JOHN DEERE CONFIDENTIAL

PD400 Inverter

User Manual

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Foreword

Read this manual carefully to learn how to operate and service your inverter correctly. Failure to do so could result in personal injury or equipment damage.

Because of the variety of uses for the products described in this manual, those responsible for the application and use of this equipment must satisfy themselves that all necessary steps have been taken to assure that each application and use meets all performance and safety requirements, including any applicable laws or regulations. Illustrations, charts, sample programs, and layout examples shown in this guide are intended solely for purposes of example. Since there are many variables and requirements associated with any particular installation, John Deere does not assume responsibility or liability (including intellectual property liability) for actual use based upon the examples shown in this manual.

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1. Preface

1.1 Publication History

Table 1: Publication History

Doc ID	Rev	Release Date	Author	Description of Release
N/A	1.00	10/12/2015		– Initial Document
227358	1.01	5/1/2017	David Torgerson	– Updated OSM Diagram – Removed FSA Diagram – Added State Descriptions – Updated Startup/Shutdown – Added Diagnostic Routine Descriptions – Updated Inverter Features – Updated Protecting the Inverter/Machine – Updated Fault Section – Updated Torque Limiting
227358	1.02	07/17/2017	David Torgerson	– Added Pin Strapping Section
227358	1.03	03/13/2018	David Torgerson	– Added Coolant Temperature Sensor – Added Loss of Coolant fault – Added Coolant Temperature fault – Added 3-phase short feature – Added DC Link Power & Current limiting – Updated/renamed Inverter Current Overloading to Junction Temperature Limiting – Added CAN Keep Alive feature – Added Quick Start Section
227358	1.04	02/01/2019	David Torgerson	– Added Variable Flow Feature – Added Disabled Output State Feature – Updated Loss of Coolant fault to be a warning – Added Loss of Coolant description – Modified Current Sensor Disabled Fault Description

1.2 References

Table 2: Reference Documents

No.	Title/Description	Revision/Info
1	JDES PD400 CAN Specification	DOC-227357
2	SAE J1939 CAN Specification Standard	March 2009
3	JDES PD400 Installation Guide	DOC-220325
4	JDES PD400 Third Party Software Notice.pdf	1/18/2017

1.3 Definitions

Table 3: Definitions

Item	Definition
∞	Symbol indicating an “infinite” value. In this case, infinite implies the range of floating point numbers represented by a 32-bit single precision float value in IEEE 754 floating point representation.
BEMF	Back Electromotive Force (i.e., machine phase voltage generated by rotation of shaft without external voltage applied to wires).
Bi-Directional	Refers to the capability of the inverter to transfer power in both directions between the source (HVDC Bus) and the motor load.
ECU	Electronic Control Unit. The controller that is sending commands to the inverter
EMC	Electromagnetic Compatibility.
EOL	End Of Line. Software configuration data programmed onto the inverter during inverter or vehicle manufacturing.
FSA	PD400 Finite State Automaton control mode
FMEA	Failure Mode Effects Analysis.
High-Voltage	Any voltage related to the DC Link and phase connections Considered to be “low voltage” by European directive 2006/95/EC Article 1 (Low Voltage Directive) Considered to be voltage class B by ISO/TR
HVDC	High-Voltage DC
IGBT	Insulated Gate Bipolar Transistor.
IPM	Internal Permanent Magnet AC machine.
JDES	John Deere Electronic Solutions.
Low-Voltage	Any voltage related to the common 12 V DC or 24 V DC vehicle system Considered to be “extra low voltage” by IEC 60050-826 Considered to be voltage class A by ISO/TR
LSB	Least Significant Byte.
LSW	Least Significant Word.
MSB	Most Significant Byte.
MSW	Most Significant Word.
NVM	Non Volatile Memory (typically EEPROM).
OOR	Out Of Range.
OSM	PD400 Operating State Manager control mode
PWM	Pulse Width Modulation.
System	Refers to the overall application in which the inverter is being used.
TBD	To be determined.

1.4 Introduction

This document is the User Manual for PD400 inverter. It contains the information needed to operate and maintain the inverter in a safe manner. It is important for the user to have a good understanding of this manual, and to consider it a permanent reference that should be available to all parties involved in the design, installation, and qualification of this inverter.

1.5 Intended Audience

This manual is intended for use by the user of the product.

1.6 Purpose of This Manual

The purpose of this manual is to provide a structured resource for the user to reference when installing and operating this equipment.

1.7 Product Receiving and Storage Responsibility

The user is responsible for receiving and storing the inverter in a manner to protect it from damage and/or extreme environmental conditions that exceed its ratings.

1.8 JDES Inverter Family

The JDES Inverter Family is a series of Power Inverters designed to provide advanced control for AC motor applications. The inverters convert high-voltage DC power to three-phase AC power to drive a variety of machines in a compact, rugged, environmentally-sealed package. The JDES series is built upon a common hardware platform accommodating a wide range of possible inverter schemes with standard, configurable software modules that determine specific family members.

The JDES series inverters were designed for use in a variety of different applications. Some of these applications include industrial heavy-duty machinery, agricultural equipment, and utility vehicles. The inverters can also be used on an electrified vehicle as an engine assist to reduce peak loading and provide brake energy re-capture.

Each JDES Inverter family member has its own specifications related to output power, number of motors that can be driven, type of motors that can be driven, compatible position feedback sensors, etc. Because of this, model-specific information or specifications will be identified throughout this manual as needed. Some of the features common to all inverters are:

- High output power handling in the kilowatt range.
- Large high-voltage range, typically 175 – 800 VDC.
- Bi-directional power handling.
- Four quadrant motor control capability.
- Compact, sealed enclosure, and fully tested to strict off-road vehicle standards for extreme environments.
- Liquid-cooled design reduces internal hotspots and further reduces the footprint size of the enclosure by the elimination of large heat sinks and fans. Can use 50/50 Ethylene Glycol/Water mix.
- Compatible with a variety of different motors.
- Multiple motor control schemes such as space vector modulated PWM voltage control and high-performance AC field-oriented control.
- Standard closed loop control schemes include speed control, torque control, and DC Bus voltage regulation control.
- Communication over CAN.
- Various position feedback sensors.

1.9 Inverter Configuration

Prior to shipping, the inverter is configured to run with a specific motor at a specific nominal HVDC Bus voltage. Inverter configuration for a specific motor is done using EOL, programmed into the inverter during manufacturing. Note that the inverter can be configured to run in AC Supply mode as well which does not require a motor. Additional parameters such as slew rates, source addresses, torque curves, fault thresholds, and various derating parameters can be modified by reprogramming the inverter. JDES will work with the end user to adjust the parameters for each application. JDES will provide default values initially which will provide a starting point. For a list of operating parameters that can be changed, contact JDES for more information. If you require a major change to your configuration, such as changing the nominal HVDC bus voltage or changing the motor, please contact JDES for assistance. In many cases, a software update may be sufficient. In other cases, JDES may have to characterize the motor to your specific operating conditions.

1.10 Available Inverter Options

John Deere Electronic Solutions offers a number of pre-configured off-the-shelf inverters for use in many applications. However, JDES understands that there are many more applications for the inverters that may only require small modifications for different position sensor technologies, additional input/output pin configurations, software customization, etc. Contact JDES for more details if a modification would allow the inverter to better fulfill your needs.

1.11 Available services from JDES

John Deere Electronic Solutions has partnered with a number of motor manufacturers to offer optimized inverter and motor packages. Contact JDES for more information.

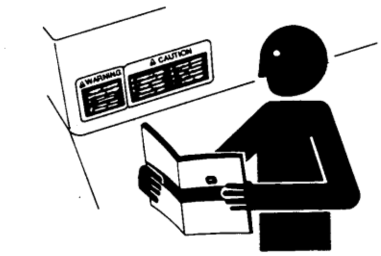
2. Proper Operation and Use of This Product

USE CAUTION! Due to the high voltages present around the inverter, JDES recommends that you put in place a detailed set of procedures to follow that include PPE and training for all people working with or around the inverter and motor.

2.1 Recognize Critical Information

Note	**The signal word NOTE indicates a situation that, if not avoided, could result in property damage.**
Caution	**The signal word CAUTION indicates a hazardous situation that, if not avoided, could result in minor or moderate injury. CAUTION may also be used to alert against unsafe practices associated with events that could lead to personal injury.**
Warning	**The signal word WARNING with this symbol indicates a hazardous situation that, if not avoided, could result in death or serious injury.**
Warning	**The signal word WARNING with this symbol indicates a hazardous situation related to electric shock that, if not avoided, could result in death or serious injury.**

2.2 Follow Instructions



Carefully read all messages in this manual. Learn how to operate the inverter properly. Do not let anyone operate without proper instruction. Keep your inverter in proper working condition. Unauthorized modifications to the inverter may impair the function and affect its life. If you do not understand any part of this manual and need assistance, contact John Deere Electronic Solutions.

Warning

Improper or careless changes to the inverter may cause unpredictable operation, resulting in potential equipment damage or personal injury.

3. Specifications, Installation, and Wiring

This information is contained in the JDES PD400 Installation Guide.

Warning

In order to insure a safe voltage state before performing any work on or around the inverter, the customer should measure DC+ to DC-, DC+ to Chassis, and DC- to Chassis, along with any other safety checks your system may require.

4. Preparing to Operate the Inverter

4.1 Calibrating Position Offset

Operation of the inverter as a motor drive requires that the inverter has information regarding the orientation of the position sensor in relation to the rotor. This is referred to as position offset. This is a critical calibration value that must be learned by the inverter for each individual machine prior to using the intended machine. If the machine is replaced or repaired, this calibration must be performed again.

More information on Position Offset Calibration can be found in the Advanced Diagnostics Class B section.

Warning	Controlling a machine without performing offset calibration may cause unintended and unpredictable operation, potentially resulting in equipment damage or personal injury.

4.2 Characterization

Control of an electric machine using an inverter requires characterization data. Characterization data contains machine parameters and capability curves. This data is programmed by JDES and is unique for each machine type. Contact JDES for more information about alternative characterization data or when changing machine types.

5. Inverter Startup and Shutdown

In order to operate, the inverter needs to be connected to a system that provides the following:

- A constant low-voltage power source connected to the unswitched battery input.
- A method of connecting and disconnecting low-voltage power to the switched battery input.
- A source of high-voltage DC power such as a battery, a grid tied power supply, or a generator-provided high-voltage DC source. Depending upon system design, a contactor may be needed allowing the inverter to be disconnected from the source.
- An active liquid cooling system with temperature and flow regulation.
- Phase wiring to electric machine, adequately sized for the application.
- Feedback wiring from machine (e.g. position sensor, temperature sensors).
- A CAN bus with an attached ECU or CAN communication tool for commanding inverter activity and monitoring inverter status.

To determine the specific operating conditions for voltages, power levels, and cooling requirements please refer to the JDES PD400 Installation Guide.

5.1 Startup Process

Enabling switched battery to the inverter begins the startup process. During startup, the inverter checks the integrity of its software components and configuration data. Issues detected during startup are reported as faults. For more information on faults that may be reported, see the Inverter Startup Faults section.

! Note The PD400 is designed to be fully functional with only switched battery. This is not considered a normal operating mode, however, and faults will be reported.

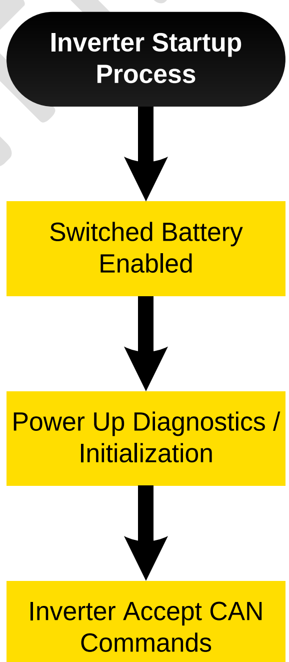


Figure 1: Startup Process Diagram

5.2 Shutdown Process

When unswitched battery is present and switched battery is removed, the inverter begins its shutdown process by transitioning to the Controlled Power Down state. During shutdown, the inverter saves some parameters for later use. The inverter also monitors the electric machine speed and DC bus voltage and continues monitoring and reacting to machine and inverter fault conditions. When the speed and voltage are at a safe level, the inverter powers off.

If unswitched battery is not connected when switched battery is disconnected, the inverter will shut down immediately. Loss of data and machine control can occur in this case.

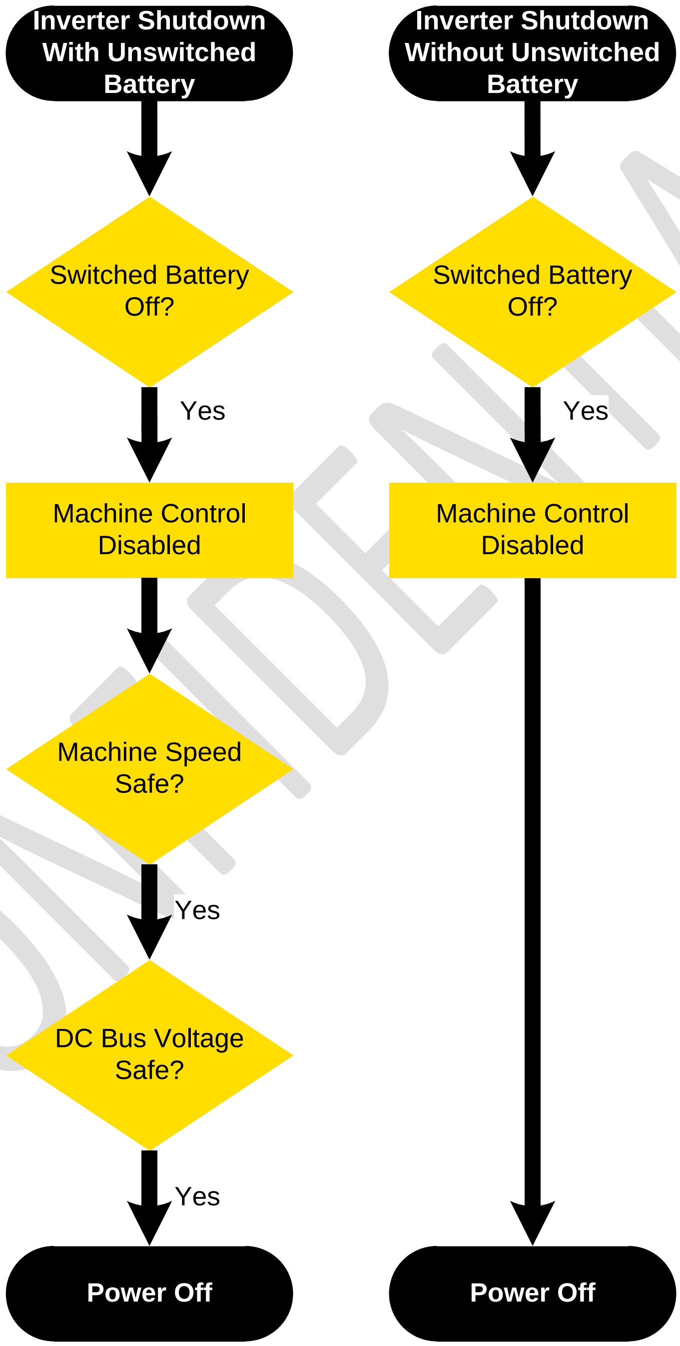
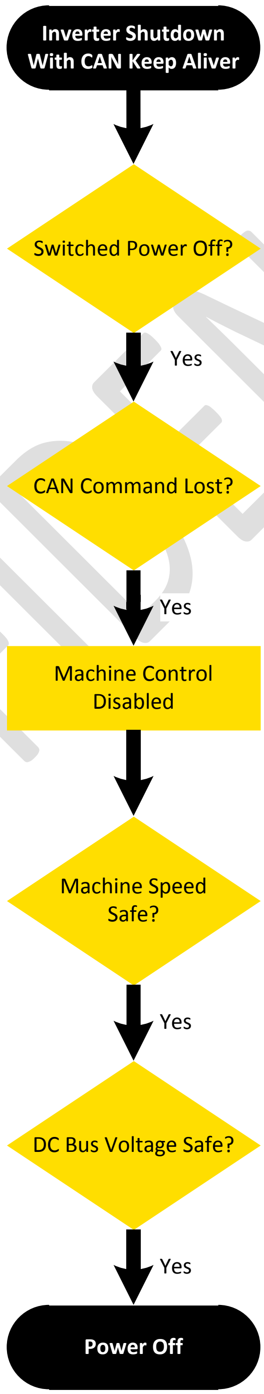


Figure 2: Shutdown Process

5.2.1. CAN Keep Alive

As described in Section 5.2, once switched battery is removed from the inverter, the shutdown process is started. When transitioning to the Controlled Power Down state, the inverter will stop actively controlling the machine. This can be undesirable if switched battery is removed inadvertently as there may be a desire for the inverter to continue to control the machine if it is still receiving valid CAN commands. With the CAN keep alive feature enabled, the inverter will need to detect that not only is switched battery removed, but that the vehicle controller has stopped sending messages to the inverter as well in order for the inverter to start the shutdown process. The inverter will wait for a configurable amount of time after it stops receiving CAN messages before going to the Controlled Power Down state. Note that the inverter will broadcast a Switched Battery Low warning while still receiving CAN commands to inform the user that it has been inadvertently removed. The problem with switched battery will need to be corrected in order for the inverter to power up again after this event.



6. Operating the Inverter

6.1 Configuration

The PD400 has two modes of control, Operating State Manager (OSM) and IEC 61800 Finite State Automaton (FSA). Each have their own methods of commanding and monitoring the inverter. This document describes the OSM. Contact JDES for more information regarding IEC 61800 FSA. These modes are explained in detail in the State Manager Descriptions section.

6.2 Commanding the Inverter

In OSM mode, commands are sent to the inverter via J1939 Proprietary A and B messages. These commands are used to command machine functions and transition between OSM states. The JDES PD400 CAN Specification defines all OSM command messages. In FSA mode, CAM21 messages are used to set operating parameters and transition between FSA states.

6.3 Monitoring the Inverter

In OSM mode, the inverter transmits periodic status messages containing several types of information. The JDES PD400 CAN Specification defines the content and format of these messages. In FSA mode, the inverter periodically transmits IEC 61800 CAM11 messages containing measurement data. In either mode, transmit rates can be configured to suit the system needs. Additional measurement and configuration data not transmitted on a periodic basis can be obtained by querying the inverter.

6.4 Faults

Faults are reported on the CAN bus through Diagnostic Trouble Codes (DTCs) embedded within J1939 DM (Diagnostic Message) protocol. The occurrence count for each DTC is stored in the inverter for diagnostic purposes and can be accessed via a J1939 DM2 request.

For details on the various DTCs and DM messages, please refer to the Fault Handling section.

For details on supported DM messages, refer to the JDES PD400 CAN Specification.

6.5 Configuring the Inverter

Application specific configuration and tuning, such as slew rates, CAN addresses, fault thresholds, etc., is done by reprogramming EOL in the inverter. The inverter is shipped with default application parameters and can be adjusted after receiving the inverter. JDES can work with the user of the inverter to configure and reprogram the inverter EOL for optimal operation and fit in the application. A list of some of the configurable parameters can be requested.

6.6 Motoring vs. Generating

The PD400 provides bi-directional power transfer capability. This means that power can transfer both from and to the HVDC bus, allowing complete four quadrant motor control capability. The terms “motoring” and “generating” are used throughout this document, and are defined as:

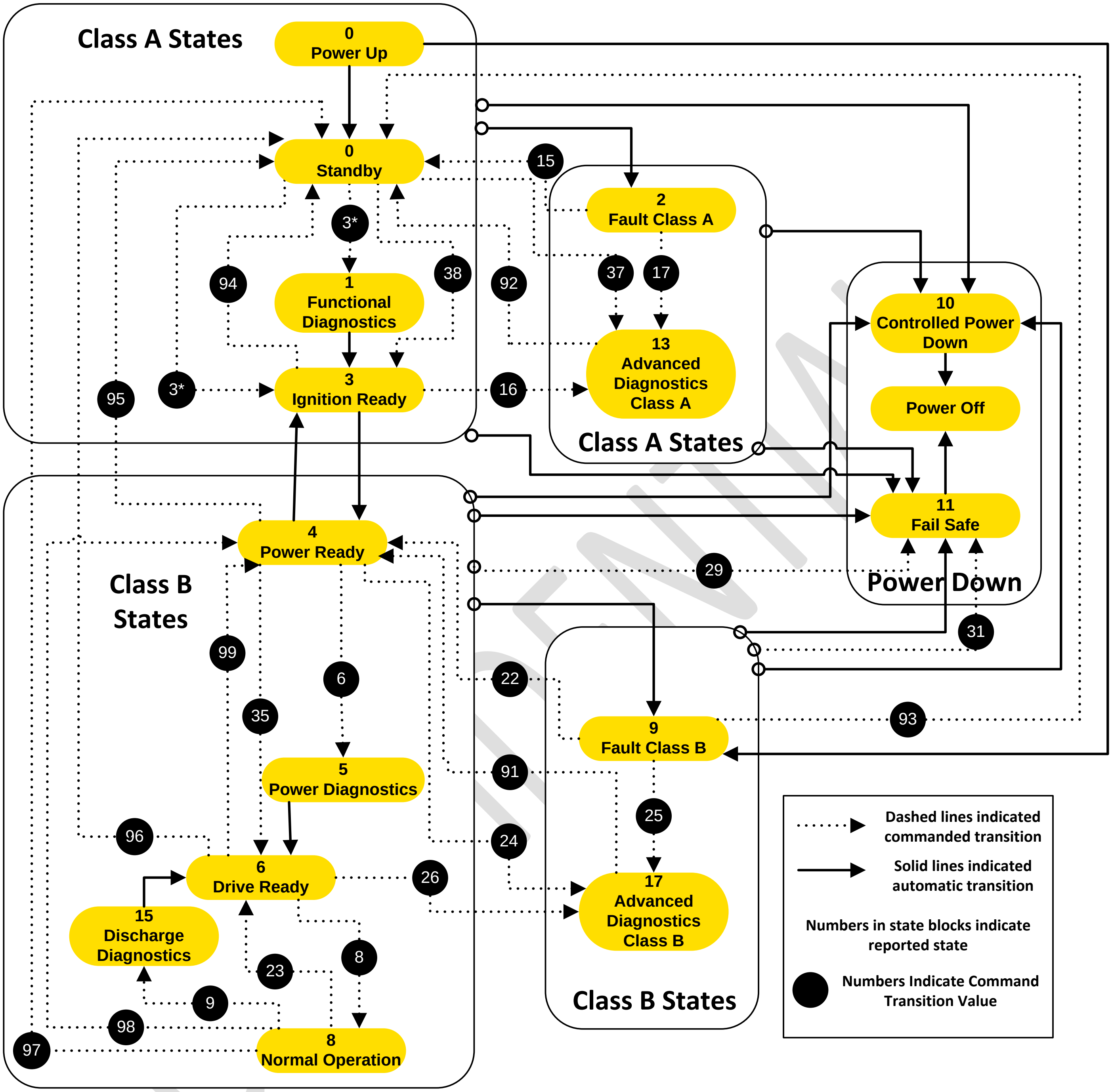
- **Motoring:** Power transfer from the HVDC bus, through the inverter to the motor load.
- **Generating:** Power transfer from the motor load, through the inverter to the HVDC bus.

Many operational setpoints, limits, and parameters can be configured independently for motoring and generating, so it is important that the user have a good understanding of these terms.

6.7 State Manager Descriptions

The state manager controls the states of the inverter. This section of the document shall provide a detailed state flow diagram of the OSM. Transitions between states is performed through the use of CAN Commands defined in the JDES PD400 CAN Specification.

6.7.1. Operating State Manager Diagram



* If Functional Diagnostics has been run in the last 10 seconds, the state manager will transition to Ignition Ready without running Functional Diagnostics tests.
If Functional Diagnostics has not been run, or if the inverter has entered a high voltage state in this power cycle, Functional Diagnostics will be performed

Figure 3: Operating State Manager Diagram

6.7.1.1. Drive Inactive States

- **Power Up:** The inverter performs initialization and data integrity checks. Upon completion, the inverter automatically transitions to Standby.
- **Standby:** The inverter awaits commands to go to another state.
- **Ignition Ready:** Upon completion of Functional Diagnostics, the inverter automatically transitions to Ignition Ready. This state can be commanded directly from Standby to skip Functional Diagnostics. The inverter automatically transitions to this state from Power Ready if the DC Bus voltage falls below the Minimum Operational Voltage.
- **Power Ready:** The inverter automatically transitions to Power Ready from Ignition Ready when the DC Bus voltage is greater than the Minimum Operational Voltage.
- **Drive Ready:** Drive Ready is an intermediate state between Power Ready, Advanced Diagnostics Class B, and Normal Operation.
- **Controlled Power Down:** The inverter automatically transitions to Controlled Power Down when switched battery is removed. If configured for HVDC Bus Dissipation, discharge will occur in this state. The inverter transitions to Power Off when speed and DC Bus voltage are below their respective thresholds.
- **Power Off:** The inverter transitions to Power Off and stops communication when all power down activities are complete.

6.7.1.2. Drive Active States

- **Normal Operation:** In Normal Operation the inverter actively controls the machine in speed, voltage, or torque mode. The inverter can switch between these control modes without disabling the drive by transmitting the corresponding CAN message while in this state. Normal Operation mode switching is often used to switch between torque and speed mode when performing shift synchronization.
- **Diagnostic States:** Functional Diagnostics, Power Diagnostics, Discharge Diagnostics, Advanced Diagnostics Class A, and Advanced Diagnostics class B can enable the inverter outputs depending on the particular diagnostic enabled or commanded in these states.
- **HVDC Bus Dissipation:** The Controlled Power Down and Fail Safe states can enable the inverter outputs if the inverter is configured for HVDC Bus Dissipation.

6.7.1.3. Fault States

- **Fault Class A:** If a low voltage critical fault is detected the inverter automatically transitions to Fault Class A. Faults that cause this transition are cleared when the OSM is commanded from Fault Class A to Standby. The inverter is capable of continuing operation after a transition to Standby, however, the root cause of the fault should be determined and corrected. See the Fault Handling section for more information on each fault.
- **Fault Class B:** If a high voltage critical fault is detected the inverter automatically transitions to Fault Class B. Faults that cause this transition are cleared when the OSM is commanded from Fault Class B to Power Ready. The inverter is capable of continuing operation after a transition to Power Ready, however, the root cause of the fault should be determined and corrected. See the Fault Handling section for more information on each fault.

– **Fail Safe:** If the inverter detects a major problem to the inverter, motor, or system the inverter automatically transitions to Fail Safe. This type of fault can only be cleared by power cycling the inverter. Faults triggering a transition to Fail Safe should be investigated by the user and fixed before attempting to restart the inverter. See the Fault Handling section for more information on each fault.

6.7.1.4. Diagnostic States

6.7.1.4.1. Functional Diagnostics

Functional Diagnostics automatically executes the tests below if they are enabled in EOL. These tests verify the inverter is operational and that it is properly connected to an external load. Functional Diagnostics should only be commanded with a low DC bus voltage. Commanding Functional Diagnostics with a DC bus voltage above 30V will trigger diagnostics failures and faults. Upon successful completion of Functional Diagnostic, the inverter will automatically transition to Ignition Ready.

Diagnostic	Purpose	Notes
Zero Current Test	Verify current sensors read zero current	Detection of non-zero current will disable that corresponding sensor. Two valid current sensors are required for inverter operation.
Switch Test	Verify IGBTs have not failed open or shorted and a load is connected to the inverter	Test failures will set a fault.

6.7.1.4.2. Advanced Diagnostics Class A

The Advanced Diagnostics Class A state allows the commanding of diagnostic and calibration routines. Diagnostic and calibration routines are selected using the Diagnostic Function Transition Command in any Inverter Command message. During routine execution, the inverter reports the routine status in the Inverter Status 2 message. Upon routine completion, the inverter reports the result of the routine. Command and status definitions for Advanced Diagnostics Class A can be found in the JDES PD400 CAN Specification. The following routines are supported by Advanced Diagnostics Class A.

Diagnostic	Purpose	Notes
Current Sensor Calibration	Recalibrate the inverter current sensors	Sensors are calibrated when manufactured, but can be field recalibrated using this function.
Phase Current Sensor Enable/Disable	Disable current sensors	May be used if a sensor is damaged. Two valid current sensors are required for inverter operation.
External Temperature Sensor Enable/Disable	Disable temperature sensors	May be used if a sensor is damaged.
IGBT Temperature Sensor Enable/Disable	Disable temperature sensors	May be used if a sensor is damaged.
Switch Test	Verify IGBTs have not failed open or shorted and a load is connected to the inverter	Must be executed at low voltage. Test failures will set a fault.

6.7.1.4.3. Advanced Diagnostics Class B

The Advanced Diagnostics Class B state allows the commanding of diagnostic and calibration routines. Diagnostic and calibration routines are selected using the Diagnostic Function Transition Command in any Inverter Command message. During routine execution, the inverter reports the routine status in the Inverter Status 2 message. Upon routine completion, the inverter reports the result of the routine. Command and status definitions for Advanced Diagnostics Class B can be found in the JDES PD400 CAN Specification.

Before operating the inverter and motor, position offset calibration should be performed. Once a position offset is found, the inverter is capable of controlling the motor. The calibrated position offset value is saved to non-volatile memory, and the inverter will retain the position offset across power cycles. The inverter and motor pair should not be operated without the correct position offset stored in the inverter.

Diagnostic	Purpose	Conditions for Execution*	Completion Result
Generator Position Offset Calibration	• Calibrate position offset	• Electric machine spinning via external source	• CAN Prognostics Message 5 transmitted • Position Offset stored in inverter non-volatile memory
Motor Position Offset Calibration	• Calibrate position offset	• Free spinning shaft (test will rotate shaft) • DC bus voltage source	• CAN Prognostics Message 5 transmitted • Position Offset stored in inverter non-volatile memory
Bleed Down Voltage Check	• Verify charge DC bus and monitor decay to determine if bleed resistor is within tolerance	• Electric machine spinning via external source	Fault, bleed resistor is out of tolerance
Generator Position Sensor/Cable Orientation Test	• Verify inverter/machine connections • Verify position offset is within tolerance	• Electric machine spinning via external source	• CAN Prognostics Message 5 transmitted • Fault, if incorrect connection are detected • Fault, if position offset is out of tolerance
Motor Cable Orientation Test	• Verify inverter/machine connections • Verify position offset is within tolerance	• Free spinning shaft (test will rotate shaft) • DC bus voltage source	• Fault, if incorrect connection are detected

*Speed and voltage thresholds to enable each routine are configured in EOL. If thresholds are not satisfied, the routine will indicate that it is unable to run.

6.7.1.4.4. Power Diagnostics

Power Diagnostics are executed in the Power Diagnostics state if enabled in the EOL. Upon completion, the inverter transitions to Drive Ready.

Diagnostic	Purpose	Conditions for Execution	Completion Result
Generator Back EMF Test	• Verify the Back EMF is within tolerance	• Electric machine spinning via external source	• CAN Prognostics Message 2 transmitted • Fault, if Back EMF is out of tolerance
Generator Position Sensor/Cable Orientation Test	• Verify inverter/machine connections • Verify position offset is within tolerance	• Electric machine spinning via external source	• CAN Prognostics Message 5 transmitted • Fault, if incorrect connection are detected • Fault, if position offset is out of tolerance
Motor Free Acceleration Test	• Verify position offset is set correctly • Verify cable orientation is correct • Verify the electric machine can reach a target speed within an expected time	• Free spinning shaft (shaft will rotate) • DC bus voltage source	• Fault, if time to reach target speed is out of tolerance
Automatic Control Circuit Test	• Verify automatic control circuit is functional by enabling the brake chopper	• Brake chopper • Brake resistor • DC bus voltage (> 125V)	• Fault, if expected current does not flow through the brake chopper

6.7.1.4.5. Discharge Diagnostics

Discharge Diagnostics are executed in the Discharge Diagnostics state if enabled in the EOL. Upon completion, the inverter transitions to Drive Ready.

Diagnostic	Purpose	Conditions for Execution	Completion Result
Motor Back EMF Test	• Verify the Back EMF is within tolerance	• Free spinning shaft (shaft will rotate) • DC bus voltage source	• CAN Prognostics Message 2 transmitted • Fault, if Back EMF is out of tolerance
Brake Resistor Measurement Test	• Verify the Brake Resistor is within tolerance	• Brake chopper • Brake resistor	• CAN Prognostics Message 2 transmitted • Fault, if incorrect brake resistance is detected
Bus Capacitor Measurement Test	• Verify the DC link capacitor is within tolerance	• None	• CAN Prognostics Message 2 transmitted • Fault, if incorrect brake resistance is detected

6.8 Modes of Operation

The modes of operation supported by the inverter are described below. Modes are changed by sending the appropriate CAN Command message. See the JDES PD400 CAN Specification for details.

Only one mode is operational at a time. Attempting to command multiple different modes simultaneously may result in erratic behavior of the inverter and machine.

6.8.1. Speed Control

Speed control mode attempts to maintain the commanded speed setpoint, independent of motor load or HVDC bus voltage, within limits. The speed setpoint is set via Inverter Command Message 2 or the corresponding IEC 61800 object.

6.8.2. Torque Control

Torque control mode attempts to maintain a constant load torque on the motor shaft, regardless of motor speed or HVDC bus voltage, within limits. Two variations of this mode exist, Relative Torque mode and Absolute Torque mode.

In Relative Torque mode, the torque setpoint is a percentage of the Reference Torque of the machine. Reference Torque is configured in the EOL and can be modified for each application. The relative torque setpoint is set via Inverter Command Message 1.

In Absolute Torque mode, the torque setpoint is in Newton-meters (Nm). The absolute torque setpoint is set via Inverter Command Message 7 or the corresponding IEC 61800 object.

6.8.3. Voltage Control

Voltage control attempts to maintain the commanded voltage setpoint on the HVDC bus, regardless of the motor speed, within limits. This mode is typically used when the electric machine is acting as a generator and power is being provided by the machine and inverter to some other device on the HVDC bus. The voltage setpoint is set via Inverter Command Message 3 or the corresponding IEC 61800 object.

6.8.4. HVDC Bus Dissipation

HVDC Bus Dissipation mode attempts to remove the residual HVDC bus energy stored in the inverter's bus capacitors. This is commonly used to quickly reduce the high-voltage present on the HVDC bus to a safe level once all motion has stopped and the system is shutting down.

! Note	Care must be taken when using this mode, as excess heat dissipation in motor or brake chopper may cause damage. Also, trying to discharge a HVDC Bus that is actively being supplied with energy (e.g. battery source) may damage the source device. The user is responsible for using this mode in a proper manner.

6.8.4.1. Dissipation Modes

There are several methods of HVDC Bus Dissipation. The desired method can be configured in the EOL. The available methods are:

- **Disabled:** No active dissipation. Resistors in the inverter will slowly dissipate the DC bus energy.
- **Brake Chopper:** The brake chopper/resistor is used to dissipate the DC bus energy.
- **Motor Winding:** The motor winding resistance is used to dissipate the DC bus energy. The inverter controls a constant current through the motor windings without producing torque. The current value can be configured in EOL and controls the rate of dissipation.

6.8.4.2. Activating Dissipation

If HVDC dissipation is disabled, it does not run.

If HVDC is not disabled, there are two cases when it becomes active.

- **Inverter Shutdown:** When the inverter begins its shutdown procedure after switched battery is disabled, it will enable the configured dissipation mode.
- **Commanded:** The vehicle controller can use the Bus Discharge Command or the IEC 61800 Discharge Mode of Operation to activate the configured dissipation mode while switched battery is still active.
  - For OSM mode, the inverter must not be in the Normal Operation state when the vehicle controller switches to the Bus Dissipation Command. After sending the dissipation command, the vehicle controller can command the inverter to the Normal Operation state to begin dissipation. Refer to the JDES PD400 CAN Specification for information on the Bus Dissipation Command.
  - For FSA mode, the inverter must not be in the Operation Enabled state when the Mode of Operation is set to Discharge Mode. After changing the Mode of Operation to Dissipation Mode, the vehicle controller can command the inverter to the Operation Enabled state to begin dissipation. Refer to the JDES PD400 CAN Specification for information on the FSA Mode of Operation object.

6.8.4.3. Other Considerations

- When the DC bus voltage has been dissipated to an EOL configurable level, the brake chopper or motor outputs are disabled.
- If the inverter detects a fault, discharge may be prematurely disabled or may never begin at all.
- Discharge does not start unless the motor speed is less than an EOL configurable threshold. If discharge has started and speed rises above the configured threshold, discharge stops and waits for speed to fall below the threshold, then continues discharging.
- If activated via OSM or FSA Command, if discharge does not successfully lower the bus in an EOL configured amount of time, discharge is halted and a timeout fault is reported. High voltage may still be present on the DC bus in this case.
- If activated via Inverter Shutdown there is no discharge timeout and the inverter continues to discharge until the DC bus voltage reaches the EOL configured level.

6.9 Inverter Features

6.9.1. Motor Speed Invert

The sign of the speed and torque information communicated with the inverter are relative to phase rotation. System configuration and electric machine orientation may result in positive commands yielding a reverse direction of system motion. In some systems it may be beneficial for a positive speed/torque command to result in forward system motion and a negative speed/torque command to result in reverse motion. The inverter's Motor Speed Invert configuration parameter allows inversion of the default speed/torque orientation.

6.9.2. Mode Swap

The inverter has the ability to perform a mode swap between two modes while in the Normal Operation (or Operation Enabled if FSA) state. The available modes an inverter can swap between are Relative Torque, Absolute Torque, Speed, and Voltage mode. Mode swapping is often used to switch between torque and speed mode when performing shift synchronization.

6.9.3. Feedforward

Feedforward information can be sent to the inverter improve dynamic voltage control response. This information can come from a vehicle controller or can be communicated across inverters via High Speed CAN or with no additional harnessing if within a dual inverter.

6.9.4. Inverter Paralleling

Paralleling can be useful in applications that have power/current requirements that are higher than one set of phase outputs can deliver. In this case, a PD400 Dual can be paralleled so that all 6 phase outputs are used to control one load, providing additional power/current capability. Contact JDES for more information on this configuration if required by the application.

6.9.5. Single Wire Disable

The inverter has a software triggered single-wire disable input that may be used in the system. This feature must be enabled through the use of the EOL before it can be used. Voltage on this input disables the inverter outputs (this is the default state). Pulling this input low allows the inverter outputs to be enabled.

6.9.6. Torque Sharing

The torque sharing feature allows multiple electric machines to be connected to the same shaft and the inverter automatically divides the torque between the machines. When using torque sharing, one inverter is configured as the master and commands torque to the inverter that is configured as the slave.

! Note	With torque sharing enabled, each inverter is able to run diagnostic routines independently. Normal Operation (or Operation Enabled) is the only state in which torque sharing is "active." Each side of the inverter must be commanded to the Drive Ready state independently. From this condition, when the master is commanded to Normal Operation (Operation Enabled), the slave inverter automatically transitions to Normal Operation (Operation Enabled).

6.9.7. Inverter Current Overloading

The ability of the inverter to exceed its continuous operating current for a limited time is controlled by estimating the Junction Temperature of the power semiconductor. As the power semiconductor heats up, the allowed current is reduced from a maximum rating to the continuous rating. Refer to Junction Temperature Limiting section of this document for more information.

6.9.8. Pin Strapped EOL Selection

Pin Strapped EOL Selection allows the inverter to be configured for multiple applications with one set of programmed files. One of six selectable EOL configurations is determined at power up using the four Machine ID[1] pins. An *Invalid Motor Type* fault will be triggered if the EOL configuration selected by the Machine ID pins is not valid. Contact JDES for assistance creating the EOL configurations and mapping them to Machine ID configurations.

6.9.9. Brake Chopper

The brake chopper (if equipped) is a feature that can protect the inverter/system in cases of unexpected high-voltage. The high-voltage may result from the inverter faulting and not being able to control Back EMF of the electric machine, large generating torque requests (downshifting), or other scenarios that cause a rise in the DC bus voltage. The brake chopper is operated in a hysteretic manner: the brake chopper is activated when the DC bus voltage is greater than 750V and remains active until the DC bus voltage drops below 725V. The hysteretic brake chopper operation is automatic and is enabled unless disabled by a brake chopper fault. These default activation/deactivation levels can be configured in the EOL. The system's brake resistor should be chosen based on the expected power dissipation.

6.9.9.1. Automatic Control Circuit

The inverter has an automatic control circuit that operates independently of the unswitched/switched battery. This circuit draws power from the DC bus and becomes operational if the DC bus voltage exceeds 500V. If the DC bus voltage reaches 800V, the duty cycle on the brake chopper turns on at 0% duty cycle and linearly increases to 100% duty cycle at the DC bus voltage of 825V. This feature attempts to prevent damage to the inverter/system in a case where the inverter is not powered, but Back EMF from an electric machine is being generated.

6.9.10. Commanded Three Phase Short Control

The inverter can be commanded, in certain circumstances, to turn on all low-side IGBT switches. This command is issued via a Three-Phase Short CAN command message. When commanded, the three-phase short will only be executed if the inverter is in the Standby, Ignition Ready, Power Ready, Drive Ready, or Normal Operation state.

6.9.11. High/Low Flow Rate[2]

The inverter has been designed to support one coolant flow rate. Refer to the Installation Guide for more information on the default flow rate. However, for some applications that operate a significant percentage of time at low power levels, it may be desirable to vary the flow rate during operation to reduce energy consumption. The inverter supports a feature which allows for two different flow rates to be utilized. These two flow rates are referred to as High Flow and Low Flow. High Flow is typically the default flow rate as specified by the Installation Guide and Low Flow will be the minimum allowed flow rate for the application. To utilize the feature, analysis will need to be performed by JDES with support from the customer. The output of the analysis will be a speed/torque curve that illustrates where high and low flow must be used.

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[1] Refer to PD400 Installation Guide

[2] Series 2 PD400 only

Note

The inverter is required to be running at either the High Flow or Low Flow rate and operation at intermediary flow values should only occur during transitional periods.

Once the feature is enabled, the desired flow rate is commanded to the inverter over CAN using J1939-74 Configurable Messages[3] based on the speed/torque curve provided. A status message can also be configured to broadcast the current flow rate the inverter is using. The inverter can immediately be commanded to low flow, however, when transitioning from low to high flow, the spool up time of the pump must be factored in requiring an additional delay before sending the command. An example torque curve showing the different operating areas is shown below.

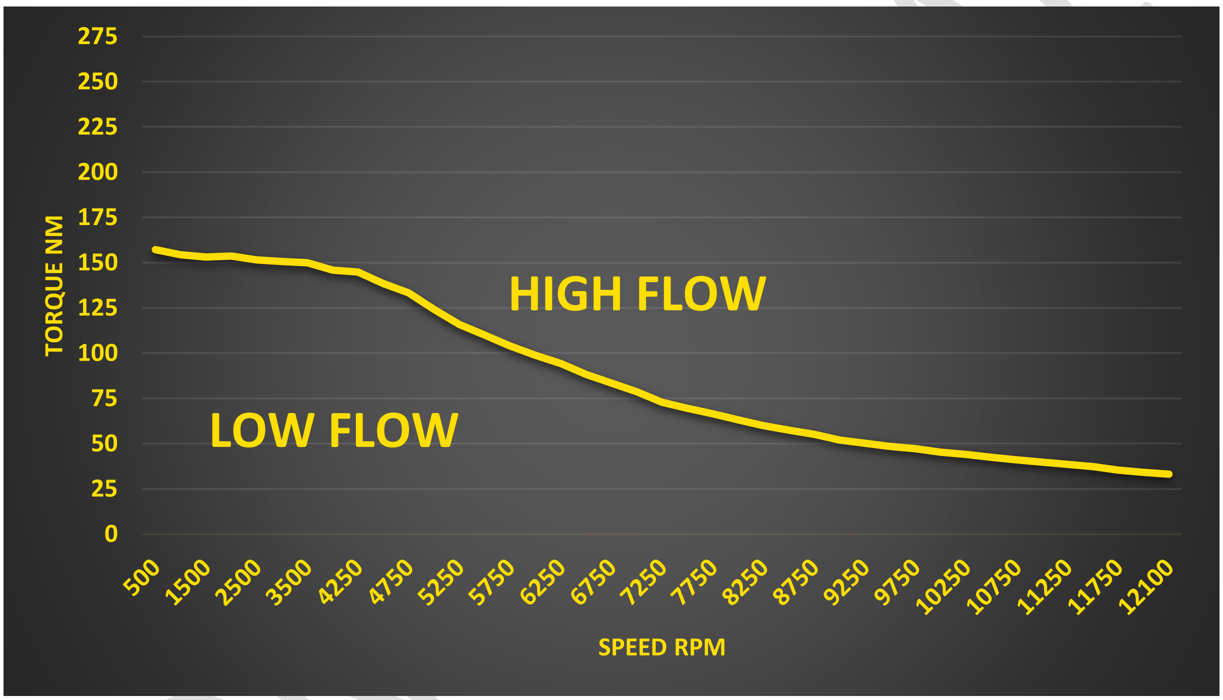

Figure 4: High/Low Flow Rate

6.9.12. Loss of Coolant

The inverter can detect that the coolant flow rate being received has been reduced or completely stopped. Upon detecting this condition, the inverter will activate a Loss of Coolant warning indicating the condition to the system. The inverter will continue to operate in a significantly reduced performance mode that is managed by Junction Temperature Limiting.

[3] Refer to PD400 CAN Specification

6.9.13. Disabled Output State

By default, unless in a UCG or Asymmetric fault scenario[4], if the inverter is in a Drive Inactive or Fault state, the IGBTs will be commanded to six-switch open. Six-switch open may be undesirable for some systems as it may cause the motor to produce uncontrolled generating torque. This condition will occur when the speed of the electric machine is high enough to generate a peak BEMF that exceeds the current battery operating voltage. There are multiple ways that this condition can be managed at the system level, but one way is to have the inverter command a three-phase short to manage the BEMF. The illustration below shows the state of the IGBTs when the inverter is in a Drive Inactive or Fault state depending on if the feature is enabled or not. If enabled, additional verification and analysis will need to be carried out by JDES, with the assistance of the customer, to ensure the characteristic current of the machine is acceptable.

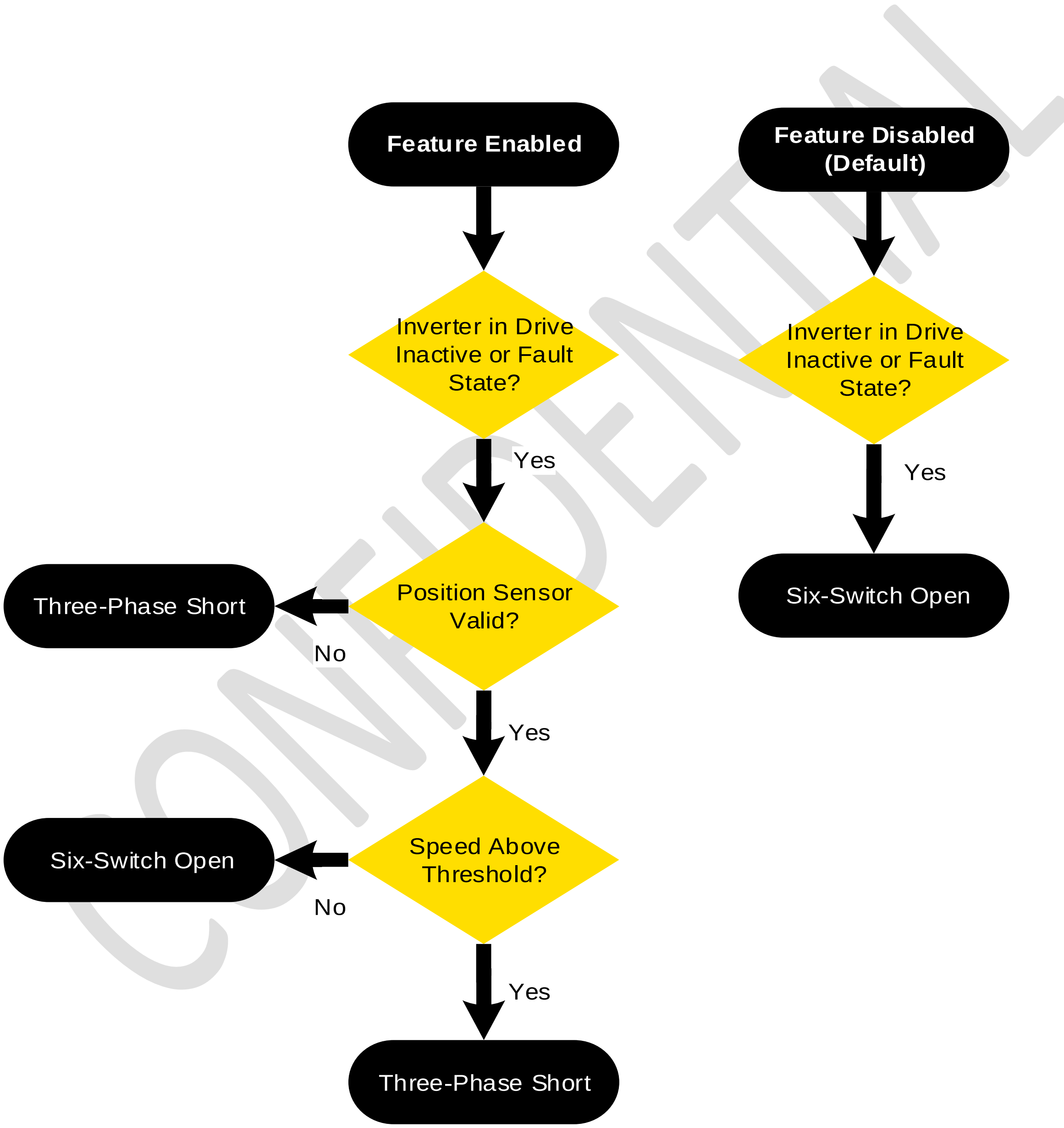

Figure 5: Disabled Output State

[4] Refer to the Fault Handling section for more information on each of these faults

6.9.14. AC Supply Mode

The inverter can be configured to operate as a 3-phase AC power supply with adjustable voltage and frequency. The CAN messages used to control this feature can be found in the PD400 CAN Specification. Operating the inverter in as an AC Supply disables some motor control features and diagnostics. Please contact JDES for more information on this configuration if your application requires it.

6.9.14.1. Operating State Manager

The AC Supply configuration is only supported when in OSM mode.

6.9.14.2. Voltage Mode

In Voltage Mode, the output voltage and frequency are set by the AC Supply Command CAN message. Changes in the voltage command are moderated by a configurable slew rate. Frequency commands are not slewed in this mode.

6.9.14.3. Frequency Mode

Frequency Mode maintains a specified V/Hz relationship. The V/Hz ratio is calculated as the commanded voltage divided by the commanded frequency set via the AC Supply Command CAN message. When the inverter transitions to Normal Operation, the V/Hz ratio is latched until the inverter leaves the Normal Operation state. The output voltage will be the V/Hz ratio multiplied by the commanded frequency. The commanded voltage has no effect while the V/Hz ratio is latched (in Normal Operation). The output frequency and voltage are slewed via configurable parameters.

6.9.14.4. Current Limiting

Current Limiting works to prevent over-currents in the inverter and can help manage instances when there is a demand for overload capability from the inverter, such as during a startup event. When the inverter detects that the output current is greater than the current limit, the voltage and/or frequency is reduced to reduce the current to the specified the current limit. The current limit can be changed dynamically via the AC Supply Limits CAN message.

6.9.14.5. Voltage Drop Compensation (Voltage-Current Adjustment)

The AC Supply is capable of adjusting the output voltage to compensate for the voltage drop between the inverter and the load. This allows the commanded voltage to appear at the load rather than the inverter terminals. The inverter uses the current measurement and a configurable voltage-to-current adjustment ratio (i.e. impedance) to adjust the output voltage. The inverter terminal voltage (command) and load voltage (desired) are available via the AC Supply Status CAN message.

7. Protecting the Inverter/Machine

The various sensors and configured inverter limits protect the inverter from damage.

7.1 Sensors

Many sensors within the inverter are used for multiple functions. In some cases, they may be used to detect abnormal inverter operation, or may detect that the inverter is approaching an operational state that may become damaging to itself, the electric machine, the HVDC bus, or the system.

7.1.1. Motor Temperature Sensors

The motor temperature sensors (also called external temperature sensors) allow the inverter to react to extreme temperature operating conditions. Multiple sensors of various types are supported by the inverter interface. Refer to the electric machine documentation to determine the number and type of sensors that are available. Because the sensor reading to temperature conversion varies based on sensor, EOL configuration for the available sensors is often necessary.

The measured temperatures are available via CAN messages. Any sensor reporting a value outside its normal temperature range is considered out-of-range and will be handled as a failed or missing sensor. Warning and fault levels can be configured in the EOL. If desired these levels can be set to values outside of the capabilities of the motor temperature sensor to effectively disable the faults.

Table 4: Motor Temperature Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Motor Winding Temperature Warning Level	Motor temperature exceeds limit and causes a warning.	Motor Winding Temperature Phase A/B/C Warning	°C	Motor Dependent
Motor Winding Temperature Fault Level	Motor temperature exceeds limit and causes a critical fault.	Motor Winding Temperature Phase A/B/C Fault	°C	Motor Dependent

7.1.2. IGBT (Baseplate) Temperature Sensors

The inverter contains sensors to monitor each IGBT baseplate temperature. The measured temperatures are available via CAN messages. If the IGBT temperature is above the warning level, a warning fault is set. If the temperature is above the fault level, a critical fault is set.

Table 5: IGBT Temperature Thresholds

Parameter	Conditions	Fault Generated	Units	Default
IGBT Baseplate Temperature Warning Level	Temperature in an IGBT of the inverter exceeds limit, causing a warning fault.	IGBT Temperature Phase A/B/C Warning	°C	115
IGBT Baseplate Temperature Fault Level	Temperature in an IGBT of the inverter exceeds limit, causing a critical fault.	IGBT Temperature Phase A/B/C Fault	°C	125

7.1.3. Ambient Air Temperature Sensor

The inverter contains a temperature sensor that measures the internal air temperature of the inverter. The measured temperature is available via a CAN message. If the sensor goes out of range, an EOL defined default temperature is reported.

Table 6: Ambient Air Temperature Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Ambient Air Over Temperature Threshold	Ambient air temperature exceeds the threshold, causing a fault.	Ambient Air Over Temperature Fault	°C	110

7.1.4. Coolant Temperature Sensor

The inverter estimates the temperature of the coolant flowing through the inverter and uses it for the junction temperature limiting feature and to detect a loss of coolant condition. The coolant temperature is available via a CAN message.

Table 7: Coolant Temperature Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Coolant Sensor Over Temperature Threshold	Coolant temperature has risen above this threshold, causing a warning fault.	Coolant Over Temperature Warning	°C	80

7.1.5. Motor Position Sensor

The position sensor is critical to control of the electric machine. All inverters are configured during manufacturing for the type of motor position sensor available on the selected electric machine. Typically, this configuration cannot be changed after the inverter is manufactured. Calibration of the position sensor is typically done when the inverter is paired with the motor. This calibration is performed via one of the Advanced Diagnostics position calibration routines.

Table 8: Motor Speed Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Over Speed Trip Threshold	Motor mechanical speed exceeds threshold, causing a critical fault. Fault is reset by switching to the Idle State once motor speed drops below limit.	Motor Trip Speed Fault	RPM	Motor Dependent

7.1.6. Inverter Current Sensors

The inverter contains current sensors for each phase and the brake chopper (if equipped). These sensors measure current in each inverter phase and are used for electric machine control and diagnostics.

Table 9: Current Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Phase Overcurrent Threshold	Current in the Phase A/B/C winding exceeds inverter limit, causing a critical fault.	Phase A/B/C Overcurrent Fault	Apk	1150
Brake Chopper Overcurrent Threshold	Current in the Brake Chopper exceeds inverter limit, causing a critical fault.	Brake Chopper Overcurrent Fault	Apk	1150

7.1.7. HVDC Bus Voltage Measurement Circuit

The inverter measures the HVDC bus voltage. This measurement is available via a CAN message. Several configurable thresholds for diagnostics and operation exist.

Table 10: HVDC Voltage Thresholds

Parameter	Conditions	Fault Generated	Units	Default
Class B Undervoltage Threshold	HVDC Bus voltage drops below limit, causing a critical fault	Class B HVDC Bus Undervoltage Fault	V	400
Class B Overvoltage Threshold	HVDC Bus voltage exceeds limit, causing a critical fault	Class B HVDC Bus Overvoltage Fault	V	800
UCG Overvoltage Threshold	HVDC Bus voltage exceeds limit, causing a fail safe fault and a three phase short. A power cycle shall be required to clear the fault.	Uncontrolled Generation (UCG) Overvoltage Fault	V	825

7.1.8. Low-Voltage (Unswitched) Measurement Circuit

The inverter monitors the low-voltage battery connection that supplies power to the low-voltage control circuitry when the inverter is powered on. The inverter expects this source to have a minimum voltage present at all times, even when the inverter is powered down. When it is powered down, current draw from this source is a few micro amps. When it is powered up, current draw is typically in the range of a few amps.

Table 11: Low-Voltage (Battery) Input Warning Thresholds

Parameter	Conditions	Fault Generated	Units	Default
ELV Undervoltage Threshold	Voltage has dropped below this limit, causing a warning.	Unswitched Battery Voltage Low Warning	V	9
ELV Overvoltage Threshold	Voltage has risen above this limit, causing a warning.	Unswitched Battery Voltage High Warning	V	40

7.1.9. Low-Voltage (Switched) Input Measurement Circuit

The low-voltage input is used to signal the inverter to power up and down. Often, this input is connected to the vehicle key-switch circuit, but this is not required. Many methods may be used to activate this input, such as a relay, another vehicle controller, or a toggle switch. When the voltage on this input is above the activation point, the inverter powers up. When the voltage drops below the deactivation point, the inverter enters the Controlled Power Down state.

7.1.10. Internal Sensor Power Supply Measurement Circuit

The internal sensor power supplies are contained within the inverter and are responsible for providing low-voltage power to all internal sensors, such as the motor position sensor, digital I/O, etc. The voltages are continuously monitored by the inverter.

Table 12: Internal Sensor Power Supply Thresholds

Parameter	Conditions	Fault Generated	Units	Default
15V Sensor Power Supply High Limit	Voltage has risen above this limit causing a warning.	15V Supply Out of Range High Warning	V	15.9
15V Sensor Power Supply Low Limit	Voltage has dropped below this limit causing a warning.	15V Supply Out of Range Low Warning	V	14
5V Sensor Power Supply High Limit	Voltage has risen above this limit causing a warning.	5V Supply Out of Range High Warning	V	5.3
5V Sensor Power Supply Low Limit	Voltage has dropped below this limit causing a warning.	5V Supply Out of Range Low Warning	V	4.7

7.3 Torque Limiting

The inverter has several features that limit torque due to a variety of operating conditions. The torque limiting features often act to protect the inverter, motor, or system from extreme conditions. When active limiting is occurring, the Derate Owner reported in the Inverter Status 2 CAN message indicates the cause of the limit.

! Note	The torque limiting features can be disabled and limit values can be adjusted if not required for the system. If disabled, many features will still trigger a fault if maximum limits are exceeded.

7.3.1. No Derate

When no condition is limiting the inverter torque, the Derate Owner reported via CAN will indicate that No Derate is active.

7.3.2. IGBT (Baseplate) Temperature Limit

IGBT temperature dynamically limits electric machine torque to avoid overheating the IGBTs. Available torque is linearly reduced from 100% to 0% when the IGBT Temperature is within a configurable pair of limits. The following figure shows the limiting curve along with the associated limits.

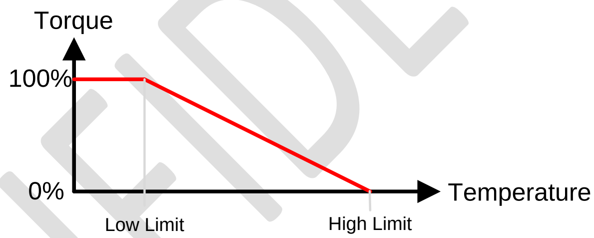

Figure 6: Torque Limiting Due to IGBT Temperature

7.3.3. Motor Winding Temperature Limiting

Winding temperature dynamically limits electric machine torque to avoid overheating the machine windings. Available torque is linearly reduced from 100% to 0% when the winding temperature is within a configurable pair of limits. The following figure shows the limiting curve along with the associated limits.

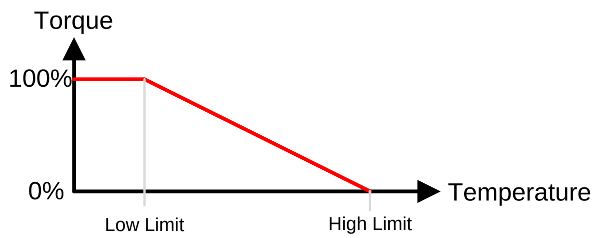

Figure 7: Torque Limiting Due to Motor Winding Temperature

7.3.4. Secondary Speed Limiting

Secondary speed limiting dynamically limits electric machine torque to provide slip protection or to prevent an engine from stalling. Available torque is linearly reduced from 100% to 0% when the speed is within a configurable pair of limits.

Two methods are available for configuring this feature, the Absolute Limit method and the Ratio Limit method. With each method, separate parameters are available to configure limits for motoring and generating.

The following figure shows the limiting curve along with the associated limits

7.3.4.1. Absolute Limiting

The Absolute Limiting method allows configuration of the limits based on absolute machine speed (rpm). The following figures show the limiting curve along with the associated limits. Note that there are different limits for motoring and generating.

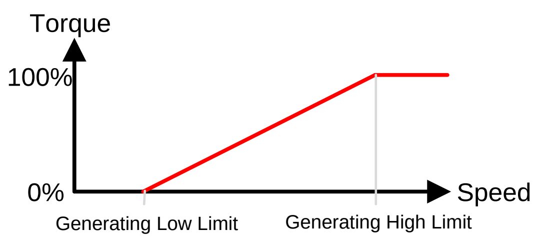

Figure 8: Secondary Speed Limiting When Generating (Absolute Method)

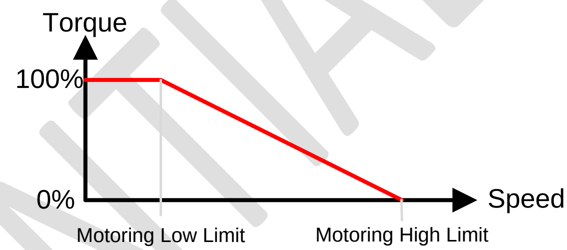

Figure 9: Secondary Speed Limiting When Motoring (Absolute Method)

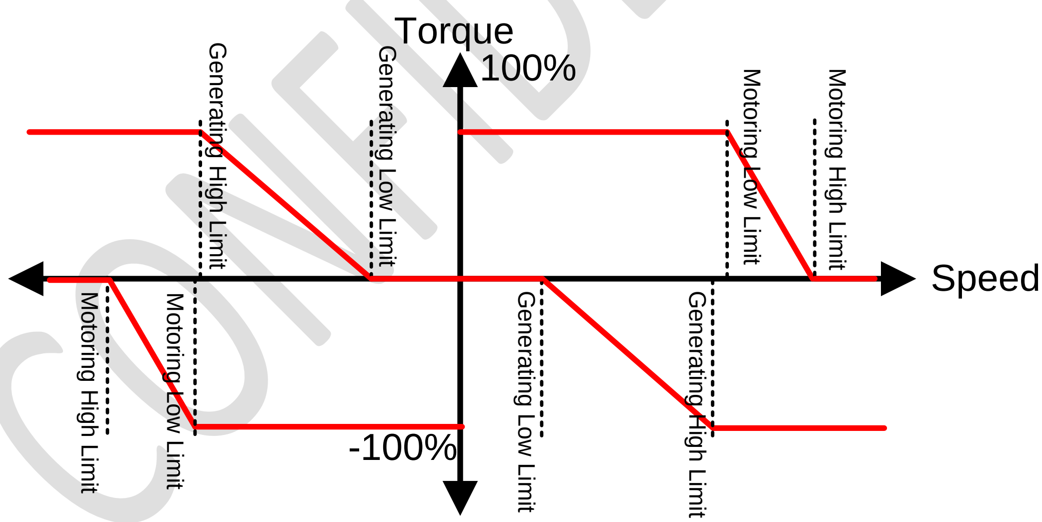

Figure 10: Secondary Speed Limiting (Absolute Method), Illustrated in 4 Quadrants

7.3.4.2. Ratio Limiting

The Ratio Limiting method allows configuration of the limits based on the relative difference from a center point. The center point can be configured statically through EOL or dynamically through the Torque Limiting CAN message. The following figures show the limiting curve along with the associated limits. Note that there are different limits for motoring and generating.

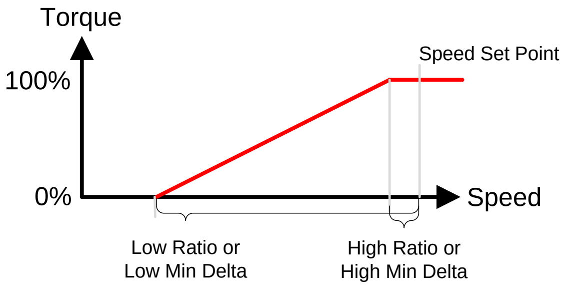

Figure 11: Secondary Speed Limiting When Generating (Ratio Method)

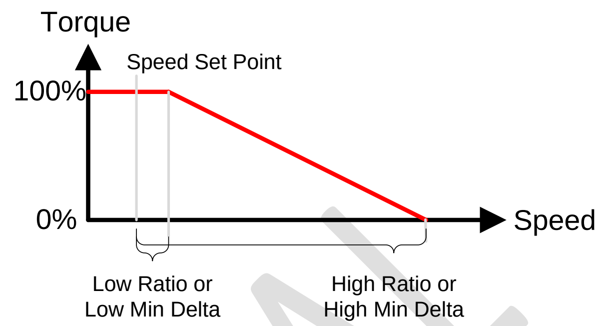

Figure 12: Secondary Speed Limiting When Motoring (Ratio Method)

7.3.5. Secondary Voltage Limiting

Secondary HVDC bus voltage limiting dynamically limits electric machine torque to avoid creating an overvoltage or undervoltage condition in the system. Available torque is linearly reduced from 100% to 0% when the voltage is within a configurable pair of limits.

Two methods are available for configuring this feature, the Absolute Limit method and the Ratio Limit method. With each method, separate parameters are available to configure limits for motoring and generating.

7.3.5.1. Absolute Limiting

The Absolute Limiting method allows configuration of the limits based on absolute HVDC bus voltage (volts). The following figures show the limiting curve along with the associated limits. Note that there are different limits for motoring and generating.

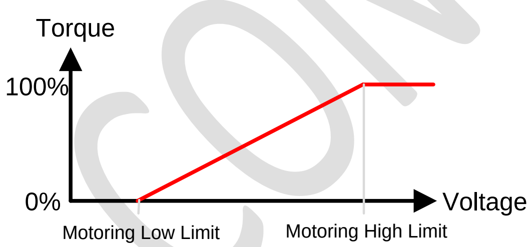

Figure 13: Secondary Voltage Limiting When Motoring (Absolute Method)

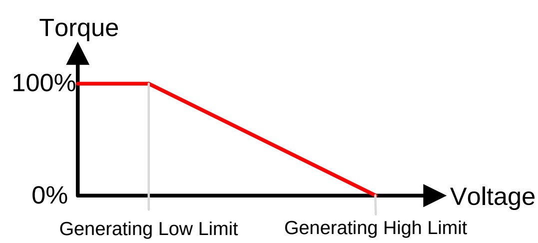

Figure 14: Secondary Voltage Limiting When Generating (Absolute Method)

7.3.5.2. Ratio Limiting

The Ratio Limiting method allows configuration of the limits based on the relative difference from a center point. The center point can be configured statically through EOL or dynamically through the Torque Limiting CAN message. The following figures show the limiting curve along with the associated limits. Note that there are different limits for motoring and generating.

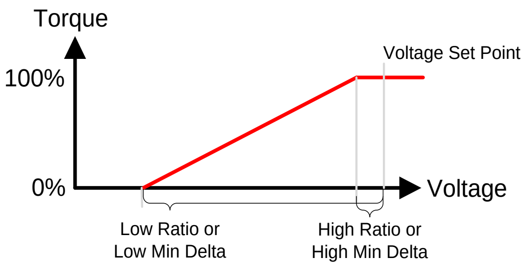

Figure 15: Secondary Voltage Limiting When Motoring (Ratio Method)

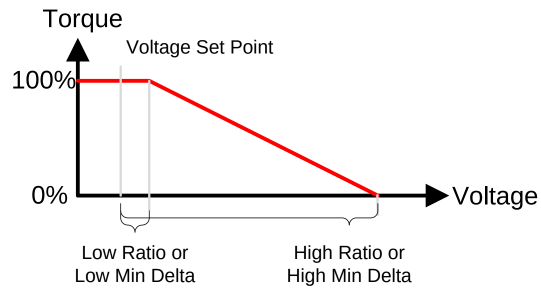

Figure 16: Secondary Voltage Limiting When Generating (Ratio Method)

7.3.6. Overload Current Protection (I^2T) Fast/Slow Limit

The inverter has an I^2T feature that can attempt to protect other components in your system from overheating. This feature is often used to protect cabling, but it can be used for any component with known I^2 heating characteristics. To properly configure the feature, the inverter must be run at rated current and the time it takes the component to reach its peak temperature must be noted. This information can be used to configure the EOL for this feature. The fast limit is used to calculate an I^2T for a component that has a fast rise time in regards to temperature and the slow limit is used for a component that has a slow rise time. There are also fault and warning thresholds that can be configured for this feature. Contact JDES for configuration and additional details regarding this feature.

! Note	Use of the I^2T feature does not guarantee the target components outside the inverter will be protected. This feature provides a component heating estimate based on the configured thermal model.

7.3.7. Direct Torque Limit (CAN Command)

A direct torque limit can be issued to the inverter via CAN Command Message 3 and the Torque Limiting Message. Command Message 3 uses one value for both the motoring and generating torque limits. The Torque Limiting Message uses separate values for the motoring and generating limits. These limits, in percent, are based off the Reference Torque parameter. For example, if the Reference Torque is configured to be 500 NM and the torque limit is 50%, the maximum torque the inverter (and electric machine) will produce is 250 NM.

7.3.8. Terminal Voltage Limiting

The inverter is equipped with a feature that monitors the machine terminal voltage. If the terminal voltage is too high this feature adjusts the current to reduce the terminal voltage by limiting the torque. This feature can be active in cases where an IPM motor is cold and it is being operated above rated speed and at high torque.

7.3.9. Peak Speed-Torque Curve

The Peak Speed-Torque Curve limits are defined by two unique tables (one for motoring and one for generating), each with 50 speed-torque pairs. By default, this curve is configured to allow the maximum torque at each speed point, at a given DC bus voltage. These values may exceed the motor manufacturer's continuous limits. Since these tables are dependent on DC bus voltage, they may increase/decrease dynamically as the voltage fluctuates. This allows the inverter to provide accurate torque while maintaining proper control of the electric machine.

7.3.10. User Defined Torque Curve

The User Defined Torque Curves are similar to the Peak Speed-Torque Curve Limits. These curves can be configured for the application, though every point must be less than the corresponding Speed-Torque Curve Limit point. These tables are dependent only on speed and have no dependence on voltage.

> **! Note** The user is responsible for motor protection and managing the duty cycle between peak and continuous motor limits.

7.3.11. Master Speed Torque Curve

Master Speed Torque Curve limiting is only applicable when using the Torque Sharing feature.

7.3.12. Junction Temperature Limiting

The inverter monitors and limits inverter current as needed to allow maximum performance while protecting the power semiconductors. The inverter allows operation above its continuous current rating (up to its peak current rating) for a limited duration. As the inverter heats, the current limit is reduced from the peak current rating to the continuous current rating. Various operating parameters such as fundamental frequency, switching frequency, coolant flow, and coolant temperature influence the component temperatures. The inverter is actively estimating the coolant temperature and broadcasts the value in the Inverter Temperature 2 CAN message. By estimating the temperature, additional performance may be allowed when the coolant temperature is colder or when first starting the system. The amount of overload used is broadcasted in the Inverter Status 4 CAN message with 0% meaning full capability available. Once 100% of overload is used, Current Limiting shall be the derate owner and the inverter shall be reduced to its continuous current level for a given operating point. Junction Temperature Limiting is always enabled.

> **! Note** The duration allowed for peak current is less than 10 seconds for most applications due to the fast temperature rise of the components. Therefore the feature is typically used for launch conditions, and the continuous rating of the inverter needs to be well understood to satisfy a given drive cycle. JDES can perform additional simulation and analysis to determine how the inverter/motor will fit into a system.

7.3.13. DC Power Torque Limiting

This feature is used to limit power consumed or generated by the inverters connected to the DC Bus. DC Link Power is estimated using the estimated motor shaft power. Maximum available motoring and generating DC Link Power is calculated using the estimated maximum motor shaft power available. Both calculations take into account the motor and inverter efficiencies.

Motoring and generating power limit settings can be adjusted via a CAN command message. DC Link Power is indirectly limited by derating motor torque as needed. The actual DC Link Power and maximum available motoring/generating power can be obtained from each inverter via a CAN status message.

7.3.14. DC Current Torque Limiting

This feature allows the vehicle controller to limit DC current consumed or generated by the inverters connected to the DC Bus. This is done in order to prevent too much current being requested by the consumers that would overpower the generator or other power source. Within each inverter, DC Link Current is calculated continuously based on the estimated DC Link Power and the measured DC Link Voltage. Maximum available motoring and generating DC Link Current is calculated based on the maximum available motoring and generating DC Link Power calculations and the measured DC Link Voltage.

Each inverter on the DC Bus has its own motoring and generating current limit settings that are adjusted using a CAN command message. DC Link Current is indirectly limited by derating motor torque as needed. The actual DC Link Current and maximum available motoring/generating current can be obtained from each inverter via a CAN status message.

8. Fault Handling

A fault occurs when the inverter detects an abnormal condition in the inverter, machine, input power source, or cabling. When a fault occurs, it is reported on the CAN bus. The inverter fault response differs depending on the severity of the fault detected. The severity levels of faults are listed below.

Warning: The inverter remains fully functional. It is still safe to continue operation, but the vehicle controller may need to reduce system performance to prevent additional faults or system damage. When it is convenient, these faults should be corrected to insure maximum system performance and lifespan.

Critical: The inverter stops operation to prevent damage to itself or the system and moves to a fault state. The inverter can be commanded to operate once the fault condition is cleared, but the root cause of the fault must be diagnosed and corrected promptly. For some critical faults, repeated events can cause premature system wear or failure.

Fail Safe: The inverter stops operating to prevent damage to itself or the system and moves to the Fail Safe state. The inverter can only recover from the Fail Safe state through a power cycle. Some Fail Safe faults indicate system damage that requires repair before continuing operation. Other Fail Safe faults indicate errors that occurred when attempting to run a diagnostic. The root cause of the fault must be diagnosed and corrected as soon as possible. For some Fail Safe faults, repeated events can cause premature system wear or failure.

The inverter reports faults on the CAN bus using the J1939 DM1 diagnostics reporting message. Each fault in the DM1 message contains a Suspect Parameter Number (SPN) and Failure Mode Indicator (FMI) code that allows the fault to be identified. The following figure shows the process of handling the different fault types.

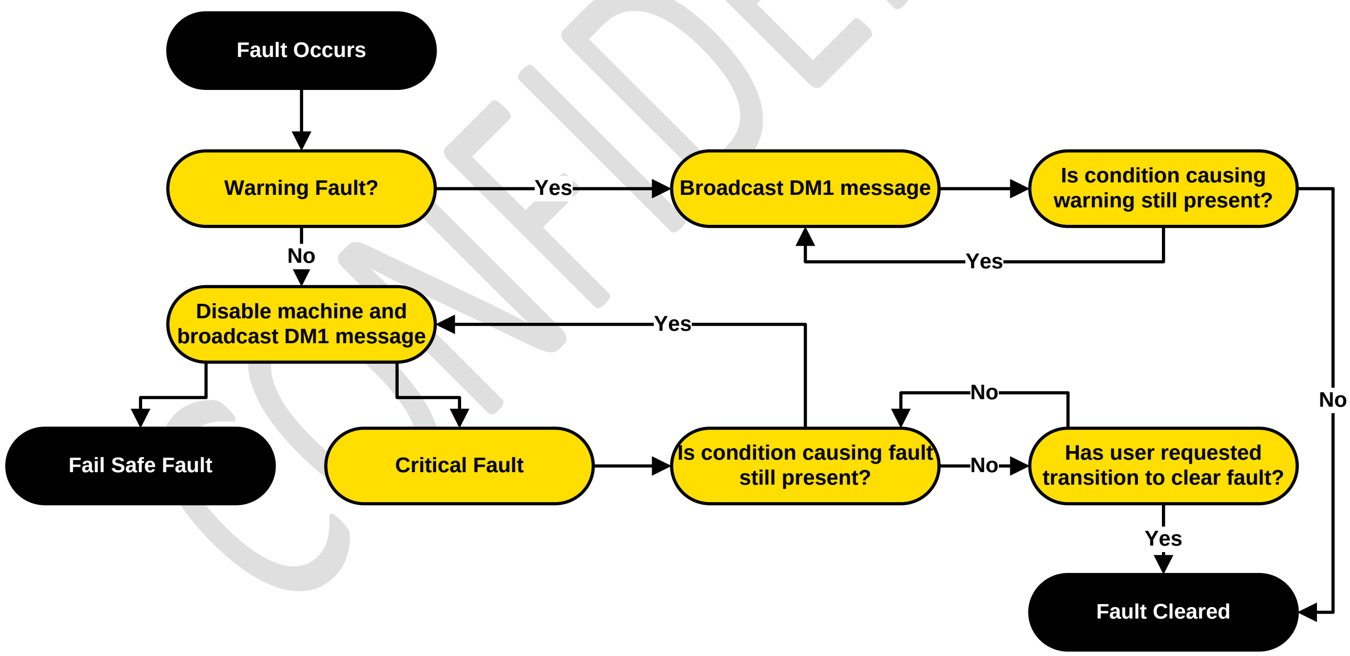

Figure 17: Inverter Fault Occurrence and Reset Process

! Note Many faults can be caused by a threshold being defined incorrectly for the system. This fact is not stated explicitly in each fault, but a user should take it into account when diagnosing a specific fault.

8.1 Inverter Startup Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
521372	**31**	EOL Compatibility Fault	**Fail Safe**	– Application code and EOL code do not match.
521601	**2**	Board Population Invalid Fault	**Fail Safe**	– Application code is not compatible with inverter hardware revision
521601	**31**	EOL Checksum Fault	**Fail Safe**	– Corrupted EOL file.
628	**31**	NVM Section Fault	**Fail Safe**	– At least one of EEPROM sections has failed and reset to default.
521257	**2**	FPGA Code Version Mismatch Fault	**Fail Safe**	– Application code and FPGA code mismatch.
521257	**9**	FPGA Communication Loss Fault	**Fail Safe**	– Invalid communication between the FPGA and microcontroller.
521257	**31**	FPGA Firmware is Corrupted Fault	**Fail Safe**	– Corrupt FPGA file.
629	**4**	Cold Start Reset Fault	**Critical**	– Inverter completed functional diagnostics, but lost switched and unswitched power before high voltage was applied.
629	**11**	Invalid Reset Fault	**Critical**	– Inverter was in a high power state but lost switched and unswitched power and was unable to shut down properly.

Table 13: Inverter Startup Faults

8.2 Diagnostic Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
Functional Diagnostics				
520302	**6**	Phase A Low Side IGBT Shorted Fault	**Fail Safe**	– IGBT failed short – Phase cable shorted to HVDC+ or HVDC-
520303	**6**	Phase A High Side IGBT Shorted Fault		
520304	**6**	Phase B Low Side IGBT Shorted Fault		
520305	**6**	Phase B High Side IGBT Shorted Fault		
520306	**6**	Phase C Low Side IGBT Shorted Fault		
520307	**6**	Phase C High Side IGBT Shorted Fault		
520302	**5**	Phase A Low Side IGBT Open Fault	**Critical**	– IGBT failed open – Phase cable not connected to machine
520303	**5**	Phase A High Side IGBT Open Fault		
520304	**5**	Phase B Low Side IGBT Open Fault		
520305	**5**	Phase B High Side IGBT Open Fault		
520306	**5**	Phase C Low Side IGBT Open Fault		
520307	**5**	Phase C High Side IGBT Open Fault		
Advanced Diagnostics B				
522919	**13**	Position Calibration Error Warning	**Warning**	– Expected position offset and calculated offset are greater than threshold – Improperly connected machine feedback cabling – Machine phase wiring not connected to proper phases
522919	**7**	Position Calibration Error Fault	**Warning**	
3579	**2**	Cable Orientation Fault	**Warning**	
Power Diagnostic Faults				
522919	**13**	Position Calibration Error Warning	**Warning**	– Expected position offset and calculated offset are greater than threshold – Improperly connected machine feedback cabling – Machine phase wiring not connected to proper phases
522919	**7**	Position Calibration Error Fault	**Critical**	
3579	**2**	Cable Orientation Fault	**Fail Safe**	
161	**31**	Free Acceleration Test Fault	**Warning**	– Motor did not accelerate quickly enough during the test – Machine is not able to free spin
521211	**30**	Automatic Control Fault	**Warning**	– Brake chopper auto control circuit is not operating as expected. – Brake chopper not connected
Advanced Diagnostic Class B				
521359	**3**	Bleed Resistor Above Rated Value Fault	**Warning**	– The passive resistance on the DC bus is higher than expected – DC Link capacitor is connected to external source
521359	**4**	Bleed Resistor Below Rated Value Fault	**Warning**	– The passive resistance on the DC bus is lower than expected – External source is discharging bus faster than expected

Table 14: Diagnostic Faults

8.3 Internal Inverter Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
521224	**3**	5V Supply Out of Range High Warning	**Warning**	– Internal 5V Supply out of range – Hardware failure
521224	**4**	5V Supply Out of Range Low Warning		
521786	**3**	15V Supply Out of Range High Warning	**Warning**	– Internal 15V Supply is out of range – Hardware failure
521786	**4**	15V Supply Out of Range Low Warning		
629	**12**	Watchdog Reset Fault	**Critical**	– The microcontroller software has failed to perform a time critical task – This fault only occurs after the inverter has reset
521065	**0**	Current Sensor Disabled Fault	**Fail Safe**	– Inverter is no longer receiving valid data from one or more current sensors – One or more current sensors read a current that is out of range – Current sensor failure – Commanding Functional Diagnostics or Advanced Diagnostics Class A – Current Sensor Zero Offset Calibration routine will attempt to enable the sensor
521065	**16**	Current Sensor Disabled Fault	**Critical**	
522915	**31**	Gate Drive Hardware Fault	**Critical**	– Hardware failure of inverter gate drive board.
522819	**2**	DC Bus Sensor Mismatch Fault	**Fail Safe**	– Primary and secondary bus voltage readings are different – Failure in internal measurement circuitry
521260	**4**	Gate Drive Power Supply Out of Range Low Fault	**Critical**	– Internal power supply failure
521260	**3**	Gate Drive Power Supply Out of Range High Fault		

Table 15: Internal Inverter Faults

8.4 System Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
521368	**3**	Switched Battery Voltage High Fault	**Critical**	– Switched battery voltage too high
521368	**4**	Switched Battery Voltage Low Fault	**Warning**	– Switched battery voltage too low
168	**3**	Unswitched Battery Voltage High Fault	**Critical**	– Unswitched battery voltage is above the threshold
168	**4**	Unswitched Battery Voltage Low Fault	**Warning**	– Unswitched battery voltage is below the threshold
522919	**2**	Position Sensor Parity Fault	**Critical**	– Machine resolver signal cannot be used for control – Improperly connected motor feedback cabling – Missing motor feedback cabling – Position sensor failed – Hardware population invalid for connected sensor – Unshielded sensor cabling
522919	**31**	Position Sensor Loss of Tracking Fault		
522919	**4**	Position Sensor Degradation of Signal Fault		
522919	**8**	Position Sensor Loss of Signal Fault		
522919	**14**	Position Sensor Erratic Fault		
521359	**5**	Discharge Timeout Fault	**Critical**	– Discharge has failed to complete within time limit – Inverter not connected to machine or brake resistor – Machine or brake resistor not connected properly – DC Link is connected to an external source
517158	**12**	Independent Interlock Fault	**Critical**	– Monitored interlock circuit has opened
523821	**2**	Invalid Motor Type Fault	**Critical**	– Commanded motor type object does not match EOL Motor Type Selection – Improper programming
517051	**19**	Mode of Operation Invalid Fault	**Critical**	– Mode of Operation Display object is not set to a valid mode and inverter has received Enable Operation command
517026	**9**	Inverter Command Missing Fault	**Critical**	– Inverter not receiving a valid command message within the time-out period. – CAN communication lost due to physical layer issues. – CAN bus is overloaded – Failure to address claim
517024	**9**	CAN B Generator Fault	**Warning**	– Missing expected Generator Heartbeat CAN message from external inverter – CAN communication lost due to physical layer issues. – CAN bus is overloaded – CAN not connected
517025	**9**	CAN B Motor Fault	**Warning**	– Missing expected Motor Feed Forward CAN message from external inverter – CAN communication lost due to physical layer issues. – CAN bus is overloaded – CAN not connected
517093	**9**	Motor 2 Feed Forward Fault		
517100	**9**	Motor 3 Feed Forward Fault		
517101	**9**	Motor 4 Feed Forward Fault		

SPN	FMI	Fault Name	Severity	Description/Possible Causes
517102	**9**	Motor 5 Feed Forward Fault		
517103	**9**	Motor 6 Feed Forward Fault		
517104	**9**	Motor 7 Feed Forward Fault		
517105	**9**	Motor 8 Feed Forward Fault		

Table 16: System Faults

8.5 Inverter Protection Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
522912	**0**	Phase A Overcurrent Fault	**Critical**	– Instantaneous phase current exceeded threshold – Short circuit on wires occurred – Motor winding failure (internal short) – Position offset not correct – Inverter lost control – Damaged IGBT
522911	**0**	Phase B Overcurrent Fault		
522910	**0**	Phase C Overcurrent Fault		
522912	**31**	Persistent Phase A Overcurrent Fault	**Fail Safe**	– Phase current exceeded threshold for 500ms
522911	**31**	Persistent Phase B Overcurrent Fault		
522910	**31**	Persistent Phase C Overcurrent Fault		
522912	**6**	Phase A RMS Overcurrent Fault	**Critical**	– RMS Phase current exceeded threshold
522911	**6**	Phase B RMS Overcurrent Fault		
522910	**6**	Phase C RMS Overcurrent Fault		
522912	**30**	Persistent Phase A RMS Overcurrent Fault	**Fail Safe**	– RMS Phase current exceeded threshold for 500ms
522911	**30**	Persistent Phase B RMS Overcurrent Fault		
522910	**30**	Persistent Phase C RMS Overcurrent Fault		
521265	**3**	Phase A Desat Fault	**Critical**	– Large magnitude, short duration current spike detected in IGBT – IGBT exceeded maximum allowed Vce voltage – Phases are shorted to each other either at the connector or through the machine – Phases are shorted to the DC Link – Internal hardware failure
521269	**3**	Phase B Desat Fault		
521270	**3**	Phase C Desat Fault		
522819	**0**	Uncontrolled Generation (UCG) Overvoltage Fault	**Fail Safe**	– Bus voltage has reached a critical level, inverter will command a three-phase low side short to protect the system
522819	**15**	Class A HVDC Bus Overvoltage Fault	**Fail Safe**	– The DC Bus experienced high voltage when DC Bus voltage expected to be low – Improper startup procedure
522819	**16**	Class B HVDC Bus Overvoltage Fault	**Critical**	– The DC Bus has exceeded defined threshold – Power supply/battery set too high – Excessive regeneration occurred due to machine braking – An instant open load was created while under heavy motoring operation creating a voltage surge – Uncontrolled generation due to BEMF of the motor
522819	**18**	Class B HVDC Bus Undervoltage Fault	**Critical**	– The DC Bus is below defined threshold – DC Bus is overloaded, causing voltage drop
520904	**16**	IGBT Temperature Phase A Fault	**Critical**	– The inverter IGBT temperature is above threshold

520905	**16**	IGBT Temperature Phase B Fault		– Inverter overworked for rated coolant flow rate and temperature
520907	**16**	IGBT Temperature Phase C Fault		
524259	**0**	Ambient Air Over Temperature Fault	**Critical**	– Inverter internal temperature is above the threshold
517092	**15**	Coolant Over Temperature Warning	**Warning**	– Coolant temperature is above the threshold
517092	**16**	Loss of Coolant Warning	**Warning**	– Loss/reduced flow of coolant has been detected – May have air in the inverter cooling system – Cooling pump may have stopped working
520904	**15**	IGBT Temperature Phase A Warning	**Warning**	– The inverter IGBT temperature is above threshold – Inverter overworked for rated coolant flow rate and temperature
520905	**15**	IGBT Temperature Phase B Warning		
520907	**15**	IGBT Temperature Phase C Warning		
524043	**0**	IGBT Temperature Sensor Disabled Fault	**Warning**	– All of the inverter IGBT temp sensors have failed
524043	**15**	IGBT Temperature Sensor Disabled Warning	**Warning**	– An IGBT temperature sensor has failed

Table 17: Inverter Protection Faults

8.6 System Protection Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
524039	**0**	Machine Overspeed Fault	**Critical**	– Exceeded speed threshold
522912	**15**	Phase A Component Overload Fast Warning	**Warning**	– The thermal time constant of the monitored component is above defined threshold. – Average current levels being commanded are greater than a specific component in the system is rated for – Component could be the motor, cables, current sensor, etc., depending on user application
522911	**15**	Phase B Component Overload Fast Warning		
522910	**15**	Phase C Component Overload Fast Warning		
522912	**17**	Phase A Component Overload Slow Warning	**Warning**	
522911	**17**	Phase B Component Overload Slow Warning		
522910	**17**	Phase C Component Overload Slow Warning		
522912	**16**	Phase A Component Overload Fast Fault	**Fail Safe**	
522911	**16**	Phase B Component Overload Fast Fault		
522910	**16**	Phase C Component Overload Fast Fault		
522912	**18**	Phase A Component Overload Slow Fault	**Fail Safe**	
522911	**18**	Phase A Component Overload Slow Fault		
522910	**18**	Phase A Component Overload Slow Fault		
521212	**16**	Motor Winding Temperature Phase A Fault	**Critical**	– The machine temperature is above threshold. – Oil flow rate too low – Oil temperature too high at inlet – Excessive operation of machine in peak torque range – Improper oil type
521217	**16**	Motor Winding Temperature Phase B Fault		
521218	**16**	Motor Winding Temperature Phase C Fault		
521212	**15**	Motor Winding Temperature Phase A Warning	**Warning**	
521217	**15**	Motor Winding Temperature Phase B Warning		
521218	**15**	Motor Winding Temperature Phase C Warning		
520804	**0**	Motor Winding Temperature Sensor Disabled Fault	**Warning**	– All machine temperature sensors are out of range
520804	**15**	Motor Winding Temperature Sensor Disabled Warning	**Warning**	– A machine winding temperature sensor is out of range
522919	**16**	Motor Trip Slip Fault	**Critical**	– The slip, or the difference between motor speed and synchronous speed in induction motor, is higher than the controllable threshold.
521258	**2**	Unbalanced Current Fault	**Warning**	– Phase currents are at uneven levels
522774	**4**	Ground Fault	**Fail Safe**	– Inverter phase current does not sum to zero
521227	**31**	Asymmetric Current Fault	**Fail Safe**	– Short circuit has occurred between a motor phase and DC+ or DC-. Three-phase low side short will be commanded.

Table 18: System Protection Faults

8.7 Brake Chopper Faults

SPN	FMI	Fault Name	Severity	Description/Possible Causes
520308	**6**	Brake Chopper Fail to Turn Off Fault	**Warning**	– Current is flowing through the brake chopper when it is commanded off.
520308	**5**	Brake Chopper Fail to Turn On Fault	**Warning**	– No current is flowing through the brake chopper when it is commanded on. – Brake resistor not connected
521360	**0**	Brake Chopper Current Sensor Disabled Warning	**Warning**	– Brake chopper current sensor is out of range
521228	**31**	Brake Chopper Gate Drive Hardware Fault	**Critical**	– Brake chopper hardware failure
516731	**0**	Brake Chopper Automatic Control Power Supply Fault	**Warning**	– Brake chopper automatic control power supply is out of range
521208	**0**	Brake Chopper IGBT Over Temperature Fault	**Warning**	– The brake chopper IGBT is above threshold – Coolant flow rate/temperature out of range
521207	**0**	Brake Resistor Over Temperature Fault	**Warning**	– The brake resistor is above threshold
521207	**3**	Brake Resistor Temperature Out of Range High Fault	**Warning**	– Brake resistor temperature sensor failure
521207	**4**	Brake Resistor Temperature Out of Range Low Fault	**Warning**	– Brake resistor temperature sensor failure
521271	**3**	Brake Chopper Desat Fault	**Fail Safe**	– Large magnitude, short duration current spike detected in brake chopper IGBT – Chopper output is shorted to a phase – Chopper output is shorted to DC Link
521211	**0**	Brake Chopper Overcurrent Fault	**Critical**	– Instantaneous phase current exceeded threshold
521211	**6**	Brake Chopper RMS Overcurrent Fault	**Critical**	– RMS current exceeded threshold
521211	**31**	Brake Chopper Overcurrent or RMS Persistent Fault	**Fail Safe**	– RMS current exceeded threshold for 500ms
521211	**15**	Brake Chopper Overload Derate Fast	**Warning**	– The thermal time constant of the resistor is above threshold.
521211	**17**	Brake Chopper Overload Derate Slow	**Warning**	
521211	**16**	Brake Chopper Overload Fault Fast	**Fail Safe**	
521211	**18**	Brake Chopper Overload Fault Slow	**Fail Safe**	

Table 19: Brake Chopper Faults

9. Performance Tuning

Being able to spin an electric machine is only part of the effort required to utilize the full capability of the inverter. Maximizing performance of the inverter involves tuning it to the specific machine being used and to the system in which it is installed. Assuming that the correct characterization data block is installed in the inverter for the type of machine being driven, the default configuration parameter values will allow stable performance in a test setup. However, the default values do not account for real-world system response, or for optimized reaction to transients, as happens in real vehicles. In this section, performance tuning is discussed as it relates to the standard inverter modes:

- Speed Control Mode
- Absolute or Relative Torque Control Mode
- Voltage Control Mode

Performance tuning for these modes involves optimizing a set of parameter values to get the desired performance, response, or efficiency from the complete system. The process used to obtain the desired performance is beyond the scope of this document.

9.1 Speed Control Mode Performance Tuning

Speed mode tuning involves adjusting controller gains and slews related to the internal speed control loop. The inverter uses a PI controller to regulate the electric machine speed, as shown in the simplified diagram below.

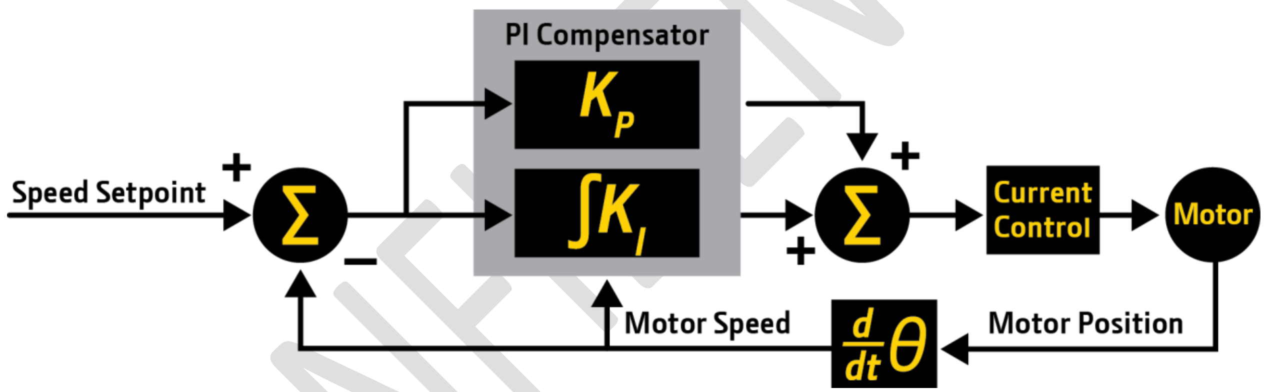

Figure 18: Speed Control

Note that the PI Compensator uses different K_P and K_I coefficients, depending on the current operating speed of the motor. The complete set of operating parameters used for the speed control loop is shown below.

Table 20: Speed Control Parameters

Object Description	**Units**	**Example Value**
Speed Command Increasing Slew Limit	rpm/s	300
Speed Command Decreasing Slew Limit	rpm/s	200
PI Compensator Coefficient Set 1		
Effective Speed Range	Rpm	2000
K_P Coefficient	Nm/rpm	1.1
K_I Coefficient	Nm/rpm Per Iteration (500µs)	0.02
PI Compensator Coefficient Set 2		
Effective Speed Range	Rpm	3000
K_P Coefficient	Nm/rpm	1.0
K_I Coefficient	Nm/rpm Per Iteration (500µs)	0.05
PI Compensator Coefficient Set 10		
Effective Speed Range	Rpm	8000
K_P Coefficient	Nm/rpm	1.5
K_I Coefficient	Nm/rpm Per Iteration (500µs)	0.001

The effective speed for each K_P/K_I set ranges from the previous set to the current set. All speeds must be monotonically increasing. The first K_P/K_I set ranges from 0 rpm to the speed entry value. All speed values are entered as absolute values (there is no difference for forward or reverse direction).

9.2 Torque Control Mode Performance Tuning

The Absolute and Relative Torque modes do not use a control loop. All closed loop control is handled by the current control loop. Absolute Torque mode feeds the setpoint directly into the current control loop, whereas Relative Torque mode first converts the setpoint to an absolute value based on the current motor speed and the speed-torque curve before feeding it to the current control loop. The following diagram illustrates the torque mode signal flow.

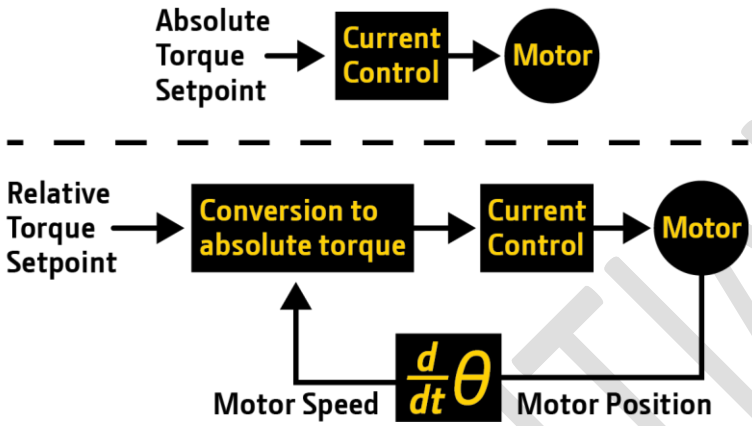

Figure 19: Absolute and Relative Torque Control

The configurable EOL slews used by these modes are shown below.

Table 21: Torque Mode Parameters

Object Description	Units	Example Value
Relative Torque Command Increasing Slew Limit	%/s	200
Relative Torque Command Decreasing Slew Limit	%/s	50
Absolute Torque Command Increasing Slew Limit	Nm/s	400
Absolute Torque Command Decreasing Slew Limit	Nm/s	200

9.3 Voltage Control Mode Performance Tuning

Voltage mode tuning involves adjusting controller gains and slews related to the internal voltage control loop. The inverter uses a PI controller to regulate the HVDC Bus voltage, as shown in the simplified diagram below.

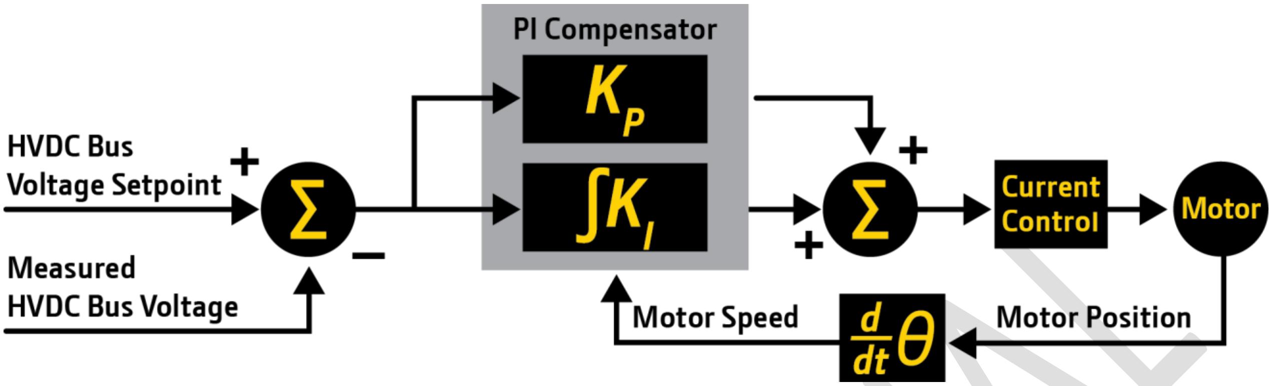

Figure 20: Voltage Regulation Control

Note that the PI controller uses different K_P and K_I coefficients over different speed ranges. The configurable EOL gains and slews used by the voltage control loop are shown below.

Table 22: Voltage Control Parameters

Object Description	Units	Example Value
Voltage Command Increasing Slew Limit	V/s	100
Voltage Command Decreasing Slew Limit	V/s	100
PI Compensator Coefficient Set 1		
Effective Speed Range	rpm	2000
K_P Coefficient	Nm/V	250
K_I Coefficient	Nm/V Per Iteration (500µs)	4
PI Compensator Coefficient Set 2		
Effective Speed Range	rpm	3000
K_P Coefficient	Nm/V	260
K_I Coefficient	Nm/V Per Iteration (500µs)	3.75
PI Compensator Coefficient Set 10		
Effective Speed Range	rpm	8000
K_P Coefficient	Nm/V	275
K_I Coefficient	Nm/V Per Iteration (500µs)	3.25

The effective speed for each K_P/K_I set ranges from the previous set to the current set. All speeds must be monotonically increasing. The first K_P/K_I set ranges from 0 rpm to the speed entry value. All speed values are entered as absolute values (there is no difference for forward or reverse direction).

10. Quick Start

10.1 Setup

Instructions for installation of the inverter and motor in either a vehicle or test lab is beyond the scope of this document. John Deere Electronic Solutions can make recommendations or demonstrate how test facilities are set up for internal testing. An installation manual is available for your particular inverter, but we are not responsible or liable for any user's application of this inverter, in either a test facility or an actual vehicle.

Caution

Refer to the appropriate installation instructions for setting up your inverter and motor, including proper coolant type and flow rates, proper electrical requirements, and any recommended practices. Before the following steps are run, it is assumed the inverter is properly connected to the motor and all necessary safety steps have been taking to ensure the inverter and motor are ready to spin.

IMPORTANT: The motor must be able to free spin in order for this test to work.

10.2 Step-by-Step Instructions to Run Motor

The following instructions are meant to allow the user to get an understanding of the state manager and are not intended as a comprehensive test.

1. Ensure that both inverter and motor are being adequately cooled and properly connected.
2. Apply low-voltage power to the switched and unswitched battery inputs on the inverter.
3. The laptop or PC should be running a CAN communication tool and have the appropriate CAN communication hardware installed.
4. If your PD400 is a dual, this quick start is only written for one side of the inverter, so after completing one side, it would be necessary to perform this on the other side as well.
5. To keep the setup simple, only connect the inverter and the communications tool to the CAN Bus.
6. Set up the CAN communications tool with the following specifications:
    a. Baud rate (default) = 500 kbps
    b. CAN Address of inverter (default) = 0xA2 (or possibly 0xA0 if you have a dual)
7. If your CAN is configured properly, you should see bus activity as soon as you are connected. Verify the proper messages are being broadcasted from the inverter as specified in the JDES PD400 CAN Specification.
8. Using some sort of CAN communication tool, monitor faults from the inverter and verify that they are the proper faults you should be receiving. If a critical or fail safe fault is triggered, the three phase outputs will be disabled.
9. Ensure your CAN communication tool has properly Address Claimed or an Inverter Command Missing fault may be present. In order to clear critical faults, the user must transition out of fault state as specified in the JDES PD400 CAN Specification.

10. Send an Inverter Command 2 (Speed Mode) message over CAN using J1939 protocol. This should be done by sending a message using your CAN communication tool with the following characteristics:

Characteristic	Value
Message Type	Extended 29 bit ID
ID	0x08EFA203
PGN	0xEF00
PF	0xEF
Priority	2
Source Address	0x03
Destination Address	0xA2
Data Field Length	8 Bytes
Data Byte 1	0xF4
Data Byte 2	0x1B
Data Byte 3	0x00
Data Byte 4	0x7D
Data Byte 5	0xFF
Data Byte 6	0xFF
Data Byte 7	0x00
Data Byte 8	0xF8
Periodic Transmit Rate	20 ms (must be less than 40 ms or a time-out fault will occur)

11. The following setup should have you requesting Speed mode. Refer to the JDES PD400 CAN Specification to confirm.
12. Change the State Transition Command (Data Byte 7) to 38 (Standby to Ignition Ready). Verify the transition using the Inverter Status 2 message.
13. Following your own internal lab protocols, apply power to the HVDC Bus. Verify the inverter is reading the correct voltage as specified by your HVDC Bus by monitoring the appropriate CAN message. The inverter should automatically transition to Power Ready State after a target voltage threshold is reached. Verify the transition using the Inverter Status 2 message.
14. Change the State Transition Command to 24 (Power Ready to Advanced Diagnostics Class B). Diagnostics Function should report 200 at this point. Verify the transition using the Inverter Status 2 message.
15. If all precautions have been taken and you are sure the inverter and motor are ready to spin, go ahead and change the State Transition (Data Byte 7) to 207 (Adv. Diag. Class B – Motor Position Sensor Calibration). Inverter will start running the Motor Position Sensor Calibration test and the motor will spin up to a user defined value. During the test, be sure to monitor the Diagnostics Status in Inverter Status 2 message. Problems will need to be corrected if Failed or Unable to Run is reported in the Diagnostics Status. The test will need to report Passed in order to move to the next step. A Passed status shall indicate that the Position Offset has been successfully calibrated and stored within the inverter.
16. Next, change the State Transition (Data Byte 7) to 91 (Advanced Diagnostics Class B to Power Ready). Verify the transition using the Inverter Status 2 message.

17. Change the State Transition Command (Data Byte 7) to 35 (Power Ready to Drive Ready). Verify the transition using the Inverter Status 2 message.
18. At this point the user can command the inverter to 100 rpm and transition from Drive Ready to Normal Operation (8). The inverter should spin up the motor to 100 rpm, as verified in an Inverter Status message, and maintain that speed until the user commands Normal Operation to Drive Ready (23). The motor should coast back down at this point and quick start routine is complete. Contact JDES if assistance is needed for this testing or it does not perform as expected.
19. Following your own internal lab protocols, power down the setup.