Innovative Thinking for Power, Control and Instrumentation

Interleaved Buck/Boost DC/DC Controller

User's Manual

UM-0048

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1. Introduction

This document is intended to provide instruction on how to employ the Oztek Buck DC/DC firmware application on a standard Oztek OZDSP3000 controller in an actual hardware system. It describes the electrical connections as well as the scaling of the various signals required by the control firmware.

1.1 Referenced Documents

Ref.	Document	Description
[1]	UM-0018	OZDSP3000 User's Manual
[2]	FS-0046	OzCan Protocol Function Specification
[3]	FS-0067	OzCan DC/DC Device Profile
[4]	UM-0015	Oztek TMS28x CAN Bootloader User's Manual

1.2 Definitions

CAN	Controller Area Network
DSP	Digital Signal Processor
EEPROM	Electrically Erasable Programmable Read Only Memory
EMC	Electro-magnetic Compatibility
EMI	Electro-magnetic Interference
GND	Ground, low side of input power supply
GUI	Graphical User Interface
HMI	Human Machine Interface
IGBT	Insulated Gate Bipolar Transistor
IPM	Intelligent Power Module
NC	Not Connected
PCB	Printed Circuit Board
PCC	Power Control Center
PI	Proportional and Integral Compensator
PLC	Programmable Logic Controller
POR	Power On Reset
PWM	Pulse width modulation

2. Functional Description

The Interleaved Buck/Boost converter is a bi-directional DC to DC converter that can be used to convert either a low DC voltage to a higher DC voltage, or vice a versa. Basic operation of a single phase is relatively simple, requiring an inductor, two switches (usually a transistor and a diode), and a capacitor. The controller alternately connects the inductor to an input voltage source to store energy and the load to discharge the energy.

This basic structure can be extended to a multi-phase interleaved topology by adding multiple sets (or phases) of switches and inductors. In this case, the phases of the switching commands at each inductor are offset uniformly (i.e. 180° for two phases, 120° for three phases, etc.) such that the ripple current, and hence ripple voltage, seen on the output is reduced due to the cancellation between the multiple phases.

2.1 Symmetric Output Hardware Implementation

Figure 1 illustrates the generic, interleaved, Buck/Boost DC/DC system topology. While component values will vary from application to application depending on the input and output voltages and power level, the overall system configuration will generally remain the same.

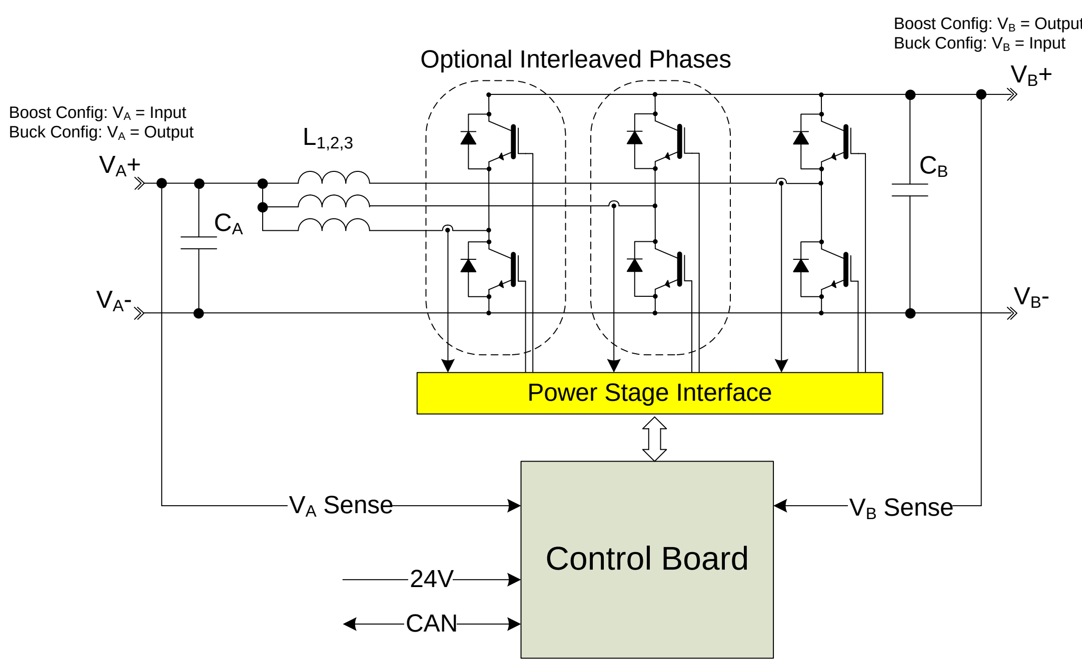

Figure 1 – Interleaved Buck/Boost System Schematic

2.1.1 Power Stage

The power stage consists of semiconductor switches, typically IGBTs for high voltage applications, as well as input and output capacitors and filter inductors. The converter can be implemented with either one, two, or three phases, requiring an additional set of switches and an inductor for each phase.

Oztek control boards are designed to interface directly with Semikron SKiiP power modules. In addition to the power devices, these modules provide current sensing, DC link voltage sensing, temperature sensing, and protection features including over voltage, over current, and desaturation protection.

2.1.2 Control Board

The control board is used to generate the gating signals to the power switches in order to control the DC/DC output voltage. The control board also provides instrumentation and user control functions.

2.1.3 Optional Pre-Charge Control

The control software provides optional features for controlling a main input contactor and/or a smaller pre-charge contactor. The pre-charge contactor controller is used to limit the inrush current associated with charging the input and/or output capacitance when applying input voltage to the converter. Lack of a pre-charge circuit can result in extremely high, potentially damaging inrush currents.

The pre-charge circuit is installed on the input to the converter. Referring to the system schematic in Figure 1, this implies that for the Boost configuration, the circuit is installed on the V_A "side" of the converter, as illustrated in Figure 2. In the Buck configuration, the circuit is installed on the V_B "side" of the converter, as illustrated in Figure 3.

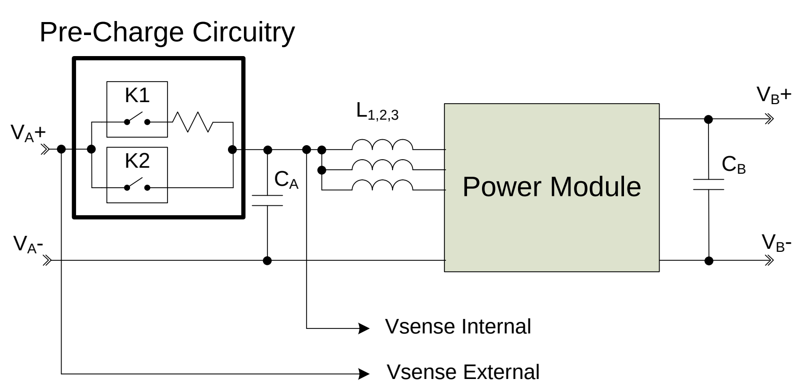

Figure 2 – Pre-Charge Circuit Boost Configuration

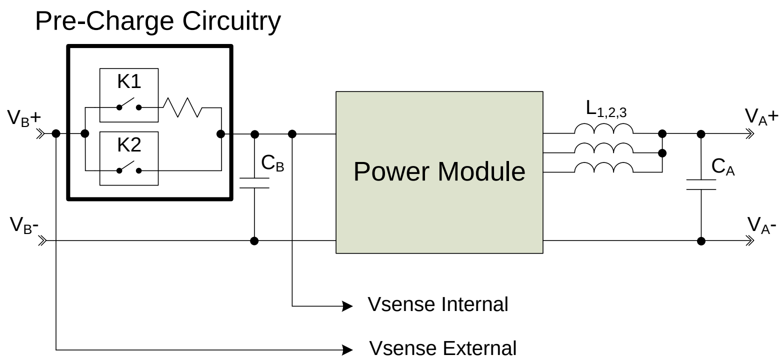

Figure 3 – Pre-Charge Circuit Buck Configuration

2.2 Description of Operation

Figure 4 presents a block diagram of the control scheme employed in the firmware. The output voltage controller consists of a digital proportional-integral (PI) compensator. The reference input to the controller sets the value of the desired DC output voltage to be maintained. This reference is compared to the measured output voltage, providing the voltage error input to the compensator. The output of the compensator represents the output current command which is limited to a min/max value before being attenuated by the interleaved phase count.

The attenuated and limited voltage regulator output serves as the current loop reference for each of the interleaved phases. The current error is calculated as the difference between this reference and each of the measured phase currents. A voltage feed forward compensated PI regulator is used to calculate the PWM duty cycle command for each phase.

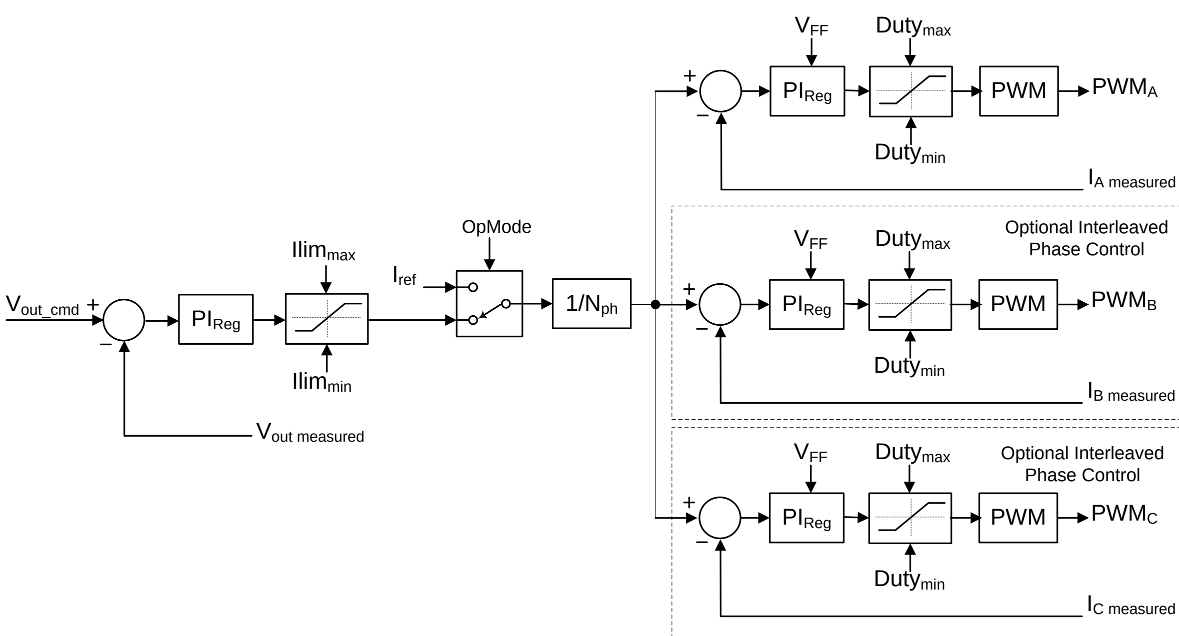

Figure 4 – Interleaved Voltage Controller

2.3 State Sequencing

A state machine is used to provide deterministic control and sequencing of the DC/DC converter hardware. If a fault is detected in any of the operating states, the hardware is placed into a safe condition and the state machine is latched into the Fault state. Figure 5 illustrates the operating states as well as the transition logic employed in the system state machine.

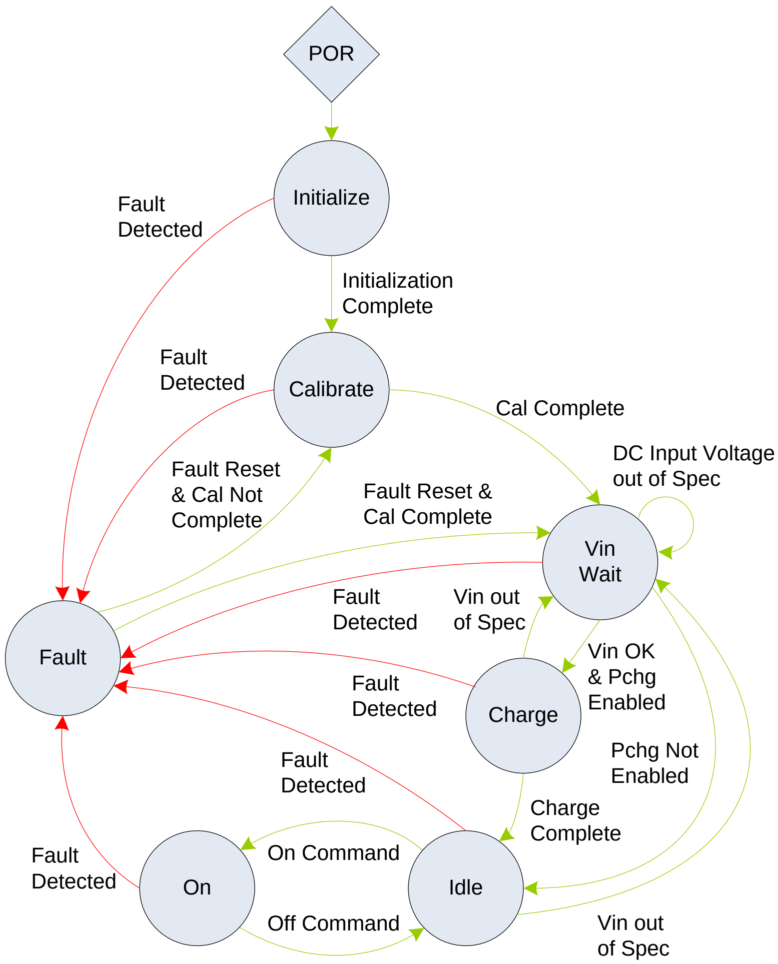

Figure 5 – System State Machine

2.3.1 Initialize

The state machine resets to the *Initialize* state following a power-on-reset (POR) event. While in this state the power hardware is not operable; the firmware is initializing hardware peripherals, configuring variables, and performing self-health tests. Upon successful initialization the state machine will auto-transition to the *Calibrate* state.

2.3.2 Calibrate

The *Calibrate* state is used to calibrate system hardware as applicable. Power hardware is not operable while in the *Calibrate* state. Following successful calibration, the state machine will auto-transition to the *Vin Wait* state.

2.3.3 Vin Wait

The *Vin Wait* state is used to wait for a valid DC input voltage before attempting to begin the DC link charging process. The state machine will remain in the *Vin Wait* state indefinitely, transitioning either on a fault or upon detecting a valid input voltage as specified in the ***Vin Under-Voltage Fault Threshold*** parameter (PID 0x8040). Power hardware is not operable while in the *Vin Wait* state.

2.3.4 Charge

If precharge control is enabled via the ***Precharge Enable*** parameter (PID 0x8098) the *Charge* state is used to charge the capacitance in a controlled manner before directly connecting to the DC input source. Once the capacitance is charged, the state machine will sequence to the *Idle* state. Power hardware is not operable while in the *Charge* state.

2.3.5 Idle

Once in the *Idle* state the converter is ready for use. The state machine will remain in the *Idle* state indefinitely, transitioning either on a fault, a turn-on command, or if the input voltage falls out of specification.

2.3.6 On

While in the *On* state the converter is processing power and controlling output voltage, depending on the configuration. The state machine will remain in the *On* state indefinitely, transitioning either on a fault or a turn-off command. When a turn-off command is received, the state machine will immediately go to the *Idle* state.

2.4 Fault and Warning Conditions

The controller provides warning indicators and fault protection in the event of conditions that may cause damage to the equipment or injure personnel. The various conditions that are monitored are listed and described in the following sections.

2.4.1 Warnings

The controller provides the warning indicators listed below. These warning conditions do not prohibit operation of the converter; they are merely reported for informational purposes only. Each warning condition described below is reported in the ***Warning Status*** instrumentation register (PID 0x4014) and also reported on the CAN bus in the Alarm Status CAN message.

2.4.1.1 High Phase Current

In the case of an interleaved topology, the firmware monitors the current in each of the interleaved phases and will set a flag (one per phase) if the current exceeds the ***Iphase Over-Current Warning Threshold*** configuration parameter (PID 0x804F). These flags remain set until the respective current falls below the ***Iphase Over-Current Recover Threshold*** configuration parameter (PID 0x8050).

2.4.1.2 High Output Current

The firmware monitors the converter output current and will set a flag if the current exceeds the ***Iout Over-Current Warning Threshold*** configuration parameter (PID 0x804B). These flags remain set until the respective current falls below the ***Iout Over-Current Recover Threshold*** configuration parameter (PID 0x804C).

2.4.1.3 IGBT High Temperature

The firmware monitors the IGBT temperature and will set a warning flag if it exceeds the ***IPM Temperature Warning Threshold*** configuration parameter (PID 0x8052). This flag will remain set until the temperature falls below the ***IPM Temperature Recover Threshold*** configuration parameter (PID 0x8053).

2.4.1.4 Auxiliary High Temperature

If the ***Auxiliary Temperature Sensor Enable*** parameter (PID 0x807A) is set to TRUE, the firmware will monitor the external temperature sensor and will set a warning flag if the temperature exceeds the ***Auxiliary Temperature Warning Threshold*** configuration parameter (PID 0x8055). This flag will remain set until the temperature falls below the ***Auxiliary Temperature Recover Threshold*** configuration parameter (PID 0x8056).

2.4.1.5 High Input Voltage

The firmware monitors the input voltage and will set a warning flag if it exceeds the ***Vin Over-Voltage Warning Threshold*** configuration parameter (PID 0x8044). This flag will remain set until the voltage falls below the ***Vin Over-Voltage Recover Threshold*** configuration parameter (PID 0x8045).

2.4.1.6 High Output Voltage

The firmware monitors the DC output voltage and will set a warning flag if it exceeds the ***Vout Over-Voltage Warning Threshold*** configuration parameter (PID 0x8047). This flag will remain set until the voltage falls below the ***Vout Over-Voltage Recover Threshold*** configuration parameter (PID 0x8048).

2.4.1.7 Local Bias Supply Tolerance Warnings

The DC/DC controller monitors the local bias supplies (24V, 15V, 5V, 3.3V, and -15V) on the control board and will set a warning flag if the corresponding supply voltage is not within the range required by the on-board hardware. The various warning flags will remain set while the supply voltages are out of tolerance and will be cleared when the supply is found to be within the required limits.

2.4.1.8 Low Input Voltage

The firmware monitors the input voltage and will set a warning flag if it is lower than the ***Vin Under-Voltage Warning Threshold*** configuration parameter (PID 0x8041). This flag will remain set until the voltage rises above the ***Vin Under-Voltage Recover Threshold*** configuration parameter (PID 0x8042).

2.4.2 Faults

The DC/DC controller provides the fault protection listed below. Whenever a fault occurs the controller will automatically turn the converter OFF, open the main input contactor and transition to the FAULT state. Each fault condition is latched and reported in the ***Fault Status*** instrumentation register (PID 0x4015) and also reported on the CAN bus in the Alarm Status CAN message.

The controller remains in the FAULT state and the latched fault flags remain set until explicitly reset with a ***Fault Reset*** command (PID 0x0004). This is true even if the source(s) of the fault(s) are no longer active. Upon receiving the ***Fault Reset*** command, the controller will attempt to clear all latched fault bits. It then examines the sources of all fault conditions and if none are active the controller will transition to the *Vin Wait* state and attempt to reconnect to the DC input. If upon re-examination any sources of faults are still active, their respective fault flags are latched again and the converter will remain in the FAULT state.

2.4.2.1 IPM Hardware Over-Temperature

The firmware provides a means to recognize a hardware-based over-temperature error signal from the IPM interface (as is present on a typical Semikron SKiiP interface).

2.4.2.2 IPM IGBT Error

The firmware provides a means to recognize a hardware-based IGBT error signal from the IPM interface (as is present on a typical Semikron SKiiP interface).

2.4.2.3 IPM Software Over-Temperature

The controller monitors the IPM temperature and will assert a fault if it exceeds the ***IPM Temperature Fault Threshold*** configuration parameter (PID 0x8051).

2.4.2.4 Software Phase Over-Current

In an interleaved topology, the firmware monitors the current for each of the interleaved phases and asserts a fault if any phase exceeds the ***Iphase Over-Current Fault Threshold*** configuration parameter (PID 0x805D).

2.4.2.5 Software Output Over-Current

The firmware monitors the output current and asserts a fault if it exceeds the ***Iout Over-Current Fault Threshold*** configuration parameter (PID 0x804A). In the case of an Interleaved topology, the output current is the sum of the interleaved phase currents.

2.4.2.6 Software Vin Over-Voltage

The firmware monitors the input voltage and will assert a fault if it exceeds the ***Input Over-Voltage Fault Threshold*** configuration parameter (PID 0x8043).

2.4.2.7 Software Vin Under-Voltage

The firmware monitors the input voltage and will assert a fault if it falls below the ***Vin Under-Voltage Fault Threshold*** configuration parameter (PID 0x8040) while the converter is in the ON state.

2.4.2.8 Software Output Over-Voltage

The firmware monitors the DC output voltage and will assert a fault if it exceeds the ***Vout Over-Voltage Fault Threshold*** configuration parameter (PID 0x8046).

2.4.2.9 Software Auxiliary Over-Temperature

If the ***Auxiliary Temperature Sensor Enable*** configuration parameter (PID 0x807A) is set to TRUE, the controller will monitor the external temperature sensor and assert a fault if the temperature exceeds the ***Auxiliary Temperature Fault Threshold*** configuration parameter (PID 0x8054).

2.4.2.10 Calibration Error

When first powering up the control board the software attempts to calibrate the controller's internal ADC. This error is asserted if the controller is unable to perform the required calibration. There is likely an issue with the control board hardware if this error occurs, in which case the board should be sent back to the factory for diagnosing and repairing of any defects (see the RMA process described at the end of this document).

2.4.2.11 Precharge Timeout Error

The firmware monitors the amount of time spent in the CHARGE State. A fault will be asserted if the ***Precharge Enable*** configuration parameter (PID 0x8098) is set to TRUE (i.e. the DC/DC is controlling the precharge function) and the elapsed time exceeds the ***Precharge Timeout Threshold*** configuration parameter (PID 0x809E).

2.4.2.12 Precharge Contactor Error

The controller monitors the status of the precharge contactor feedback signal if the precharge contactor monitor is enabled in the ***Contactor Monitor Enables*** configuration parameter (PID 0x809A). If, after the time specified in the ***Contactor Debounce Time*** configuration parameter (PID 0x809C) has passed, the precharge contactor is not in the state commanded by the controller, a fault will be asserted.

2.4.2.13 Input Contactor Error

The controller monitors the status of the DC input contactor feedback signal if the input contactor monitor is enabled in the ***Contactor Monitor Enables*** configuration parameter (PID 0x809A). If, after the time specified in the ***Contactor Debounce Time*** configuration parameter (PID 0x809C) has passed, this contactor is not in the state commanded by the controller, a fault will be asserted.

2.4.2.14 Relay Driver Hardware Error

The controller monitors the status of the relay drive circuit on the control board that is used to drive the precharge and main line contactors. This hardware circuit provides the ability to detect open load, short circuit, over-voltage and over-current conditions. A fault is asserted if any of these conditions are reported.

2.4.2.15 Communications Timeout

If the CAN bus interface is used and the ***CAN Timeout*** configuration parameter (PID 0x8011) is set to a non-zero value, the controller will monitor the amount of time elapsed between received CAN messages. A fault will be asserted if the specified timeout threshold is exceeded.

2.4.2.16 Configuration Memory Error

This fault occurs any time a read from the configuration memory is performed and the CRC for the block being read does not match the CRC stored in the memory. This may occur if the data was corrupted in transmission during the read or this may occur if the data stored in memory was corrupted. Unlike all other fault sources, this fault condition is not cleared with the ***Fault Reset*** command (PID 0x0004) as the fault condition indicates the possibility that the control parameters are not as intended. Instead, this fault is considered a major system fault and needs to be addressed as follows:

1. Attempt to reload the system configuration using the ***Configuration Reload*** command (PID 0x0007) or cycle power to the control board. Either of these actions will reset the CPU on the control board which then forces a re-initialization of the application, including reading the configuration parameters from the external configuration memory. If this completes without error, this implies the previous error occurred while the data was being read.
2. If after executing step 1 above a configuration error is still present, this may indicate bad data in the configuration memory. In this case, the memory will need to be reset to the factory defaults using the ***Configuration Reset*** command (PID 0x0006). Once the memory contents have been reset and any values changed to their customized settings, step 1 above should be executed to force a reload of the system variables.
3. If neither of the above result in clearing the configuration error, then there is likely an issue with the control board hardware. At this point the board should be sent back to the factory for diagnosing and repairing of any defects (see the RMA process described at the end of this document).

3. OZDSP3000 Hardware Interfacing

The OZDSP3000 is a highly integrated DSP control solution for power control applications. Typical applications include DC/DC converters, voltage output inverters, grid-tie inverters, AC induction motor controllers, brushless DC motor controllers, and Active Front-End regulators. This section describes how to utilize the OZDSP3000 along with the Buck/Boost DC/DC control firmware in a typical application.

3.1 Application Interfaces

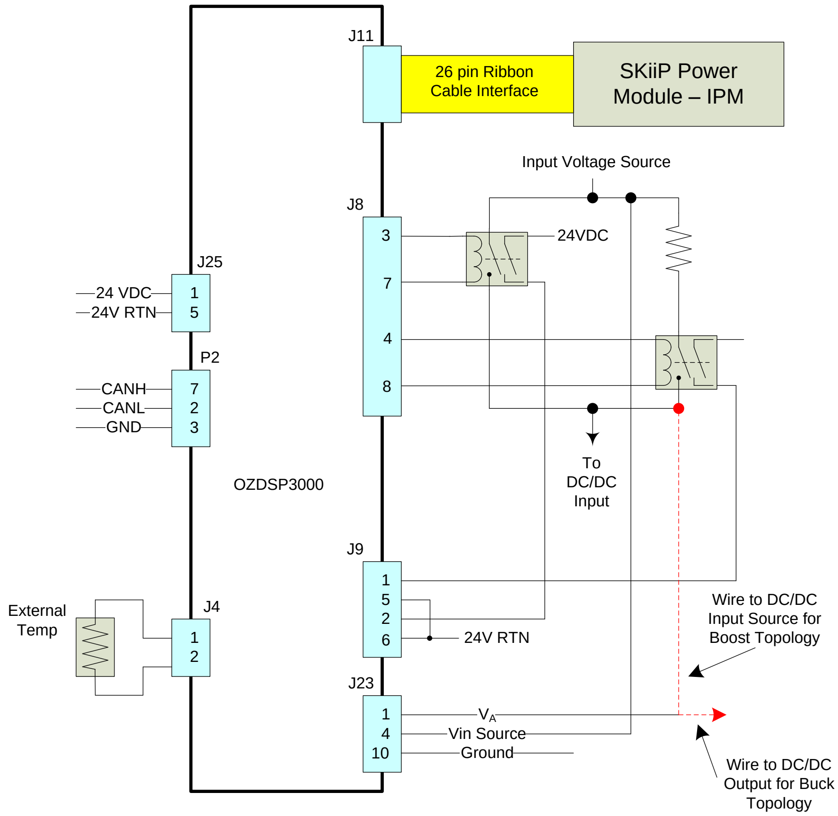

Figure 6 – OZDSP3000 Interleaved Buck/Boost DC/DC Application Electrical Connections

3.1.1 J11: SKiiP Power Module Interface – IPM

Connector J11 provides an interface to SKiiP style Semikron power modules. This interface complies with Semikron's required specifications. The OZDSP3000 supplies 24V power to the power module via pins 14 and 15. PWM commands (15V logic level) are supplied to the top and bottom switches of each of the three half bridges via signals INV_TOP_U(V,W) and INV_BOT_U(V,W) respectively. Feedback of phase currents, temperature, and DC link voltage are provided on INV_IOUT_U(V,W), INV_TEMP, INV_UDC signals respectively. Error signals from the module are similarly provided via INV_ERR_U(V,W) and INV_OVT. Please refer to the Semikron datasheet for the particular module being used for more information.

Table 1 – J11 SKiiP Power Module Pin Assignment

Pin #	Description
1	Ground
2	INV_BOT_U (Phase A)
3	INV_ERR_U (Phase A)
4	INV_TOP_U (Phase A)

Pin #	Description
5	INV_BOT_V (Phase B)
6	INV_ERR_V (Phase B)
7	INV_TOP_V (Phase B)
8	INV_BOT_W (Phase C)
9	INV_ERR_W (Phase C)
10	INV_TOP_W (Phase C)
11	INV_OVR_TEMP
12	n/c
13	INV_UDC
14	24V
15	24V
16	n/c
17	n/c
18	Ground
19	Ground
20	INV_TEMP
21	INV_IOUT_U_RTN (Phase A)
22	INV_IOUT_U (Phase A)
23	INV_IOUT_V_RTN (Phase B)
24	INV_IOUT_V (Phase B)
25	INV_IOUT_W_RTN (Phase C)
26	INV_IOUT_W (Phase C)

- **OZDSP3000 Connector Part Number:** (AMP) 499922-6
- **Mating Connector Part Number:** (AMP) 1658621-6
- **Power:** 24V @ 1.5A

3.1.2 Custom Driver Interface Considerations

When attempting to use the OZDSP3000 Interleaved Buck/Boost DC/DC controller with a custom designed power stage the hardware must be designed to provide the appropriate signals expected at the J11 interface. Generally some sort of custom printed circuit board will be required to interface the J11 signals to the gate drivers, current sensors, etc.

3.1.2.1 Power

The OZDSP3000 supplies 24V on J11, pins 14 & 15. This 24Vmay be used to power the electronics on the interface board. The supply is capable of providing 1.5A.

3.1.2.2 Switch Commands

The six switching commands are provided on pins 2, 4, 5, 7, 8, and 10. These switch command signals are driven off of the OZDSP3000 at 15V logic level using MC14504B level shifting devices.

3.1.2.3 Error Inputs

The OZDSP3000 expects three logic level, error inputs; one associated with each phase, on pins 3, 6, and 9. When active, these inputs cause the DC/DC firmware to latch the system off into the Fault state. Pull-ups to 3.3V are provided on board and the signals are active high. Depending on the features provided in the custom design, these signals can be used to interface single error sources, multiple protection circuits, or none at all.

The custom interface board should drive the pin with an open-collector style circuit. In the case where no protection is provided, the pins should be grounded to disable the faults.

3.1.2.4 DC Link Voltage Sensing

The OZDSP3000 expects a signal proportional to DC link voltage to be provided on J11, pin 13 with respect to pins 18 and 19. This signal should be scaled such that 0-10 V represents the measurable DC link voltage range.

3.1.2.5 DC Link Hardware Over-Voltage Protection

When designing a custom interface it is highly recommended that hardware over voltage protection be implemented. This can be implemented with a comparator using the DC link voltage sense output. The output of this comparator can be used to gate off the switch commands as well as assert the Error inputs on each phase.

3.1.2.6 Hardware Over-Current and Desaturation Protection

Semikron SKiiP power modules provide fast hardware over current and desaturation protection. When designing a custom power solution, these additional protection features should also be considered. When including over current, desaturation, and over voltage protection into the design, the fault flags must be logically OR'd together and reported using the open collector Error signal inputs to the OZDSP3000.

3.1.2.7 Current Sense Signals

The OZDSP3000 expects to receive a current sense signal for each half bridge phase output. This should be a bipolar signal where +/-10V corresponds to the full scale current range. The current sense signals should be provided on the following pins:

Table 2 – J11 Current Sense Pin Assignment

J11 Pin #	Description
22	Current Phase A (U)
21	Gnd Reference for Current Phase A
24	Current Phase B (V)
23	Gnd Reference for Current Phase B
26	Current Phase C (W)
25	Gnd Reference for Current Phase C

3.1.2.8 Temperature Sense Signals

The OZDSP3000 expects to receive a 0-10V temperature signal on pin 20 that corresponds to the hot spot temperature of the power devices.

3.1.3 J8: Relay Driver Interface

The DC/DC firmware can automatically control a 24VDC pre-charge contactor as well as a 24VDC input interface contactor.

Table 3 – J8 Relay Drive Pin Assignment

Pin #	Description
3	Input interface relay 24V DC drive
7	Input interface relay drive return
4	Pre-charge relay 24V DC drive
8	Pre-charge relay drive return

- **OZDSP3000 Connector Part Number:** (Molex) Micro-Fit 2x4 Header: 43045-0824
- **Mating Connector Part Number:** (Molex) Micro-Fit 2x4 Receptacle: 43025-0800
- **Output Range:** 24V, 2A continuous, 5A inrush

3.1.4 J9: Contactor Status Feedback

The DC/DC firmware provides the optional ability to monitor switch closure feedback from both the pre-charge as well as the input interface contactors. These switch closure, status feedback signals should be wired to the opto-coupler inputs on J9, as illustrated in Figure 6.

Table 4 – J9 Contactor Status Pin Assignment

Pin #	Description
1	Pre-charge contactor status (switched 24V)
5	24V Return
2	Input contactor status (switched 24V)
6	24V Return

- **OZDSP3000 Connector Part Number:** (Molex) Micro-Fit 2x4 Header: 43045-0824
- **Mating Connector Part Number:** (Molex) Micro-Fit 2x4 Receptacle: 43025-0800
- **Input Range:** Logic high: 0V or floating. Logic low: 3V – 25V

3.1.5 J23: Voltage Feedback

The DC/DC firmware expects to sense the input voltage source (if precharge is enabled) as well as the V_A voltage (Input for Buck output for Boost) on J23. The standard hardware variant is designed to accept 380VDC voltages directly. Interfacing to other voltages may require a modification to the gain of the sense amplifier (consult Oztek for more information).

Table 5 – J23 High Voltage Sense Pin Assignment

Pin #	Description
1	V_A Voltage
4	Input voltage source (required for precharge)
7	*No connect*
10	Ground

- **OZDSP3000 Connector Part Number:** (Waldom/Molex) 26-60-4100
- **Mating Connector Part Number:** (Tyco) 4-644465-0

3.1.6 J25: Bias Power Input

The OZDSP3000 requires 24VDC power input on terminal block J25. Note that there are two redundant connections for both 24V and 24V Return (only one of each needs to be connected for the controller to operate). Note that Pin 3 is used for SPI boot enable; it should be left floating or connected to ground for normal Flash Boot operation. Alternatively, this pin can be tied to 24V to enable the on-board SPI boot loader, which facilitates in-system firmware updates over the CAN interface at power up.

Table 6 – J12 RS-485 Pin Assignment

Pin #	Description
1	24 VDC
2	24 VDC
3	SPI Boot Enable
4	24V Return
5	24V Return

- **OZDSP3000 Connector Part Number:** (Phoenix Contact) 1733606
- **Mating Connector Part Number:** n/a (terminal block style)
- **Voltage:** 24V nominal, 18V min, 28V max

- **Current:** 4.5A maximum (Inrush current while powering three SKiiP modules)

3.1.7 J4: External Temperature Input

Connector J4 may optionally be used by the user to connect an external temperature sensor for monitoring purposes (such as a cabinet's internal ambient temperature). This interface provides connections for a typical 10kΩ thermistor.

Table 7 – J4 Pin Assignment

Pin #	Description
1	Temperature input (pulled up to +3.0V through 2kΩ).
2	Ground (24V Return)

- **OZDSP3000 Connector Part Number:** (Molex) Micro-Fit 2 Position Header: 43650-0215
- **Mating Connector Part Number:** (Molex) Micro-Fit 2 Position Receptacle: 43645-0200

3.1.8 P2: Isolated CAN Bus Interface

Connector P2 provides an isolated CAN Bus communications interface. The interface is a shielded, female, DB9 style connector.

Table 8 – P2 CAN Bus Pin Assignment

Pin #	Description
2	CAN Low
3	CAN Ground (Isolated)
7	CAN High

- **OZDSP3000 Connector Part Number:** (AMP) 747844-5
- **Mating Connector Part Number:** Industry Standard DB9 Male

3.1.8.1 J18/19 CAN Termination Jumpers

Jumper blocks J18 and J19 provide a means to terminate the CAN bus lines CAN high (CANH) and CAN low (CANL). Note that termination should only be placed at the end terminals of the CAN communication network, reference Figure 7.

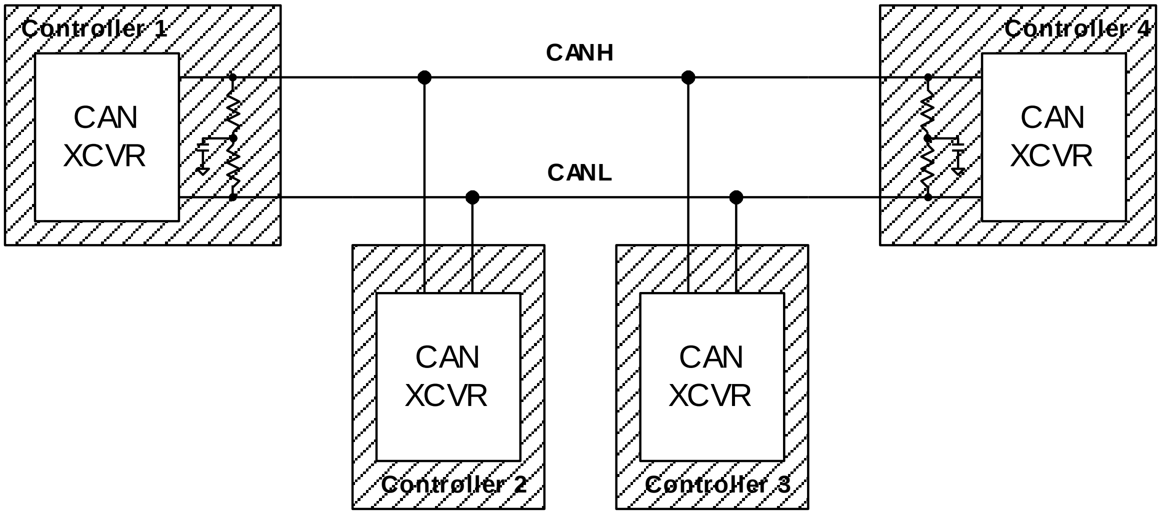

Figure 7 – Multi-Node CAN Network Configuration

Standard 0.1" jumpers should be installed on both J18 and J19 to enable the termination. With no jumpers installed, the lines remain un-terminated. Refer to Figure 8 for the applicable interface circuit.

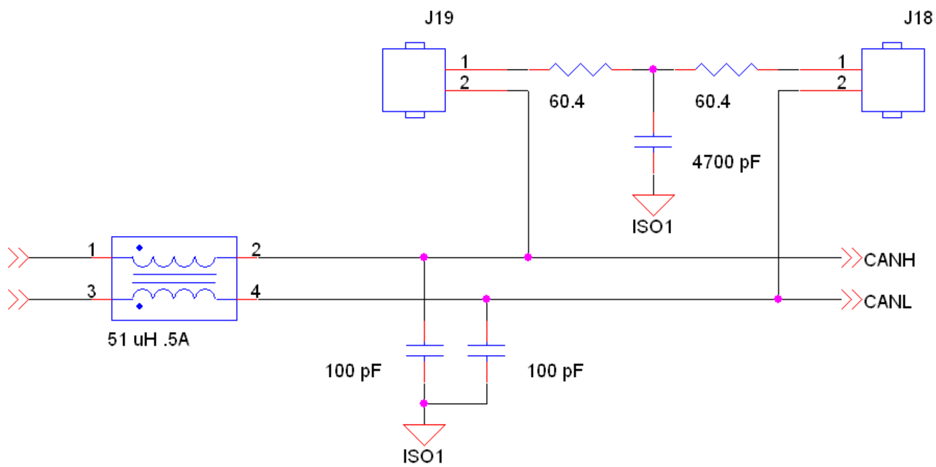

Figure 8 – CAN Interface Circuit

3.2 Electrical Interfaces

The approximate location of the connectors, jumper blocks, LEDs, and test hooks are illustrated in Figure 9.

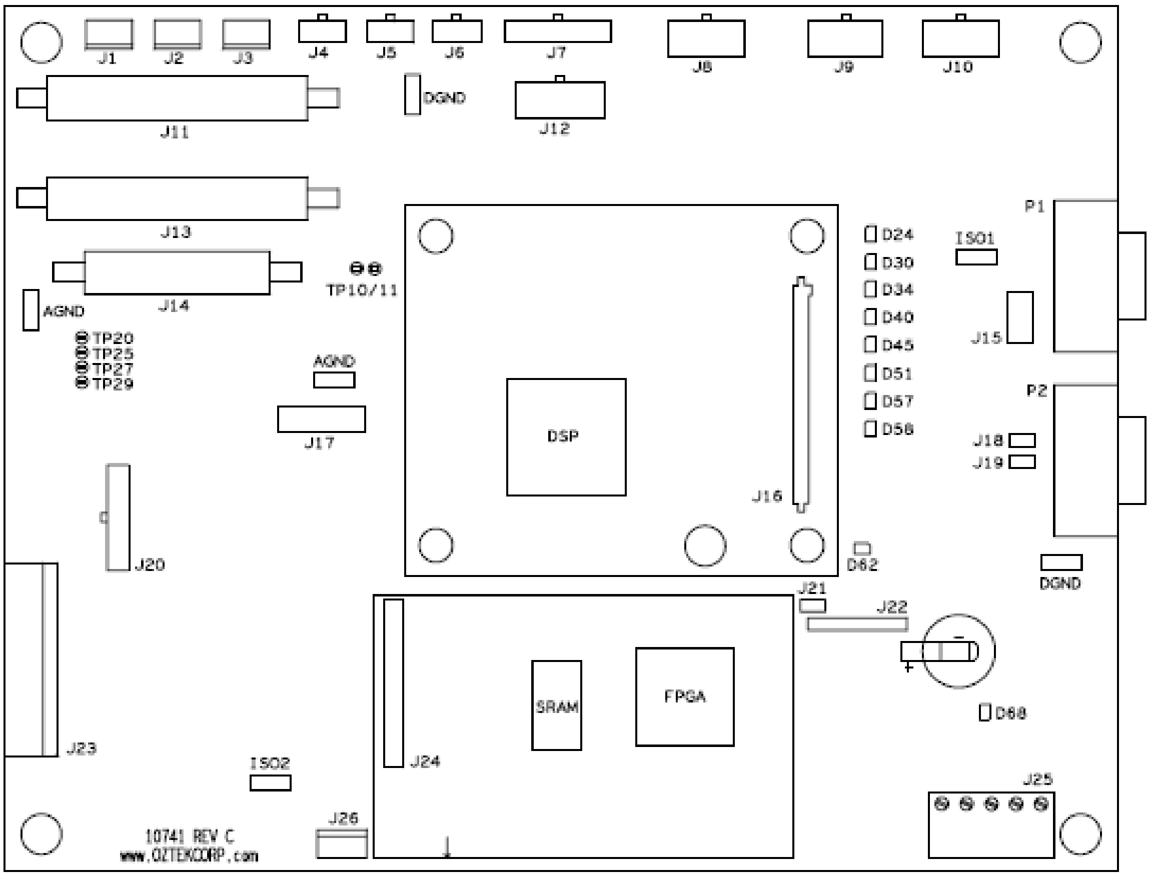

Figure 9 – Approximate Connector, Jumper, LED, and Test Hook Locations

3.3 Mechanical Interface

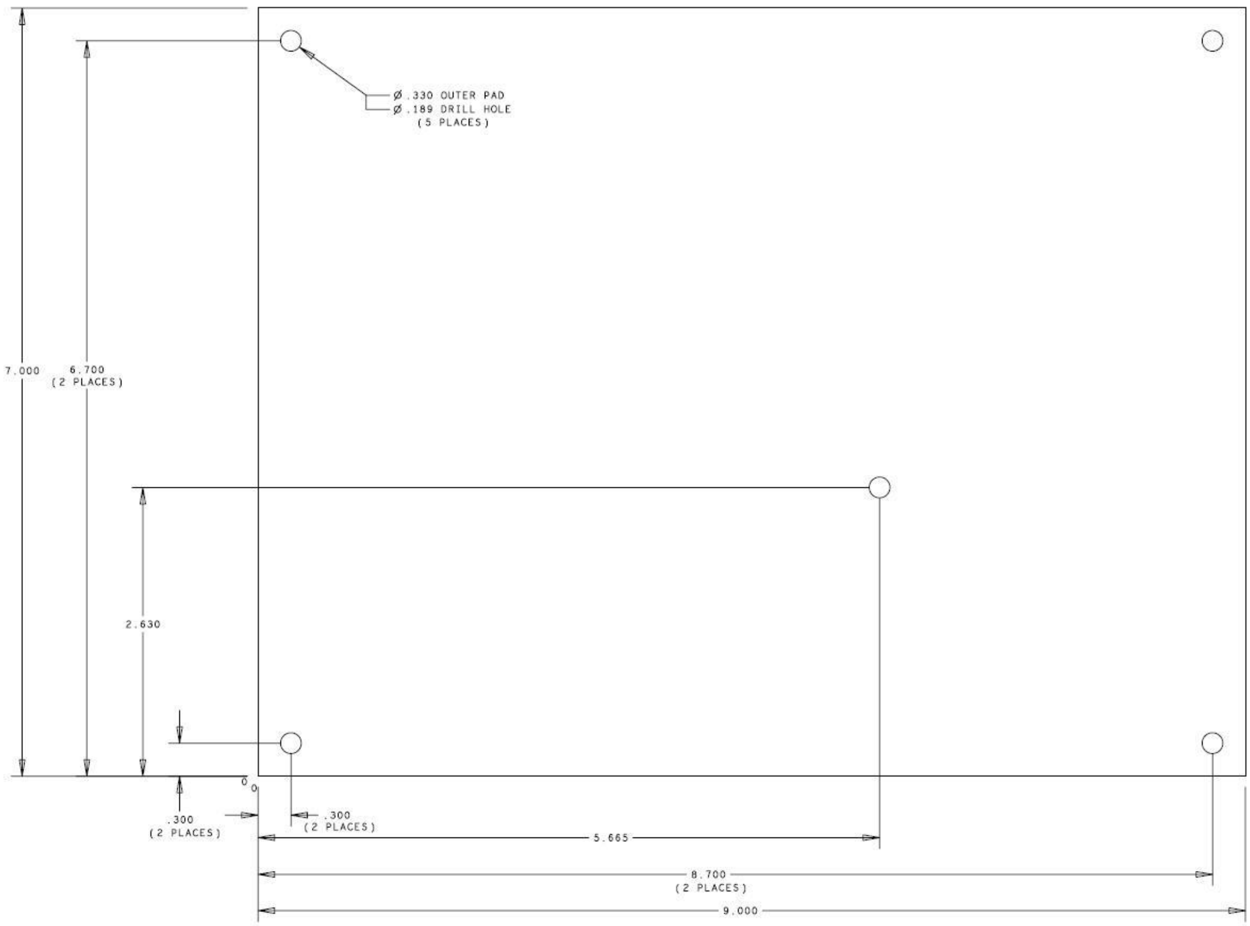

Figure 10 – OZDSP3000 Mechanical Dimensions

4. Parameter Register Interface

The DC/DC is controlled, monitored, and configured via a parameter register set. This register set can be accessed through a CAN bus serial communication link.

4.1 Register Properties

4.1.1 Parameter ID

The Parameter ID (PID) listed in the tables below represents a numerical identifier for each parameter.

4.1.2 Data Types

The actual parameters are stored internally as either 16-bit or 32-bit quantities and are treated as either signed or unsigned entities. The tables below indicate this information using the following abbreviations for the *Data Type*:

- U16 – Parameter is an unsigned 16-bit entity
- U32 – Parameter is an unsigned 32-bit entity
- S16 – Parameter is a signed 16-bit entity
- S32 – Parameter is a signed 32-bit entity

Parameters that are specified as Boolean are stored as 16-bit entities – a value of all zeros indicates FALSE and any non-zero value indicates TRUE. Unless otherwise specified in the parameter description, the parameters are stored and treated as 16-bit unsigned values.

4.1.2.1 Specifying Fixed-Point Parameters

Some parameters listed in the following sections are specified as 32-bit signed numbers with the units specified as Q16 fixed point numbers. Using this data format, the lower 16-bits (LSW) represents the fractional portion of the parameter and the upper 16-bits (MSW) represent the integer portion of the parameter. For example, the number 10.25 would be entered as 0x000A4000, where the MSW = 0x000A (hex) = 10 (decimal) and the LSW = 0x4000 (hex) = 0.25 (0x4000/0xFFFF).

Similarly, for numbers specified as Q24 fixed point numbers, the lower 24-bits represent the fractional portion of the parameter and the upper 8-bits represent the integer portion. For example, the number 4.5 would be entered as 0x04800000, where the upper 8-bits = 0x04 (hex) and the lower 24 bits = 0x800000 (hex) = 0.5 (0x800000/0xFFFFFF).

4.1.3 Access Level

The access level for each register is defined as follows:

- **W** (writeable) – the parameter is writable by the user
- **R** (readable) – the parameter is readable by the user
- **P** (password-protected) – the parameter may only be accessed by supplying a password

4.2 Volatile Registers

4.2.1 Command Registers

Table 9 – Command Register Set

PID	Data Type	Description	Units	Min	Max	Access Level
0x0000	U16	On/Off Control	ENUM	0	1	R/W
0x0001	U16	Control Mode	ENUM	0	0	R/W
0x0002	S16	Output Voltage Setpoint	0.1 V	0	32767	R/W
0x0003	S16	Output Current Setpoint	0.1 A	-32768	32767	R/W
0x0004	U16	Fault Reset	ENUM	0	1	R/W
0x0005	U16	Configuration Password	n/a	0	65535	R/W
0x0006	U16	Configuration Reset	ENUM	0	1	R/W/P
0x0007	U16	Configuration Reload	ENUM	0	1	R/W
0x0008	U16	Isolated Digital Output Control	ENUM	0	15	R/W

4.2.1.1 On/Off Control

This register is used to turn the converter ON or OFF as follows:

0 – OFF: This turns the converter OFF
1 – ON: This turns the converter ON
2 to 255 – Not Supported

4.2.1.2 Control Mode

This register is used to set the converter's Control mode. Note that writes to this register are only allowed if the converter is in the "Idle" or Off state. Control modes are enumerated as follows:

Value	Mode
0	Voltage Control Mode
1	Current Control Mode
2-255	*Unknown: Reserved for future use*

4.2.1.3 Output Voltage Setpoint

This register is used to adjust the desired output voltage set point when the converter is operating in voltage control mode. The default voltage following a power-on reset is specified in the configuration memory (see Section 4.3.3.4 for details). The value sent in this command does not change the default voltage stored in the configuration memory, rather it merely provides a dynamic and temporary override from the default value.

4.2.1.4 Output Current Setpoint

This register is used to adjust the desired output current set point when the converter is operating in current control mode. The default current following a power-on reset is specified in the configuration memory (see Section 4.3.3.4 for details). The value sent in this command does not change the default current stored in the configuration memory, rather it merely provides a dynamic and temporary override from the default value.

4.2.1.5 Fault Reset

This register is used to reset any latched fault conditions and to return the controller to the IDLE state if no further faults exist.

0 – NOP: No reset action requested
1 – RESET: Request to attempt a fault reset (register is auto cleared to 0)
2 to 255 – Not Supported

4.2.1.6 Configuration Password

This register is used to supply a password for those configuration operations that are password protected. The password is cleared to zero at the end of the next parameter read or write operation.

4.2.1.7 Configuration Reset

This register causes the system to restore its non-volatile configuration memory to the factory default configuration.

0 – NOP: No reset action requested
1 – RESET: Request to reset the configuration (register is auto cleared to 0)
2 to 255 – Not Supported

Successful execution of this command requires the following conditions be met:

- ***The* Configuration Password *register (PID 0x0005) must have been previously loaded with the correct password***
- ***The system must be in a non-operation state, i.e. the converter must be 'OFF'***

CAUTION: Upon execution, all currently stored configuration data will be permanently destroyed and over written with the factory default configuration data.

4.2.1.8 Configuration Reload

This register causes any modifications to the configuration register space to be loaded from the non-volatile configuration space.

0 – NOP: No reload action requested
1 – RELOAD: Reload the operational parameters from the configuration space (register is auto cleared to 0)
2 to 255 – Not Supported

Successful execution of this command requires the following conditions be met:

- ***The system must be in a non-operation state, i.e. the converter must be 'OFF'***

CAUTION: Either execution of this command or a Power-On Reset (POR) is required before changes to the configuration space are used for operation.

4.2.1.9 Isolated Digital Output Control

This register is used to set the output state for the 4 general-purpose open-collector digital outputs located on connector J10. The four output pins are controlled using the 4 lower bits in this register as shown in the table below. Writing a '0' to a particular bit will result in a high impedance output (i.e. open-collector output is off). Writing a '1' to a particular bit will result in the open-collector output being asserted (i.e. 0V from collector to emitter).

Bit	Output	J10 Pin # Collector	J10 Pin # Emitter
0	DOUT0	5	1
1	DOUT1	6	2
2	DOUT2	7	3
3	DOUT3	8	4

4.2.2 Instrumentation Registers

Table 10 – Instrumentation Register Set

PID	Data Type	Description	Units	Access Level
0x4000	U16	DC/DC Operating State	ENUM	R
0x4001	U16	DC/DC Control Mode	ENUM	R
0x4002	S16	Input Voltage – Internal	0.1 V	R
0x4003	S16	Input Voltage – External	0.1 V	R
0x4004	S16	Output Voltage	0.1 V	R
0x4005	S16	Current, Phase A	0.1 A	R
0x4006	S16	Current, Phase B	0.1 A	R
0x4007	S16	Current, Phase B	0.1 A	R
0x4008	S16	Output Current	0.1 A	R
0x4009	U16	IGBT Temperature	1 DegC	R
0x400A	U16	Aux Temp	1 DegC	R
0x400B	U16	Contactor Status	ENUM	R

PID	Data Type	Description	Units	Access Level
0x400C	U32	Warning Status	n/a	R
0x400D	U32	Fault Status	n/a	R
0x400E	U16	Register Operation Status	ENUM	R
0x400F	U16	DSP Software Revision – Major	Integer	R
0x4010	U16	DSP Software Revision – Minor	Integer	R
0x4011	U16	FPGA Revision – Major	Integer	R
0x4012	U16	FPGA Revision – Minor	Integer	R
0x4013	U16	PCB Hardware Revision	Integer	R
0x4014	U16	Isolated Digital Input Status	ENUM	R

4.2.2.1 DC/DC Operating State

The present DC/DC operating state is enumerated as shown in the table below. See section 2.3 for details on each of these operating states.

Value	State
0	Initializing
1	Calibrating
2	Pre-Charge
3	Charge
4	Idle
5	On
6	Fault
7	Turn-Off
8-255	***Unknown: Reserved for future use***

4.2.2.2 DC/DC Control Mode

The configured control mode is enumerated as follows:

Value	Mode
0	Voltage Control Mode
1	Current Control Mode
2-255	*Unknown: Reserved for future use*

4.2.2.3 Input Voltage - Internal

This register reports the measured voltage at the input to the DC/DC.

4.2.2.4 Input Voltage - External

This register reports the measured input voltage sensed on the source’s (external) side of the input contactor. This measurement is optional and is generally only used when the pre-charge function has been enabled.

4.2.2.5 Output Voltage

This register reports the measured output voltage.

4.2.2.6 Current Phase A, B, C

These registers report the three individual average phase currents as reported by each IPM interface.

4.2.2.7 Output Current

This register reports the total output current for the converter, i.e. the sum of all phases.

4.2.2.8 IGBT Temperature

This register reports the measured temperature reported by the IGBT power module.

4.2.2.9 Auxiliary Temperature

This register reports the measured auxiliary temperature input (if enabled, see section 4.3.8). This register will return zero when an external temperature sensor is not used.

4.2.2.10 Contactor Status

The Pre-charge and DC Input contactors open/closed status bits are mapped as follows:

Bit	Status
0	DC Input Contactor: 0 = Open, 1 = Closed
1	Pre-Charge Contactor: 0 = Open, 1 = Closed
2-15	***Reserved for future use***

4.2.2.11 Warning Status

Warning bits are active when set to ‘1’, and not present when set to ‘0’. See section 2.4 for details on each warning. The warning bits are mapped into the register as follows.

Bit	Warning
0	Phase A High Current
1	Phase B High Current
2	Phase B High Current
3	*Reserved*
4	*Reserved*
5	*Reserved*
6	Output High Current
7	*Reserved*
8	IGBT High Temperature
9	*Reserved*
10	Auxiliary High Temperature
11	Vin High Voltage
12	*Reserved*
13	*Reserved*
14	Output High Voltage
15	*Reserved*
16	*Reserved*
17	24V Supply Out of Tolerance
18	15V Supply Out of Tolerance
19	5V Supply Out of Tolerance
20	3.3V Supply Out of Tolerance

Bit	Warning
21	-15V Supply Out of Tolerance
22	Vin Low Voltage
23-31	*Reserved*

4.2.2.12 Fault Status

Fault bits are active when set to a ‘1’ and not present when set to a ‘0’. If a fault occurs, the corresponding bit is set to a ‘1’ and remains set until a “1” is written to the ***Fault Reset*** command register (PID 0x0004). When a fault occurs, the controller will go to the FAULT state and the converter will stop operating. The controller will stay in the FAULT state until the ***Fault Reset*** command is received. See section 2.4 for details on each fault condition. The fault bits are mapped as follows:

Bit	Fault
0	IPM Hardware Over Temperature
1	IPM IGBT Error
2	IPM S/W Over Temperature
3	S/W Phase A Over Current
4	S/W Phase B Over Current
5	S/W Phase C Over Current
6	*Reserved*
7	*Reserved*
8	*Reserved*
9	*Reserved*
10	*Reserved*
11	*Reserved*
12	Output Over Current
13	*Reserved*
14	S/W Vin Over Voltage
15	*Reserved*
16	*Reserved*
17	S/W Output Over Voltage
18	*Reserved*
19	*Reserved*
20	Auxiliary Over Temperature
21	Calibration Error
22	Pre-Charge Timeout
23	Pre-Charge Contactor Fault
24	Input Contactor Fault
25	Relay Driver
26	Communications Timeout
27	Configuration Memory
28	S/W Vin Under Voltage
29-31	*Reserved for future use*

4.2.2.13 Register Operation Status

This register is updated after every parameter read or write operation and indicates whether the operation was completed successfully. The status is enumerated as follows:

Value	State
0	Operation completed successfully
1	Error – Illegal/unsupported Parameter ID was supplied by the user
2	Error – A write was attempted to a Read-Only Parameter
3	Error – A read was attempted from a Write-Only Parameter
4	Error – User-provided data is not within legal range
5	Error – Configuration Memory Hardware Error
6	Error – Configuration Memory CRC Mismatch
7	Error – Invalid password provided for operation
8	Error – Operation not allowed when the DC/DC Converter is "ON"
9-255	*Unknown: Reserved for future use*

4.2.2.14 DSP Software Revision – Major/Minor

These values represent the major and minor revisions of the DSP Software stored in FLASH and actively running.

4.2.2.15 FPGA Firmware Revision – Major/Minor

These values represent the major and minor revisions of the FPGA on the DSP control board.

4.2.2.16 Board Hardware Revision

This value represents the hardware revision of the DSP control board running the application.

4.2.2.17 Isolated Digital Input Status

This register reports the state of the four isolated digital inputs located on connector J9. The input state for each pin is mapped to the lower 4 bits in this register according to the table below. When a voltage is applied across the input pins, the corresponding bit in this register will return a '1'. When 0V is applied across the input (i.e. the optically isolated input is OFF), the corresponding bit in this register will return a '0'. Note – two of the four isolated inputs (IN0 and IN1) may be configured to monitor contactor state and may therefore be unavailable as general purpose inputs. See the **Contactor Monitor Enables** configuration parameter (PID 0x809A) for further details.

Bit	Output	J9 Pin # Input	J9 Pin # Return
0	IN0	1	5
1	IN1	2	6
2	IN2	3	7
3	IN3	4	8

4.3 Non-Volatile Configuration Registers

Many operating parameters in this application have been made configurable so as to support the various DC/DC Converter product variants as well as to support other similar products in the future. As such, the software contains provisions for storing these configuration parameters in an external non-volatile EEPROM device.

> **CAUTION:** EEPROM devices have limited write cycle capability. While they can handle 1 million write cycles, care should be taken not to continuously write to Configuration Registers. Poorly designed HMI and master controller applications that needlessly update configuration registers in a continuous fashion serve no purpose and will result in premature EEPROM failure.

Once one or more configuration parameters have been updated by writing to the applicable configuration register, the actual operating configuration variables remain unaffected until one of two events occur: either the user cycles power on the control board or the ***Configuration Reload*** command register (PID 0x0007) is written to. In the second case, the reload is only allowed if the converter is ***not*** enabled. Attempts to reload the system configuration while the converter is in operation will result in the command being ignored and an error being reported in the ***Register Operation Status*** register (PID 0x4016).

The ***Configuration Reset*** command register (PID 0x0006) is used to reset the EEPROM back to the original factory default values. The user should take care when using this command as any custom configuration settings will be lost when the entire contents of the configuration memory is overwritten with the specified factory defaults. This command is only allowed if the converter is ***not*** enabled. Attempts to reset the EEPROM data while the converter is in operation will result in the command being ignored and an error being reported in the ***Register Operation Status*** register.

There are multiple scenarios in which the firmware may automatically program the configuration memory at startup with the factory default values. First, when the drive boots following a reset, it attempts to read a predefined read-only header stored in the EEPROM. If the header does not match the expected value, the memory is considered uninitialized and the firmware will automatically write the default factory configuration values into the memory. This would be the case if a control board were just being loaded with the firmware and operated for the first time, in which case the configuration memory wouldn't contain valid data.

The second scenario in which the firmware will automatically update the configuration memory occurs when the firmware has been updated on the control board and its associated configuration memory map is not compatible with the previously programmed version of the firmware. The configuration memory contains two factory revision values; a major and a minor revision. At startup the firmware will read the major revision value and compare it against the default major revision for that particular build of the firmware. If the two do not match, the firmware will automatically reset the configuration memory to the factory defaults. Differences in the minor revision will not cause the memory to be reset. Using this factory configuration revision scheme, the minor revision number is expected to change for minor changes that do not change the layout and format of the data in the configuration memory (i.e. a simple change to a default value for a particular parameter or its legal data range). The major revision number is required to change any time new parameters are added or parameter locations or formats are changed. The user must take care when updating the firmware to understand whether or not the configuration memory will be reset so as not to lose any custom settings previously stored. The present factory revision of the configuration memory is stored in the ***Factory Configuration Revision*** registers (PIDs 0x8001 – 0x8002).

4.3.1 Configuration Control Parameters

Table 11 – Configuration Control Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8000	U16	EEPROM Header	Integer	0xDCDC	0	0xFFFF	R
0x8001	U16	Factory Configuration Revision – Major	Integer	1	0	0xFFFF	R
0x8002	U16	Factory Configuration Revision – Minor	Integer	0	0	0xFFFF	R
0x8003	U16	Application Configuration Data Revision	Integer	0	0	0xFFFF	RWP
0x8004	U16	Hardware Configuration	ENUM	0	0	0xFFFF	R
0x8005	U16	User Configuration Revision	Integer	0	0	0xFFFF	RW
0x8006	U16	Configuration Password	Integer	0x1111	0	0xFFFF	RWP

4.3.1.1 EEPROM Header

This is a read-only header word that is used to indicate whether or not the configuration memory contains valid configuration data. This header word is a fixed constant and is not expected to change for any revision of the converter firmware. At startup the firmware attempts to read this value and if it does not match the expected value the firmware assumes the configuration memory does not contain valid configuration data (i.e. not previously programmed). If this is the case, the firmware will automatically reset the contents of the configuration memory to the factory defaults.

4.3.1.2 Factory Configuration Revision – Major

This is a read-only value that represents the major revision of the factory configuration stored in the configuration memory. Major revision changes to the default factory configuration are those that are not compatible with previous configurations, such as when new parameters are added to the memory that are required for proper converter operation, or if existing parameters change locations or formats. At startup the firmware will read this value from the memory and compare it against the factory default for the present build of the firmware. If the two values do not match, the firmware will automatically reset the memory to the factory default values. Updates to the major factory revision value are expected to increment the previous value by +1.

4.3.1.3 Factory Configuration Revision – Minor

This is a read-only value that represents the minor revision of the factory configuration stored in the configuration memory. Minor revisions are those that do not require reloading the memory to the factory default values. This could be a result of a minor value change to the default value for a particular parameter or the addition of a new parameter that is not needed for proper converter operation. Updates to the minor factory revision value are expected to increment the previous value by +1.

4.3.1.4 Application Configuration Data Revision

This value is used to represent the revision of the application-specific configuration data as programmed by the factory. This field is meant to store the revision of any custom configuration settings programmed at the factory for a specific end-user application. The factory default (prior to customization) for this field is zero, indicating that no custom settings have been made to the configuration memory. Application-specific updates to the configuration data are expected to increment this parameter by +1. This parameter is password protected to prevent accidental modification by the end-user.

4.3.1.5 Hardware Configuration

This read-only register is provided for future use only. It is presently not used by the DC/DC converter application and will return a value of zero when read.

4.3.1.6 User Configuration Revision

This is a generic parameter that is provided to allow the user or a higher-level controller to maintain revision information for custom settings to the configuration memory. The firmware does not use this value. The protocol for numbering and maintaining custom configurations is left up to the user.

4.3.1.7 Configuration Password

This parameter defines the configuration password stored in the configuration memory. To access any parameter that is marked as "password-protected", the user must provide a password that matches the value stored in this parameter. See the Parameter Read/Write messages described in FS-0067 (OzCan DC/DC Device Profile) for further details on providing this password value.

Note that this parameter is password protected as well. The firmware has its own unpublished "master password" that can be used to override the password stored in this register. In the event that the password is changed from the factory default listed then subsequently lost, contact Oztek for the "master password" or for other alternatives to reset the value in the configuration memory.

4.3.2 CAN Interface Parameters

The following set of parameters are provided to allow for customizing the CAN interface for the end-user's application.

Table 12 – CAN Interface Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8010	U16	CAN Automatic Alarm Transmit Enable	Boolean	TRUE	FALSE	TRUE	RW
0x8011	U16	CAN Timeout	1 ms	0	0	65535	RW
0x8012	U16	CAN Group ID	Integer	4	1	15	RW
0x8013	U16	CAN Module ID	Integer	1	1	31	RW
0x8014	U16	CAN Baud Rate	ENUM	250kbps	50kbps	1Mbps	RW
0x8015	U16	CAN Status Destination Group ID	Integer	1	0	15	RW
0x8016	U16	CAN Status Destination Module ID	Integer	1	0	31	RW
0x8017	U16	CAN Update Rate – Voltage Status	1 ms	100	0	65535	RW
0x8018	U16	CAN Update Rate – Current Status	1 ms	100	0	65535	RW
0x8019	U16	CAN Update Rate – System Status	1 ms	100	0	65535	RW
0x801A	U16	CAN Update Rate – Alarm Status	1 ms	100	0	65.535	RW
0x801B	U16	CAN Broadcast Message Receive Enable	ENUM	0	0	3	RW

4.3.2.1 CAN Automatic Alarm Transmit Enable

This is a Boolean parameter that is used to enable automatic transmission of the Alarm Status message upon a change of value of any warning or fault bit. Note that when enabled (parameter is set to *true*), the checks for whether or not an automatic transmission should be sent occur on 1ms boundaries, so there may be up to 1ms of latency between when the offending event occurs and when the Alarm message is sent. When disabled (parameter is set to *false*), a change in any warning or fault bit does not cause an automatic transmission of the Alarm Status message.

4.3.2.2 CAN Timeout

This parameter specifies the timeout period to use when checking for CAN communications errors. This value specifies the timeout period in terms of milliseconds. Setting this parameter to zero disables checking for CAN communications timeouts. When CAN timeout checking is enabled (parameter is set to a legal non-zero value), a timeout counter is used to time the period of inactivity on the CAN bus. This timer is reset upon the receipt of any of the valid receive messages supported by this application.

4.3.2.3 CAN Group ID

This parameter specifies the Group ID used by the firmware. For more information see FS-0067.

4.3.2.4 CAN Module ID

This parameter specifies the Module ID used by the firmware. For more information see FS-0067.

4.3.2.5 CAN Baud Rate

This parameter is used to configure the serial baud rate for the CAN interface. The legal values are as follows:

- 0 = 1 Mbps
- 1 = 500 kbps
- 2 = 250 kbps
- 3 = 125 kbps
- 4 = 100 kbps
- 5 = 50 kbps

4.3.2.6 CAN Status Destination Group ID

This parameter specifies the Destination Group ID that this firmware will use when sending the Status messages. Note that the Illegal CAN Message and Configuration Response messages use the Group/Module information from the sending device as the Destination Group/Module when responding, so this parameter is not used for those messages. For more information see FS-0067.

4.3.2.7 CAN Status Destination Module ID

This parameter specifies the Destination Module ID that this firmware will use when sending the Status messages. Note that the Illegal CAN Message and Configuration Response messages use the Group/Module information from the sending device as the Destination Group/Module when responding, so this parameter is not used for those messages. For more information see FS-0067.

4.3.2.8 CAN Update Rate – Voltage Status Messages

This parameter specifies the rate at which Input and Output Voltage Status CAN messages will be automatically transmitted by the firmware. This value specifies the period between message transmissions in terms of milliseconds. Setting this parameter to zero disables automatic/periodic transmission of this message. All other values (1ms – 65,535ms) are valid.

4.3.2.9 CAN Update Rate – Current Status Messages

This parameter specifies the rate at which IMP-A and IMP-B Current Status CAN messages will be automatically transmitted by the firmware. This value specifies the period between message transmissions in terms of milliseconds. Setting this parameter to zero disables automatic/periodic transmission of this message. All other values (1ms – 65,535ms) are valid.

4.3.2.10 CAN Update Rate – System Status Message

This parameter specifies the rate at which System Status CAN messages will be automatically transmitted by the firmware. This value specifies the period between message transmissions in terms of milliseconds. Setting this parameter to zero disables automatic/periodic transmission of this message. All other values (1ms – 65,535ms) are valid.

4.3.2.11 CAN Update Rate - Alarm Status Message

This parameter specifies the rate at which Alarm Status CAN messages will be automatically transmitted by the firmware. This value specifies the period between message transmissions in terms of milliseconds. Setting this parameter to zero disables automatic/periodic transmission of this message. All other values (1ms – 65,535ms) are valid.

4.3.2.12 CAN Broadcast Message Receive Enable

This parameter determines whether or not the DC/DC controller will accept broadcast messages from the host controller. See reference document FS-0046 (“OzCan Protocol Function Specification”) for more details on the use of broadcast messages. The legal values for this parameter are encoded as follows:

- 0 = Do Not Accept Broadcast Messages
- 1 = Accept Group-wide Broadcast Messages (Module ID = 0)
- 2 = Accept System-wide Broadcast Messages (Group ID = 0)
- 3 = Accept both Group-wide and System-Wide Broadcast Messages

4.3.3 System Measurement Scaling Parameters

Table 13 – System Measurement Scaling Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8020	U16	A-Neutral Voltage Measurement – Full Scale	0.1 V	5003	0	65535	RW
0x8021	U16	B-Neutral Voltage Measurement – Full Scale	0.1 V	5003	0	65535	RW
0x8022	U16	IPM Voltage Measurement – Full Scale	0.1 V	6012	0	65535	RW
0x8023	n/a	*Reserved*	n/a	n/a	n/a	n/a	n/a
0x8024	U16	Phase Current Measurement – Full Scale	0.1 A	1504	0	65535	RW

4.3.3.1 A-Neutral Voltage Measurement – Full Scale

This parameter defines the full scale value of the voltage sensed using the Phase A to Neutral connections of the Isolated High Voltage Sense interface on J23. When the converter is configured for the Boost topology, via the ***Default Control Topology*** configuration parameter (PID 0x8033), this interface is used to measure the input voltage. When configured for the Buck topology, the interface is used to measure output voltage. This full scale value is relative to the signal at the DSP’s ADC input that would cause a full scale ADC reading (i.e. ADC reading of 0xFFF).

4.3.3.2 B-Neutral Voltage Measurement – Full Scale

This parameter defines the full scale value of the voltage sensed using the Phase B to Neutral connections of the Isolated High Voltage Sense interface on J23. When the precharge feature is enabled, via the ***Precharge Enable*** configuration parameter (PID 0x8098), this interface is used to measure the input source voltage, that is the voltage input to the precharge circuitry. This full scale value is relative to the signal at the DSP’s ADC input that would cause a full scale ADC reading (i.e. ADC reading of 0xFFF).

4.3.3.3 IPM Voltage Measurement – Full Scale

This parameter defines the full scale value of the IPM high voltage measurement signal on J11. When the converter is configured for the Boost topology, via the ***Default Control Topology*** configuration parameter (PID 0x8033), this interface is used to measure the output voltage. When configured for the Buck topology, the interface is used to measure input voltage. This full scale value is relative to the signal at the isolated high voltage ADC input that would cause a full scale ADC reading (i.e. ADC reading of 0xFFF).

4.3.3.4 Phase Current Measurement – Full Scale

This parameter defines the full scale value of the individual IPM phase current measurements. This full scale value is relative to the signal at the DSP's ADC input that would cause a full scale ADC reading (i.e. ADC reading of 0xFFF).

4.3.4 Default Operating Parameters

Table 14 – Default Operating Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8030	U16	Default Control Mode	ENUM	0	0	1	RW
0x8031	U16	Default Voltage Setpoint	0.1 V	4000	0	65535	RW
0x8032	U16	Default Current Setpoint	0.1A	0	0	65535	RW
0x8033	U16	Control Topology	ENUM	0	0	1	RW

4.3.4.1 Default Control Mode

This parameter defines the default power-on control mode for the converter. The legal values are as follows:

- 0 = Voltage Control Mode
- 1 = Current Control mode
- *All other values are reserved for future use*

4.3.4.2 Default Voltage Setpoint

This parameter defines the default voltage set point to use when turning on in voltage control mode following a power-on-reset (POR) of the control board. This value is used if the ***Output Voltage Setpoint*** command (PID 0x0002) has not been issued following a power-on-reset of the control board. Writing the ***Output Voltage Setpoint*** command register with a legal value will override the default value stored in this register.

4.3.4.3 Default Current Setpoint

This parameter defines the default current set point to use when turning on in current control mode following a power-on-reset (POR) of the control board. This value is used if the ***Output Current Setpoint*** command (PID 0x0003) has not been issued following a power-on-reset of the control board. Writing the ***Output Current Setpoint*** command register with a legal value will override the default value stored in this register.

4.3.4.4 Control Topology

This parameter defines the control mode for the converter. The legal values are as follows:

- 0 = Boost Topology
- 1 = Buck Topology
- *All other values are reserved for future use*

4.3.5 Fault and Warning Parameters

Table 15 – Fault and Warning Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8040	U16	Vin Under-Voltage Fault Threshold	0.1 V	100	0	65535	RW
0x8041	U16	Vin Under-Voltage Warning Threshold	0.1 V	150	0	65535	RW
0x8042	U16	Vin Under-Voltage Recover Threshold	0.1 V	200	0	65535	RW
0x8043	U16	Vin Over-Voltage Fault Threshold	0.1 V	650	0	65535	RW
0x8044	U16	Vin Over-Voltage Warning Threshold	0.1 V	600	0	65535	RW
0x8045	U16	Vin Over-Voltage Recover Threshold	0.1 V	550	0	65535	RW
0x8046	U16	Vout Over-Voltage Fault Threshold	0.1 V	4250	0	65535	RW
0x8047	U16	Vout Over-Voltage Warning Threshold	0.1 V	4200	0	65535	RW
0x8048	U16	Vout Over-Voltage Recover Threshold	0.1 V	4150	0	65535	RW
0x8049	U16	Iout Over-Current Fault Threshold	0.1 A	3750	0	65535	RW
0x804A	U16	Iout Over-Current Fault Time	0.1 ms	0	0	65535	RW
0x804B	U16	Iout Over-Current Warning Threshold	0.1 A	3500	0	65535	RW
0x804C	U16	Iout Over-Current Recover Threshold	0.1 A	3250	0	65535	RW
0x804D	U16	Iphase Over-Current Fault Threshold	0.1 A	1250	0	65535	RW
0x804E	U16	Iphase Over-Current Fault Time	0.1 ms	0	0	65535	RW
0x804F	U16	Iphase Over-Current Warning Threshold	0.1 A	1150	0	65535	RW
0x8050	U16	Iphase Over-Current Recover Threshold	0.1 A	1050	0	65535	RW
0x8051	U16	IPM Temperature Fault Threshold	°C	85	20	150	RW
0x8052	U16	IPM Temperature Warning Threshold	°C	75	20	150	RW
0x8053	U16	IPM Temperature Recover Threshold	°C	70	20	150	RW
0x8054	U16	Auxiliary Temperature Fault Threshold	°C	85	20	150	RW
0x8055	U16	Auxiliary Temperature Warning Threshold	°C	75	20	150	RW
0x8056	U16	Auxiliary Temperature Recover Threshold	°C	70	20	150	RW
0x8057	U16	IPM Error Pin Active High	Boolean	TRUE	FALSE	TRUE	RW
0x8058	U16	IPM Over Temp Pin Active High	Boolean	TRUE	FALSE	TRUE	RW

4.3.5.1 Input Under-Voltage Fault Threshold

This parameter defines the DC input under voltage fault threshold. If the DC input voltage falls below this value when the converter is ON, or if the user attempts to turn the converter on when the input is below this value, the application will automatically transition to the FAULT state and operation of the inverter will be disabled (and forced OFF). This fault is not generated when the converter is OFF or when this parameter is set to a value of zero.

4.3.5.2 Input Under-Voltage Warning Threshold

This parameter defines the DC input voltage threshold below which the firmware will report a low voltage warning. Once below this warning threshold, the voltage must rise above the corresponding recover threshold before the firmware will clear the low voltage warning.

4.3.5.3 Input Under-Voltage Recover Threshold

See warning threshold description above.

4.3.5.4 Input Over-Voltage Fault Threshold

This parameter defines the DC input over voltage fault threshold. If the DC input voltage rises above this value the application will automatically transition to the FAULT state and operation of the inverter will be disabled (and forced OFF).

4.3.5.5 Input Over-Voltage Warning Threshold

This parameter defines the DC input voltage threshold above which the firmware will report a high voltage warning. Once above this warning threshold, the voltage must drop below the corresponding recover threshold before the firmware will clear the high voltage warning.

4.3.5.6 Input Over-Voltage Recover Threshold

See warning threshold description above.

4.3.5.7 Output Over-Voltage Fault Threshold

This parameter defines the DC output over voltage fault threshold. If the DC output voltage rises above this value the application will automatically transition to the FAULT state and operation of the inverter will be disabled (and forced OFF).

4.3.5.8 Output Over-Voltage Warning Threshold

This parameter defines the DC output voltage threshold above which the firmware will report a high voltage warning. Once above this warning threshold, the voltage must drop below the corresponding recover threshold before the firmware will clear the high voltage warning.

4.3.5.9 Output Over-Voltage Recover Threshold

See warning threshold description above.

4.3.5.10 Output Over-Current Fault Threshold

This parameter defines the output over-current fault threshold. If the current rises above this value for the duration specified in the corresponding *Fault Time* parameter (see next section), the converter will automatically transition to the FAULT state and operation of the application will be disabled (and forced OFF). In an interleaved topology, the output current is the sum of all interleaved phases.

4.3.5.11 Output Over-Current Fault Time

This parameter defines the output over-current fault timer period. If this parameter is set to zero, the over-current fault will trip immediately in the event that the current rises above the programmed fault threshold. Any non-zero value programmed in this parameter is interpreted as the duration of the over-current event before the over-current fault is tripped. Note that the timer that monitors the over-current condition is an up/down counter and hence acts like a simple integrator – it does not clear when the over-current condition is removed, it instead counts down until it reaches zero. In an interleaved topology, the output current is the sum of all interleaved phases.

4.3.5.12 Output Over-Current Warning Threshold

This parameter defines the output current threshold above which the firmware will report a high output current warning. Once above this warning threshold, the output current must fall below the corresponding recover threshold before the firmware will clear the high output current warning. In an interleaved topology, the output current is the sum of all interleaved phases.

4.3.5.13 Output Over-Current Recover Threshold

See warning threshold description above.

4.3.5.14 Phase Over-Current Fault Threshold

In an interleaved topology, this parameter defines the output over-current fault threshold for each interleaved phase. If the current rises above this value for the duration specified in the corresponding *Fault Time* parameter (see next section), the converter will automatically transition to the FAULT state and operation of the application will be disabled (and forced OFF).

4.3.5.15 Phase Over-Current Fault Time

This parameter defines the per-phase over-current fault timer period. If this parameter is set to zero, the over-current fault will trip immediately in the event that any phase current rises above the programmed fault threshold. Any non-zero value programmed in this parameter is interpreted as the duration of the over-current event before the over-current fault is tripped. Note that the timer that monitors the over-current condition is an up/down counter and hence acts like a simple integrator – it does not clear when the over-current condition is removed, it instead counts down until it reaches zero.

4.3.5.16 Phase Over-Current Warning Threshold

In an interleaved topology, this parameter defines the output current threshold for each interleaved phase above which the firmware will report a high output current warning. Once above this warning threshold, the output current must fall below the corresponding recover threshold before the firmware will clear the high output current warning.

4.3.5.17 Phase Over-Current Recover Threshold

See warning threshold description above.

4.3.5.18 IPM Temperature Fault Threshold

This parameter defines the IPM temperature fault threshold. If the temperature rises above this value the converter will automatically transition to the FAULT state and operation of the application will be disabled (and forced OFF).

4.3.5.19 IPM Temperature Warning Threshold

This parameter defines the IPM temperature threshold above which the firmware will report a high temperature warning. Once above this warning threshold, the temperature must fall below the corresponding recover threshold before the firmware will clear the high temperature warning.

4.3.5.20 IPM Temperature Recover Threshold

See warning threshold description above.

4.3.5.21 Auxiliary Temperature Fault Threshold

This parameter defines the auxiliary temperature fault threshold. If the ***Auxiliary Temperature Sensor Enable*** configuration parameter (PID 0x807A) is set to TRUE and the temperature rises above this value the converter will automatically transition to the FAULT state and operation of the application will be disabled (and forced OFF).

4.3.5.22 Auxiliary Temperature Warning Threshold

This parameter defines the auxiliary temperature threshold above which the firmware will report a high temperature warning (if the ***Auxiliary Temperature Sensor Enable*** configuration parameter is set to TRUE). Once above this warning threshold, the temperature must fall below the corresponding recover threshold before the firmware will clear the high temperature warning.

4.3.5.23 Auxiliary Temperature Recover Threshold

See warning threshold description above.

4.3.5.24 IPM Error Pin Active High

This parameter determines the polarity of the hardware error input pins from the power module interface (“INV_ERR_U/V/W” listed in section 3.1.1). When this parameter is set to TRUE, the input pins are treated as active high, meaning a high input is considered a fault condition.

4.3.5.25 IPM Over Temp Pin Active High

This parameter determines the polarity of the hardware over temperature input pin from the power module interface (“INV_OVR_TEMP” listed in section 3.1.1). When this parameter is set to TRUE, the input pin is treated as active high, meaning a high input is considered a fault condition.

4.3.6 Converter Control Parameters

Table 16 – Converter Control Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8060	U16	Pulse Width Modulation Frequency	1 Hz	10000	1000	25000	RW
0x8061	U16	Pulse Width Modulation Deadband Enable	Boolean	TRUE	FALSE	TRUE	RW
0x8062	U16	Pulse Width Modulation Deadband Time	10 ns	65	25	1000	RW
0x8063	U16	Pulse Width Modulation Max Duty Cycle	%	95	0	100	RW
0x8064	U16	Pulse Width Modulation Min Duty Cycle	%	0	0	100	RW
0x8065	U16	Interleaved Phase Count	U16	3	1	3	RW
0x8066	U16	Voltage Control ISR Period	Tpwm	5	1	500	RW
0x8067	U16	Instrumentation ISR Period	Tpwm	10	1	500	RW

4.3.6.1 Pulse Width Modulation Frequency

This parameter defines the fundamental PWM switching frequency for the power stage. Note that the current control loops and PWM modulation value are updated at twice this frequency, essentially at the peak and valley of the triangle PWM carrier waveform.

4.3.6.2 Pulse Width Modulation Deadband Enable

This parameter enables software deadband for the converter half bridges. The deadband is implemented as a turn on delay when turning on a power device after having just turned off its complement.

4.3.6.3 Pulse Width Modulation Deadband Time

This parameter defines the amount of dead band time to use between switching the complementary top and bottom switches in the half bridges (i.e. the time that both PWM outputs are OFF). This parameter is only used if the ***Pulse Width Modulation Deadband Enable*** parameter (PID 0x8061) is set to TRUE.

4.3.6.4 Pulse Width Modulation Max/Min Duty Cycle

These parameters specify the minimum and maximum duty cycles allowed on the PWM outputs to the power switches. The DC/DC controller will clamp the PWM pulses to these values, preventing any pulses narrower than the minimum specified value or greater than the maximum specified value. These parameters can be used to guarantee minimum pulse widths if required by the power switches. The dead band time (either enforced by the power module hardware or by the DC/DC software parameter) should be taken into account when setting these parameters.

4.3.6.5 Interleaved Phase Count

This parameter is used to specify the number of phases implemented in an interleaved converter topology.

4.3.6.6 Voltage Control ISR Period

This parameter is used to specify the rate at which to execute the outer voltage control loop as a number of fundamental PWM periods.

4.3.6.7 Instrumentation ISR Period

This parameter is used to specify the rate at which to execute instrumentation updates as a number of fundamental PWM periods.

4.3.7 Temperature Monitor Parameters

Table 17 – IPM Temperature Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8070	U16	IPM Temp Sensor Type	ENUM	1	0	1	RW
0x8071	S32	IPM Temperature Coefficient C0	Q16	18.515	-32768	32767	RW
0x8072	S32	IPM Temperature Coefficient C1	Q16	119.94	-32768	32767	RW
0x8073	S32	IPM Temperature Coefficient C2	Q16	-27.232	-32768	32767	RW
0x8074	S32	IPM Temperature Coefficient C3	Q16	5.9997	-32768	32767	RW
0x8075	S32	IPM Temperature Coefficient A	Q30	8.7304E-4	-2	1.99999	RW
0x8076	S32	IPM Temperature Coefficient B	Q30	2.9129E-4	-2	1.99999	RW
0x8077	S32	IPM Temperature Coefficient C	Q30	0	-2	1.99999	RW
0x8078	U32	IPM Temperature Bias Resistor	Ohms	2490	1	65535	RW
0x8079	U32	IPM Temperature Bias Voltage	mV	15000	1	65536	RW

4.3.7.1 IPM Temp Sensor Type

This parameter defines the type of temp sensor used in the power module interface. The software can interface to either a positive temperature coefficient style sensor as used in Semikron SKiiPs or a standard, negative temperature coefficient thermistor.

- 0 = Semikron SKiiP PTC
- 1 = NTC Thermistor

All other values are reserved for future use

4.3.7.2 IPM Temp Coefficients (C0 through C3)

These parameters are used by the PTC Semikron style, temperature calculation algorithm. They define the coefficients used by the 3rd order polynomial fitting routine within the firmware to convert raw ADC readings to degrees C. The temperature is calculated using the normalized ADC measurements (values in the range of 0 to 1, corresponding to the 12-bit ADC input range of 0x000 to 0xFFF) and the coefficient parameters as follows:

$$\text{Temperature} = C3 \cdot X^3 + C2 \cdot X^2 + C1 \cdot X + C0$$

Where: X is the normalized ADC reading in the range of 0 – 1
C0 – C3 are the coefficient parameters

The factory default values for these coefficients are based on the temperature sensors contained within a typical Semikron SKiiP power module. When non-SKiiP based temperature sensing is employed, it is left up to the user to generate these coefficients for the specific sensor's temperature-to-voltage transfer function. As was previously mentioned, the inverter temperature input to the control board is expected to be a 0 to 10V signal (see section 3.1.2.8). The temperature transfer function can be derived using a common tool like Microsoft Excel in which the temperature vs. voltage data from the device's datasheet are entered, any scaling performed based on the analog signal conditioning prior to the control board connection, and then normalizing the resulting voltage by diving by the 10V input range. The resulting ADC-to-temperature curve can be plotted and a 3rd order polynomial trend line can be generated to match the curve.

4.3.7.3 IPM Temp Coefficients (A,B,C, Bias Resistor, Bias Voltage)

These parameters are used by the NTC thermistor style, temperature calculation algorithm. The Bias Resistor and Bias Voltage refer to the component values of the typical interface circuit illustrated below in Figure 11.

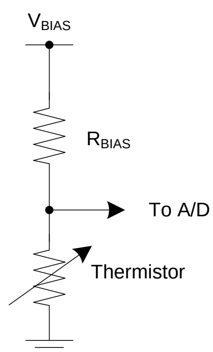

Figure 11 – Thermistor Interface Circuit

The coefficients A, B, and C are the Stein-Hart coefficients used to define the thermistor characteristics in the Steinhart-Hart equation:

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

where:

- T is the temperature (in Kelvin)
- R is the resistance at T (in Ohms)

4.3.8 Auxiliary Temperature Monitor Parameters

Table 18 – Auxiliary Temperature Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x807A	S32	Aux Temperature Enable	Bool	False	False	True	RW
0x807B	S32	IPM Temperature Coefficient A	Q30	10.324E-4	-2	1.99999	RW
0x807C	S32	IPM Temperature Coefficient B	Q30	2.3856E-4	-2	1.99999	RW
0x807D	S32	IPM Temperature Coefficient C	Q30	1.5914E-7	-2	1.99999	RW
0x807E	U32	IPM Temperature Bias Resistor	Ohms	2000	1	65535	RW
0x807F	U32	IPM Temperature Bias Voltage	mV	15000	1	65535	RW

4.3.8.1 Auxiliary Temperature Sensor Enable

This Boolean parameter is used to determine if the controller should monitor an external, NTC, thermistor style temperature sensor provided by the user (see section 3.1.7 for connection details). This parameter should be set to FALSE if an external temperature sensor is not used. When set to TRUE, the temperature is calculated according to the user-provided temperature coefficients (see next section) and is also monitored for possible over-temperature conditions according to the ***Auxiliary Temperature Fault/Warning Threshold*** configuration parameters (PIDs 0x8054 – 0x8056).

4.3.8.2 IPM Temp Coefficients (A,B,C, Bias Resistor, Bias Voltage)

These parameters are used by the NTC thermistor temperature calculation algorithm. The Bias Resistor and Bias Voltage refer to the component values of the typical interface circuit illustrated in Figure 11.

The coefficients A, B, and C are the Stein-Hart coefficients used to define the thermistor characteristics in the Steinhart-Hart equation:

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

where:

- T is the temperature (in Kelvin)
- R is the resistance at T (in Ohms)

4.3.9 Voltage Regulator Parameters

Table 19 – Voltage Regulator Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8080	U16	Voltage Command Slew Limit	1 V/s	100	1	65535	RW
0x8081	S32	Kp – Proportional Gain	Q16	60	0	32767.99	RW
0x8082	S32	Ki – Integral Gain	Q16	3770	0	32767.99	RW
0x8083	S16	Current Limit Max	0.1A	3300	-100	100	RW

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8084	S16	Current Limit Min	0.1A	-3300	-100	100	RW

4.3.9.1 Voltage Command Slew Limit

This parameter defines the slew rate to use when operating in voltage control mode and the commanded output voltage is changed. This slew rate is used both at initial turn-on when the output voltage is changed from the present value to the programmed set point or when the programmed set point is changed after the converter has already been turned on.

4.3.9.2 Voltage Controller Gain Constants (Kp, Ki)

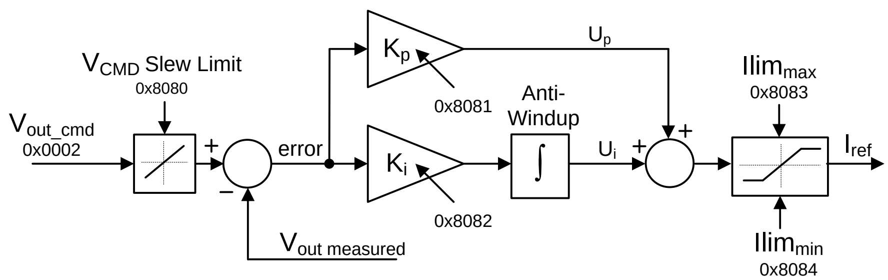

Figure 12 – Voltage Controller Block Diagram

These parameters define the gain constants for the PI controller that regulates the output voltage when the converter is operating in voltage control mode. The integral gain (K_i) parameter should be entered as the continuous gain (or sometimes referred to as the "analog" gain). The firmware handles converting this to the discretized gain by automatically dividing this by the sample frequency at which the controller is updated (specified as a number of PWM periods by the ***Voltage Control ISR Period*** parameter – PID 0x8066).

As Figure 12 above illustrates, the PI topology used by the DC/DC application sums the proportional and integral correction terms and then clamps the output to the specified current limits based on the ***Current Limit Min/Max*** configuration parameters (PIDs 0x8083 – 0x8084).

It is important to note that the voltage controller uses real word engineering units. The floating point application software scales the digitized feedback voltage using the full scale measureable voltage constant specified by configuration parameters 0x8020 or 0x8021, depending on the selected ***Control Topology*** (PID 0x8033).

4.3.9.3 Current Limit Max/Min

These parameters specify the maximum and minimum current command. In a multi-loop control configuration in which an outer voltage control loop feeds an inner current control loop, the output of the voltage loop serves as the current command or reference. This parameter serves as a clamp on the output of the voltage controller, thereby limiting the total output current.

4.3.10 Current Regulator Parameters

Table 20 – Current Regulator Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8090	U16	Current Command Slew Limit	1 A/s	100	1	65535	RW
0x8091	S32	Kp – Proportional Gain	Q16	0.00096	0	32767.99	RW
0x8092	S32	Ki – Integral Gain	Q16	0.2961	0	32767.99	RW
0x8093	*n/a*	*Reserved*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
0x8094	S16	Nominal Feed Forward Voltage	V	400	1	65535	RW

4.3.10.1 Current Command Slew Limit

This parameter defines the slew rate to use when operating in current control mode and the commanded output current is changed. This slew rate is used both at initial turn-on when the output current is changed from the present value to the programmed set point or when the programmed set point is changed after the converter has already been turned on.

4.3.10.2 Current Controller Gain Constants (Kp, Ki)

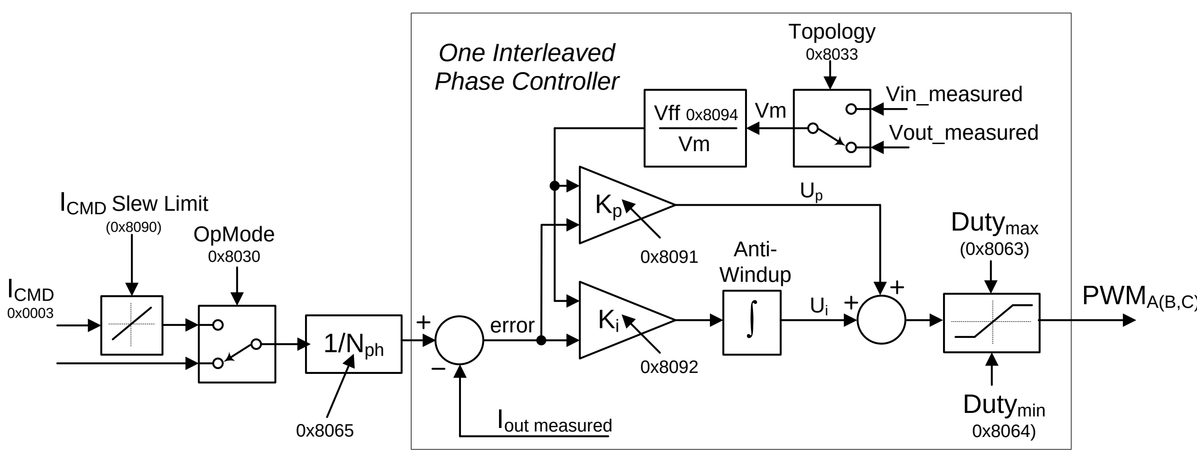

Figure 13 – Current Controller Block Diagram

These parameters define the gain constants for the PI controller that regulates the output current when the converter is operating in current control mode. The integral gain (K_i) parameter should be entered as the continuous gain (or sometimes referred to as the "analog" gain). The firmware handles converting this to the discretized gain by automatically dividing this by the sample frequency which is fixed at twice the PWM frequency.

As Figure 13 above illustrates, the PI topology used by the DC/DC application sums the proportional and integral correction terms and then clamps the output to the specified PWM duty cycle limits based on the ***PWM Max/Min Duty Cycle*** configuration parameters (PIDs 0x8063 – 0x8064).

It is important to note that the current controller uses real word engineering units. The floating point application software scales the digitized feedback current using the full scale measureable current constant specified by the ***Phase Current Measurement – Full Scale*** configuration parameter 0x8024.

4.3.10.3 Nominal Feed Forward Voltage

The controller incorporates a voltage feed forward term within the digital controller. When operating in the Boost configuration, output voltage is fed forward while in the Buck configuration, input voltage is used. This parameter defines the nominal voltage for which the current control PID was designed. The feed forward algorithm then corrects the system gain for any variations in actual measured voltage from the nominal. The feed forward gain adjust feature can be disabled by setting this parameter to zero.

4.3.11 Pre-charge Parameters

Table 21 – Pre-charge Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x8098	U16	Pre-charge Enable	Boolean	FALSE	FALSE	TRUE	RW
0x8099	U16	Contactor Enables	ENUM	0	0	3	RW
0x809A	U16	Contactor Monitor Enables	ENUM	0	0	3	RW
0x809B	U16	Connect Voltage Threshold	0.1 %	950	0	1000	RW
0x809C	U16	Contactor Debounce Time	1 ms	10	1	10000	RW
0x809D	U16	Contactor Close Time	1 ms	500	1	10000	RW
0x809E	U16	Pre-charge Timeout Threshold	1 ms	20000	0	65535	RW

4.3.11.1 Pre-charge Enable

This Boolean parameter enables the use of the pre-charge contactor control in the DC/DC controller. If this parameter is set to FALSE, it is assumed that the pre-charge function is performed by another piece of equipment. In this case, the controller will not attempt to close any contactors (pre-charge or main input) when first starting up. Instead, it simply transitions to the IDLE state once above the minimum voltage specified in the *Vin Under-Voltage Fault Threshold* parameter.

If this parameter is set to TRUE, the DC/DC controller will attempt to close the pre-charge contactor (if enabled) prior to entering the CHARGE state. Once in the CHARGE state, the controller will wait for the voltage to rise to the specified *Connect Voltage Threshold*. At this point, the pre-charge contactor will be opened and the main input contactor will be closed (if enabled).

4.3.11.2 Contactor Enables

This parameter is used to determine which contactors are present and should be controlled by the converter. The enumerated values for this parameter are as follows:

- 0 = No Contactor Control
- 1 = Control Pre-charge Contactor only
- 2 = Control Input Contactor only
- 3 = Control Both Contactors

4.3.11.3 Contactor Monitor Enables

This parameter is used to determine if contactor feedback monitors are enabled. If enabled, the converter will monitor the state of the contactors. If the contactor state does not match the commanded state at any point in time the converter will go to the FAULT state. The enumerated values for this parameter are as follows:

- 0 = No monitoring (i.e. no contactor feedback is provided or checked)
- 1 = Monitor Pre-charge Contactor only
- 2 = Monitor Input Contactor only
- 3 = Monitor Both Contactors

4.3.11.4 Connect Voltage Threshold

This parameter defines the voltage threshold to charge to, as a percentage of the voltage source input measurement, prior to closing the main input contactor (if enabled).

4.3.11.5 Contactor Debounce Time

This parameter is used to specify the debounce time for both the main input contactor and the pre-charge contactor. This field is used to delay reporting a change of state in the contactor prior to considering the change valid.

4.3.11.6 Contactor Close Time

This parameter is used to specify the actuation time for both the main input contactor and the pre-charge contactor. This field should be set to the longest expected delay from when the contactor is driven open/closed by the software to when the contactor has mechanically changed state (including all expected debounce time).

4.3.11.7 Pre-charge Timeout Threshold

This parameter specifies the maximum amount of time to wait before reporting a pre-charge timeout fault. If the DC link has not charged to the *DC Link Pre-charge Threshold* (see above) within this amount of time, the controller will transition to the FAULT state. This parameter is only used if the *DC Link Pre-charge Enable* parameter (see above) is set to TRUE (i.e. the converter is controlling the pre-charge function). If the *DC Link Pre-charge Enable* parameter is set to FALSE, the controller will simply wait indefinitely for the DC link voltage to rise above the minimum acceptable DC link voltage specified in the *Vin Under-Voltage Fault Threshold*. Setting this parameter to zero will disable the pre-charge timeout monitor.

4.3.12 Instrumentation Parameters

The table below summarizes the filter cutoff values for the various measurements reported to the user, as well as the rate at which these measurements are updated by the DC/DC controller. Unless a clear need exists, it is recommended that the user not change these values from the factory default values.

Table 22 – Instrumentation Parameter Summary

PID	Data Type	Description	Units	Factory Default	Min	Max	Access Level
0x80A0	U16	Low Pass Cutoff Freq – Input Voltage	1 Hz	5	1	5000	RW
0x80A1	U16	Low Pass Cutoff Freq - Output Current	1 Hz	5	1	5000	RW
0x80A2	U16	Low Pass Cutoff Freq - Output Voltage	1 Hz	5	1	5000	RW
0x80A3	U16	Low Pass Cutoff Freq - Temperatures	1 Hz	2	1	5000	RW

4.3.12.1 Low Pass Cutoff Freq – Input Voltage

This parameter defines the cutoff frequency for the digital low pass filter used to calculate the input voltage.

4.3.12.2 Low Pass Cutoff Freq – Output Current

This parameter defines the cutoff frequency for the digital low pass filter used to calculate the output current.

4.3.12.3 Low Pass Cutoff Freq – Output Voltage

This parameter defines the cutoff frequency for the digital low pass filter used to calculate the output voltage.

4.3.12.4 Low Pass Cutoff Freq – Temperatures

This parameter defines the cutoff frequency for the digital low pass filter used to calculate the inverter and auxiliary temperatures.

5. Maintenance and Upgrade

The firmware image on the OZDSP3000 can be upgraded in-system using the resident CAN bootloader. For detailed information on how to upgrade the firmware or directly interface with the bootloader, please reference UM-0015 Oztek TMS28x CAN Bootloader User's Manual.

Warranty and Product Information

Limited Warranty

What does this warranty cover and how long does it last? This Limited Warranty is provided by Oztek Corp. ("Oztek") and covers defects in workmanship and materials in your OZDSP3000 controller. This Warranty Period lasts for 18 months from the date of purchase at the point of sale to you, the original end user customer, unless otherwise agreed in writing. You will be required to demonstrate proof of purchase to make warranty claims. This Limited Warranty is transferable to subsequent owners but only for the unexpired portion of the Warranty Period. Subsequent owners also require original proof of purchase as described in "What proof of purchase is required?"

What will Oztek do? During the Warranty Period Oztek will, at its option, repair the product (if economically feasible) or replace the defective product free of charge, provided that you notify Oztek of the product defect within the Warranty Period, and provided that through inspection Oztek establishes the existence of such a defect and that it is covered by this Limited Warranty.

Oztek will, at its option, use new and/or reconditioned parts in performing warranty repair and building replacement products. Oztek reserves the right to use parts or products of original or improved design in the repair or replacement. If Oztek repairs or replaces a product, its warranty continues for the remaining portion of the original Warranty Period or 90 days from the date of the return shipment to the customer, whichever is greater. All replaced products and all parts removed from repaired products become the property of Oztek.

Oztek covers both parts and labor necessary to repair the product, and return shipment to the customer via an Oztek-selected non-expedited surface freight within the contiguous United States and Canada. Alaska, Hawaii and locations outside of the United States and Canada are excluded. Contact Oztek Customer Service for details on freight policy for return shipments from excluded areas.

How do you get service? If your product requires troubleshooting or warranty service, contact your merchant. If you are unable to contact your merchant, or the merchant is unable to provide service, contact Oztek directly at:

USA
Telephone: 603-546-0090
Fax: 603-386-6366
Email techsupport@oztekcorp.com

Direct returns may be performed according to the Oztek Return Material Authorization Policy described in your product manual.

What proof of purchase is required? In any warranty claim, dated proof of purchase must accompany the product and the product must not have been disassembled or modified without prior written authorization by Oztek. Proof of purchase may be in any one of the following forms:

- The dated purchase receipt from the original purchase of the product at point of sale to the end user
- The dated dealer invoice or purchase receipt showing original equipment manufacturer (OEM) status
- The dated invoice or purchase receipt showing the product exchanged under warranty

What does this warranty not cover? Claims are limited to repair and replacement, or if in Oztek's discretion that is not possible, reimbursement up to the purchase price paid for the product. Oztek will be liable to you only for direct damages suffered by you and only up to a maximum amount equal to the purchase price of the product. This Limited Warranty does not warrant uninterrupted or error-free operation of the product or cover normal wear and tear of the product or costs related to the removal, installation, or troubleshooting of the customer's electrical systems. This warranty does not apply to and Oztek will not be responsible for any defect in or damage to:

a) The product if it has been misused, neglected, improperly installed, physically damaged or altered, either internally or externally, or damaged from improper use or use in an unsuitable environment
b) The product if it has been subjected to fire, water, generalized corrosion, biological infestations, or input voltage that creates operating conditions beyond the maximum or minimum limits listed in the Oztek product specifications including high input voltage from generators and lightning strikes
c) The product if repairs have been done to it other than by Oztek or its authorized service centers (hereafter "ASCs")
d) The product if it is used as a component part of a product expressly warranted by another manufacturer
e) The product if its original identification (trade-mark, serial number) markings have been defaced, altered, or removed
f) The product if it is located outside of the country where it was purchased
g) Any consequential losses that are attributable to the product losing power whether by product malfunction, installation error or misuse.

Disclaimer

Product

THIS LIMITED WARRANTY IS THE SOLE AND EXCLUSIVE WARRANTY PROVIDED BY OZTEK IN CONNECTION WITH YOUR OZTEK PRODUCT AND IS, WHERE PERMITTED BY LAW, IN LIEU OF ALL OTHER WARRANTIES, CONDITIONS, GUARANTEES, REPRESENTATIONS, OBLIGATIONS AND LIABILITIES, EXPRESS OR IMPLIED, STATUTORY OR OTHERWISE IN CONNECTION WITH THE PRODUCT, HOWEVER ARISING (WHETHER BY CONTRACT, TORT, NEGLIGENCE, PRINCIPLES OF MANUFACTURER'S LIABILITY, OPERATION OF LAW, CONDUCT, STATEMENT OR OTHERWISE), INCLUDING WITHOUT RESTRICTION ANY IMPLIED WARRANTY OR CONDITION OF QUALITY, MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE TO THE EXTENT REQUIRED UNDER APPLICABLE LAW TO APPLY TO THE PRODUCT SHALL BE LIMITED IN DURATION TO THE PERIOD STIPULATED UNDER THIS LIMITED WARRANTY. IN NO EVENT WILL OZTEK BE LIABLE FOR: (a) ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING LOST PROFITS, LOST REVENUES, FAILURE TO REALIZE EXPECTED SAVINGS, OR OTHER COMMERCIAL OR ECONOMIC LOSSES OF ANY KIND, EVEN IF OZTEK HAS BEEN ADVISED, OR HAD REASON TO KNOW, OF THE POSSIBILITY OF SUCH DAMAGE, (b) ANY LIABILITY ARISING IN TORT, WHETHER OR NOT ARISING OUT OF OZTEK'S NEGLIGENCE, AND ALL LOSSES OR DAMAGES TO ANY PROPERTY OR FOR ANY PERSONAL INJURY OR ECONOMIC LOSS OR DAMAGE CAUSED BY THE CONNECTION OF A PRODUCT TO ANY OTHER DEVICE OR SYSTEM, AND (c) ANY DAMAGE OR INJURY ARISING FROM OR AS A RESULT OF MISUSE OR ABUSE, OR THE INCORRECT INSTALLATION, INTEGRATION OR OPERATION OF THE PRODUCT. IF YOU ARE A CONSUMER (RATHER THAN A PURCHASER OF THE PRODUCT IN THE COURSE OF A BUSINESS) AND PURCHASED THE PRODUCT IN A MEMBER STATE OF THE EUROPEAN UNION, THIS LIMITED WARRANTY SHALL BE SUBJECT TO YOUR STATUTORY RIGHTS AS A CONSUMER UNDER THE EUROPEAN UNION PRODUCT WARRANTY DIRECTIVE 1999/44/EC AND AS SUCH DIRECTIVE HAS BEEN IMPLEMENTED IN THE EUROPEAN UNION MEMBER STATE WHERE YOU PURCHASED THE PRODUCT. FURTHER, WHILE THIS LIMITED WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS, YOU MAY HAVE OTHER RIGHTS WHICH MAY VARY FROM EU MEMBER STATE TO EU MEMBER STATE OR, IF YOU DID NOT PURCHASE THE PRODUCT IN AN EU MEMBER STATE, IN THE COUNTRY YOU PURCHASED THE PRODUCT WHICH MAY VARY FROM COUNTRY TO COUNTRY AND JURISDICTION TO JURISDICTION.

Return Material Authorization Policy

Before returning a product directly to Oztek you must obtain a Return Material Authorization (RMA) number and the correct factory "Ship To" address. Products must also be shipped prepaid. Product shipments will be refused and returned at your expense if they are unauthorized, returned without an RMA number clearly marked on the outside of the shipping box, if they are shipped collect, or if they are shipped to the wrong location.
When you contact Oztek to obtain service, please have your instruction manual ready for reference and be prepared to supply:

- The serial number of your product
- Information about the installation and use of the unit
- Information about the failure and/or reason for the return
- A copy of your dated proof of purchase

Return Procedure

Package the unit safely, preferably using the original box and packing materials. Please ensure that your product is shipped fully insured in the original packaging or equivalent. This warranty will not apply where the product is damaged due to improper packaging. Include the following:

- The RMA number supplied by Oztek clearly marked on the outside of the box.
- A return address where the unit can be shipped. Post office boxes are not acceptable.
- A contact telephone number where you can be reached during work hours.
- A brief description of the problem.

Ship the unit prepaid to the address provided by your Oztek customer service representative.

If you are returning a product from outside of the USA or Canada - In addition to the above, you MUST include return freight funds and you are fully responsible for all documents, duties, tariffs, and deposits.

Out of Warranty Service

If the warranty period for your product has expired, if the unit was damaged by misuse or incorrect installation, if other conditions of the warranty have not been met, or if no dated proof of purchase is available, your unit may be serviced or replaced for a flat fee. If a unit cannot be serviced due to damage beyond salvation or because the repair is not economically feasible, a labor fee may still be incurred for the time spent making this determination.

To return your product for out of warranty service, contact Oztek Customer Service for a Return Material Authorization (RMA) number and follow the other steps outlined in "Return Procedure".

Payment options such as credit card or money order will be explained by the Customer Service Representative. In cases where the minimum flat fee does not apply, as with incomplete units or units with excessive damage, an additional fee will be charged. If applicable, you will be contacted by Customer Service once your unit has been received.