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Low Speed Operation

Revision 0.5

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Table of Contents

Revision History

Version	Description of Versions / Changes	Responsible Party	Date
0.1	Initial version	Chris Brune	10/22/2014
0.2	Added information on the removal of short period higher current feature for firmware 651E and newer. Added ratio of current information for CM inverters for firmware 651E and newer.	Andrew Louie	2/24/2022
0.3	Add low speed current limit information for CM inverters for firmware 651E and newer.	Andrew Louie	3/2/2022
0.4	Correct CM200DX and CM200DZ output current plots	Andrew Louie	3/8/2022
0.5	Change CM inverter output current plots to Arms. Added detail on output current at zero speed.	Andrew Louie	3/15/2022

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1. Introduction

Inverters can be subject to excessive concentration of heat when the output frequency for the inverter (motor speed) is quite low.

If one imagines a sine wave of current that normally flows from an inverter the instantaneous value of the current is constantly moving from a negative peak value to a positive peak value. The constantly changing current causes the losses in the IGBT transistors and diodes of the inverter to be spread equally between all the parts. If the sine wave stops at a particular position, for example at the peak of the sine wave, then the losses will be concentrated in a subset of the power transistors/diodes.

To keep the heating of the power transistors/diodes at a reasonable level the software reduces the maximum current that can be output when operated at low frequency.

To try and minimize the effect on the performance of the motor the inverter does allow a higher current for a short period of time. However, this short period higher current feature is removed in firmware version 651E and newer versions. It was removed in 651E because it is not very effective. Stall current limits were increased by allowing variable PWM and higher current limits at lower switching frequency.

The amount of current allowed in the steady state depends on the output frequency of the inverter.

Inverter output current ratings are typically listed in Amps Root Mean Square (A_{RMS}). Current in A_{RMS} is relevant for sinusoidal current. When the motor is spinning current output is sinusoidal. However, at zero motor speed current is DC. At zero speed the amount of current in each motor phase winding will depend on the motor position. A single phase winding can vary ± maximum output current. zero speed output current in amps DC (A_{DC}) is equal to the output current listed in A_{RMS} times $\sqrt{2}$. The A_{DC} value is what a current meter would reflect when motor is not spinning, even if meter is set to RMS measurement mode on some meters.

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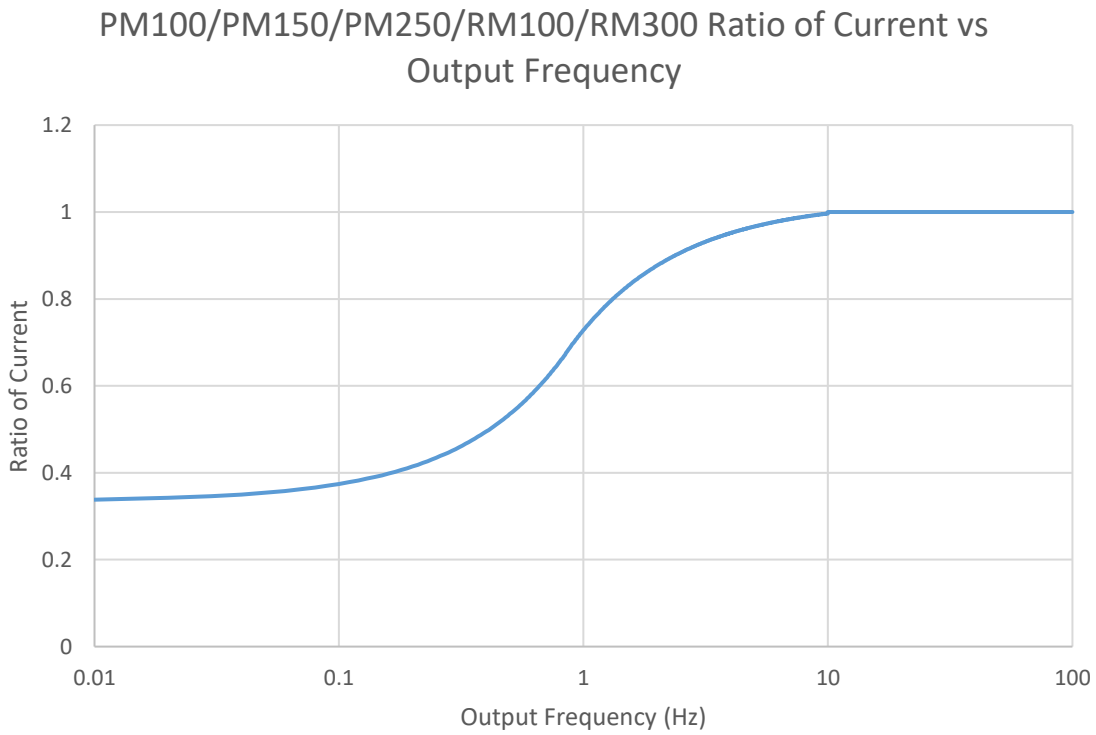
2. PM & RM Series Inverters



Above is a graph of the output current capability versus frequency for PM100, PM150, PM250, RM100, and RM300. A value of 1 represents the maximum rating of the inverter. For example, for a PM100DX the rated current is 350Arms at 12kHz PWM switching frequency, so the value of 1 represents 350Arms at 12kHz PWM switching frequency.

As of 10/22/2014 all PM series and RM series inverters have used the same current ratio versus frequency chart shown above. This may change in the future as we do more analysis on the allowable current at low speeds.

3. CM Series Inverters

CM series inverters with 651D and older firmware use the same current ratio versus frequency chart shown above for PM series and RM series inverters. For CM series inverters with 651E and newer firmware, the ratio of current is dependent on PWM switching frequency. CM series inverters have current limits that depend on PWM switching frequency, DC bus voltage, and coolant temperature. The current capability with 45^{O}C coolant and nominal bus voltage (350/650 VDC) for CM inverters while motoring is shown in the following pages.

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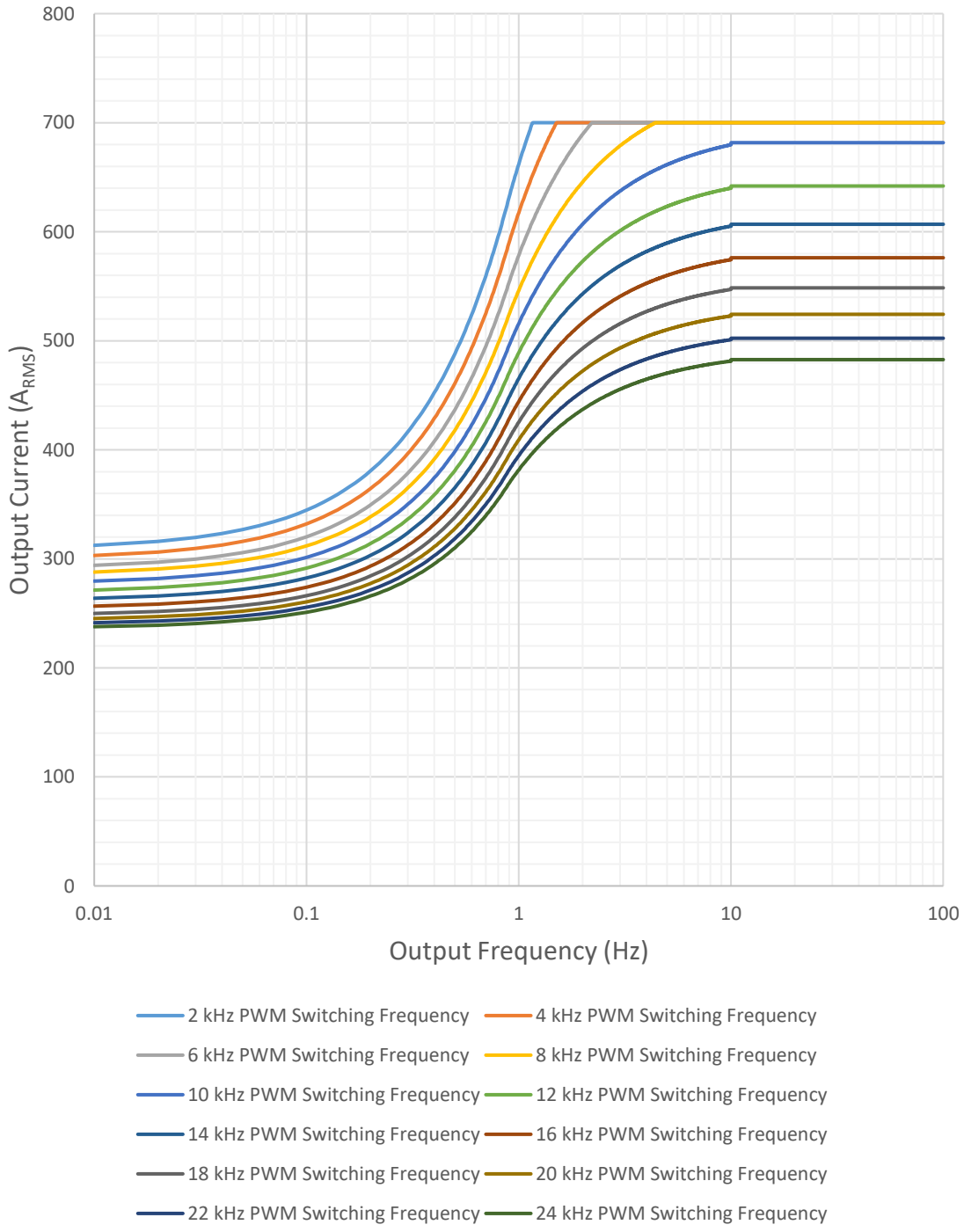
CM200DX Output Current vs Output Frequency at Various Switching Frequency with 45°C Coolant at 350VDC Bus Voltage Motoring



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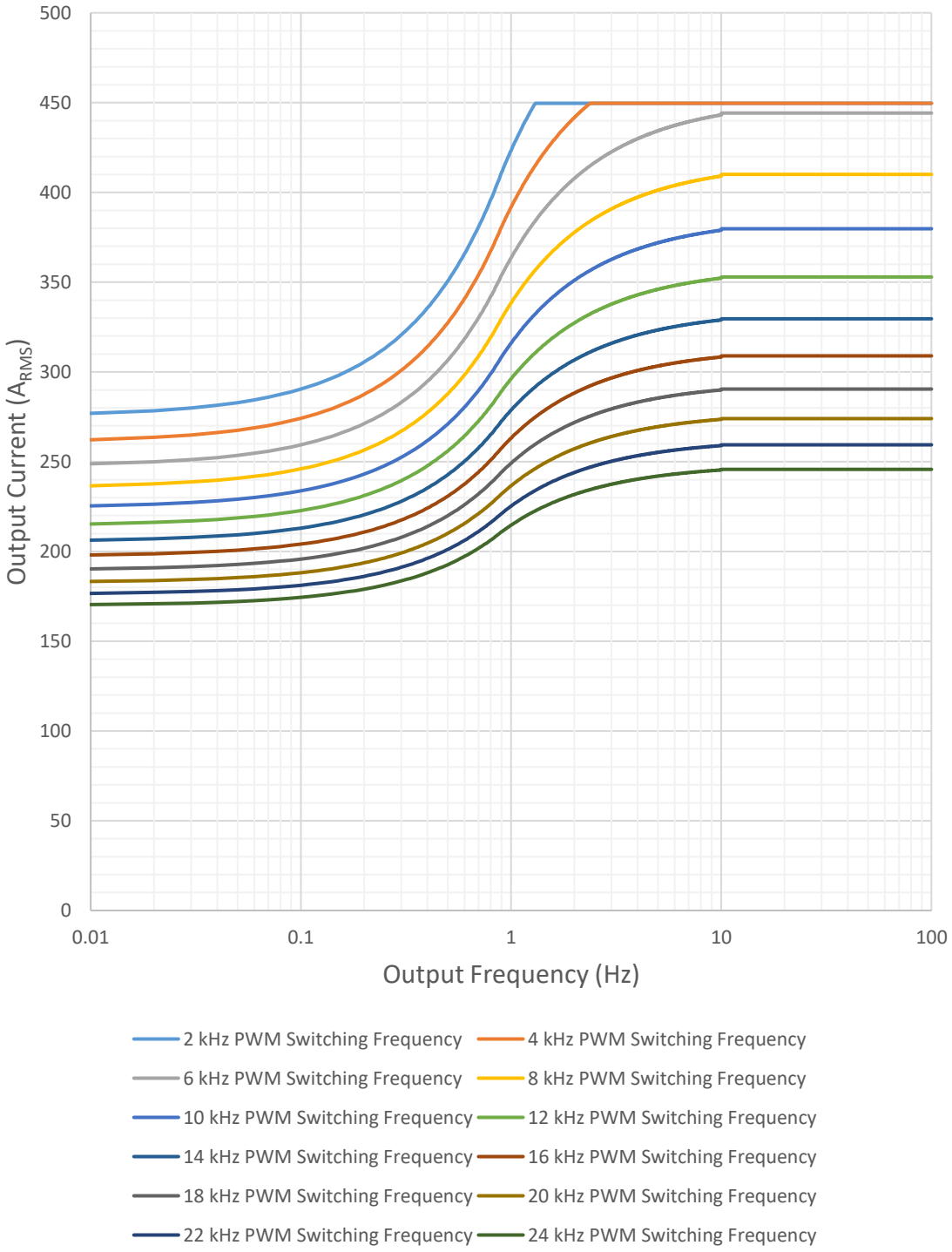
CM200DZ Output Current vs Output Frequency at Various Switching Frequency with 45°C Coolant at 650VDC Bus Voltage Motoring



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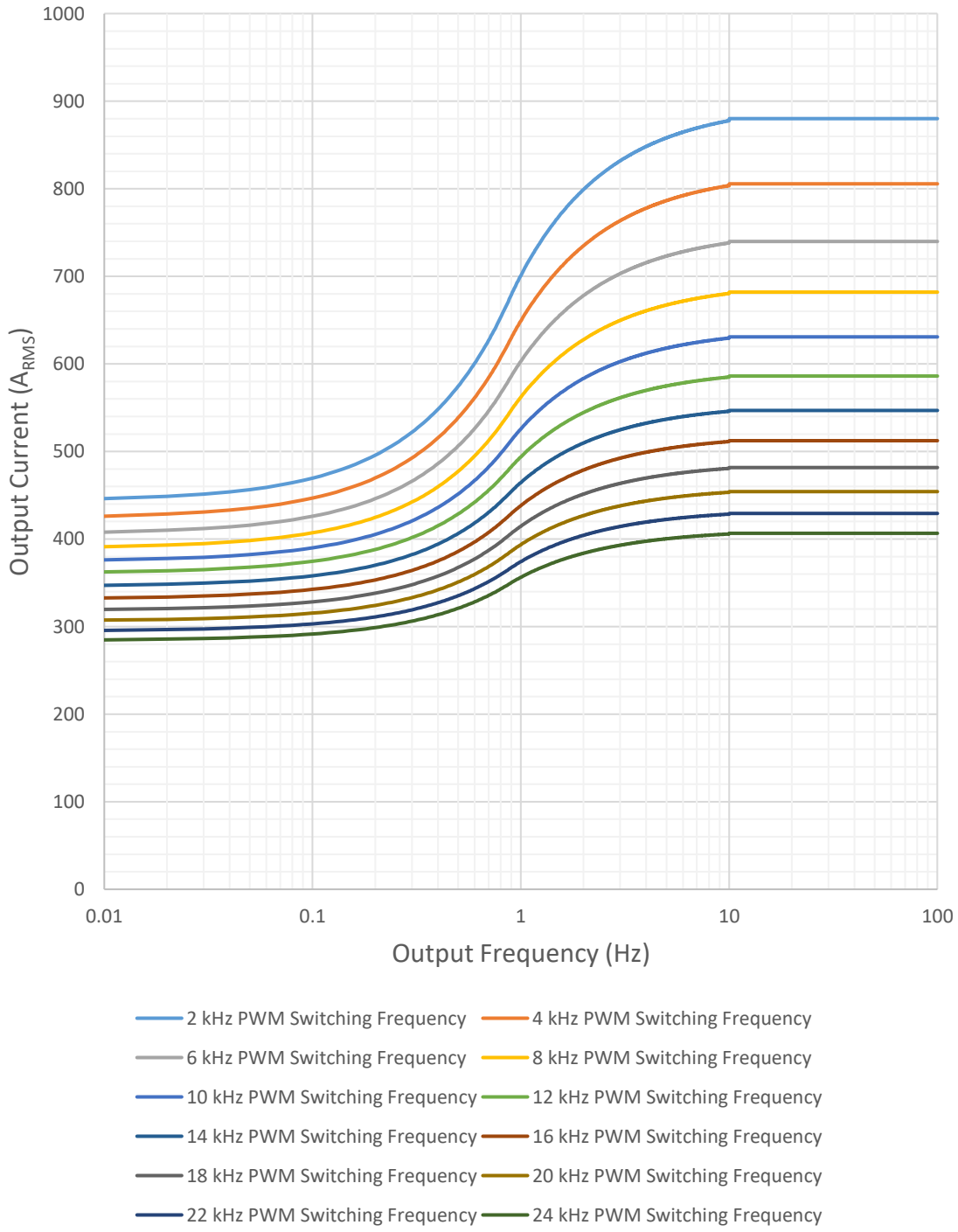
CM350DZ Output Current vs Output Frequency at Various Switching Frequency with 45^{O}C Coolant at 650VDC Bus Voltage Motoring



For CM series inverters and Gen5 PM series inverters, PWM switching frequency is variable and can change automatically depending on operating conditions. See Gen 5 Variable PWM Manual. The inverter rated current depends on the PWM switching current, DC bus voltage, and coolant temperature. The rating is calculated automatically in software. The low-speed ratio of current is then applied to the current rating to further reduce the current limit. This is how low speed current is limited in firmware version 651E and newer.

See Appendix A, B & C for low-speed ratio of current at various switching frequencies.

4. Output Frequency

The speed that a motor has at a particular frequency is related to the motor poles.

$$Speed = Frequency * 120 \ / \ Number\ of\ Poles$$

For example a Remy motor has 10 poles. So an output frequency of 1 Hz represents a speed of 12 rpm. So the Remy motor would achieve about 73% of rated current when it has reached 12 rpm.

5. Short Period High Current

Often times in the starting of a vehicle the reduction in torque is not noticed due to the gear lash and tire windup. It would be more noticeable for larger vehicles when operated on an incline.

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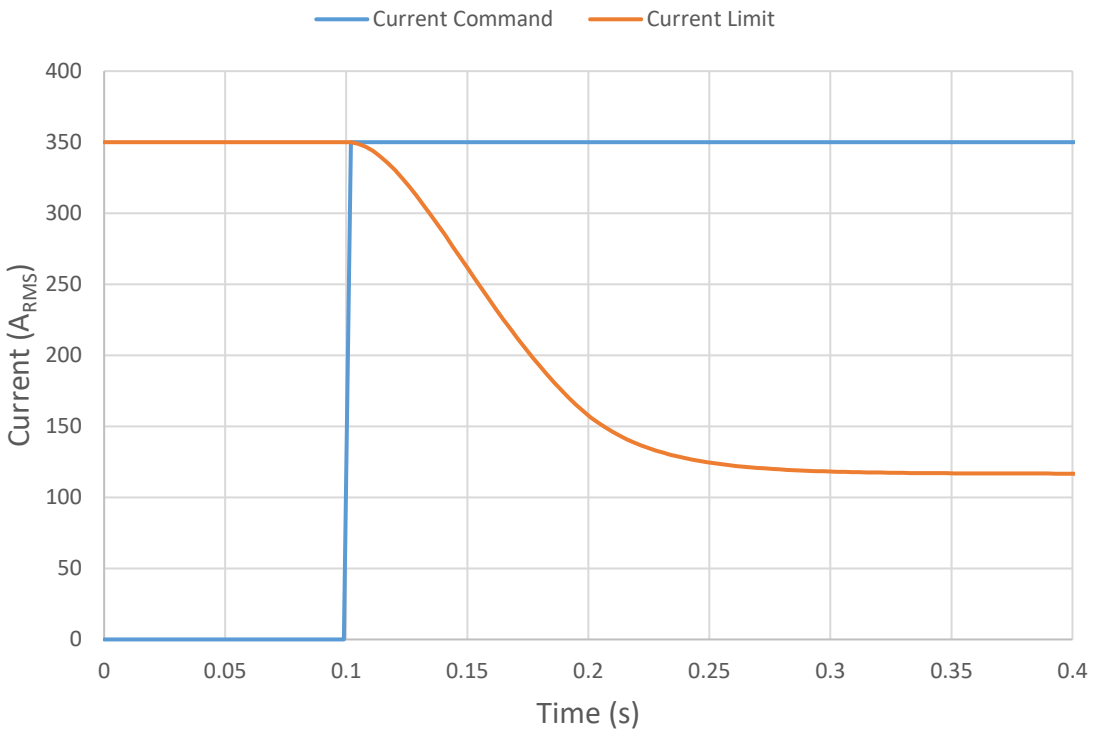

As noted above the inverter will allow a higher current for a short amount of time. The amount of time is dependent on how high the current has been in the immediate past.

The graph above shows an example where the current in a PM100DX is ramped instantaneously from 0 to 350A_{RMS} at time 0.1 seconds. The Current Limit line shows how the current will be reduced after a short time. The above example assumes that the motor speed is 0 at all times.

There are NOT any user adjustable features associated with this low speed current limiting. The software automatically adjusts as needed depending on the type of inverter being operated.

Again, firmware 651E and newer does not have this short period higher current feature shown in the graph above.

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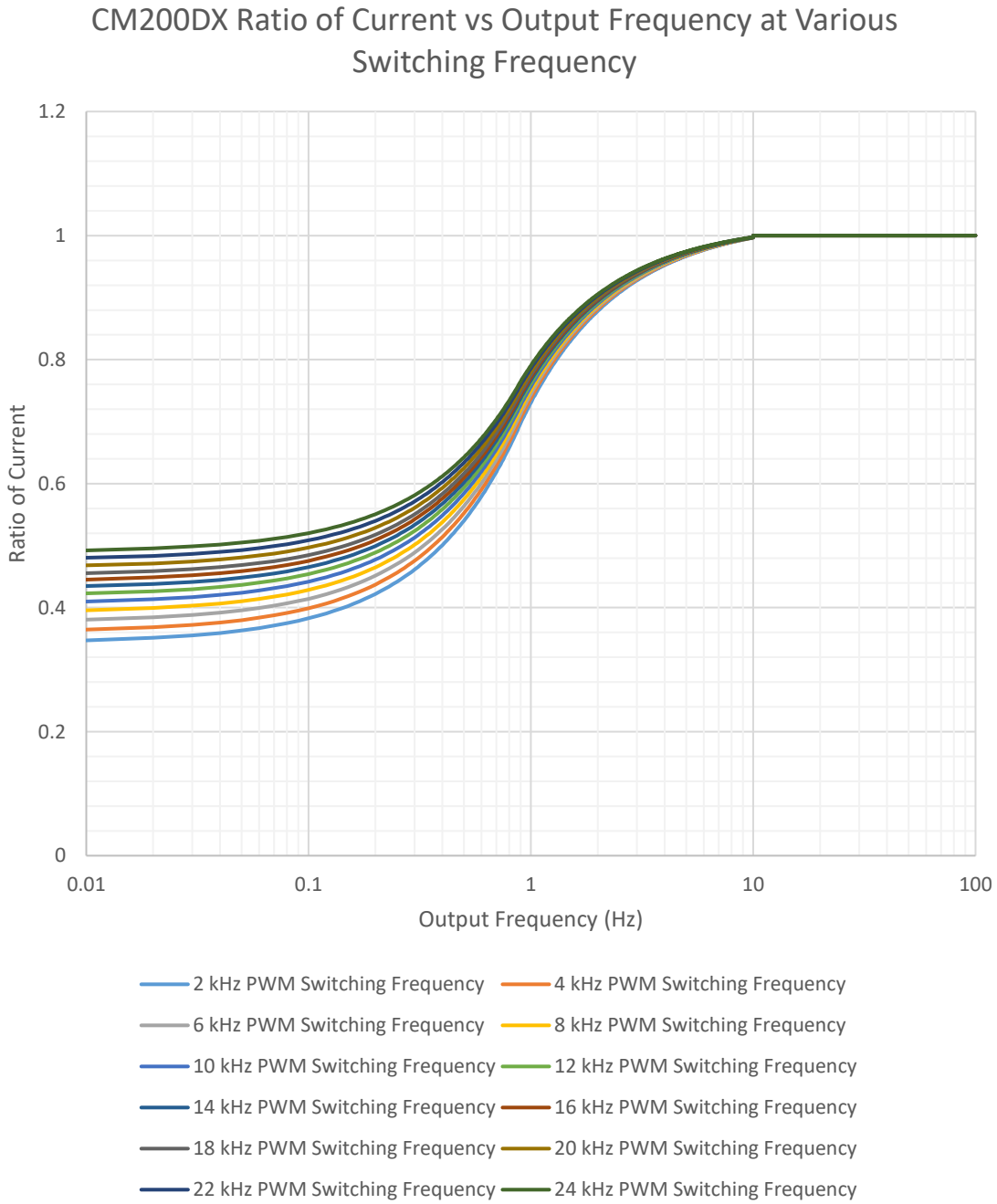
Appendix A CM200DX Low Speed Ratio of Current



Even though the low-speed ratio of current is higher with higher PWM switching frequency the current is higher with lower PWM switching frequency as shown in Section 3. This is because the current limit at various switching frequency has more variance and opposite trend with switching frequency than the ratio of current.

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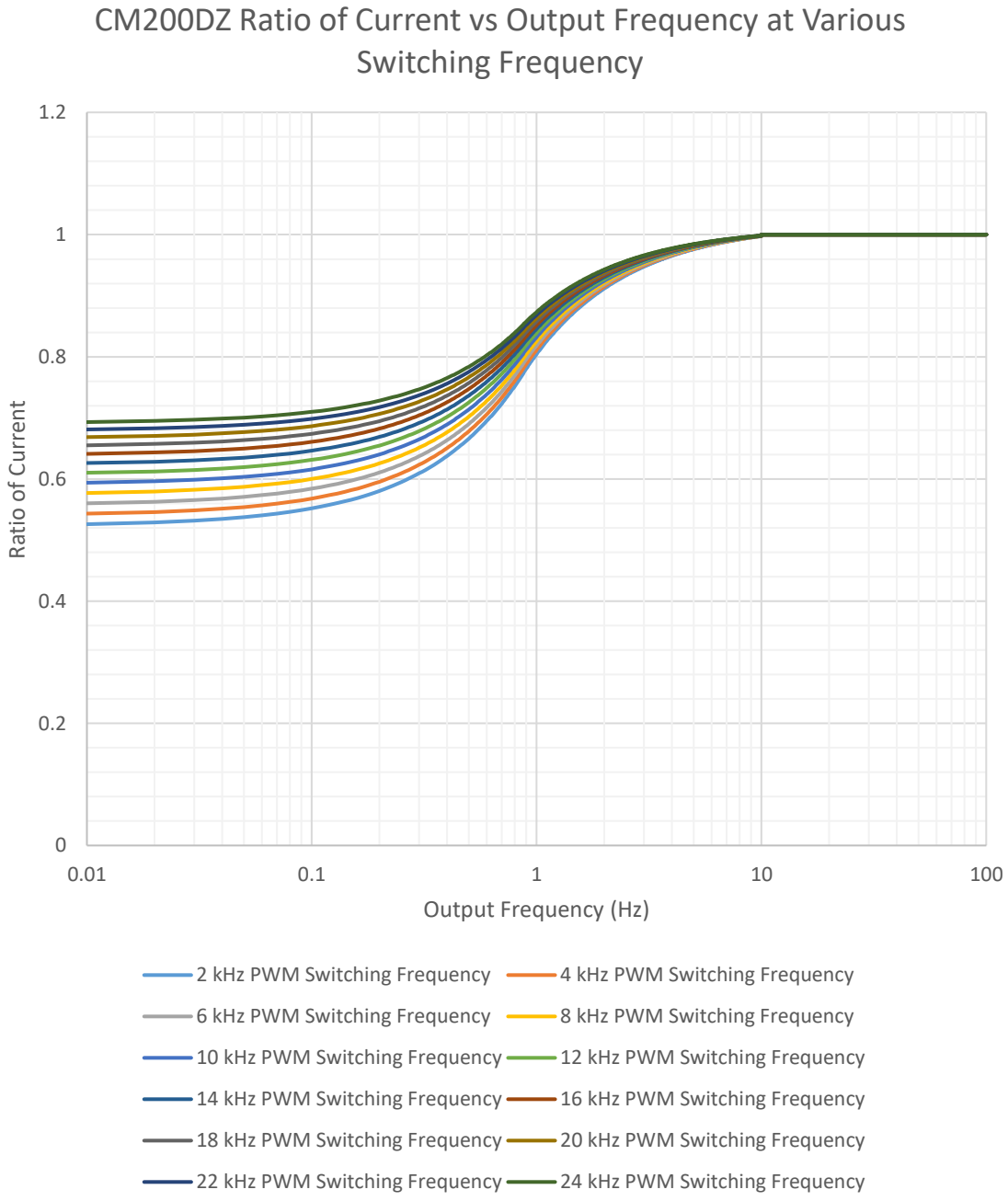
Appendix B CM200DZ Low Speed Ratio of Current



Even though the low-speed ratio of current is higher with higher PWM switching frequency the current is higher with lower PWM switching frequency as shown in Section 3. This is because the current limit at various switching frequency has more variance and opposite trend with switching frequency than the ratio of current.

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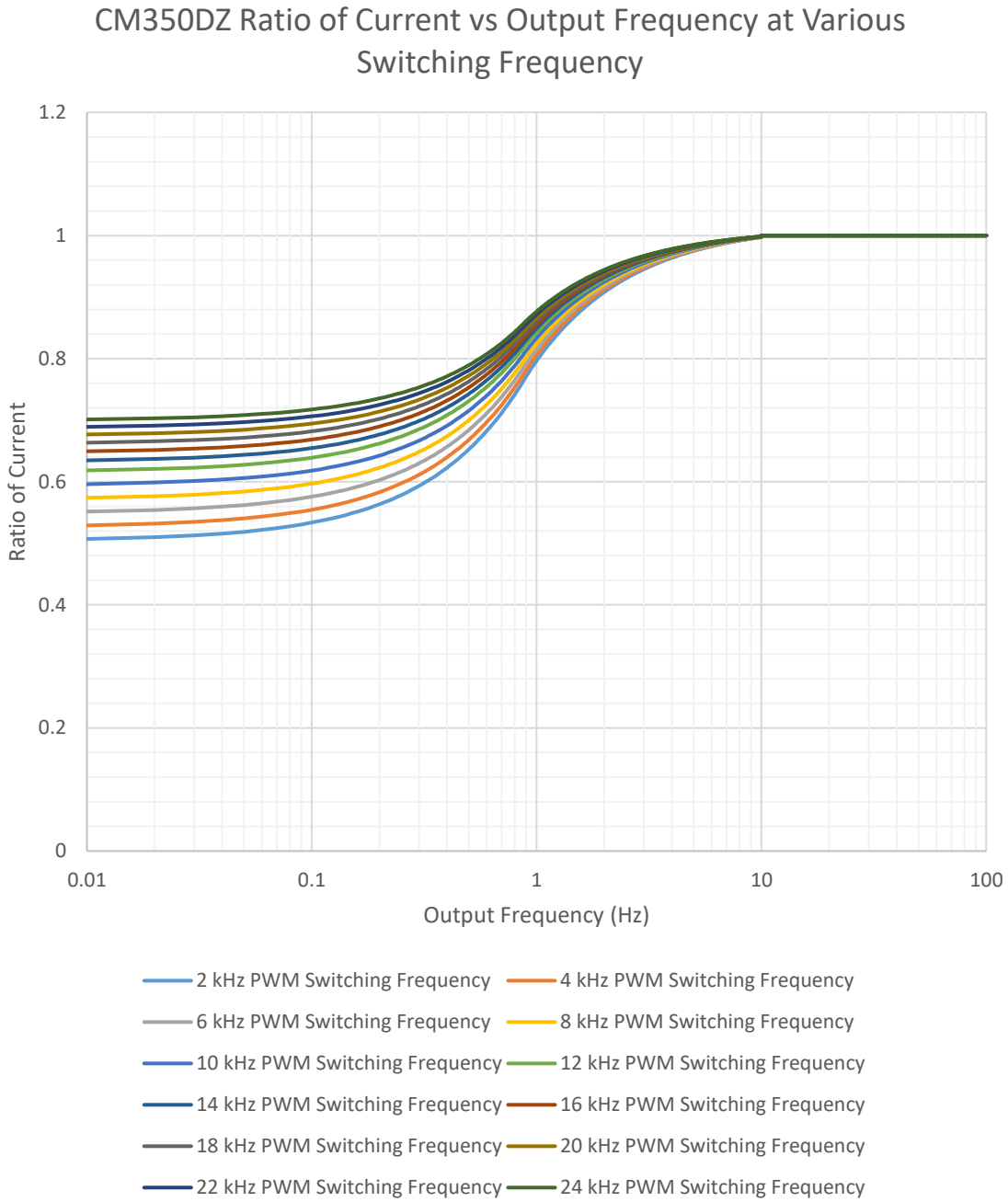
Appendix C CM350DZ Low Speed Ratio of Current



Even though the low-speed ratio of current is higher with higher PWM switching frequency the current is higher with lower PWM switching frequency as shown in Section 3. This is because the current limit at various switching frequency has more variance and opposite trend with switching frequency than the ratio of current.