SENSITRON
SEMICONDUCTOR

TECHNICAL DATA
DATASHEET 6041, Rev -

DC Solid State Power Controller Module

Description:

This SPDP100D375 is a Solid State Power Controller (SSPC) Module; the electronic equivalent to an electromechanical circuit breaker with isolated control and status. It is designed to operate with minimal heatsink requirements. It is a microcontroller-based solid state relay rated up to 100A, designed to be used in high reliability 375V DC applications. These modules have integrated current sensing with no derating over the full operating temperature range.

This product is programmable with a simple jumper configuration connector in steps as 60A / 80A / 100A. The product series also allows programming the Instant Trip level at three different levels: 95A, 128A and 161A. The Battle Override, that allows the protection to be turned off, is a standard option.

Compliant Documents & Standards:

MIL-STD-704F Aircraft Electrical Power Characteristics, 12 March 2004
MIL-STD-217F, Notice 2 Reliability Prediction of Electronic Equipment, 28 Feb 1995

Module Features:

- Minimal heat sinking or external cooling required
- Extremely Low Power Loss, No Derating Over the Full Temperature Range
- IMS Base Plate construction
- Solid State Reliability
- High Power Density
- Silver plated contacts for buss bars
- Gold over nickel plated base plate
- Sub D connector shell is steel with 30u" gold plated socket contacts

Electrical Features:

- 375VDC Input with Very Low Voltage Drop; 330mV, typ. @ 100A, 25^0C
- True I^2t Protection with Nuisance Trip Suppression
- I^2t Protection level externally programmable
- Instant Trip Protection level externally programmable
- Reports Loss of Line Voltage
- Reports Over Temperature condition and turns off during this condition
- Output Leakage Sink for safe output voltage when SPDP100D375 turned off
- No trip operation up to 300µF (typ) of output capacitance
- Instant Trip Protection (40 µsec typ) for Loads Above programmed Instant Trip level
- Unlimited Interrupt Capability; Repetitive Fault Handling Capability
- Thermal Memory
- Internally Generated Isolated Supply to Drive the Switch
- Low Bias Supply Current: 75 mA typical @ 5V DC
- High Control Circuit Isolation: 750V DC Control to Power Circuit
- Soft Turn-On to Reduce EMC Issues
- EMI Tolerant
- Module Reset with a Low Level Signal; Reset Circuit is Trip-Free
- TTL/CMOS Compatible, Optically Isolated, Input and Outputs
- Schmitt-Trigger Control Input for Noise Immunity

Table 1 - Electrical Characteristics (at 25 °C and Vbias = 5.0V DC unless otherwise specified)

Control & Status (TTL/CMOS Compatible)	
BIAS (Vcc)	5.0V DC Nominal, 7.0V DC Absolute Maximum 4.5V to 5.5 VDC
BIAS (Vcc) Current	75 mA typ 125 mA max
S1 and S2 Status Signals	V_{oh}=3.7V, min, at I_{oh}=-20mA V_{ol}=0.4V, max, at I_{ol}=20mA
CONTROL and Battle Short Signals V_{T+} (Positive-going input threshold voltage) V_{T-} (Negative-going input threshold voltage) ΔV_T Hysteresis (V_{T+} V_{T-})	 2.0V, min, 3.5V, max 1.2V, min, 2.3V, max 0.6V, min, 1.7V, max
Reset	Cycle CONTROL Signal

Power	
Input Voltage – Continuous – Transient	0 to 425V DC, 500V DC Absolute Maximum +600V or –600V Spike ($\le$ 10 uS)
Power Dissipation	See Table 4
Current	See Table 4 See Figures 1 - 3, Trip Curves
Max Voltage Drop	See Table 4
Trip Level	>110% of rating

Trip time	See Figures 1 - 3, Trip Curves
Output Rise Time (turn ON)	700 usec typ
Output Fall Time under normal turn-off	250 usec typ
Output Fall Time under Fault	50 usec typ
Min Load Requirement	0A

Protection	
Short Circuit Protection	600 A
Instant Trip	95A, 128A and 161A programmable

Table 2 - Physical Characteristics

Temperature	
Operating Temperature	T_A = -40 °C to +100 °C
Storage Temperature	T_A = -55 °C to +125 °C

Environmental	
Altitude	Up to 30,000 ft Can be installed in an unpressurized area
Case Dimensions	4.96” x 2.60” x 2.04”
Operating Orientation	Any
Weight	650 g
MTBF (Estimate: MIL STD 217F)	200 Khrs at 25°C Full load

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I^2T Trip Curves

The SPDP100D375 is an electronic circuit breaker that will disconnect, trip, when an overcurrent is detected. Very high overload currents will trip the breaker immediately but moderate overload currents, $I_{overload}$, will trip after a time, T_{Trip} that is inversely proportional to the square of the overload current. This is called the I^2T algorithm because it basically adheres to the equation where the product of trip time and squared overload current is kept constant:

$$I_{overload}^2 \times T_{Trip} = CONSTANT$$

The trip curves shown in Figure 1, Figure 2, and Figure 3, plot the time to trip versus the applied overload current for several programming configurations. The two curves on each plot show the error band of the expected trip times. Overload currents that endure for a time that puts it above and to the right of the upper trip curve, in the ALWAYS TRIP region, will always cause a trip to occur. Low, transient overload currents that fit in below and to the left of the lower trip curve, in the NEVER TRIP region, are guaranteed not to trip the SPDP100D375.

For example, a unit programmed for 80A rating and 128A instant trip, has a trip curve as shown in Figure 2. If the unit is turned on into a 180% load (144A), the unit may trip instantly but will certainly trip if this overload endures from 0.3 seconds to 2 seconds. If the overload comes and goes earlier than the trip time, the unit will not trip. If the overload continues, the unit will trip and the trip time will be between 0.3 seconds and 2 seconds. Instant trip, for this configuration, will occur somewhere above 141% (113A) but certainly at no higher than 179% (143A). Applied overload currents that are above the instant trip level are acted upon immediately and do not adhere to the I^2T algorithm.

Figure 1 - Trip Curve (Unit programmed for 100A Rating, 161A instant trip)

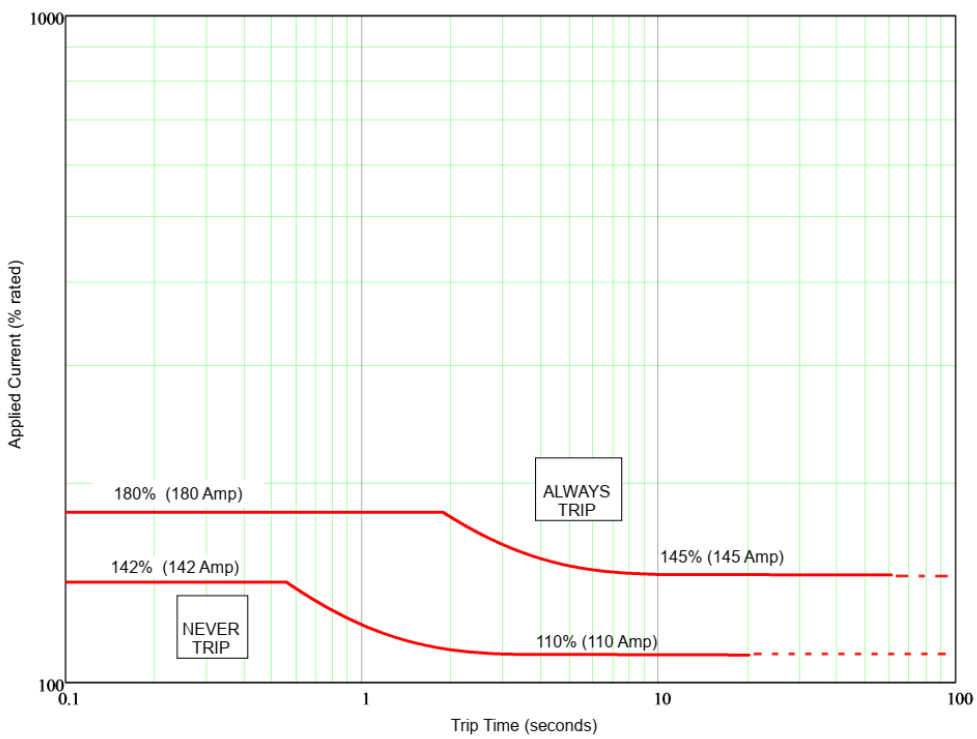

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Figure 2 - Trip Curve (Unit programmed for 80A Rating, 128A instant trip)

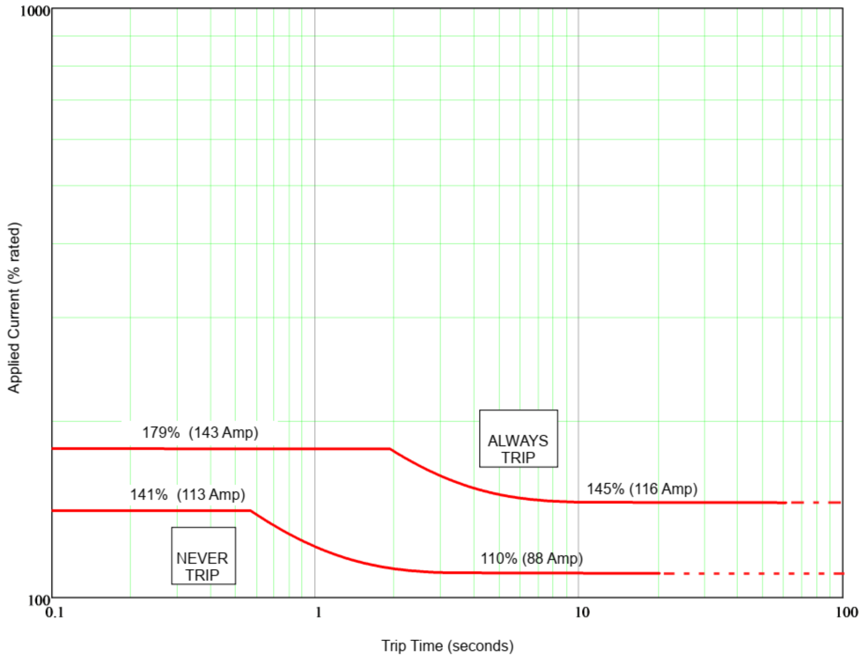

Figure 3 - Trip Curve (Unit programmed for 60A Rating, 95A instant trip)

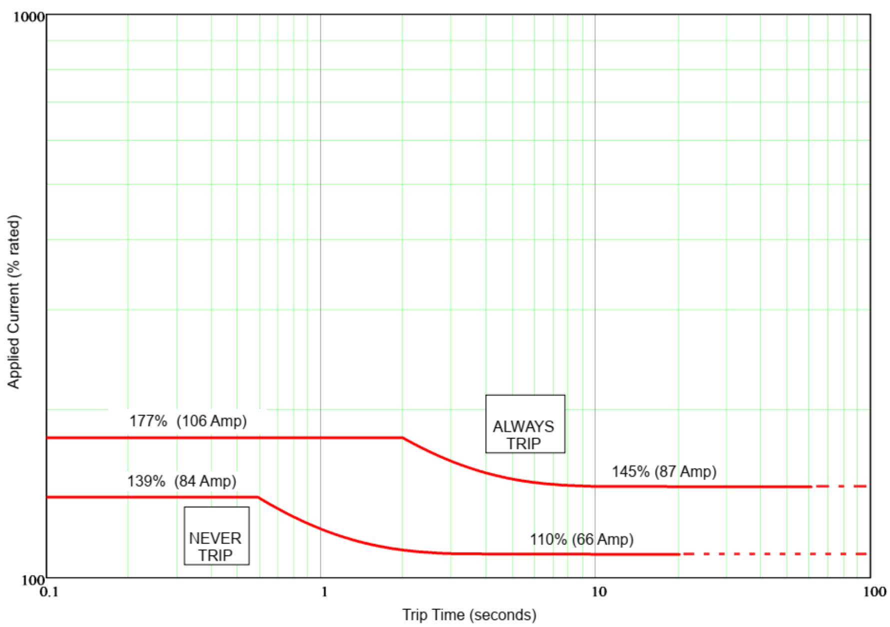

Table 3 - Signal Timing – (-40°C to 100°C @ LINE = 375V DC)

Parameter	Symbol	Min (μs)	Max (μs)
Turn ON Delay	tON	340	1560
LOAD Rise Time	tRISE	370	1000
Turn OFF Delay	tOFF	200	1250
LOAD Fall Time	tFALL	200	450

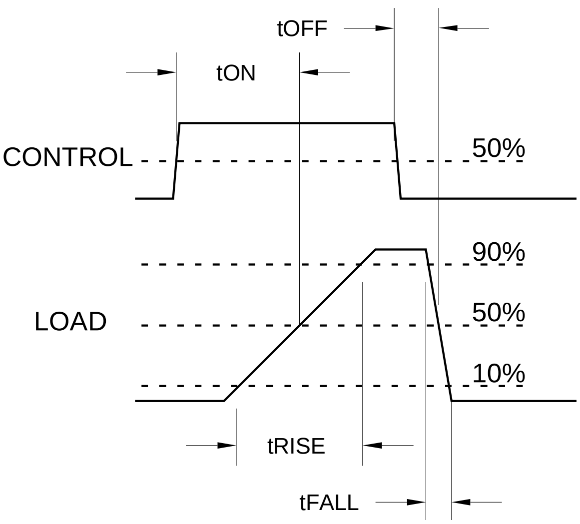

Figure 4 - Mechanical Dimensions and Pin Assignments (All dimensions are in inches)

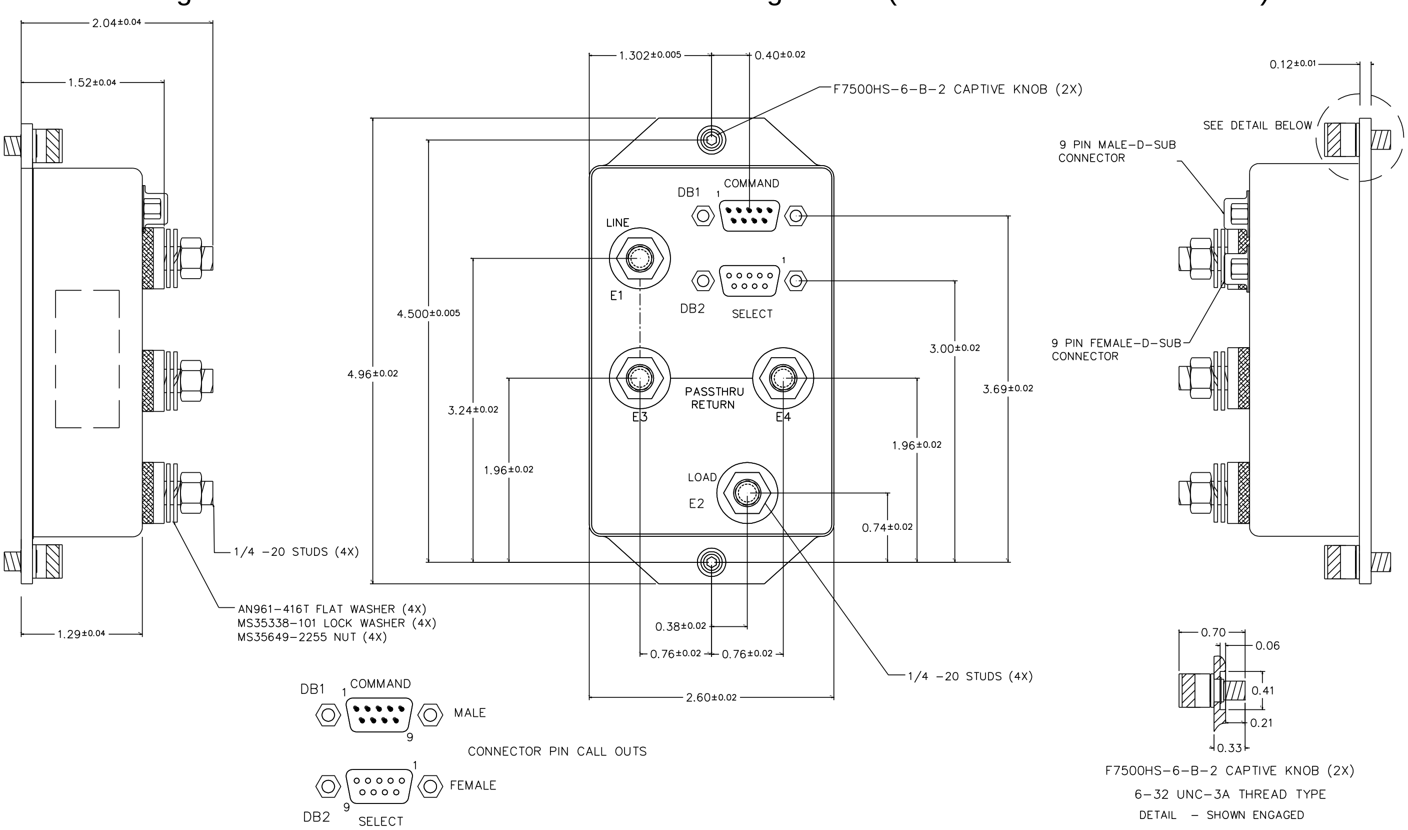

Table 4 – Individual Power Dissipation Data (includes Vbias Power)

	SPDP100D375 Set for 60 Amp Rating	SPDP100D375 Set for 80 Amp Rating	SPDP100D375 Set for 100 Amp Rating
Current Rating @ 100^{O}C	60A	80A	100A
Power Dissipation	5W typ @ 36A 25^{O}C 12W max @ 60A 25^{O}C 20W max @ 60A 100^{O}C	8W typ @ 48A 25^{O}C 21W max @ 80A 25^{O}C 36W max @ 80A 100^{O}C	12W typ @ 60A 25^{O}C 33W max @ 100A 25^{O}C 56W max @ 100A 100^{O}C
Max Voltage Drop	120mV typ @ 36A 25^{O}C 198mV max @ 60A 25^{O}C 336mV max @ 60A 100^{O}C	160mV typ @ 48A 25^{O}C 265mV max @ 80A 25^{O}C 450mV max @ 80A 100^{O}C	198mV typ @ 60A 25^{O}C 331mV max @ 100A 25^{O}C 561mV max @ 100A 100^{O}C

Table 5 – PIN-OUT Information

Connector Pin	DB1 (COMMAND)	DB2 (SELECT)	Power (E1 – E4)
1	BATTLE SHORT	60A (Current Rating)	E1- Line
2	S2 STATUS	PROG RET	E2- Load
3	S1 STATUS	80A (Current Rating)	E3- PASSTHRU Return
4	CONTROL	PROG RET	E4- PASSTHRU Return
5	+5V BIAS	NC (NO CONNECTION)	
6	PWR RTN	95A (Instant TRIP)	
7	NC (NO CONNECTION)	PROG RET	
8	BIAS RTN	128A (Instant TRIP)	
9	TEMPERATURE	PROG RET	

Programming Connector DB2

The SPDP100D375 must be programmed before use to one of three current ratings and to one of three instant trip levels. The programming is accomplished by shorting pins of the DB2 connector together. Table 6 and Table 7 list these connections and resulting setting.

For example, to have an 80 A current rating and a 95 A instant trip level, short DB2 pin 3 to DB2 pin 4, and short DB2 pin 6 to DB2 pin 7. Leave all other pins open.

Table 6: Programming I2T Current Rating

DB2 Pin 1 Connection	DB2 Pin 3 Connection	Current Rating
-open -	-open-	100A
-open-	DB2 Pin 4	80A
DB2 Pin 2	-open-	60A

Table 7: Programming Instant Trip Current Level

DB2 Pin 6 Connection	DB2 Pin 8 Connection	Instant Trip Level
-open -	-open-	161A
-open -	DB2 Pin 9	128A
DB2 Pin 7	-open-	95A

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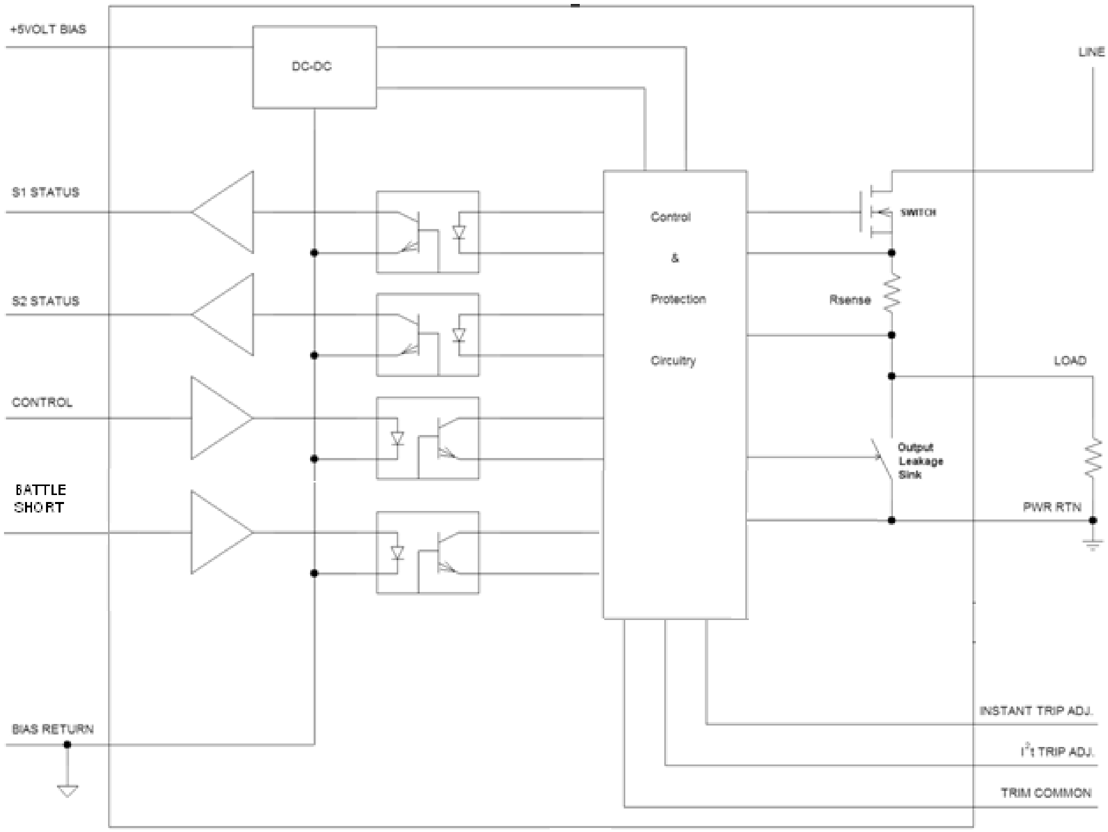
Figure 5 - Electrical Block Diagram



Description

Figure 5 shows the block diagram of the SPDP100D375. It uses a NL27WZ14 device for digital I/O. This TTL compatible device has a Schmitt-Trigger input to minimize the effects of noise on the input. Its outputs can each drive more than 10 standard TTL loads. It's also compatible with CMOS inputs and outputs. The NL27WZ14 is isolated from the remainder of the module circuitry by three optocouplers.

The block labeled "Control & Protection Circuitry" gets power from the DC-DC converter and is referenced to the output of the SSPC. This block contains an amplifier to gain up the voltage developed across the sense resistor. It also contains a microcontroller with on-board timers, A/D converter, clock generator and independent watchdog timer. The microcontroller implements a precision I^2t protection curve as well as an Instant Trip function to protect the wiring and to protect itself. It performs all of the functions of multiple analog comparators and discrete logic in one high-reliability component.

The code programmed in the microcontroller acquires the output of the internal A/D converter, squares the result and applies it to a simulated RC circuit. It checks the output of the simulated circuit to determine whether or not to trip (turn off the power Mosfets). Because the microcontroller simulates an analog RC circuit, the SSPC has 'thermal memory'. That is, it trips faster if there had been current flowing prior to the overload than if there hadn't been current flowing. This behavior imitates thermal circuit breakers and better protects the application's wiring since the wiring cannot take as much an overload if current had been flowing prior to the overload.

The watchdog timer operates from its own internal clock so a failure of the main clock will not stop the watchdog timer. The code programmed in the microcontroller will periodically reset the watchdog timer preventing it from timing out. If the code malfunctions for any reason, the watchdog timer is not reset and it times out. When the watchdog timer times out, it resets the microcontroller. Since the code is designed to detect levels and not edges, the output of the module, and therefore the output of the SPDP100D375, immediately reflects the command on its input.

The "Control & Protection Circuitry" block also has the ability for the user to adjust the current rating by adding appropriate jumpers at the DB2 connector. When setting the current rating, select a configuration that is at least 15% above the full load rating. Example: if the max load is 66A, the product should be configured to 80A.

The Power Mosfets used in the SPDP100D375 Series have been selected for very low $R_{ds(on)}$ and result in low voltage drop and low power dissipation. In most applications, the SPDP100D375 will be operated at 50 – 80% of rated current to provide a safety margin. As can be seen in Table 4, when the SPDP100D375 is operated at 60 Amps, 60% of rated current, about 12W is dissipated by the device. Minimal heat sinking is required for operation at room temperature. However, if the SPDP100D375 is to be operated at maximum rating and/or at elevated temperatures, the dissipation warrants heatsinking. Mounting the product on a plate with some airflow is usually sufficient.

The product has a baseplate temperature sensor that is calibrated for 10mV / ^{0}C.

$$Vsensor = Tbaseplate * 10mV/°C + 500mV$$

This sensor operates from the 5V Bias supply. This sensor can be used by customer to determine heatsink size and other cooling, if necessary. Another identical temperature is used to measure and trip the switch in case of over temperature. An independent sensor is used to avoid grounding issues.

For temporary overloads, no additional heatsinking is required provided the SPDP100D375 is allowed some time to cool down. The SPDP100D375 has sufficient thermal mass that the temperature will rise only a few degrees under the worst-case overload. Repetitive overloads should be avoided. When the SPDP100D375 reports a trip condition, the controller driving the SPDP100D375 should allow no more than four repetitions and then allow thirty seconds to cool down before trying to turn on again.

The SPDP100D375 will trip on overloads in the ALWAYS TRIP region of the trip curves shown in Figure 1, Figure 2, and Figure 3. and will never trip when in the NEVER TRIP region. The SPDP100D375 can be reset by bringing the CONTROL pin to a logic low. When the "CONTROL" pin is brought back to logic high, the SPDP100D375 will turn back on. If the overload is still present, the SPDP100D375 will trip again. Cycling the "5 Volt BIAS" power will also reset the SPDP100D375. If the "CONTROL" pin is at logic high when the "5 Volt BIAS" power is cycled, the SPDP100D375 will turn back on when the "5 Volt BIAS" power is re-applied.

Battle Short input allows the customer to override the TRIP function keeping the device turned on exceeding current limitations. Assertion of Battle Short command while the Control is High is interpreted as valid Battle Short command. In this case, the Output will be turned ON and TRIP detection disabled. This mode shall only be used when absolutely necessary since this overrides all the protection features (I2t, Instant Trip, Over temperature) and may allow the product to fail, if any faults were to occur. As the Battle Short input floats high, it must be connected to the BIAS return voltage to prevent override of the protection features.

Status Outputs

The "S1" and "S2" status outputs of the SPDP100D375 show whether or not there is an over temperature condition and whether or not the line voltage is present. When an unsafe temperature condition is present, the "S1" status goes to a logic high state and the output of the SPDP100D375 is turned off. When the temperature drops about 15 ^{o}C to a safe condition, the "S1" status output goes back low and the output of the SPDP100D375 is turned back on. Both "S1" and "S2" status outputs go to a high level when line voltage drops below 5 volts.
Table 6 shows the states of the "S1" and "S2" status outputs.

Table 8 – Control and Status

	COMMAND	CONTROL INPUT	STATUS S2	STATUS S1	OUTPUT	SSPC STATUS
1	OFF	0	0	0	OFF	Normal Off
2	OFF	0	0	1	OFF	Over Temp
3	OFF	0	1	0	ON	SSPC Fail
4	OFF	0	1	1	OFF	No Line Voltage
5	ON	1	0	0	ON	Normal On
6	ON	1	0	1	OFF	Over Temp
7	ON	1	1	0	OFF	Tripped
8	ON	1	1	1	OFF	SSPC Failure

High Voltage Considerations

The SPDP100D375 series is designed for 375VDC systems. The SPDP100D375 contains an Output Leakage Sink to ensure that the output is at a safe voltage when the SPDP100D375 is off (whether the SPDP100D375 is turned off or is off due to loss of 5V BIAS Power). This circuitry absorbs the leakage current from the main switch and keeps the output voltage less than 1.5VDC over the temperature range. Figure 5 shows the Output Leakage Sink as a simple switch. However, the Output Leakage Sink is a transistor operating as a current source with a value of 83 mA. When the current into the output leakage sink is less than 83 mA, the transistor saturates and the output leakage sink looks like a resistor of about 36 Ohms. 83 mA can be used to determine how long it takes to discharge a particular load capacitance if the load is a pure capacitance. If the load is a combination of resistance and capacitance, it's likely that the RC time constant will discharge the capacitance faster than the output leakage sink.

Sufficient spacing should be allowed for on the user's PCB between the 375VDC line supply and the 375VDC power return and between the CONTROL and 5VDC Bias circuits and the 375VDC circuit to prevent arcing. Due to the small size of the SPDP100D375 series, the spacing between pins is small so conformal coating should be used to prevent arcing, especially if transient voltages above 375VDC are possible.

Conductor Size

MIL-W-5088L has a chart that shows wire size as a function of wire temperature and current. This chart is for a single copper wire in free air. For an ambient temperature of 70 ^{o}C, the chart allows a 24-gauge wire to handle 10 Amps continuously at a wire temperature of 200^{o}C – a wire temperature rise of 130^{o}C. For a wire temperature limited to 150^{o}C, the chart requires a 22-gauge wire and for a wire temperature of 105^{o}C, the chart requires a 20-gauge wire.

Amendment 1 of MIL-W-5088L has a table for copper wire in a bundle, group or harness with condition on the number of wires, percent of total harness capacity, etc. This table shows that an 18 gauge wire is necessary for 200^{o}C operation, 16-gauge for 150^{o}C and 14-gauge for 105^{o}C. MIL-W-5088L has various figures showing derating for harnesses as a function of the number of current carrying conductors for different altitudes. MIL-W-5088L only specifies wire for DC or RMS AC conditions, not for transient or overload conditions. MIL-W-5088L and its amendment should be consulted to determine minimum wire sizes for other currents and conditions.

For transient or overload conditions, the transient or overload happens so quickly that heat is not transferred from the wire to the surroundings. The heat caused by the I^2R heating of the wire causes the temperature to rise at a linear rate controlled by the heat capacity of the wire. The equation for this linear rise in temperature, with respect to time, can be solved as: I^2t = constant. Every wire has an I^2t rating that's dependent on the temperature rise allowed and the diameter of the wire. If the I^2t rating of the SSPC or circuit breaker is less than the I^2t rating of the wire, then the SSPC or circuit breaker can protect the wire. Using the trip curve in Figure 1, the maximum Instant Trip level is at 375% and it intersects the I^2t curve at 300mS. So, the maximum I^2t rating for the 100 Amp SSPC would be: $(3.75*50)^2 * 0.3 = 10.55 \times 10^3$ Amp^2-Seconds. Every wire size in the paragraphs above has an I^2t rating that exceeds the SPDP100D375 I^2t rating for the temperature rises stated. Therefore, to select a wire size, it's simply a matter of determining the maximum temperature rise of the application and deciding whether or not the wire will be in a bundle and use the information above.

Application Connections

Due to the presence of the circuitry that keeps the output at safe voltage when the SPDP100D375 is off, the SPDP100D375 may only be configured as a high-side switch as shown in Figure 5.

Rise Time & Fall Time

The rise and fall times of the SPDP100D375 are pre-set at the factory for a nominal 700uS rise time and 250µS fall time with a LINE supply of 375VDC (see Table 3 for min/max limits). The rise and fall times will vary linearly with supply voltage. The “PWR RTN” pin is used to control the rise and fall times. If the “PWR RTN” pin is left open, the rise and fall times will be less than 50uS. Leaving the “PWR RTN” pin open can be useful when a faster rise or fall time is desirable; however, the Output Leakage Sink will not be functional with the “PWR RTN” pin open.

With the “PWR RTN” pin connected as in Figure 5, the SPDP100D375 can turn on into a capacitive load without tripping for any power supply voltage within the ratings. The capacitive load capability is proportional to the programmed instant trip level as shown in Table 9.

Table 9 - Capacitive Load Capability

Instant Trip Level	Capacitive Load Capability (typical)
161A	300uF
128A	240uF
95A	170uF

Wiring and Load Inductance

Wiring inductance can cause voltage transients when the SPDP100D375 is switched off due to an overload. Generally, these transients are small but must be considered when long wires are used on either the “LINE” or “LOAD” pins or both. If longer wire lengths are used, a transient suppressor may be used at the “LINE” pin so that the total voltage between the “LINE” and “LOAD” pins is less than 500 Volts. The SPDP100D375 series includes a reverse biased diode from the “LOAD” to “PWR RTN” pins to prevent damaging transients on the output due to inductive loads.

Paralleling

Do not parallel different models of this series as the current sharing will not be predictable. For example, putting two SPDP100D375s in parallel will not double the rating to 100 Amps. Due to differences in the $R_{ds(on)}$ of the Power Mosfets in the SSPCs, the current will not share equally. In addition, there are unit-to-unit differences in the trip curves so that two SPDP100D375s in parallel may possibly trip at 140 Amps. Also, both SPDP100D375s will not trip together; the SPDP100D375 carrying the higher current will trip first followed by the other SPDP100D375. Multiple SPDP100D375s may be used in parallel as long as these complexities are appreciated.

Connectors

Busbars are typically used to make the power connections. The product has 2 terminals for input and 2 for output. This RETURN bus bar connections are shorted together inside the module using a copper strap. This configuration allows the customer to run the bus in parallel on both the input and output sections.

The 9-pin D-Sub connector DSUB1 is used for control; we recommend using a standard cable of no more than 3 ft. This will ensure that the noise and other interference are kept to a minimum. The DSUB2 is used for setting the current levels and instant trip levels. We expect the customer to configure this connector locally; any cables attached to this connector may cause nuisance trip or malfunction of the unit since the internal control points are brought out of the pins. As a general rule, current-carrying power circuit should be kept well away from the control circuit and other low-level circuits in the system. It’s unlikely, but possible, that magnetic coupling could affect the control circuit when turning normal loads on and off. However, in the case of an overload, the magnetic coupling could be 10 times greater than with normal loads. Effects of such coupling could cause ‘chattering’ when turning on and off, oscillation, and the possibility of turning the

SPDP100D375 back on after an overload. SPDP100D375 is a Trip-Free device. Once tripped it will not turn back on until reset and commanded on again. Reset is accomplished by bringing the “CONTROL” pin low and turning the SSPC back on is accomplished by bringing the “CONTROL” pin high. Sufficient magnetic coupling between the current-carrying power circuit and the control circuit can negate the Trip-Free characteristic.

MIL-STD-704F

This standard covers the characteristics of the electrical systems in Military Aircraft. The device meets all of the requirements of MIL-STD-704F including Normal, Emergency, Abnormal and Electric Starting conditions with the Ripple, Distortion Factor and Distortion Spectrum defined in the standard. In addition, the unit can withstand $\pm$ 600 V spikes for 10µS. This capability is beyond that required by MIL-STD-704F.