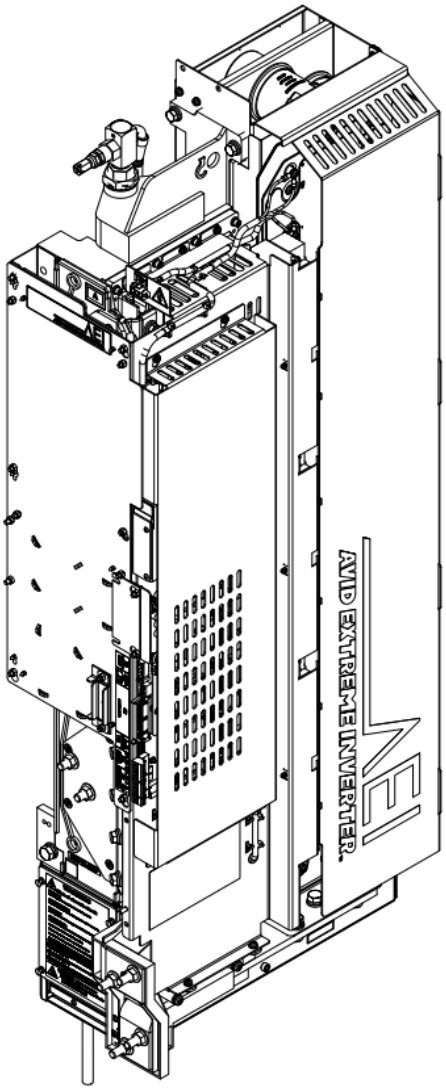

REV: 06
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Contents

1. Related Documents

DTS-MID0012
Avid Extreme Liquid Cooled Inverter Module
Data Sheet

DTS-MID0124
Avid Extreme Inverter – Auxiliary Power Unit
Data Sheet

2. Introduction

2.1 Overview

- Special Order #0006 (***SO0006***) can be used with AEI1000L Avid Extreme Inverter modules (any grade or option) to create a three-channel DC current controller for charging/discharging DC energy storage elements such as ultra-capacitors or batteries.

- SO0006 equips the AEI1000L with a dedicated interface board for connecting the AEI to a control system (typically PLC based) and is re-programmed from the default program to provide the necessary interface and current control functionality.

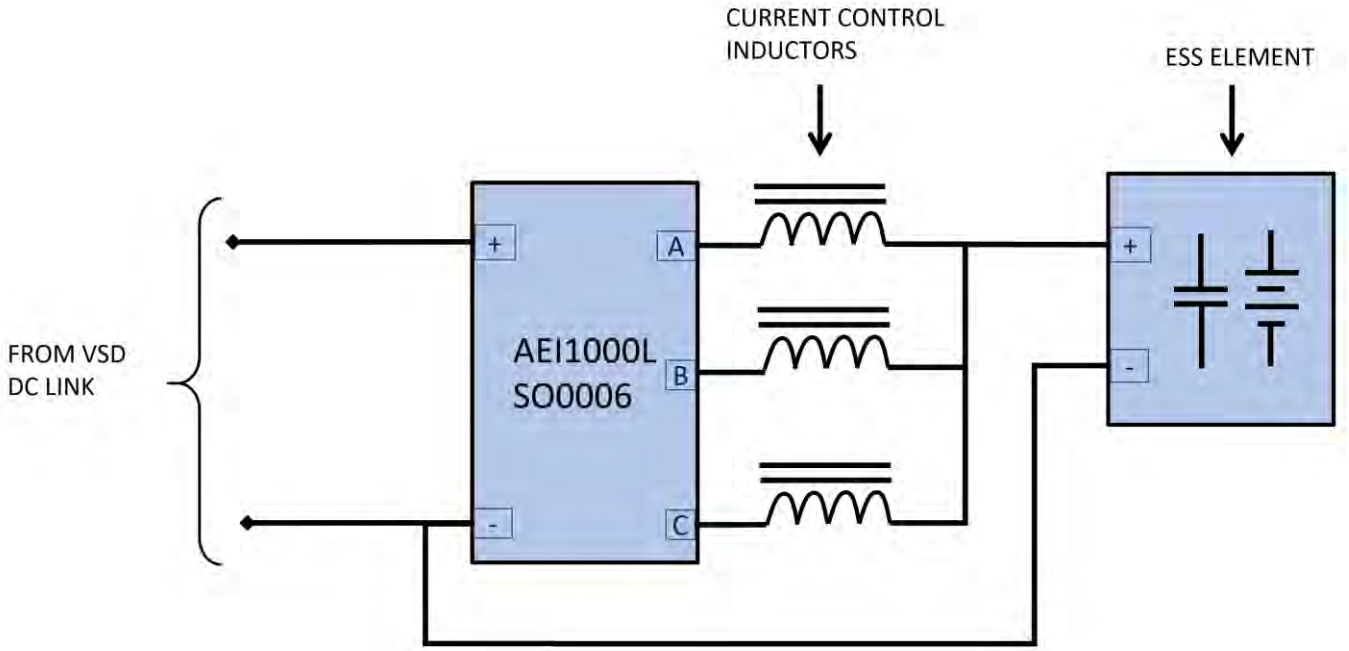
- The AEI1000L-SO0006 modules are typically connected to the DC link of a large variable speed drive (VSD) (often the common DC link of a multi-drive system) to provide control of power to and from an energy storage element as the drives operate in motoring and regenerating modes.

2.2 Application Power Circuit Examples

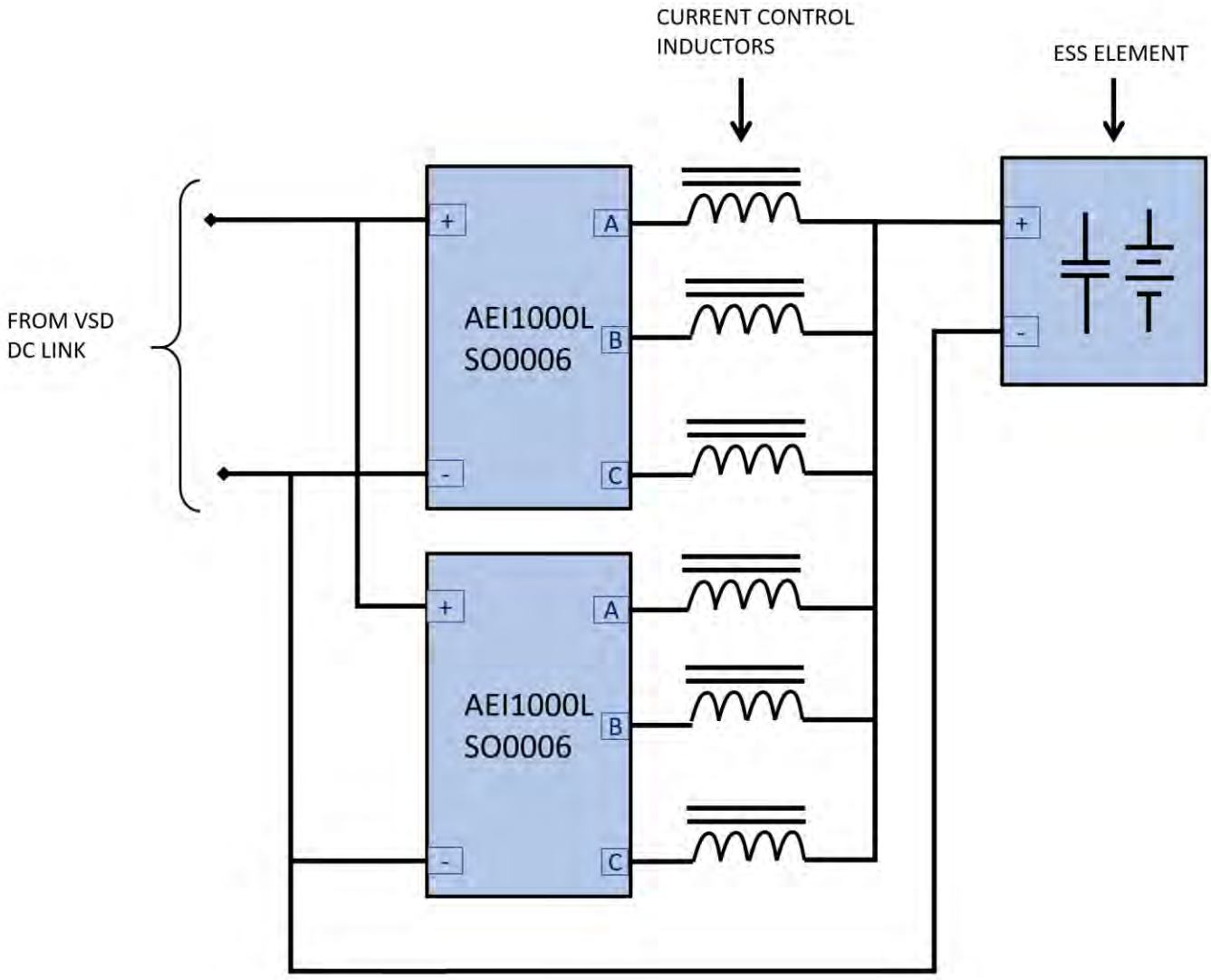
- The following schematics show the basic configurations possible when connecting ESS elements to the DC link of a VSD system.

- These schematics do not show application specific elements such as fuses, disconnects / contactors / breakers or precharge arrangements. Some notes for consideration regarding these elements are provided in Section 3.

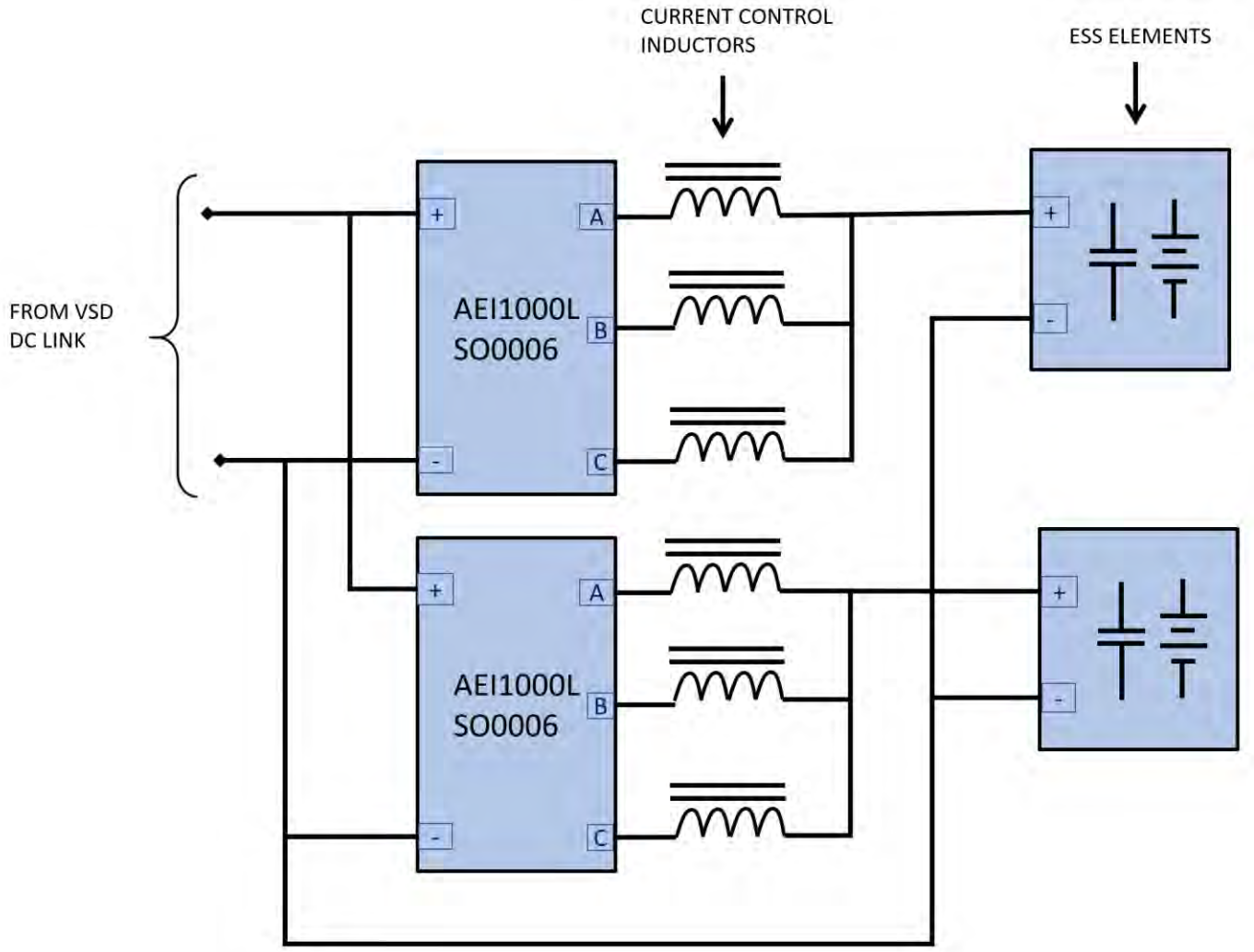
2.2.1 Single AEI1000L-SO006 and Single ESS Element



2.2.2 Multiple AEI1000L-SO0006 and Single ESS Element



2.2.3 Multiple AEI1000L-SO0006 and Multiple ESS Elements



2.2.4 IMPORTANT NOTE

- It is critically important that the ESS element is compatible with this topology. Specifically, that the negative terminal of the ESS element is connected directly to the negative potential of the system DC link.

- This must include normal operation and fault conditions.

2.3 Control Overview

- Each AEI1000L-SO0006 module operates as three individually current-controlled DC current sources capable of +/-1000A peak per channel, with a single current reference applied to all channels.
- The AEI1000L-SO0006 units control ***CURRENT***. It is the responsibility of other sub-systems to determine the necessary current, based upon power-flow requirements and State-of-Charge (SOC) of the ESS Elements.
- The current reference can be provided as a frequency modulated RS422 signal, or as a value written via MODBUS RTU protocol over a 2-wire RS485 link.
- Each channel implements current control via a 2.5kHz PWM waveform applied to the current control inductors.
- B & C channels' PWM switching patterns are delayed by 120° and 240° respectively. This shifts the PWM ripple in the ESS elements to 7.5kHz, with an amplitude of less than ⅓ of the per-channel value.
- Furthermore, if more than one unit is used to charge a single ESS element, then the PWM between "master" and "slave" charging units can be locked and phase-shifted to increase the ripple frequency and reduce amplitude still further.

3. General Application Guidance

3.1 Control Inductors

- The control inductors allow the DC current into the ESS elements to be controlled by the PWM output of the AEI1000L-SO0006 units.
- The inductors used are of the DC type. Three phase AC inductors may not be used since the three-phase condition that $I_A + I_B + I_C = 0$ does not apply.
- The exact inductance and current required will vary according to DC-link and ESS voltage ranges, and the maximum ripple current tolerable in the application.
- A simple analysis can predict the maximum and minimum current in the charging inductor (assuming V_{DC} is substantially larger than V_{ESS} – as it must be):

$$I_{ripple}[pk-pk\ A] = \frac{400\mu s\ .\ V_{ESS}\ .(V_{DC} - V_{ESS})}{L\ [H]\ .\ V_{DC}}$$

- And easily:

$$I_{max,min}\ [A] = I_{average}[A]\ \pm \frac{I_{ripple}\ [pk-pk\ A]}{2}$$

- To maximize DC link capacitance lifetime and maintain good headroom for control overshoots (the unit trips on instantaneous overcurrent at 2000A), it is recommended to maintain I_{max} < 1500A.

- If air-gapped iron-core inductors are used, then the minimum value at maximum current must be specified to the manufacturer. The value at lower currents may increase by around 30% due to desaturation of the core.

- Avid Controls recommends the following minimum specification for 1000A per-channel operation using V_{DC} max of 1050V and V_{ESS} min of 515V:

    - Inductance Minimum @ 1500A: 100 µH
    - Inductance Maximum < 1500A: 130 µH
    - Peak Current: 1000 Adc + 1000 A pk-pk ripple @ 2.5kHz
    - Continuous Current: 500 Adc + 1000 A pk-pk ripple @ 2.5kHz
    - Minimum end-end working voltage: 1200 V
      (turn-to-turn insulation ***must*** support this voltage)

- Other application and certification requirements will be as-per the users' requirements.

3.2 ESS Element Working Voltage

- The recommended working range for the ESS voltage is from zero to 100V below the MINIMUM DC link voltage.

- The user should consider the required ramping rate of charge current together with the charging inductor value when determining the maximum ESS working voltage.

- It is the responsibility of the system engineer to ensure that the ESS elements cannot be dangerously over-charged. In general, this means:

    - When the ESS management system determines that SOC has reached the nominal maximum working voltage, the current demand to the AEI1000L-SO0006 must be reduced to zero, or the AEIL1000L disabled.

    - When the ESS management system determines that SOC has reached the maximum safe voltage, the charger should be disconnected from the ESS elements.

3.3 Disconnects / Pre-charge / Over-Current

- The schematics given in section 2.2 show only the active elements in the ESS charging control. Actual applications must address various other considerations:

3.3.1 Disconnects

- At different stages of construction, shipping, commissioning and servicing systems using the AEI1000L-SO0006 it is likely that it will be necessary to disconnect elements of the system:
    - Disconnect the AEI1000L-SO0006 DC+/- connections from the VSD DC link
    - Disconnect the ESS Element from the AEI1000L-SO0006
- In each case, the user must select the disconnect elements based on:
    - Current rating
    - Voltage rating
    - Remote or manual operation
    - Load or non-load operation

3.3.2 Pre-charge

- If system operation includes the possibility of connecting the AEI1000L-SO0006's DC terminals to a pre-established VSD DC link, then a pre-charge circuit must be provided.
- Design of the pre-charge circuit is the responsibility of the system engineer.
- If the connection between the AEI1000L-SO0006 and the VSD DC link is fixed, then the AEI1000L-SO0006's will be pre-charged alongside the VSD DC link. It will be necessary to ensure the additional capacitance of the AEI1000L-SO0006's is accounted for in the design of the pre-charge circuit.

3.3.3 Overcurrent Protection

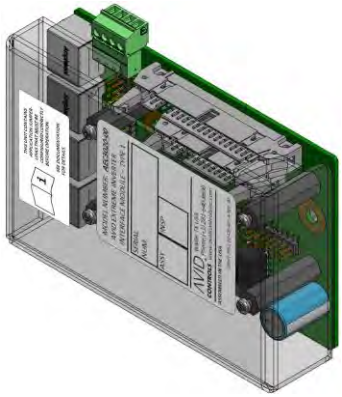
- The AEI1000L-SO0006 units have an instantaneous over-current trip point of 2000A. This is achieved by disabling the gate-drive signals to the IGBT's.
- Additional protection of the cables and the ESS elements is likely required. This must be implemented in the overall system using a combination of fuses, breakers, contactors etc. each of which must be rated for the appropriate DC operation.

3.4 Overcharging Protection

- As previously stated, the AEI1000L-SO0006 does not monitor the SOC of the ESS elements.
- This must be done by the management system and appropriate measures taken to prevent over-charging.

4. Control

4.1 Interface Module

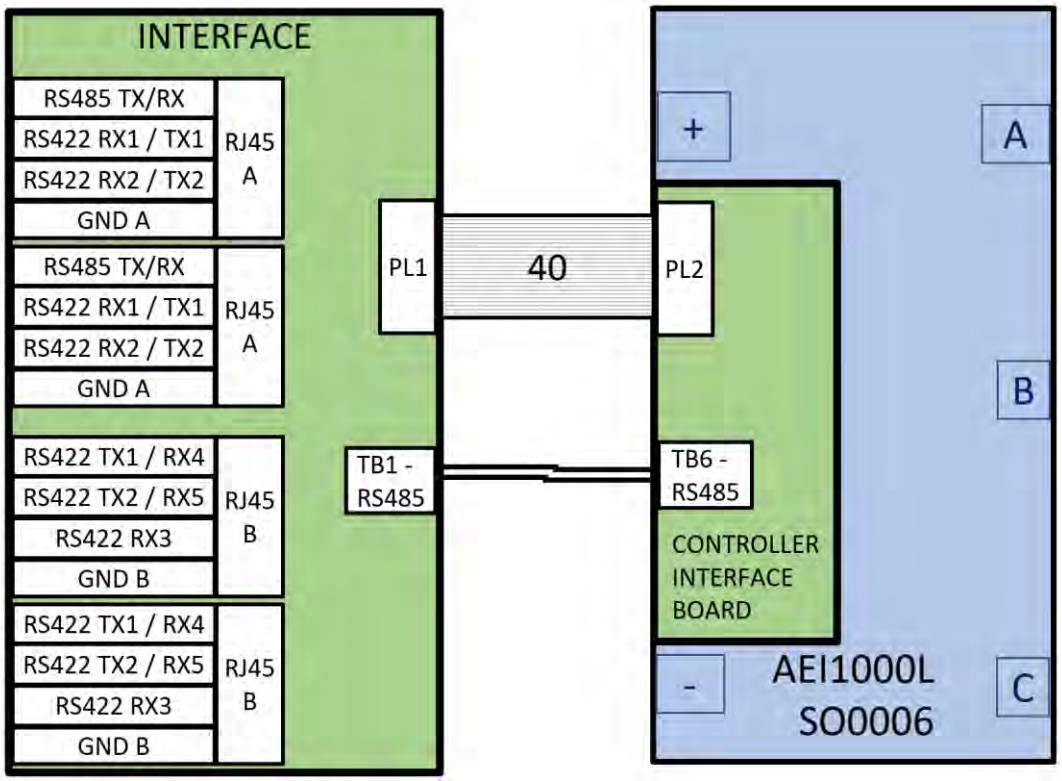


4.1.1 Overview

- The AEI1000L-SO0006 does not require an external controller, such as the MV3000 Common Drive Controller, for operation.

- An interface module (Avid Model Number AEC3020-00) is mounted onto each AEIL1000L-SO0006 to provide connections to a system controller (usually a PLC) and additional connections between Master and Slave AEI1000L-SO0006 units.

- The following figure shows the basic functions of the Interface Module:



- There are two pairs of RJ45 connectors, RJ45-A & RJ45-B. Each pair is connected in exact parallel to enable daisy-chain multi-drop connections using off-the-shelf shielded-twisted-pair (STP) CAT-5E or better Ethernet patch cables. THESE ARE NOT ETHERNET CONNECTIONS – THE CHOICE OF RJ45 AND STANDARD PATCH CABLES WAS MADE FOR EASE OF USE ONLY.

- Each channel A & B have an isolated ground – isolated from each other and isolated from the equipment chassis. This isolation is for improved signal integrity not for safety – circuits connected to channels A & B must be at Safe-Extra-Low-Voltage (SELV) potential. Jumper links on the Interface Board allow Channel A & B 0V (ground) to be connected together or to chassis-ground if that is needed.

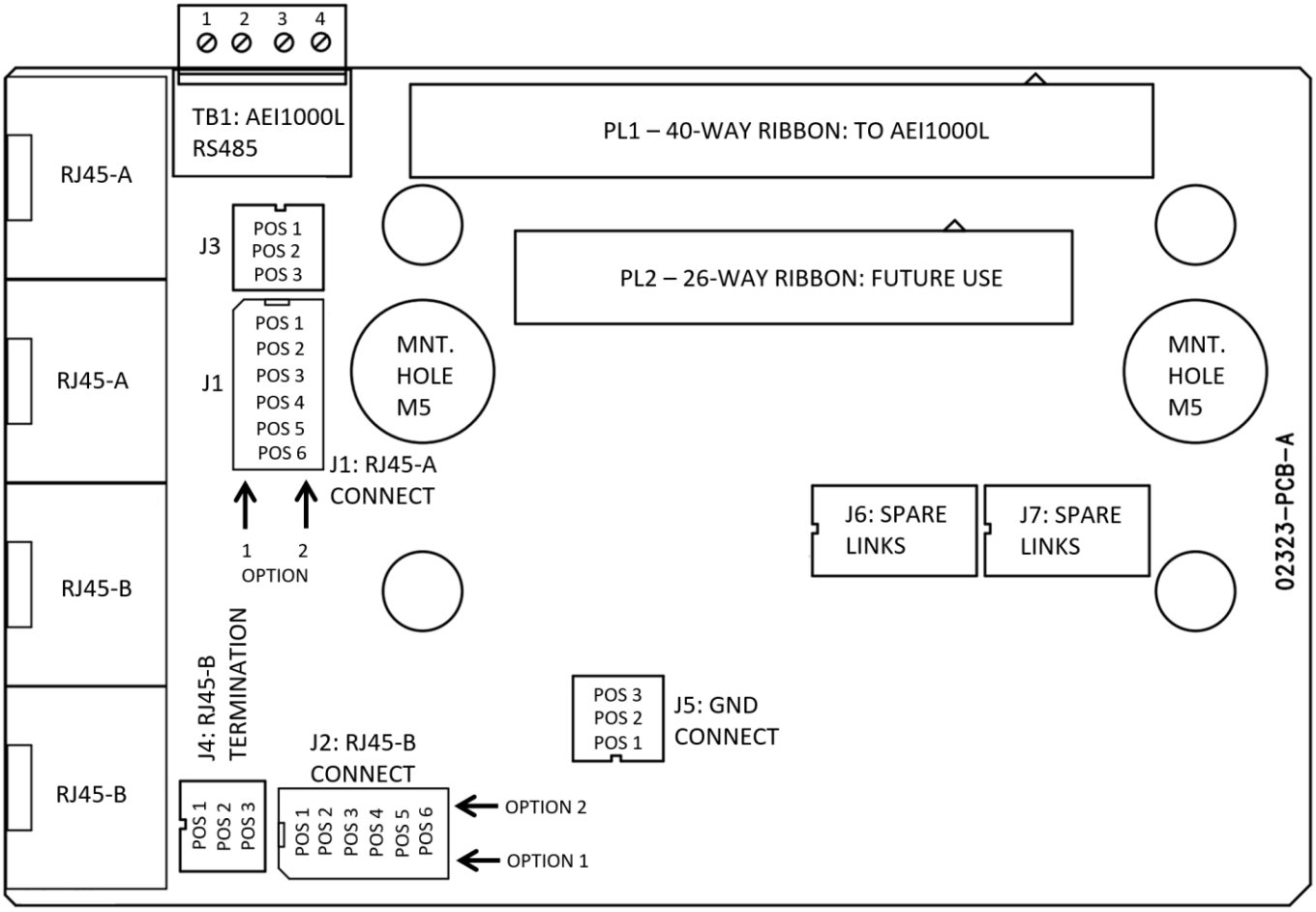
4.1.2 Logical Signals

- The following table indicates the logical signals available on the Interface Module, and the possible uses in the AEI1000L-SO0006 modules:

SIGNAL	AVAILABLE ON	USES	NOTES
MODBUS RS485	RJ45-A	MODBUS-RTU Comms Link	115200 Baud 8N1 Data Node address via DIP switches See section 4.4 for full details
RX1	RJ45-A	Current Reference (Frequency Modulated)	Maximum Freq. = 500kHz See section 4.7.1 for full details
RX2	RJ45-A	Slave PWM sync-in signal	
TX1	RJ45-A and RJ45-B	Master PWM sync-out signal	
TX2	RJ45-A and RJ45-B	Future use	
RX3	RJ45-B	Can optionally be used as an external enable input	
RX4	RJ45-B	Option for SOC (Volts) input (FM)	Maximum Freq. = 500kHz See section 4.7.4 for full details
RX5	RJ45-B	Future use	

4.1.3 Connectors & Jumper Links

- The following figure shows the location of connectors and jumper links on the interface board (it is necessary to remove the polycarbonate cover to access these jumpers) :



TB1

PIN	SIGNAL	NOTES
1	RS485 TERMINATION	Connect Pin-to-Pin to RS485 connector (TB6) on Controller Interface Board of AEI1000L-SO0006 Fit link in J3-POS1 to connect internal 120Ω resistor at end of RS485 link.
2	RS485-DATA+	
3	RS485-DATA-	
4	CH A Ground	

PL1

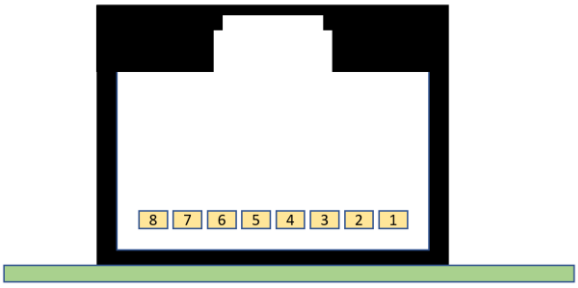
- This is connected to the standard 40-way controller interface of the AEI1000L-SO0006.
- A short (less than 100mm) length ribbon should be used.
- This connection does not require shielded ribbon cable.

PL2

- This is not currently used.

RJ45-A & RJ45-B

- The pin-out of the RJ45's comply with the normal Ethernet 4-pair usage:



(Board Edge View)

PAIR	RJ45 PINS	TYP. PATCH CABLE COLOR
1	4, 5	BLUE
2	1, 2	ORANGE
3	3, 6	GREEN
4	7, 8	BROWN

RJ45-A, J1 & J3

Pin	Pair	J1 position used to select function	J1 fitted in option 1 location	J1 fitted in option 2 location	J1 not fitted	J3 position to fit to add 120Ω termination
1	2	6	RS485-DATA+		No Connect	Position 1
2		5	RS485-DATA-		No Connect	
4	1	4	RS422-RX1+	RS422-TX1+	No Connect	Position 3
5		3	RS422-RX1-	RS422-TX1-	No Connect	
3	3	2	RS422-RX2+	RS422-TX2+	No Connect	Position 2
6		1	RS422-RX2-	RS422-TX2-	No Connect	
7	4	None	Connected to CH A Ground			None
8						

Notes:

- All RS422/RS485 signals on RJ45-A are referenced to CH A Ground.
- For pairs 1 & 3, fitting the jumper on J3 will add the termination resistor to the RJ45's irrespective of where, or if, a jumper is fitter in the corresponding J1 locations.

RJ45-B, J2 & J4

Pin	Pair	J2 position used to select function	J2 fitted in option 1 location	J2 fitted in option 2 location	J2 not fitted	J4 position to fit to add 120Ω termination
1	2	6	RS422-RX3+		No Connect	Position 3
2		5	RS422-RX3-		No Connect	
4	1	4	RS422-RX4+	RS422-TX1+	No Connect	Position 2
5		3	RS422-RX4-	RS422-TX1-	No Connect	
3	3	2	RS422-RX5+	RS422-TX2+	No Connect	Position 1
6		1	RS422-RX5-	RS422-TX2-	No Connect	
7	4	None	Connected to CH B Ground			None
8						

Notes:

- All RS422 signals on RJ45-B are referenced to CH B Ground.
- For all pairs, fitting the jumper on J4 will add the termination resistor to the RJ45's irrespective of where, or if, a jumper is fitter in the corresponding J2 locations.

J5

- Jumpers can be fitted to J5 to connect CH A Ground, CH B Ground and Chassis Ground together, as per the following table:

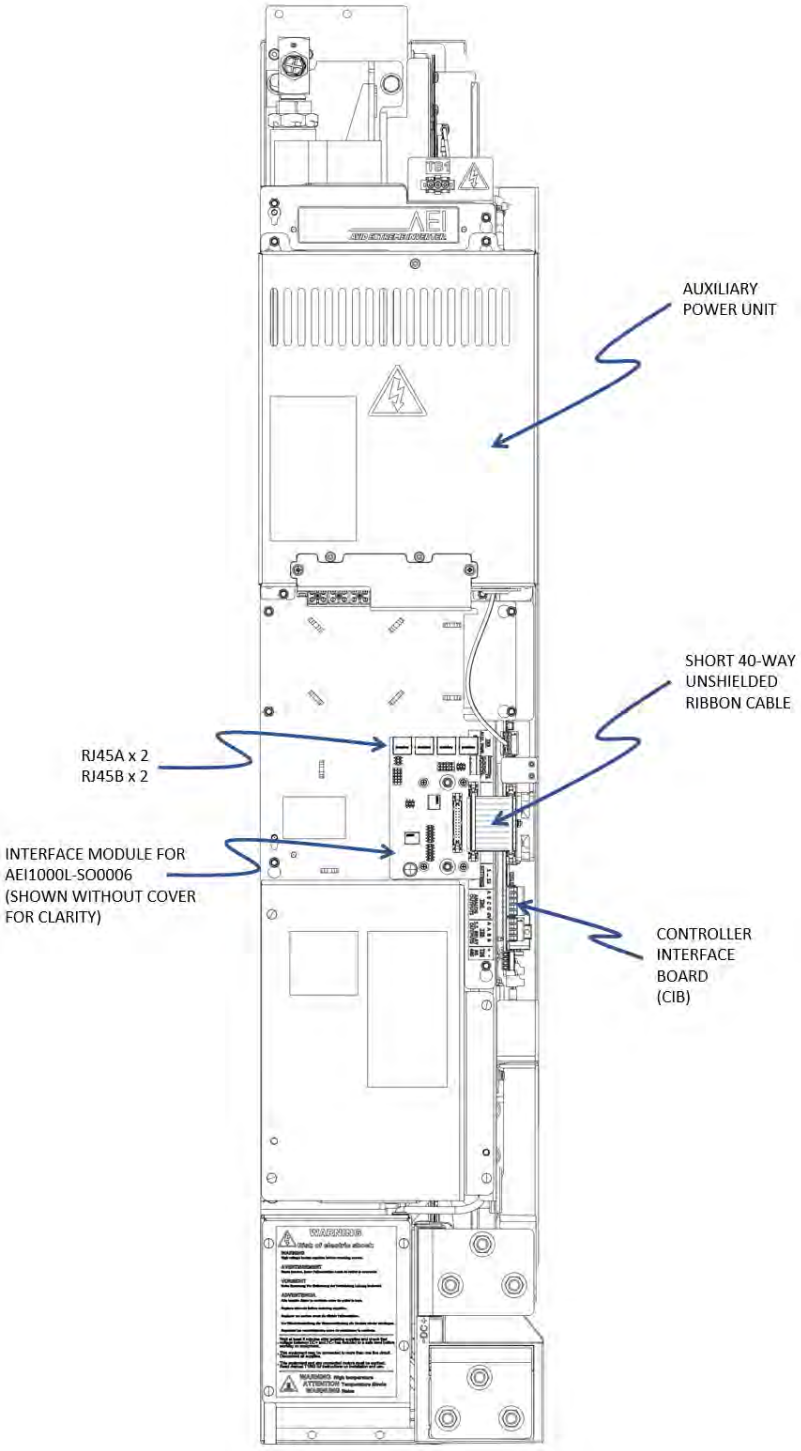
J5 Position	Connection if link fitted
1	CH B Ground to Chassis Ground
2	CH A Ground to CH B Ground
3	CH A Ground to Chassis Ground

J6 & J7

- These have no function but are provided as a convenience to store unused jumper links.

4.1.4 Mechanical Arrangement

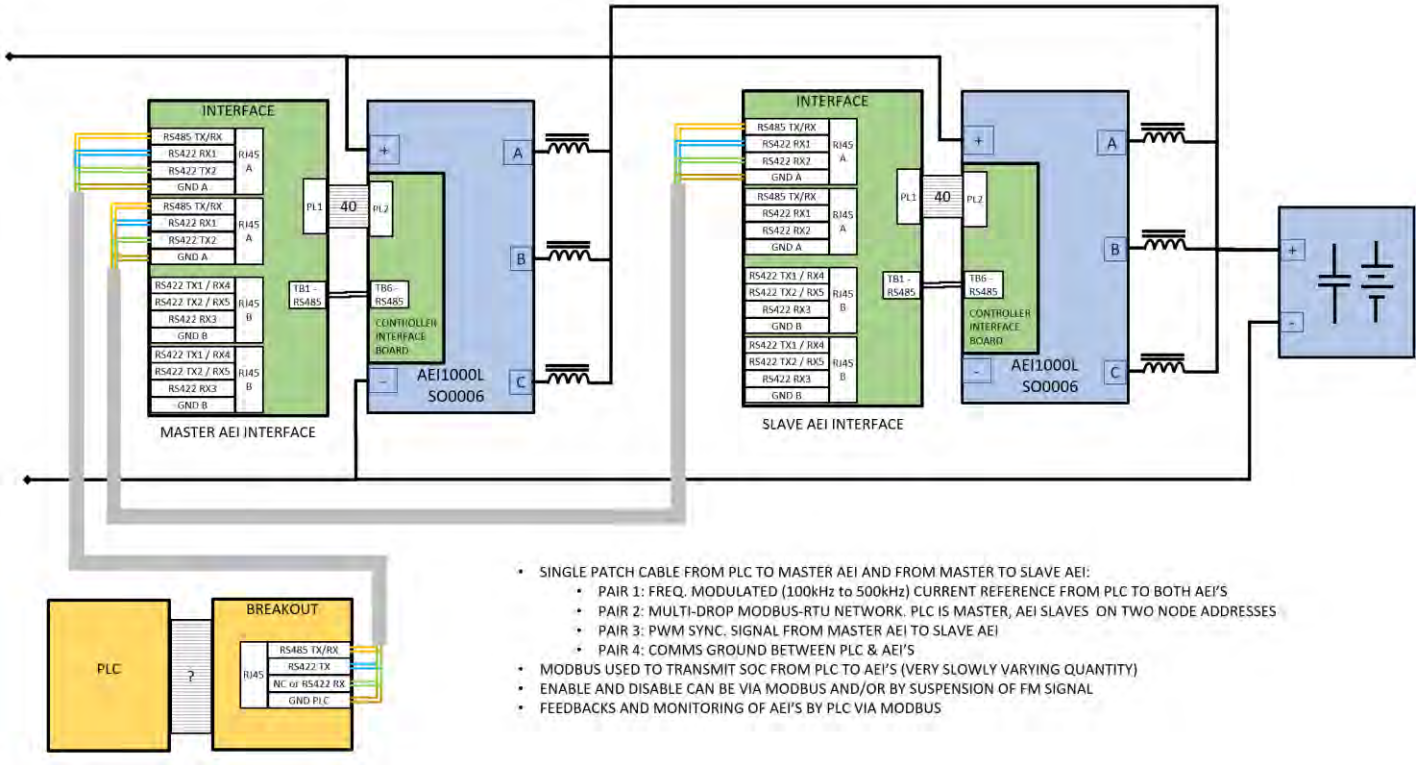
- Mechanical details are generally identical to standard AEI1000L modules – which are provided in Avid document DTS-MID0012.
- The following illustrates the location and orientation and dimensions of the interface board:



4.2 Control System Connection Examples

- When making connections between the RJ45-based interconnection of the AEI1000L-SO0006 modules and other components in the system, standard break-out modules such as the ASI IMRJ0845 DIN Rail RJ45 Terminal Block Interface Module may be needed:

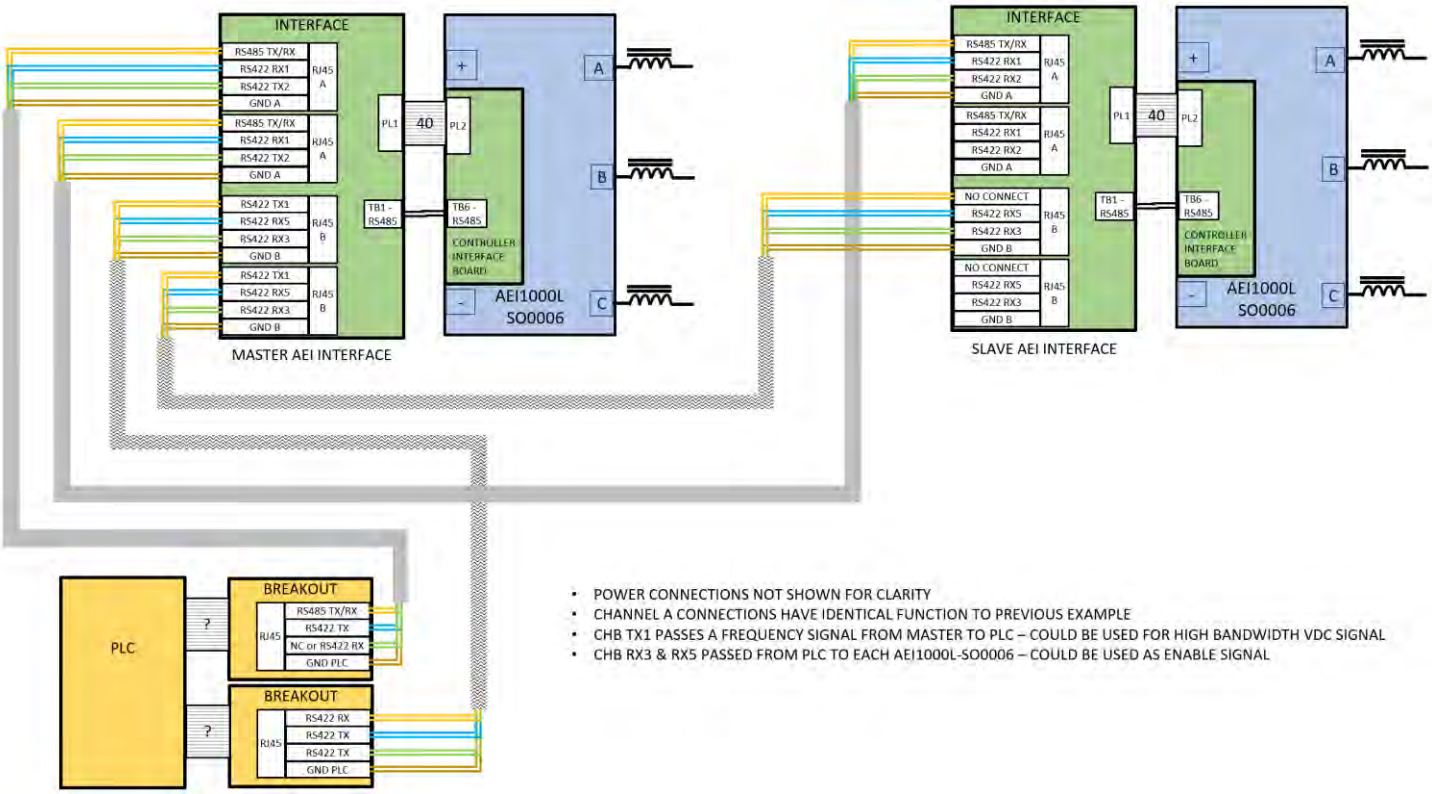
- The following shows a minimum interconnect scheme between a PLC and two AEI1000L-SO0006 modules operating in Master/Slave PWM mode:



- This would be used with the following link settings on the interface boards:

Link	Master Interface Position	Slave Interface Position	Note
J1 – Pos 1 & 2	OPTION 2	OPTION 1	Connect PWM sync. from master (TX2) to slave (RX2)
J1 – Pos 3 & 4	OPTION 1	OPTION 1	Connects PLC frequency signal (I REF) to RX1on all AEI's
J1 – Pos 5 & 6	OPTION 1 OR OPTION 2		Connect RS485 to CIB
J3 – Pos 1	NOT FITTED	FITTED	Terminate RS485 at slave end
J3 – Pos 2	NOT FITTED	FITTED	PWM Sync. terminated at slave end (RX2)
J3 – Pos 3	NOT FITTED	FITTED	Terminate frequency signal (RX1) at slave end
J2 – Pos 1 & 2	NOT FITTED		Channel B is not used
J2 – Pos 3 & 4			
J2 – Pos 5 & 6			
J4 – Pos 1			
J4 – Pos 2			
J4 – Pos 3			

- The following shows an additional link to allow two extra RS422 signals to be passed from the PLC to the AEI1000L-SO0006's and a RS422 signal to be passed from the master AEI1000L-SO0006 to the PLC (for example to provide a DC link voltage feedback):



- This would be used with the following link settings on the interface boards:

Link	Master Interface Position	Slave Interface Position	Note
J1 – Pos 1 & 2	OPTION 2	OPTION 1	Connect PWM sync. from master (TX2) to slave (RX2)
J1 – Pos 3 & 4	OPTION 1	OPTION 1	Connects PLC frequency signal (I REF) to RX1on all AEI's
J1 – Pos 5 & 6	OPTION 1 OR OPTION 2		Connect RS485 to CIB
J3 – Pos 1	NOT FITTED	FITTED	Terminate RS485 at slave end
J3 – Pos 2	NOT FITTED	FITTED	PWM Sync. terminated at slave end (RX2)
J3 – Pos 3	NOT FITTED	FITTED	Terminate frequency signal (RX1) at slave end
J2 – Pos 1 & 2	OPTION 1	OPTION 1	Connect RX4 to signal from PLC to both AEI's
J2 – Pos 3 & 4	OPTION 2	NOT FITTED	Connect TX1 of master to RX channel on PLC
J2 – Pos 5 & 6	OPTION 1	OPTION 1	Connect RX3 to signal from PLC to both AEI's
J4 – Pos 1	NOT FITTED	FITTED	Terminate RX4 signal at slave
J4 – Pos 2	NOT FITTED	FITTED	Terminate TX1 signal at end of open line (slave)
J4 – Pos 3	NOT FITTED	FITTED	Terminate RX3 signal at slave

4.3 PWM Master / Slave Operation

- The AEI1000L-SO0006 uses fixed frequency PWM at 2.5kHz to implement current control.

- When more than one AEI1000L-SO0006 is used to charge storage elements that are connected in parallel (i.e. a single charge/discharge current) it is recommended to operate the PWM in Master/Slave mode with a time (phase) offset between the two units.

- This is achieved by:
  - Connecting TX2 of the master to RX2 of the slave(s). This will be used to transmit the reference 2.5KHz A-phase PWM clock.

  - In the master AEI1000L-SO0006, set the PWM mode to Master by setting Modbus register ***SETUP_BITS*** bit 4 to 1 (parameters are described in section 4.6).

  - In the slave AEI1000L-SO0006, set the PWM mode to Slave by setting Modbus register ***SETUP_BITS*** bit 4 to 0.

  - Set a 60° phase shift between the two PWM's by setting Modbus register ***SETUP_PWM_DELAY*** to a value of 20000. This will give a 200µs phase shift between master and slave. Obviously, if more than two AEI1000L-SO0006 units are used in parallel, appropriate values of delay should be set.

- It is possible to synchronize PWM with a process in the PLC. To do this, all AEI1000L-SO0006 units are set to Slave mode and the PLC must generate a 2.5kHz clock connected to RX2 of each AEI1000L-SO0006. This clock must comply to the limits of frequency and duty cycle specified in section TBD.

4.4 Modbus Interface

- The PLC (or other external controller) uses the Modbus interface to each of the AEI1000L-SO0006 units is used to:
    - Read basic information about the units (serial number, ratings, scaling etc.)
    - Set up operational parameters (reference options, control gains etc.)
    - Transmit low-bandwidth control variable to the AEI1000L-SO0006's (state-of-charge, enable permits etc.)
    - Monitor status and feedbacks from each AEI1000L-SO0006 (trips, currents etc.)

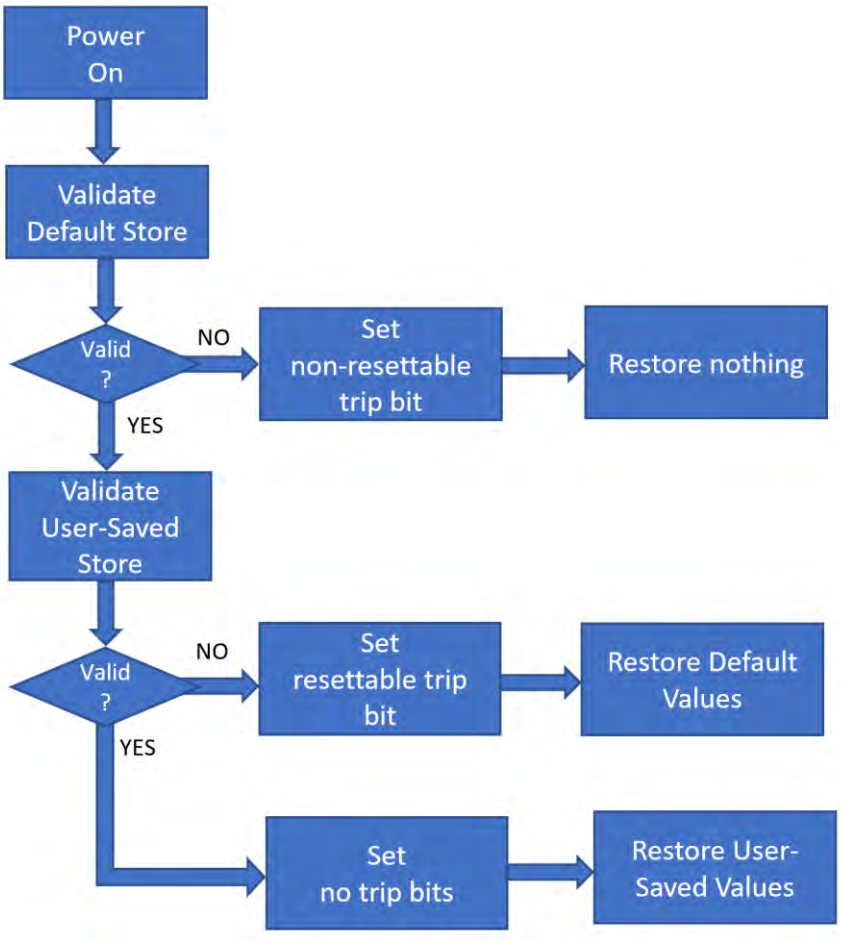
- The RS485 port is implemented via TB6 and associated DIP switches ON THE CIB OF THE AEI1000L-SO0006 units. The interface board just provides connection from RJ45 CHA to the CIB and allows the termination resistor to be connected.

- Physical and data specifications for the RS485 link:
    - Electrical Levels: TIA/EIA RS485, 5V
    - Isolation: Reference to GND-CHA of the interface board
    - Baud Rate: 115200 bits per second
    - Parity: None
    - Data Bits: 8
    - Stop Bits: 1
    - Modbus Protocol: Modbus-RTU

- Only Modbus functions 03d (0x03) ***Read Holding Registers*** and 16d (0x10) ***Write Multiple Registers*** may be used. Any other function will result in an exception.

4.5 Non-Volatile Register Storage

- Those registers that are used as setup parameters are stored in non-volatile storage in the AEI1000L-SO0006 units.
- Due to limitations of the E^2PROM devices used to store these, it is not possible to auto-store at power down, so a Command Register (see section 4.6.6 for complete details) is used to initiate the storing of the current register set.
- The Command Register can also be used to restore the register set to the at-power-up or default values at any time.
- The following flowchart shows the power-up sequence:



4.6 Modbus Registers

- The AEI1000L-SO0006 implements a total of 61 Modbus registers from address 00 to 60.
- Each register has a defined ***type*** which identifies how the 16-bits should be interpreted:

Type	Interpretation
SIGNED INTEGER	• Signed (2s-compliment) number. • Bit 15 has a decimal value of -32768 • Representable range is -32768 to +32767
UNSIGNED INTEGER	• Unsigned number. • Bit 15 has a decimal value of +32768. • Representable range is 0 to 65535.
POSITIVE INTEGER	• Can be considered UNSIGNED or SIGNED. • Bit 15 is always zero, so its assigned value is immaterial. • Representable range is 0 to 32767. • Values written with bit 15 set to 1 will always be detected as out-of-range
BIT FIELD	• Does not represent a numeric value. • Individual bits or groups of bits have their own specific meaning.

- Reading or writing a register outside the 00 to 60 range will result in a Modbus exception.
- Writing to a read-only register or writing an out-of-range value will ***NOT*** result in a Modbus exception – but no actual write to those registers will occur.

4.6.1 Register Groups

- There are five distinct groups of registers:

Group	Register Range	Used For	Attributes
0: ID	00 to 07	AEI1000L unit identification and scaling values.	Set by Avid during manufacture. Read-Only.
1: SETUP	08 to 27	Setup Parameters	Read-Write. Restored from E^2PROM at power-up or by command. Saved to E^2PROM by command.
2: PROCESS	28 to 35	Process Inputs	Read-Write. Zeroed at power-up.
3: FEEDBACK	36 to 59	Feedbacks	Read-Only. Continuously updated.
4: COMMAND	60	Command	Write-Only. Specific values trigger defined actions when written.

4.6.2 Group 0 - Identification and Scaling

Modbus Register	Name	Type	Meaning & Scaling	Notes
00	ID_TYPE_ VERSION	UNSIGNED INT	Program type & version of the ESS control FPGA	Considered as a five-digit decimal number: • The highest two digits represent the program type. For the AEI1000L-SO006 this is ***01***. • The lowest three digits represent the program version. Even numbers will represent fully released versions while odd number represent R&D versions that are not fully released or controlled.
01	ID_SER_NUM	UNSIGNED INT	Avid QMS Serial Number of the AEI1000L-SO0006	Will be a number > 10000
02	ID_I_100	POSITIVE INT	Scaling of current references and feedbacks. Scaled as 1 A per least-significant-bit	Value is 1000A for AEI1000L-SO0006
03	ID_V_100	POSITIVE INT	Scaling of voltage parameters, inputs & feedbacks. Scaled as 0.1V per least-significant-bit	Value is 10000 (1000.0V) for AEI1000L-SO0006
04 to 07	ID_RESERVED	N/A	Reserved for use in future versions.	Will read 0 via Modbus

4.6.3 Group 1 – Setup Parameters

Modbus Register	Name	Type	Meaning & Scaling	Max, Min & Default	Notes
08	SETUP_BITS	BIT FIELD	BIT 0: CURRENT REF. SOURCE — 0: FM ON RX1, 1: MODBUS BIT 1: STORE VOLTS SOURCE — 0: FM ON RX4, 1: MODBUS BIT 2: RX3 REQUIRED FOR ENABLE — 0: YES, 1: NO BIT 4: PWM MASTER — 0: SLAVE, 1: MASTER BIT 3, 15..5: RESERVED – LEAVE THESE VALUES AT ZERO	Max = 65535 Min = 0 Default = 0	See sections 4.7.1, 4.7.2 & 4.3 for more details
09	SETUP_FREQ_REF_MIN	UNSIGNED INT	8 Hz per least-significant-bit	Max = 25000 Min = 1250 Default = 12500	See section 4.7.1 for more details
10	SETUP_FREQ_REF_MAX	UNSIGNED INT	8 Hz per least-significant-bit	Max = 62500 Min = 2500 Default = 62500	
11	SETUP_PWM_DELAY	UNSIGNED INT	10 ns per least-significant-bit	Max = 40000 Min = 0 Default = 0	See section 4.3 for more details
12	SETUP_IREF_RAMP_RATE	POSITIVE INT	0.01 % of I_100 per 400µs per least-significant-bit	Max = 10000 Min = 4 Default = 400	See section 4.7.6 or more details
13	SETUP_CURRENT_CONTROL_KP	UNSIGNED INT	1/256 per-unit per least-significant-bit (1 per-unit is defined as a P-term of V_100 when the current error is I_100)	Max = 5120 Min = 0 Default = TBD	See section 4.7.6 for more details
14	SETUP_CURRENT_CONTROL_KI	UNSIGNED INT	1/4096 per-unit-per-PWM-period per least-significant-bit	Max = 30000 Min = 0 Default = TBD	
15	SETUP_MODBUS_TIMEOUT	POSITIVE INT	10 ms per least-significant-bit	Max = 1000 Min = 5 Default = 100	See section 4.7.6 for more details
16	SETUP_I_REF_DB_WIDTH	POSITIVE INT	0.01% of full scale least-significant-bit	Max = 1000 Min = 0 Default = 0	See section 4.7.2 for more details
17	SETUP_I_REF_DB_HYST	POSITIVE INT		Max = 200 Min = 0 Default = 0	
18	SETUP_I_REF_DB_STEP	POSITIVE INT		Max = 1000 Min = 0 Default = 0	
19	SETUP_I_REF_SCALE_U	POSITIVE INT	1024 is equivalent to a scale factor of 1	Max = 4096 Min = 0 Default = 1024	See section 4.7.3 for more details
20	SETUP_I_REF_SCALE_V	POSITIVE INT			
21	SETUP_I_REF_SCALE_W	POSITIVE INT			
22	SETUP_I_DEMAND_POS_LIM	SIGNED INT	0.01% of I_100 amps	Max = 10000 Min = 0 Default = 10000	See section 4.7.6 for more details
23	SETUP_I_DEMAND_NEG_LIM	SIGNED INT	0.01% of I_100 amps	Max = 0 Min = -10000 Default = -10000	
24 to 27	SETUP_RESERVED	N/A	Reserved for use in future versions.	N/A	No values should be written to these registers via MODBUS

4.6.4 Group 2 – Process Inputs

Modbus Register	Name	Type	Meaning & Scaling	Max, Min , Default	Notes
28	PROCESS_ BITS	BIT FIELD	BIT [0]: U-PHASE ENABLE PERMIT BIT [1]: V-PHASE ENABLE PERMIT BIT [2]: W-PHASE ENABLE PERMIT BIT [15..3]: RESERVED	Max = 65535 Min = 0 Default = 0	See section TBD for more details
29	PROCESS_ MODBUS_ IREF	SIGNED INT	0.01% of I_100 per least-significant-bit	Max = 10000 Min = -10000 Default = 0	See section TBD for more details
30	PROCESS_ MODBUS_ ESS_VOLTS	POSITIVE INT	0.01% of V_100 per least-significant-bit	Max = 10000 Min = 0 Default = 0	
31 to 35	PROCESS_ RESERVED	N/A	Reserved for use in future versions.	N/A	Modbus may write any value to these registers. They will be zero at power up

4.6.5 Group 3 – Feedbacks

<table>
<tr><th>Modbus Register</th><th>Name</th><th>Type</th><th>Meaning & Scaling</th><th>Notes</th></tr>
<tr><td>36</td><td>FEEDBACK_ STATUS_BITS</td><td>BIT FIELD</td><td>
<table>
<tr><th>BIT</th><th>MEANING</th></tr>
<tr><td>0</td><td>HEALTHY</td></tr>
<tr><td>1</td><td>ENABLED</td></tr>
<tr><td>2</td><td>CURRENT FOLLOWING (ALL CURRENT FEEDBACKS WITH 10 % OF CURRENT DEMAND)</td></tr>
<tr><td>3</td><td>ZERO CURRENT (< 1% OF I_100)</td></tr>
<tr><td>4 – 15</td><td>RESERVED</td></tr>
</table>
</td><td></td></tr>
<tr><td>37</td><td>FEEDBACK_ TRIPS_0</td><td>BIT FIELD</td><td>
<table>
<tr><th>BIT</th><th>MEANING</th><th>BIT</th><th>MEANING</th></tr>
<tr><td>0</td><td>DEFAULT STORE ERROR</td><td>8</td><td>CURRENT CONTROL FAIL</td></tr>
<tr><td>1</td><td>USER STORE ERROR</td><td>9</td><td>DC LINK O-VOLTS</td></tr>
<tr><td>2</td><td>MODBUS TIMEOUT</td><td>10</td><td>TIMED O-CURRENT</td></tr>
<tr><td>3</td><td>REFERENCE LOSS</td><td>11</td><td>O-TEMP – U PH</td></tr>
<tr><td>4</td><td>STORAGE VOLTS LOSS</td><td>12</td><td>O-TEMP – V PH</td></tr>
<tr><td>5</td><td>INST O-CURRENT – U PH</td><td>13</td><td>O-TEMP – W PH</td></tr>
<tr><td>6</td><td>INST O-CURRENT – V PH</td><td>14</td><td>FAN FAIL</td></tr>
<tr><td>7</td><td>INST O-CURRENT – W PH</td><td>15</td><td>PWM_SYNC_LOSS</td></tr>
</table>
</td><td>See section 4.9 for more details</td></tr>
<tr><td>38</td><td>FEEDBACK_ TRIPS_1</td><td>BIT FIELD</td><td>Bits 0 to 15 = RESERVED</td><td></td></tr>
<tr><td>39</td><td>FEEDBACK_ RESERVED</td><td>N/A</td><td>Reserved for use in future versions.</td><td>Modbus will read 0 at this register</td></tr>
<tr><td>40</td><td>FEEDBACK_ CURRENT REFERENCE</td><td>SIGNED INT</td><td>0.01% of I_100 per least-significant-bit</td><td></td></tr>
<tr><td>41</td><td>FEEDBACK_ CURRENT_ U</td><td>SIGNED INT</td><td>0.01% of I_100 per least-significant-bit</td><td></td></tr>
<tr><td>42</td><td>FEEDBACK_ CURRENT_V</td><td>SIGNED INT</td><td>0.01% of I_100 per least-significant-bit</td><td></td></tr>
<tr><td>43</td><td>FEEDBACK_ CURRENT_W</td><td>SIGNED INT</td><td>0.01% of I_100 per least-significant-bit</td><td></td></tr>
<tr><td>44</td><td>FEEDBACK_VDC</td><td>POSITIVE INT</td><td>0.01% of V_100 per least-significant-bit</td><td></td></tr>
<tr><td>45</td><td>FEEDBACK_SOC_ VOLTS</td><td>POSITIVE INT</td><td>0.01% of V_100 per least-significant-bit</td><td></td></tr>
<tr><td>46</td><td>FEEDBACK_IGBT_ TEMP_U</td><td>SIGNED INT</td><td>0.1 °C per least-significant-bit</td><td></td></tr>
<tr><td>47</td><td>FEEDBACK_IGBT_ TEMP_V</td><td>SIGNED INT</td><td>0.1 °C per least-significant-bit</td><td></td></tr>
<tr><td>48</td><td>FEEDBACK_IGBT_ TEMP_W</td><td>SIGNED INT</td><td>0.1 °C per least-significant-bit</td><td></td></tr>
<tr><td>49</td><td>FEEDBACK_CIB_ TEMP</td><td>SIGNED INT</td><td>0.1 °C per least-significant-bit</td><td></td></tr>
<tr><td>50</td><td>FEEDBACK_ OVERLOAD_ REMAINING</td><td>POSITIVE INT</td><td>0.1 % per least-significant-bit</td><td>Percentage of the unit overload remaining prior to trip.
See section 4.9 for more details.</td></tr>
</table>

Modbus Register	Name	Type	Meaning & Scaling	Notes
51, 52	FEEDBACK_RX1_ FREQUENCY	UNSIGNED LONG	Hz: Register [51] is the low word, [52] is the high word	Provided for debugging purposes
53	FEEDBACK_ I_DEMAND_U	SIGNED INT	0.01% of I_100 per least-significant-bit	After the SCALE, RAMP and LIMIT functions of each phase current controller
54	FEEDBACK_ I_DEMAND_V	SIGNED INT	0.01% of I_100 per least-significant-bit	
55	FEEDBACK_ I_DEMAND_W	SIGNED INT	0.01% of I_100 per least-significant-bit	
56 to 59	FEEDBACK_ RESERVED	N/A	Reserved for use in future versions.	Modbus will read undefined values at these registers

4.6.6 Group 4 - Command Register

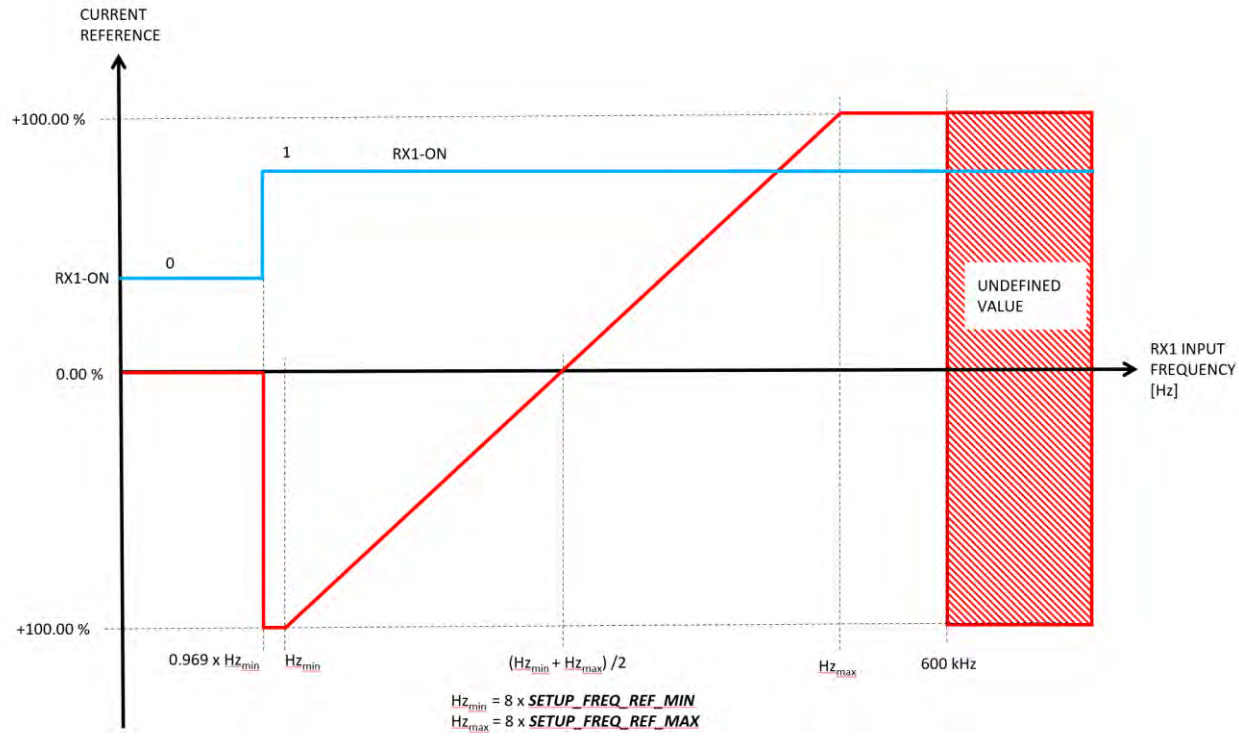
- Writing to this register will issue a command to the AEI1000L-SO0006.
- Reading this register will return zero.
- The following are the implemented commands:

Command Value	Action
0	No action. The only reason to write this value would be to prevent a Modbus timeout – but that can be achieved by reading any register.
1	Save SETUP registers' current values to E^2PROM. See section 0.
2	Restore SETUP registers from previously saved values in E^2PROM. This happens automatically at power-up. See section 0.
3	Set SETUP registers to their default values.
4	Reset TRIPS
5 to 65535	Undefined. Do not write these values to the command register.

4.7 Detailed Control Description

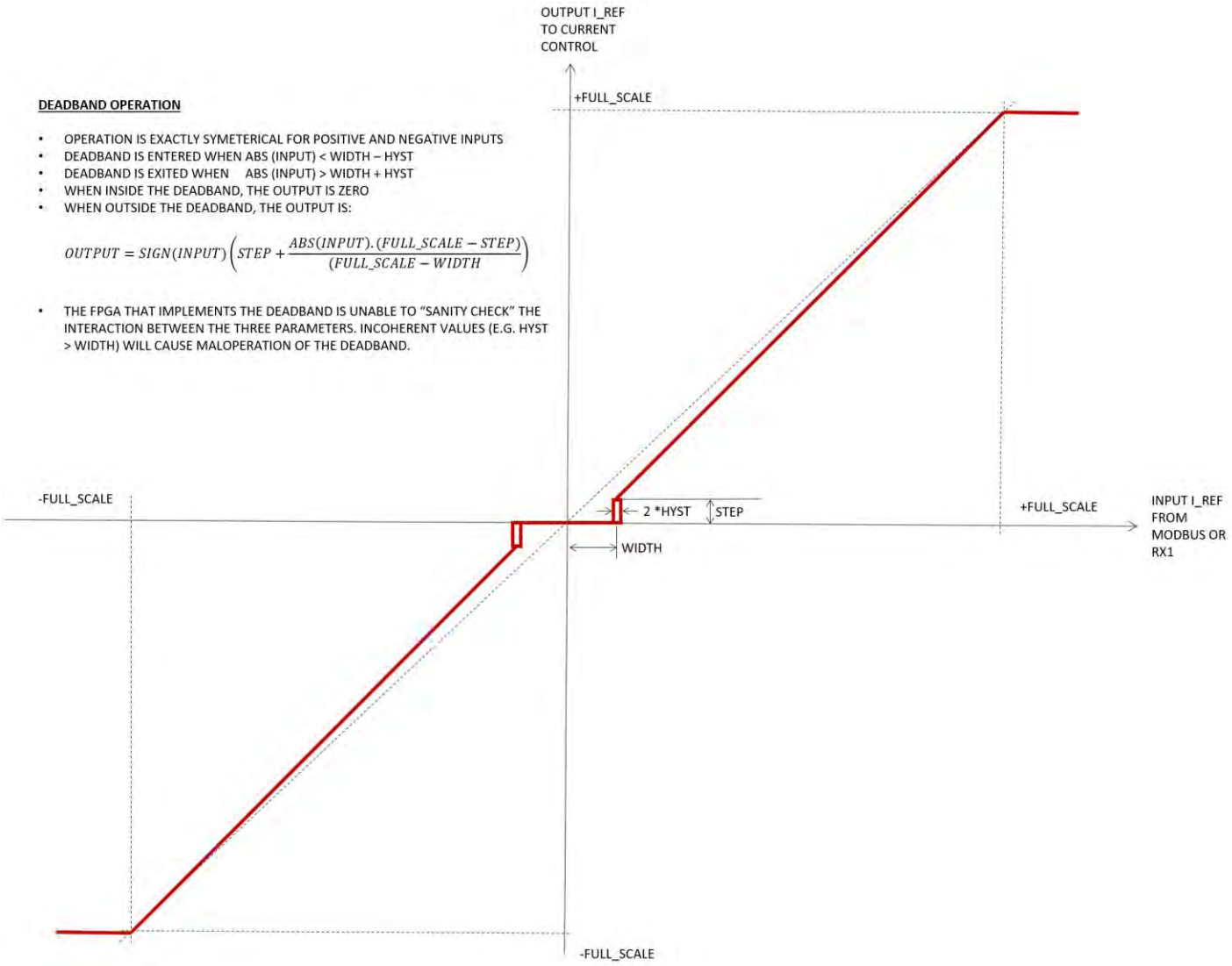
4.7.1 Current Reference Input

- Current Reference can be input into the AEI1000L-SO0006 via a Modbus write to ***PROCESS_MODBUS_IREF*** register, or using a frequency modulated RS422 signal via RX1 on RJ45A.
- Bit 0 of the ***SETUP_BITS*** register selects the reference source: 0 = Frequency on RX1, 1 = Modbus.
- The frequency range of the RX1 input is set by registers ***SETUP_FREQ_REF_MIN*** and ***SETUP_FREQ_REF_MAX*** – with scaling of 8 Hz per least-significant-bit.
- If the input frequency falls below 96.9% of ***SETUP_FREQ_REF_MIN***, the reference value will be set to zero and RX1-ON signal will be zeroed.
- If current reference is from RX1 the unit will trip on Reference Loss – this will disable the unit. The trip will need to be reset before the unit can re-enable.
- Frequencies above 600kHz may be filtered by the incoming receiver circuits and result in erroneous frequency measurements.
- The measurement of frequency occurs once per 400µs PWM period. Accuracy and bandwidth will degrade if there are fewer than 10 cycles on RX1 in that period. The default of 100 kHz is considered optimal.
- The relationship between reference value and RX1-ON and incoming frequency is shown here:



4.7.2 Current Reference Deadband

- A deadband function is provided on the current reference:



4.7.3 Current Reference Phase Scaling

- After the deadband, the current reference is scaled for each phase.
- The scaling is set by SETUP PARAMETERS 19, 20 and 21 which control the scale of U, V and W phase respectively.
- These scale factors are themselves scaled such that 1024 is unity scale. The range for the parameters is 0 to 4096 (scale factor of 0 to 4). The default is 1024, which is unity scale.
- The outputs of the scaling blocks are clamped to the range -100.00% to +100.00%.

4.7.4 Storage Voltage Input

- To avoid control transients producing a large spike of current at start-up, it is highly recommended to provide an input to the AEI1000L-SO0006 indicating the voltage level in the storage element. This may be referred to as State-of-Charge (Volts).

- This value is invariably monitored by the management system of the capacitor or battery storage devices, and will be available in the control PLC.

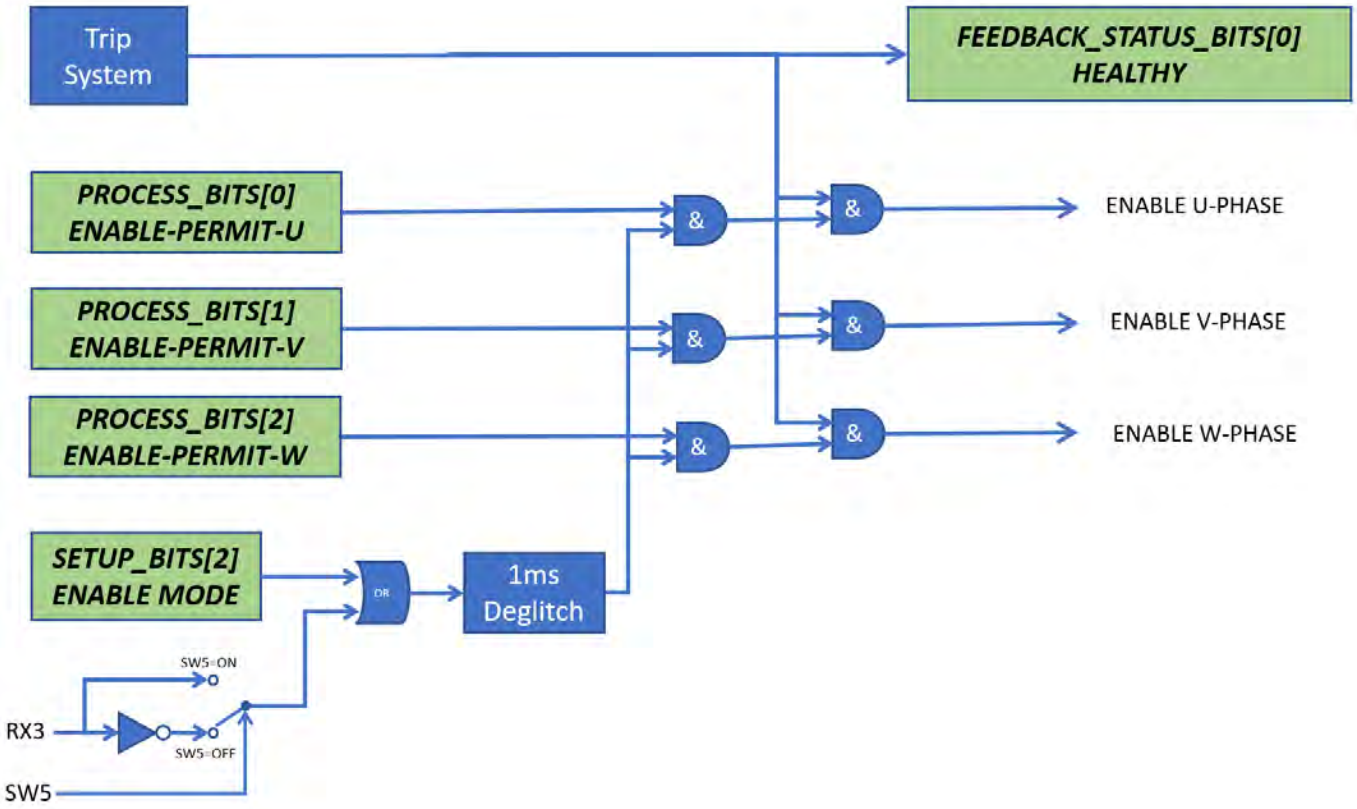
- Note that this value is only read (on a phase-by-phase basis) on the transition from DISABLED to ENABLED. Once control is running, the current PI's handle changes in capacitor terminal voltage.

- This input can be provided to the AEI1000L-SO0006 directly via Modbus register ***PROCESS_ MODBUS_ ESS_VOLTS*** or can be input as a frequency modulated input on RX4. Since it varies only slowly, either signal path is acceptable.
- In either case, an input of 0.00% is zero volts and 100.00% is 100% of V_100.

- If the FM input is chosen, then frequencies up to Hz_{min} (8 x ***SETUP_FREQ_REF_MIN***) correspond to 0.00% and frequencies above Hz_{max}(8 x ***SETUP_FREQ_REF_MAX)*** correspond to 100.00%.

4.7.5 Enable Logic

- The logic for enabling each phase of the AEI1000L-SO0006's outputs is shown here:

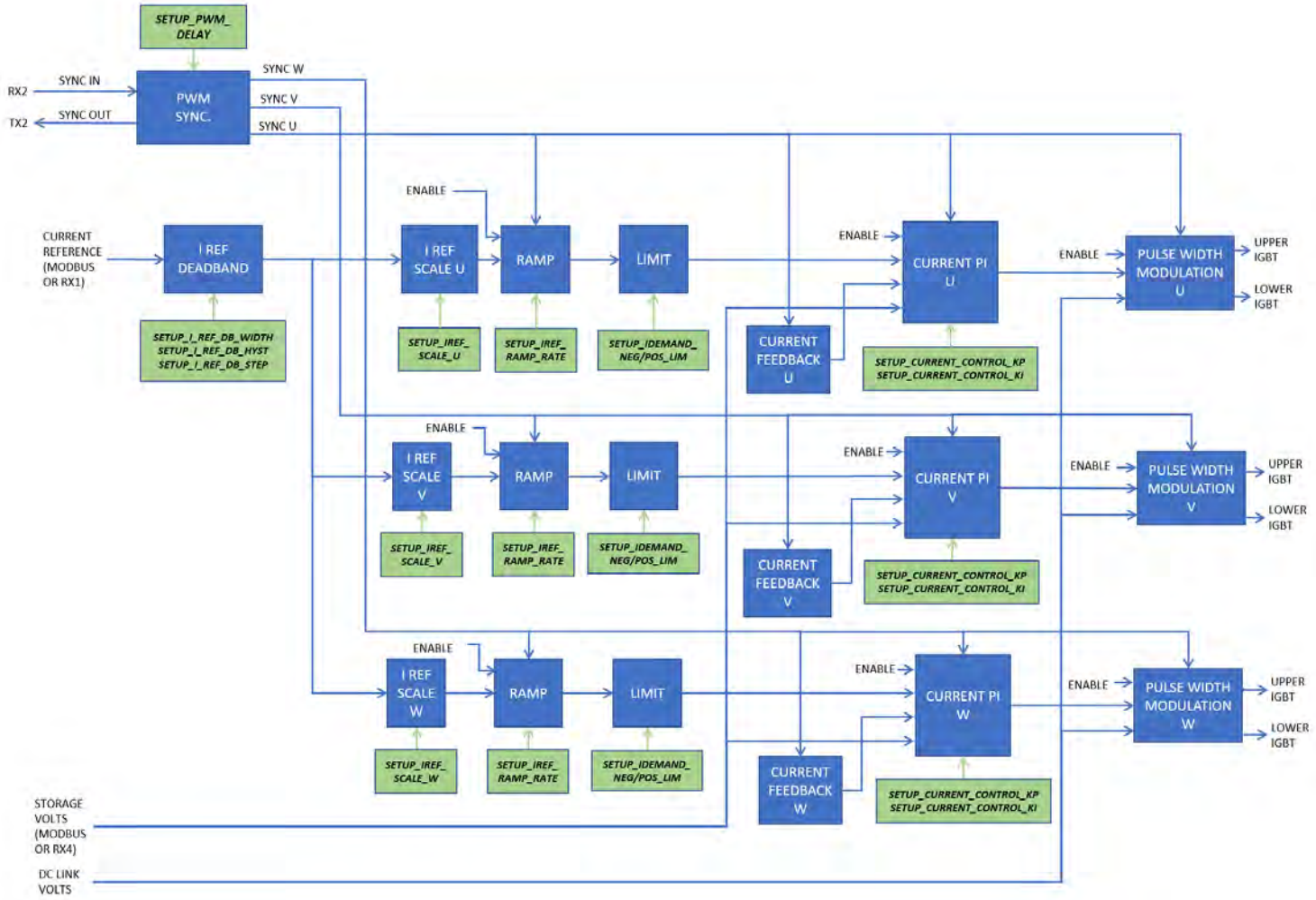


- The operation of RX3, SW5 and SETUP_BITS[2] is restated in the following truth-table:

SETUP_BITS[2]	SW5	RX3	Is Enable Allowed
0 RX3 Required (Default)	OFF (Default)	0 (Driven low)	YES
		1 (Driven high or not connected)	NO
	ON	0 (Driven low)	NO
		1 (Driven high or not connected)	YES
1 RX3 Not Required	Don't Care	Don't Care	YES

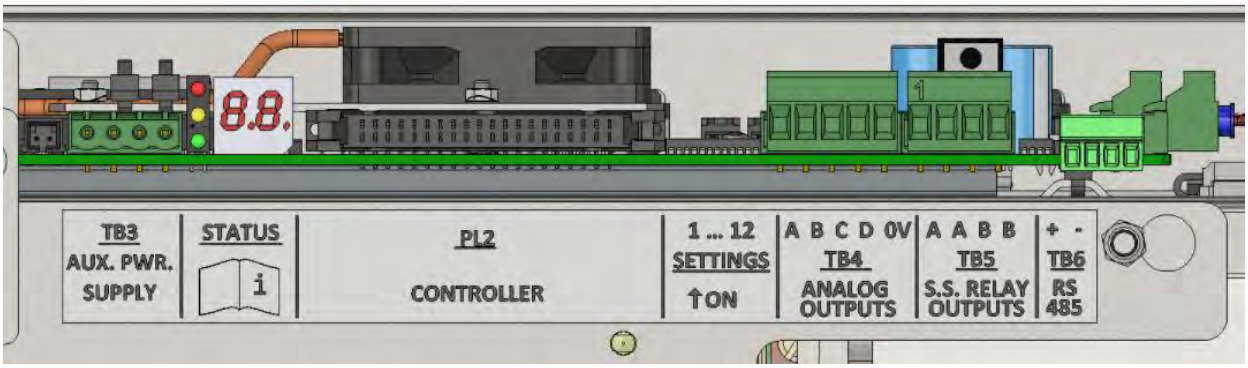
4.7.6 Current Control

- The following diagram shows the arrangement of the reference, current control and PWM system:



4.8 Local Settings, Indication and Diagnostic Outputs

- The AEI1000L-SO0006 Controller Interface Board local indication and diagnostic outputs have different functions than the standard AEI1000L modules:



4.8.1 DIP Switch Settings

4.8.1.1 Over-volts Trip Mode (SW1 to SW4)

- The overvoltage thresholds and delays are configured by **SW1** to **SW4**.
- The following table defines the operation of these switches:

SWITCH SETTINGS				DC Link Voltage Trip Instant	DC Link Voltage Trip Delayed	Delay Time	Notes
SW1	**SW2**	**SW3**	**SW4**				
OFF	OFF	OFF	OFF	1188 Vdc	None	N/A	Legacy behavior for non-renewable energy systems
OFF	OFF	OFF	ON	1262 Vdc	1188 Vdc	0.5s	Units configured in one of these modes are used in position 1 of the system. ***Default is 1s delay.***
OFF	OFF	ON	OFF			1.0s	
OFF	OFF	ON	ON			1.5s	
OFF	ON	OFF	OFF			2.0s	
OFF	ON	OFF	ON			2.5s	
OFF	ON	ON	OFF			3.0s	
OFF	ON	ON	ON			3.5s	
ON	OFF	OFF	OFF			4.0s	
ON	OFF	OFF	ON			4.5s	
ON	OFF	ON	OFF			5.0s	
ON	OFF	ON	ON			5.5s	
ON	ON	OFF	OFF			6.0s	
ON	ON	OFF	ON			6.5s	
ON	ON	ON	OFF			7.5s	
ON	ON	ON	ON	1290 Vdc	None	N/A	This mode may be used in positions 2 to 6 of a parallel inverter system.

4.8.1.2 RX3 Polarity (SW5)

- SW5 controls the polarity of the RX3 input when it is selected as an ENABLE input:

SW5 (RX3 Polarity)	RX3 Polarity
OFF (Default)	RX3 must be driven low to ENABLE RX3 driven high or left unconnected is DISABLE
ON	RX3 must be driven low to DISABLE RX3 driven high or left unconnected is ENABLE

- See section 0 for complete details.

4.8.1.3 Unused Switches (SW6 to SW12)

- These switches are not used on the AEI1000L-SO0006. They should be left in the OFF position.

4.8.1.4 RS485 DIP Switches (Adjacent to TB6)

- RS485 SW1, SW2 & SW3 set the Modbus Node Address as follows:

SWITCH SETTINGS			MODBUS NODE ADDRESS	Notes
SW1 (RS485)	**SW2 (RS485)**	**SW3 (RS485)**		
OFF	OFF	OFF	1	As can be seen, the MODBUS node address is: ***1 + SW[]*** ***The default is OFF-OFF-OFF:*** Node Address = 1
OFF	OFF	ON	2	
OFF	ON	OFF	3	
OFF	ON	ON	4	
ON	OFF	OFF	5	
ON	OFF	ON	6	
ON	ON	OFF	7	
ON	ON	ON	8	

- RS485 SW4 is not used on the AEI1000L-SO0006 and should be left in the OFF position.

4.8.2 Analog Outputs

Analog Channel	Signal	Scaling, Range etc.
A	Current Reference	-10V to +10V equivalent to -100.00% to +100.00%
B	U-Phase Current	-10 V to + 10 V equivalent to +/- 2000 A
C	V-Phase Current	
D	W-Phase Current	

4.8.3 LED Indication

4.8.3.1 Discrete LEDs

- The RED and GREEN LEDs combine to indicate the status of the AEI1000L-SO0006, as defined here:

● - OFF ● - ON ✹ - FLASHING

RED LED	GREEN LED	Meaning
●	●	Auxiliary supply is not present
●	✹	Internal error present on C.I.B. or auxiliary supply is out of tolerance
●	●	Unit healthy (not tripped) and disabled (IGBT's not switching)
●	✹	Unit healthy (not tripped) and at least one phase enabled (IGBT's switching)
✹	●	Unit faulted. Fault codes will be displayed on 2-digit display. Fault bits can be read via Modbus.

- The YELLOW LED indicates the state of the RS485 Modbus link:

● - OFF

- No activity is detected on the RS485 data lines.

✹ - FLASHING

- Activity is detected on the RS485 data lines, but no valid Modbus messages to this Modbus Node Address are being received.

● - SOLID ON

- Valid messages to this Modbus Node Address are being received and responded to.

4.8.3.2 Two-Digit Display

- When the unit is not tripped, this will display the peak rectified output current: MAXIMUM (|Iu|, |Iv|, |Iw|). This will be scaled as a percentage of 1000A.
- Note that 1000A is the maximum demand value for current, but due to normal closed-loop operation, the actual current can exceed this. To represent this, the most-significant digit of the LED display uses a hexadecimal convention. Examples:

  00 to 99 = 00% to 99% of 1000A = 0 A to 990 A
  A0 to A9= 100% to 109% of 1000A = 1000A to 1090 A
  B0 to B9= 110% to 119% of 1000A = 1100A to 1190 A

- When the unit is tripped, this will cycle through all active trip bits (00 = FEEDBACK_ TRIPS_0 [0] to 31 = FEEDBACK_ TRIPS_1 [15]) – see section 4.9 for more details.

4.8.4 Solid-State Relays

4.8.4.1 Solid-State Relay A

- Module fault indication
- Relay energized indicates no fault condition.
- Relay de-energized indicates a fault condition.

4.8.4.2 Solid-State Relay B

- Module enabled.
- Relay energized indicates the module is enabled and controlling current.
- Relay de-energized indicates the module is disabled.

4.8.4.3 Solid-State Relays – Electrical Specification

- Maximum operating voltage is 60Vdc / 40Vac (rms)
- Maximum load current is 0.4 A.
- Typical ON resistance is 0.5 Ω.
- NOT overload (short-circuit) or overvoltage protected.
- For reference, on-board devices are ***Panasonic AVQ202A*** or ***AVQ252GA*** solid-state relay.

4.9 Trips

- If the unit trips, the bit fields ***FEEDBACK_ TRIPS_0*** (trip bits 0 to 15) and ***FEEDBACK_ TRIPS_1*** (trip bits 16 to 31) will indicate which trips have occurred.
- All trip bits are latched and require a RESET command. There is an automatic reset at start-up that occurs 2s after the FPGA configures.
- The following table lists and explains the possible trips:

Trip Bit	Explanation
0	Default Storage CRC Fail • The internal storage for ID & SETUP defaults has become corrupted. • This trip cannot be reset. • Contact Avid Controls for support.
1	User Setup Storage CRC Fail • The storage of user save SETUP registers has become corrupted. • Default values have been restored. • The user must re-load and re-save the SETUP values.
2	Modbus Timeout • The AEI1000L-SO0006 has not received a valid Modbus message (node address, function, data, CRC all valid) within the timeout period.
3	Reference Loss • The ***Current Reference*** was set to be FM from RX1, and the input frequency has fallen below the minimum value **OR** ***Current Reference*** was via MODBUS and MODBUS has timed out.
4	Storage Volts Loss • The ***Storage Volts*** input was set to be FM from RX4, and the input frequency has fallen below the minimum value **OR** ***Storage Volts*** was via MODBUS and MODBUS has timed out.
5, 6, 7	Instantaneous Over-Current U-Phase, V-Phase, W-Phase • The instantaneous current in the respective phase has exceeded 2000A, either positive or negative **OR** the SKiiP module has indicated a fault.
8	Current Control Fail • At least one enabled phase's current error has exceeded 10% of I_100 for more than 100ms. • This generally indicates a connection problem between the unit and the storage element, or that the output is voltage limited.

Trip Bit	Explanation
9	DC Link Over-Volts • The DC link voltage and duration have exceeded the specified limits.
10	Timed Overcurrent • If the value of the maximum phase current exceeds 500A, an Excess-Amps-Seconds integrator will evaluate the overload, such that at 1000A the unit will trip in 300s seconds. • Mathematically, this can be stated as: $\int [MAX(\lvert Iu\rvert,\lvert Iv\rvert,\lvert Iw\rvert) - 500A].dt > 150{,}000$ A-s
11, 12, 13	Over-Temperature U-Phase, V-Phase, W-Phase • The temperature of the respective IGBT module has exceeded the recommended maximum level. • If coolant temperature and flow rates are maintained as specified, this trip should not occur.
14	Fan Fail • The internal capacitor cooling fans have failed. • If an APU-G is used to power the AE1000L-SO0006, the fans will not run until the DC link is energized. This trip will need to be reset when the DC link is energized.
15	PWM Sync. Loss • A PWM slave unit cannot synchronize to the signal on RX2
16	Internal Fault • A fault has been detected with the hardware
17, 18, 19	SKiiP Fault U-Phase, V-Phase, W-Phase • The SKiiP module has indicated a fault condition
20	Electronics Overtemperature • The CIB temperature sensor exceeds 65C
21 to 31	Reserved • These trips bits will never be active.

5. Specification

5.1 Electrical – Power Section

Specification	AEI1000L SO0006	Notes & Applicable Conditions
DC Current Peak, per channel	1000A	5 minutes maximum duration (long term rms current as specified below) DC Link Voltage less than or equal to = 1100V Coolant Temp. = 60°C PWM Frequency = 2.5kHz
Long Term Current RMS, per channel	500A	Total RMS current, per phase, including ripple current
Recommended peak current (crest of ripple current at maximum DC current)	1500A	
Instantaneous Overcurrent Trip Level, per channel	2000A	
Continuous DC Link Operating Voltage	1188V	
Short Term (< 7.5s) DC Link Operating Voltage	1262V	
Non-Operating DC Link Withstand Voltage	1350V	
PWM Frequency	2.5kHz	
DC Link Capacitance	11600 µF	+20/-10 %

5.2 Electrical – Control & Interface Section

Specification	AEI1000L SO0006	Notes
Control Power Source	Avid Auxiliary Power Unit (APU) Model Numbers: AEI-APU-D AEI-APU-E AEI-APU-F	Customers wishing to provide their own auxiliary power **MUST** contact Avid Controls for further information. See Avid Data Sheet DTS-MID0124 for complete data.
Analog Outputs	4 Channels +/-10V	Optional indication for phase currents and DC link voltage. See section 0 for more details
Trip Indication	• Two-digit LED display for visual diagnostics. • Modbus registers to identify all active trips. • Two 24V Solid-State relay outputs for indication of fault status.	See section 4.9 for more details.
Operational Indication	Two-digit LED display for display of current	See section 4.8.3 for details.
MODBUS RS485	Two wire RS485 fully isolated MODBUS RTU Protocol	See section 4.6 for more details.
DC Link Voltage Feedback Accuracy	+/- 4V @ 1000V DC	Measured internally within inverter unit
Digital Control I/O	1 x 2-wire RS485 Link 5 x 2-wire RS422 Inputs 2 x 2-wire RS422 Ouput	Connected via Interface Board to 4 x RJ45 4-pair (CAT-5E STP cables should be used) See section 4.1for details.
Frequency Modulated Input	Via RX1 or RX4 Dedicated functions	Frequency Range 10kHz to 500kHz Duty Cycle 45% to 55%
PWM Synchronizing	Via RS422 TX2 & RX2	Output Frequency (TX2) = 2.5 kHz +/- 2.5 Hz Output Duty Cycle (TX2) = 49.5 % to 50.5 % Input Frequency (RX2) = 2.45 kHz to 2.55 kHz Input Duty Cycle (RX2) = 45% to 55%

5.3 Cooling

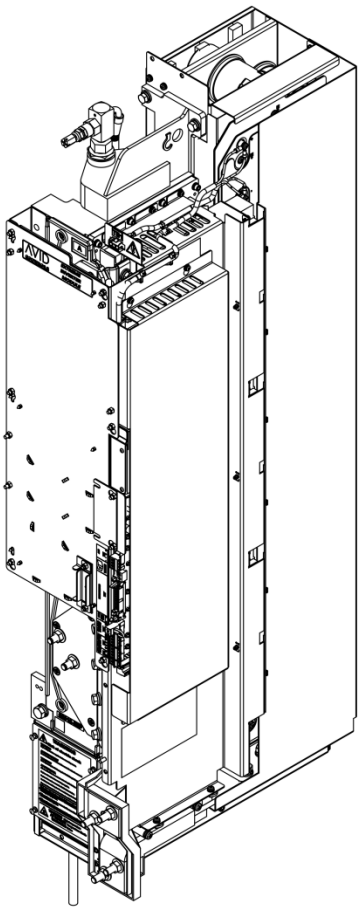
Specification	***Value***
Coolant Type	Water / Ethylene Glycol Maximum 50% Ethylene Glycol With suitable corrosion inhibitors
Minimum Coolant Flow	25 liters/min (6.6 US-GPM)
Maximum Coolant Inlet Pressure	300kPa (45psi)
Maximum Coolant Inlet Temperature	60°C
Minimum Coolant Inlet Temperature	0°C
Coolant Strainer	Coolant must be strained to remove particles. Maximum recommended strainer mesh is 0.7mm (0.028”) Inspect and clean strainer every six months
Coolant Lifetime	Check coolant constituent concentration every six months. Remove coolant, flush system with de-ionized water and refill with new coolant every 24 months.
Coolant Connection Options	• 1x hose-barb top, 1x hose-barb bottom (Option A) • 2x hose-barb at bottom of unit (Option B) • 2x Quick-Disconnect at bottom of unit (Option C)
Maximum heat load to coolant	• 9.1 kW

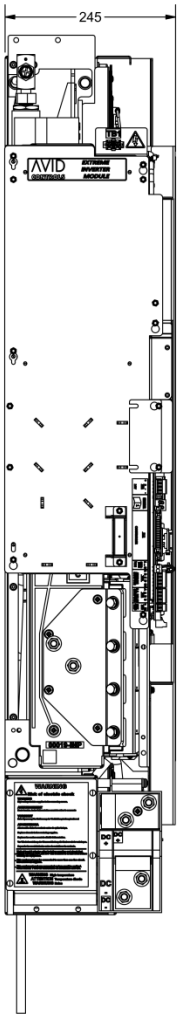
5.4 Environmental

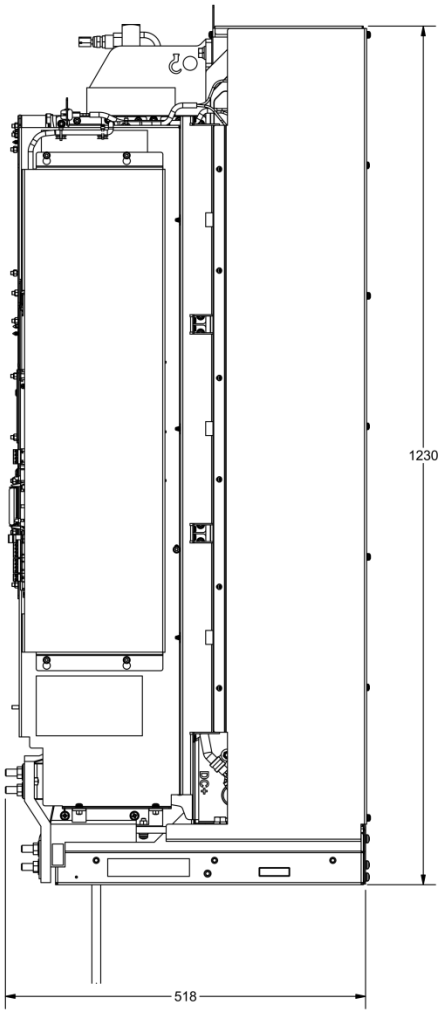
Specification	***Value***
Ambient Temperature (Internal cabinet temperature)	0 to 50°C
Cabinet air	Pollution Degree 2 as per IEC60664-1, UL 840 & CSA C22.2 No. 0.2-93 i.e. clean, free from dust, condensation and conductive or corrosive gases. Maximum chemicals 15ppm H_2S, 25ppm NO_2, 25ppm SO_2
Humidity	5% to 95% RH Unit must not be operated in the presence of condensation.

5.5 Mechanical

Specification	***Value***
Dimensions	248mm W x 1232mm H x 546mm D (9.75” W x 48.5” H x 21.5” D)
Enclosure	IP00 (IEC 60529:1989; BS EN 60529:1992) NEMA 1 Must always be installed within suitable enclosure with restricted access
Mass	105kg (231 lb.)







6. Document Revision History

Rev.	Date	Author	Changes
00	Provisional	Gary Pace	Document created
01	June 21 2021	Gary Pace	Ongoing refinement, HIL system described
02	August 16 2021	Gary Pace	Interface Module defined
03	September 2 2021	Gary Pace	Appendix A (HIL Description) Removed
04	December 8 2021	Gary Pace	Changes for FPGA VERSION 04: • ***RX3 required for enable*** bit parameter sense reversed. This means RX3 is required by default. • SW5 controls the polarity of RX3 when used for enable input. • With SW5 in OFF position, RX3 polarity is different
05	April 4 2022	Gary Pace	Changes for FPGA VERSION 06: • Deadband function added to current reference • Individual phase scale factors added to current reference • Raw value of RX1 frequency, in Hz, added to feedbacks • Correction to jumper-link tables in section 4.2
06	May 9 2022	Gary Pace	Changes for FPGA VERSION 08: • RX3 is de-glitched (1ms) before using for ENABLE function • Bit 2 of SETUP_BITS is correctly described in section 4.6.3 • Registers 22 & 23 used as current demand limits • Registers 53 to 55 used as phase current demand feedbacks