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Hot Spot Manual

Revision 0.4

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1. Introduction

Cascadia Motion inverters have a peak current rating and continuous current rating based on hardware temperature limitations. To protect inverter components from overheating, a Hot Spot Model has been implemented to limit the duration of peak current. This model allows peak current for a limited duration, dependent on coolant temperature, while continuing to protect the inverter against currents that exceed the continuous rating.

This methodology is implemented in the form of a simple thermal model fed into a PI regulator. The target max hot spot temperature is typically 125 °C (Tmax/Ref/Target). This regulator allows the inverter to have the full peak current for typically 30 seconds, then the hot spot temperature model and PI regulator derates the maximum motor current as necessary to maintain a max hot spot temperature at the Tmax value. The hot spot temperature is not a physical temperature at any particular location. The hot spot temperature is just a model value used to protect the inverter based on testing at Cascadia Motion.

The Hot Spot Thermal Model takes in: actual motor current in Apk, coolant temperature in °C, and available maximum current limit (peak_current) to predict a hot spot temperature in °C and actual maximum inverter current (Max current). With time the temperature in the model will change as it reacts to the actual operating conditions.

The general architecture of control is presented below in Figure 1.

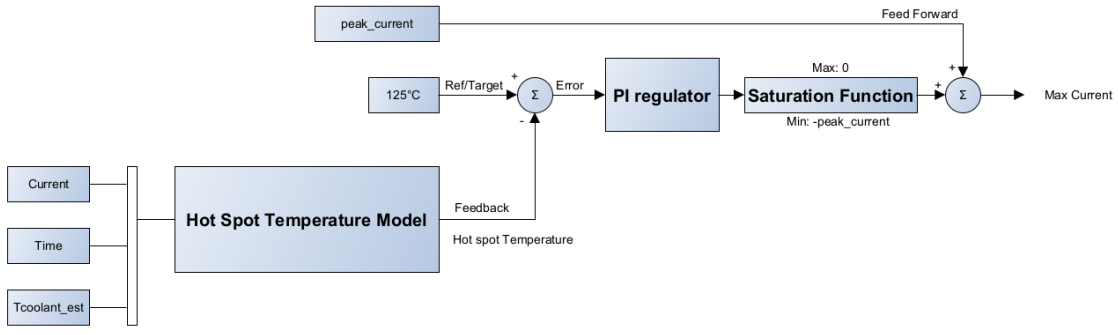

Figure 1. General architecture of Hot Spot Thermal Model.

Through this methodology, compared to a steady state model, more current is allowed for a limited duration, assuming the hot spot temperature is not already at its maximum target of Tmax. The maximum current limit (peak_current)

depends on DC Bus Voltage, Coolant temperature, and PWM frequency can vary significantly from the data sheet rating.

The Hot Spot Model assumes a motor current squared heating effect (resistive heating). Elements of the inverter that are most impacted by long duration currents experience resistive heating (e.g. bus bars, DC link capacitor, etc.).

2. Implementation

2.1 Overview

The Hot Spot Thermal Model is implemented in the code base only for GEN5 inverters. These inverters are listed in the table below. No user input is required to utilize the model and its inverter protection.

Hot Spot Thermal Model Inverters
CM200DX
CM200DZ
CM350DZ
CM350SiC

2.2 Continuous Current Rating

The Hot Spot Thermal Model results in a continuous current rating that is dependent on the coolant temperature. Higher coolant temperatures result in lower continuous current ratings. The datasheet continuous current rating for CMxxx inverters is indicated at a coolant temperature of 45°C. The hot spot temperature limit (Tmax) is 125°C for most CMxxx inverters (see table below). So, the deltaT for these inverters is 80°C.

The continuous current rating that results from different coolant temperatures can be calculated using the following formula:

Continuous Current Rating at Tc = sqrt((Tmax-Tc) * (Icont @ deltaT)^2 / deltaT)

Parameter	CM200DX	CM200DZ	CM350DZ	CM350SiC
Tmax (°C)	125	125	125	100
deltaT (°C)	80	80	80	55
Icont @ deltaT (Arms)	300	200	500	400

The above table gives the deltaT and continuous current rating (in Arms) for various inverters at the time of the manual being written.

For example, the continuous current rating for the CM350DZ at 65°C would be sqrt((125 – 65) * 500^2 / 80) = 433Arms.

If the coolant temperature is less than 45°C, then the continuous current rating will increase above the rating at 45°C. However, practically speaking it is quite difficult for an installation to guarantee coolant temperatures less than 45°C under all ambient conditions.

2.3 Hot Spot Settings/Reporting

There are no required user inputs to activate the Hot Spot Thermal Model outside of using the appropriate inverter. The model is always active.

There are two new signals relayed over CAN which report the state of the hot spot limiter. CAN details are provided in the latest DBC file.

CAN Signal	Description
INV_Hot_Spot_Temp	The output of the Hot Spot Temperature Model. Reported in °C.
INV_Limit_Hot_Spot	A status flag that indicates when the output of the PI regulator is limiting the maximum motor current. It does not indicate if actual motor current limiting is occurring, just that it could be occurring.

3. Performance

3.1 CM200DX Hot Spot Performance

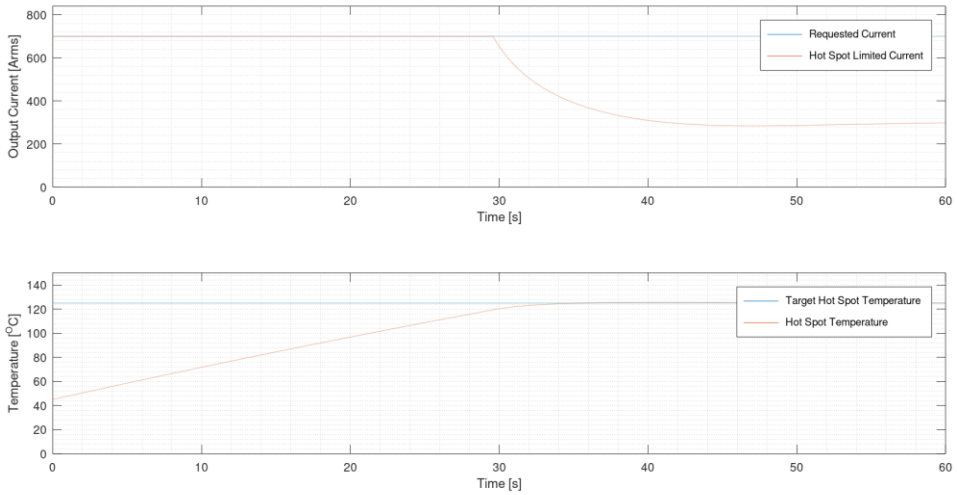

Figure 2. CM200DX Hot Spot Regulator Output Current

Hot Spot Model performance shown above is with a coolant temperature of 45 °C. A peak output current of 700 Arms is allowed for approximately 30 seconds. It then gradually derates to the continuous current of 300 Arms.

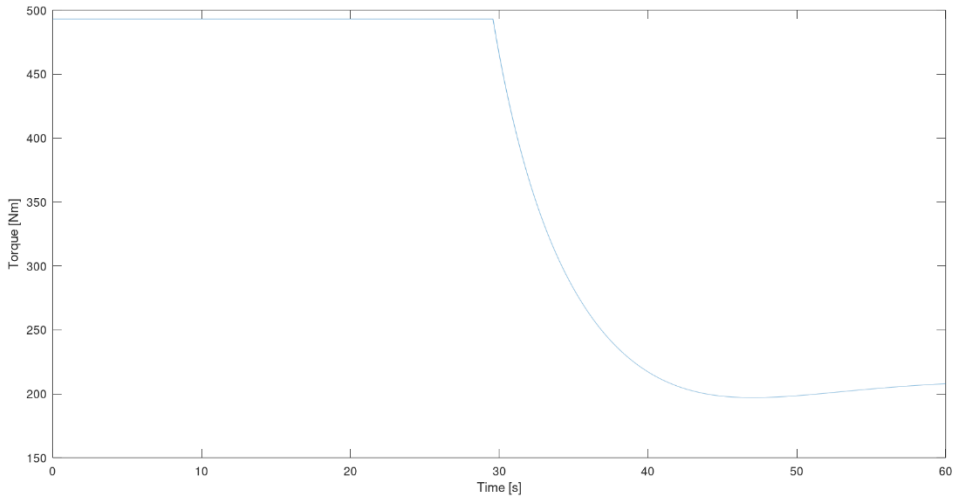

Figure 3. iM225DX-D Hot Spot Regulator Output Torque

Figure 3 shows the resulting torque for an iM225DX-D at 2,800 rpm, 6 kHz PWM, 400 Vdc Bus, 45 °C coolant, and 70 °C motor temperature.

3.2 CM200DZ Hot Spot Performance

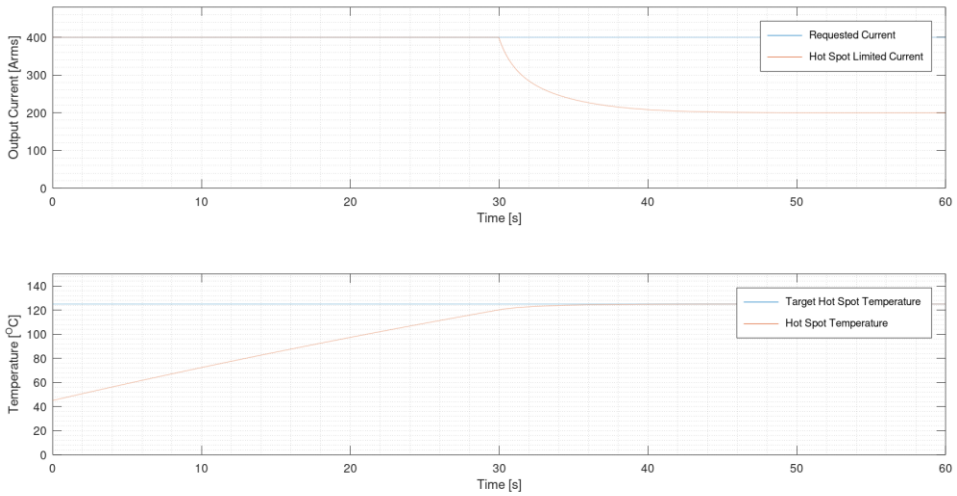

Figure 4. CM200DZ Hot Spot Regulator Output Current

Hot Spot Model performance shown above is with a coolant temperature of 45 °C. A peak output current of 400 Arms is allowed for approximately 30 seconds. It then gradually derates to the continuous current of 200 Arms.

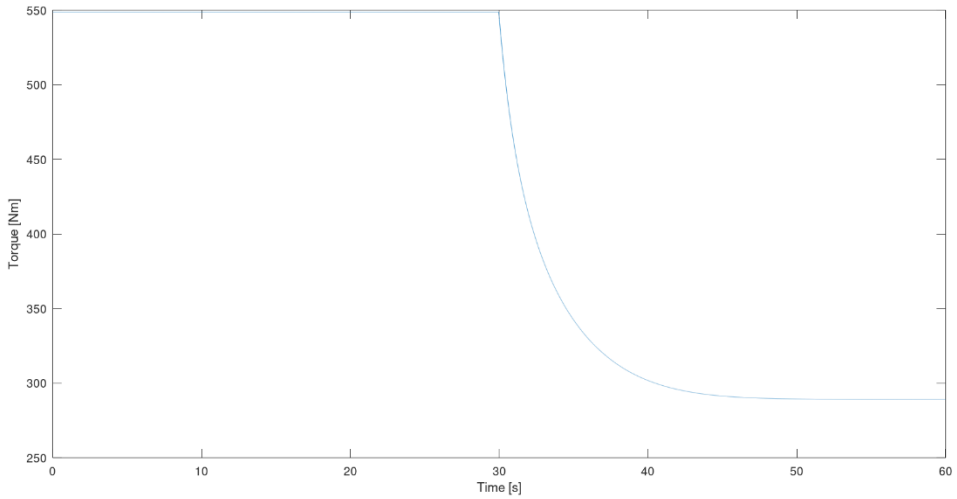

Figure 5. iM225DZ-S Hot Spot Regulator Output Torque

Figure 5 shows the resulting torque for an iM225DZ-S at 2,800 rpm, 6 kHz PWM, 700 Vdc Bus, 45 °C coolant, and 70 °C motor temperature.

3.3 CM350DZ Hot Spot Performance

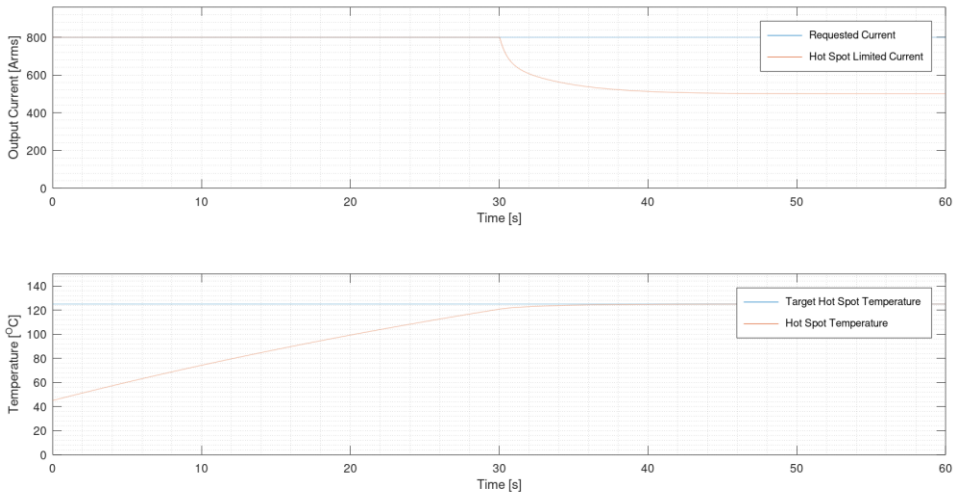

Figure 6. CM350DZ Hot Spot Regulator Output Current

Hot Spot Model performance shown above is with a coolant temperature of 45 °C. A peak output current of 800 Arms is allowed for approximately 30 seconds. It then gradually derates to the continuous current of 500 Arms.

The CM350DZ is capable of a peak output of 800 Arms when output frequency is between 10 Hz and 30 Hz electrical at 2 kHz PWM, up to 850 Vdc bus. Also, at 6 kHz PWM, 450 Vdc bus, when output frequency is between 10 Hz and 400 Hz electrical.

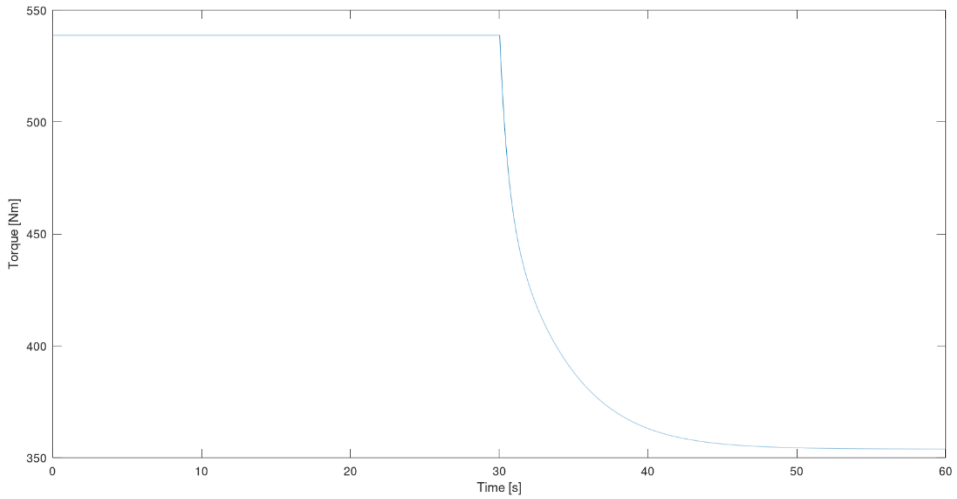

Figure 7. iM375DZ-D Hot Spot Regulator Output Torque

Figure 7 shows the resulting torque for an iM375DZ-D at 200 rpm, 2 kHz PWM, 700 Vdc Bus, 45 °C coolant, and 70 °C motor temperature.

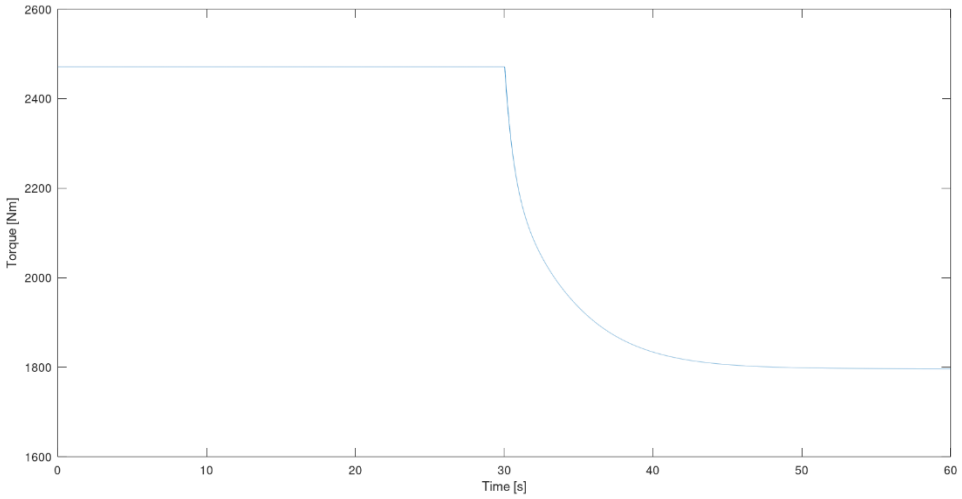

Figure 8. iM425DZ-D Hot Spot Regulator Output Torque

Figure 8 shows the resulting torque for a Cascadia Motion integrated module iM425DZ-D at 100 rpm, 2 kHz PWM, 700 Vdc Bus, 45 °C coolant, and 70 °C motor temperature.

Revision History

Version	Description of Versions / Changes	Responsible Party	Date
0.1	Initial version.	Andrew Louie & Christian Tigges	1/17/2023
0.2	Updated formatting.	Chris Brune	2/7/2023
0.3	Added section on continuous current rating	Chris Brune	2/13/2023
0.4	Correct CM350SiC deltaT. Added clarification about Tmax.	Chris Brune	2/16/2023