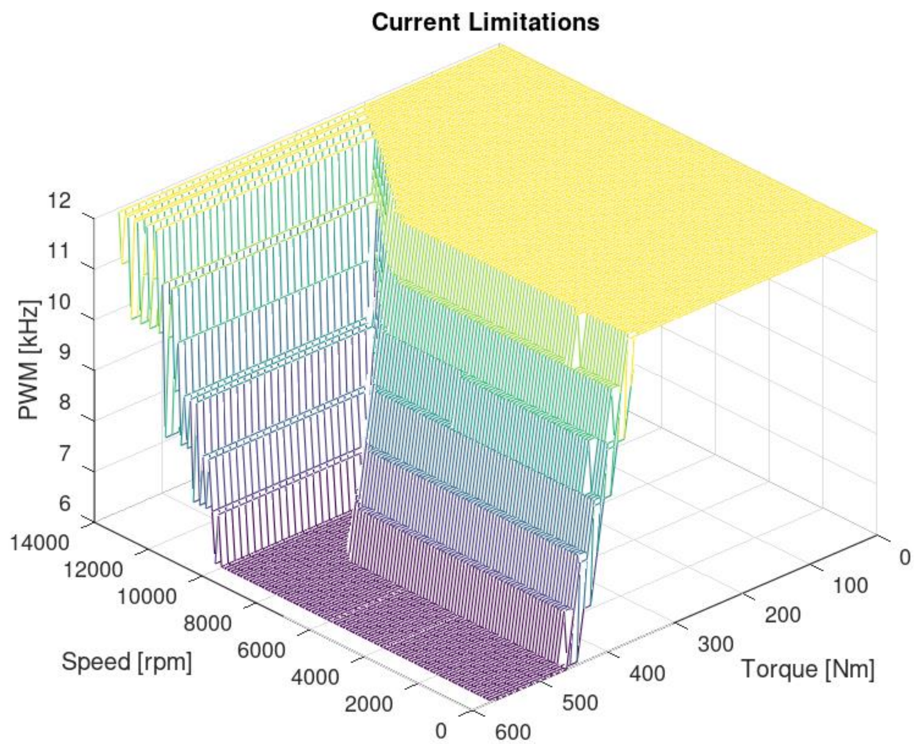

Figure 3. Example of Current Limitation for Continuous Variable PWM Method

There is hysteresis built into the PWM frequency transitions that is not shown in the above figure. The inverter will transition to a lower PWM frequency, to gain more current capability, when it reaches 90% of its current limit at the current PWM frequency, and will increase its PWM frequency, trending towards nominal for improved noise and drivability, when the current in the inverter drops below to 80% of the capability at the higher PWM frequency.

2.4 Continuous Variable PWM Map

The Continuous Variable PWM Method then considers the minimum PWM frequency from different criteria such as the speed and current presented prior and selects the highest of the PWM frequencies required by each criteria collectively. It also then applies the saturation from the Minimum PWM Frequency EEPROM Parameter and Maximum PWM Frequency EEPROM Parameter. This results in a map that would look like Figure 4 (for iM-375DZ-D).

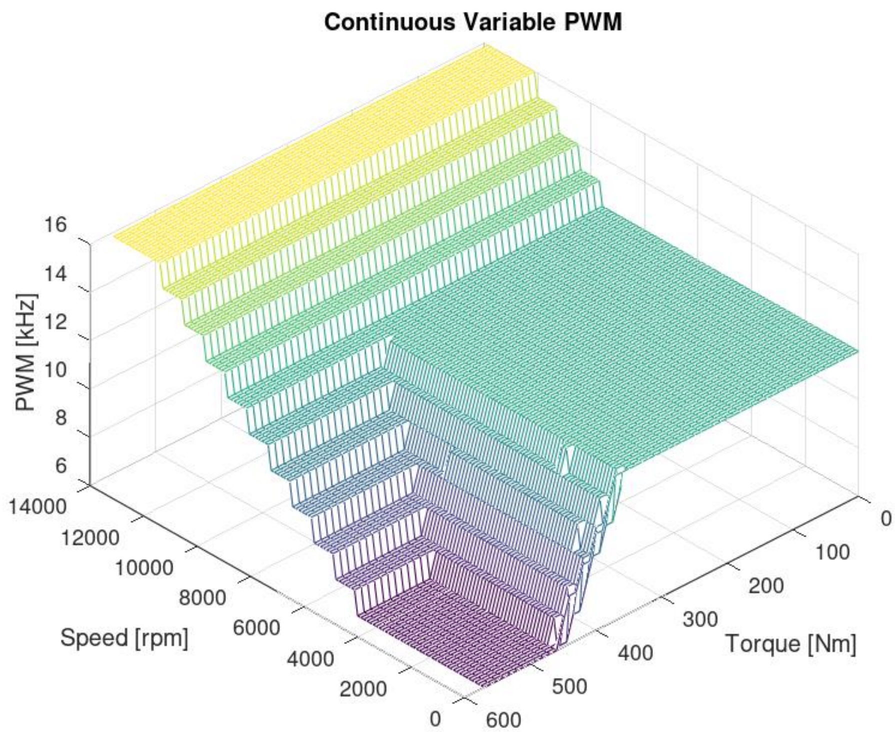

Figure 4. Example of PWM frequency map for Continuous Variable PWM Method

The above map is calculated continuously by the inverter for the current operating point and the figure above is just for a representation and idea of what to expect. High current commands will drop the PWM as necessary, until the PWM must increase to maintain control with higher speed.

2.5 Low Speed/Stall Condition

Features related to Low Speed / Stall operating condition are still present and the feature applied with the same criteria as it has been prior. The inverter will enter stall if:

- Motor Electrical Speed < 30 Hz.
- Motor Current > 20% of stall PWM current limit (calculated internally).

When entering the Stall condition, the inverter can switch to a different and lower PWM frequency to maximize the amount of available current. The EEPROM Parameter controlling the frequency used in Stall cannot be set greater than the minimum PWM Frequency.

It is extremely important to note that some motors can have extremely high losses or become uncontrollable if operated at very low PWM frequencies. When the PWM frequency is lowered the PWM induced ripple current in the motor will increase. A low Stall PWM frequency should not be chosen unless the operation at that PWM frequency has been validated.

2.6 Modes

The Continuous Variable PWM Method can be used in three different modes.

- Nominal PWM Frequency Only (With Stall)
- Continuous Variable PWM Method Enabled (With Stall)
- Continuous Variable PWM Method Enabled (Without Stall)

Nominal PWM Frequency Only (With Stall) is chosen by setting:

- PWM_Var_Freq_Mode_EEPROM(0=NOM_1=VARS_2=VAR) = **0**

This will run the nominal PWM set by PWM_Nominal_Freq_EEPROM_(kHz) for all operating conditions other than stall, and will run the stall PWM PWM_Stall_Freq_EEPROM_(kHz) when the conditions are met for stall.

Continuous Variable PWM Method Enabled (With Stall) is chosen by setting:

- PWM_Var_Freq_Mode_EEPROM(0=NOM_1=VARS_2=VAR) = **1**

This mode is typically what is used with Cascadia Motion motors. This mode will allow entering the Stall mode when the conditions are met.

Continuous Variable PWM Method Enabled (Without Stall) is chosen by setting:

- PWM_Var_Freq_Mode_EEPROM(0=NOM_1=VARS_2=VAR) = **2**

This setting has the same functionality as Mode “1” but prevents entering the Stall Condition region. This mode is useful for motors that either don’t work well at lower PWM frequency or the inverter doesn’t benefit from it.

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3. Continuous Variable PWM Operation

3.1 EEPROM Settings

The following EEPROM settings are used to setup Continuous Variable PWM.

EEPROM Parameter	GUI Address	CAN Address	Value Range	Description
PWM_Nominal_Freq_EEPROM_(kHz)	0x0150	241	6 – 24	This sets the nominal PWM frequency in kHz. The typical setting is 10 [kHz]
PWM_Minimum_Variable_Freq_EEPROM_(kHz)	0x01BE	246	6 – 24	This sets the Minimum PWM used by the Continuously Variable PWM in [kHz]. The typical setting is 6 [kHz]
PWM_Maximum_Variable_Freq_EEPROM_(kHz)	0x01BF	247	6 – 24	This sets the Maximum PWM used by the Continuously Variable PWM in [kHz]. The typical setting is 12 [kHz]
PWM_Stall_Freq_EEPROM_(kHz)	0x01BD	245	2 – 24	This sets the Stall PWM. The typical setting is 2 [kHz]
PWM_Var_Freq_Mode_EEPROM (0=NOM_1=VARS_2=VAR)	0x0179	250	0,1,2	This sets the PWM mode you wish to run. • 0 = Nominal PWM only, with stall region • 1 = Continuous Variable PWM, with stall region • 2 = Continuous Variable PWM, no stall region
PWM_Var_Dwell_Rate_EEPROM_(x3ms)	0x01C0	248	1 – 65535	This sets the minimum time the Continuous Variable PWM Method will stay at a given PWM frequency before transitioning. A typical setting is 10 for 0.03 [s].

Alongside the EEPROM settings listed above, it is highly recommended to limit the torque ramp rate of the system (via EEPROM Torque_Rate_Limit_EEPROM_(Nm)_x_10) to no more than 70 Nm/3ms or a setting of 700 for HVH250-115 motor core motors (e.g. iM-225/iM-375). This rate corresponds to a torque ramp rate of ~ 23,000 Nm/s, any rate faster than this may cause stability issues.

3.2 Recommended EEPROM Settings

The Cascadia Motion motors and inverters (e.g. iM-225DX-D, im-375DZ-D, iM425DZ-D, etc.) are typically configured to have the recommended settings as shown in the table below.

EEPROM Parameter	Recommended Setting
PWM_Nominal_Freq_EEPROM_(kHz)	10
PWM_Minimum_Variable_Freq_EEPROM_(kHz)	6
PWM_Maximum_Variable_Freq_EEPROM_(kHz)	12
PWM_Stall_Freq_EEPROM_(kHz)	2
PWM_Var_Freq_Mode_EEPROM (0=NOM_1=VARS_2=VAR)	1
PWM_Var_Dwell_Rate_EEPROM_(x3ms)	10

3.3 EEPROM Setting Safety Checks

To help avoid improper setting of PWM frequency values, the Continuously Variable PWM Method has some built in safety checks for the EEPROM parameters associated with it. These checks only apply when the Continuously Variable PWM Method is enabled via the PWM_Var_Freq_Mode_EEPROM(0=NOM_1=VARS_2=VAR) parameter.

In the order these checks are applied, they are listed below:

1) If any of the PWM frequency settings are set outside the acceptable range of the inverter they default to 12 [kHz].
   a) Example: For an iM-375DZ-D using a CM350DZ if the PWM_Nominal_Freq_EEPROM_(kHz) is set to 30 [kHz] it will revert to 12 [kHz].

2) If the Maximum PWM setting (PWM_Maximum_Variable_Freq_EEPROM_(kHz)) is less than the minimum required PWM for 10 switching events per electrical revolution using the speed from the Max Speed EEPROM Parameter, then the Maximum PWM Frequency setting is raised to the PWM frequency required for 10 switches per electrical cycle.
   a) Example: For the iM-375DX-D if PWM_Maximum_Variable_Freq_EEPROM_(kHz) is set to 8 [kHz] and Max_Speed_EEPROM_(RPM) is set to 11000 rpm. The PWM_Maximum_Variable_Freq_EEPROM_(kHz) will change to 10 [kHz]. Based on, 11000 [rpm] * 10 [Poles]/120 * 10 = 9166.7 [Hz] which rounds up to 10 [kHz].

3) If the Minimum PWM frequency (PWM_Minimum_Variable_Freq_EEPROM_(kHz)) is greater than the Nominal PWM frequency (PWM_Nominal_Freq_EEPROM_(kHz)) the Minimum PWM frequency EEPROM parameter will be set to the Nominal PWM frequency.
   a) Example: If PWM_Minimum_Variable_Freq_EEPROM_(kHz) is set to 10 [kHz] and PWM_Nominal_Freq_EEPROM_(kHz) is set to 8 [kHz], PWM_Minimum_Variable_Freq_EEPROM_(kHz) will revert to 10 [kHz]

4) The Maximum PWM frequency (PWM_Maximum_Variable_Freq_EEPROM_(kHz)) cannot be less than the Nominal PWM frequency (PWM_Nominal_Freq_EEPROM_(kHz)). If so the Maximum PWM frequency will be set to the Nominal PWM frequency.

5) The Stall PWM frequency (PWM_Stall_Freq_EEPROM_(kHz)) cannot be greater than the Minimum PWM frequency (PWM_Minimum_Variable_Freq_EEPROM_(kHz). If so the Stall PWM frequency will be set to the Minimum PWM frequency.
   a) When the Continuously Variable PWM Method is not enabled this check happens with the Nominal PWM frequency.

4.0 Upgrading from 6525 or Earlier

New Cascadia Motion CMxxx inverters may come with the appropriate firmware already flashed for Continuously Variable PWM Method, but it is also possible to upgrade an existing CMxxx inverters with older firmware to use this functionality. All this requires is reprogramming the inverter with the latest CM firmware (version equal to our higher than 6526). Continuously Variable PWM Method was first introduced in firmware 6526. Reprogramming the inverter is a topic covered in the general Software Manual and will not be discussed here. Instead, a simple guide to check the new Continuously Variable PWM Method settings are correct is presented below.

Step 1: Save all existing EEPROM parameters to a file for reference.

- Reprogramming can reset resolver calibrations and user settings, so it's best to save these before reprogramming.

Step 2: Reprogram the inverter with software 6526 or later.

- After the reprogram the GUI may present an error saying the EEPROMs have changed. Click OK as this is expected.

Step 3: Check and change the EEPROM settings.

- The new list of EEPROMs should now include those listed in this manual but they may have odd or erroneous values.

- Change these to the desired settings. The recommended settings are listed with the EEPROM descriptions in this manual.
- Set the PWM_Var_Freq_Mode_EEPROM (0=NOM_1=VARS_2=VAR) = 1 to turn on the CVPWM

Step 4: Power cycle the inverter and check that the EEPROM values are as expected.

Revision History

Version	Description of Versions / Changes	Responsible Party	Date
0.1	Initial version.	Christian Tigges	10/28/2022
0.2	Adding guide to upgrade firmware to use CVPWM.	Christian Tigges	12/1/2022
0.3	Editing for clarity and consistency.	Chris Brune	12/2/2022