2010 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND ENERGY (P&E) MINI-SYMPOSIUM
AUGUST 17-19 DEARBORN, MICHIGAN

SOLID STATE POWER CONTROLLERS PROVIDE IMPROVED PERFORMANCE FOR POWER DISTRIBUTION

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ABSTRACT

The design of power distribution systems for modern tanks and fighting vehicles involves a number of challenges, including demands for increasing amounts of electrical power. In response to these needs, Solid State Power Controllers (SSPCs) provide a number of advantages over electromechanical circuit breakers and relays. These include increased reliability, higher volume and weight power densities, lower power dissipation, reduced EMI emissions, very rapid short circuit protection, and precise I^2t overload protection. The latter protects wiring, loads and the SSPCs themselves against overheating, while reliably avoiding "nuisance trips" when switching into capacitive or incandescent lamp loads. Further, SSPCs provide capabilities in the area of real time feedback, enabling system-level diagnostics and prognostics, and predictive, condition-based maintenance, thereby providing increased availability and continued mission readiness.

INTRODUCTION

The design of primary and secondary power distribution systems for modern ground and air platforms entails a number of challenges. These include needs for increased amounts of electrical power for C^4I and other equipment; improved reliability and system availability; reduced weight, volume and thermal footprint; along with capabilities to shed loads, and for enabling system prognostics and diagnostics.

SSPCs (Solid State Power Controllers) provide a number of functional and performance advantages over electromechanical circuit breakers and relays. SSPCs provide accurate measurements, digital processing, low loss switching with controlled rise and fall time for reduced EMI (electro magnetic interference) emissions, very rapid short circuit protection, along with "I-squared t" (I^2t) overload protection. I^2t protection protects wiring, loads and the SSPCs themselves against overheating, while reliably avoiding "nuisance trips" when switching into capacitive or incandescent lamp loads.

Relays and breakers present reliability problems, as they are subject to arcing, oxidation, erosion, and welding; along with problems associated with moving parts. The latter include contact bounce, and difficulties operating in environments with high vibration, dust, or sand. Relative to electromechanical switching, SSPCs provide an advantage in reliability of an order or magnitude or more, providing increased vehicle and system availability.

In comparison to electromechanical breakers and relays, SSPCs increase electrical energy efficiency by providing lower power dissipation, along with higher power weight and volume densities.

By means of bus or network connectivity, SSPCs provide real time feedback to vehicle diagnostic computers. Data reported from SSPCs can be used for system-level diagnostics and prognostics, enabling predictive, condition-based maintenance, thereby providing increased availability and continued mission readiness. Reported data, which includes the status of the on-board SSPCs, allows management computers to make advance determinations of pending failures of generators, batteries, wiring, connectors, and loads.

SOLID STATE POWER CONTROLLERS

In addition to basic ON/OFF power switching, typical SSPCs provide a number of protective features, including rapid short circuit protection, enabling circuit deactivation times on the order of 1 mS. The circuit deactivation involves a gradual removal of the channel's switching MOSFET(s)' gate drive over a period of 500 µS to 1mS, to minimize EMI emissions. Referring to Figure 1, for overload protection, SSPCs implement an "I-squared t" (I^2t) detection method to protect wires and loads. I^2t protection prevents the high inrush currents for switching into motors, solenoids, capacitive loads such as electronic power supplies, or incandescent light bulb loads from resulting in "nuisance trips". With I^2t protection, SSPCs will instantly trip when the measured load current is ten or more times the rated current.

For lower values of current, the SSPC’s processor performs a continuous calculation, resulting in longer trip times for overload situations involving load currents of between one and ten times the rated value.

SSPCs will instantly trip when the measured load current exceeds a typical level of ten or more times the rated current. For lower values of current, the SSPC’s processor performs a continuous calculation, resulting in longer trip times for overload situations involving load currents of between one and ten times the rated value.

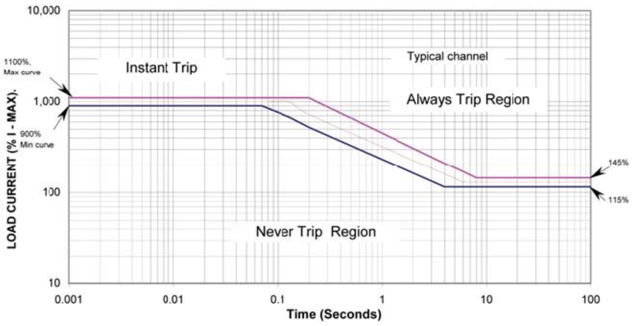

Figure 1. SSPC I^2t Trip Curve.

Modern SSPC boards are processor-based, providing advantages in the areas of flexibility, measurement and computational accuracy, and connectivity to an external power management computer by means of a data bus or network interface, such as CAN (Controller Area Network) Bus, Ethernet, or MIL-STD-1553. Other features include capabilities for programming different values for the SSPC channels’ rated currents to accommodate varying loads, and the capability to parallel multiple SSPC channels, enabling higher current capacities.

To support prognostics, diagnostics, health monitoring, and fault detection and isolation, a power management computer can poll the values of various SSPC parameters over the board’s bus or network interface. For each SSPC channel, these parameters include basic on/off and built-in test status, along with output voltage and current; and board rail and/or load temperatures. This data will allow a power management computer to make advance determinations of pending failures of generators, batteries, wiring, connectors, loads, along with the status of the on-board SSPCs.

Figure 2 is an example of a multi-channel 28 volt SSPC board, DDC’s RP-26200. This board includes 16 SSPC load channels, with each channel capable of delivering up to 25 amps of current with capability to be paralleled with other channels to support larger loads, and a total capacity of 200 to 300 amps. For load current switching, each SSPC channel includes one or more MOSFETs. For minimizing EMI emissions, in particular for dealing with fault conditions, the SSPCs provide control of their output voltage rise and fall times. For channel activation, controlled rise times reduce the inrush current for switching into loads such as motors, solenoids, electronic power supplies, and incandescent lamps. For the case of incandescent lamps, this provides the added benefit of increasing the lifetime of the light bulbs.

SSPCs provide a number of functional and performance advantages over electromechanical circuit breakers and relays. These advantages are described in the following paragraphs.

Figure 2. DDC RP-26200 16-Channel Solid State Power Controller Board.

WEIGHT AND VOLUME

Relative to electromechanical switching, SSPCs provide advantages in the areas of weight and volume. From a system-level top-down perspective, referring to Figure 3, a representative system providing electromechanical switching of 80 amps of 28V power to 8 loads is 4.25” X 7” X 10.9” or 324 cu. in., and weighs 11.5 pounds. Referring to Figure 4, an SSPC module switching 480 amps of 28V power to 32 loads is 11” X 7.8” X 3.1” or 266 cu. in., and weighs 12.5 pounds.

Figure 3. Electromechanical Relay/Circuit Breaker System Box.

Figure 4. Solid State Power Controller Module.

As a matter of comparison and referencing Figure 5, the power-to-volume ratio for the electromechanical switching system shown in Figure 3 is 6.9 watts/cu. in., while that for the SSPC module shown in Figure 4 is 50.5 watts/Cu-in. At a system level, this provides SSPCs an advantage in power-to-volume density of 7.3 to 1. This reduction in volume frees up additional space for crew and/or equipment.

The power to weight ratio for the electromechanical switching system (Figure 3) is 194.8 watts/lb., while that for the SSPC module (Figure 4) is 1072 watts/lb. This provides SSPCs an advantage in power-to-weight density of about 4.6 to 1. This reduction in weight translates to fuel savings.

These differences in system volume and weight density are attributable to multiple factors. These include:

- As explained below, solid state components exhibit inherently lower volume and weight than electromechanical relays and breakers.
- In addition to directly reducing overall size and weight, the reduced component sizes also reduce the size and weight of the associated PC (printed circuit) boards and chasses.
- Solid state components attach directly to printed circuit boards. In some cases, relays and breakers mount on metal frames rather than PC boards, and interconnect by means of discrete wires, rather than PC board traces.

	Electromechanical Switching Box	**SSPC Module**
Voltage	28V	28V
Current	80 A	480 A
Loads	8	32
Dimensions	4.25" x 7" x 10.9"	11" x 7.8" x 3.1"
Volume	324 in^3	266 in^3
Weight	11.5 lbs	12.5 lbs
Power-to-Volume Density	**6.9 W/in^3**	**50.5 W/in^3**
Power-to-Weight Density	**194.8 W/lb**	**1072 W/lb**

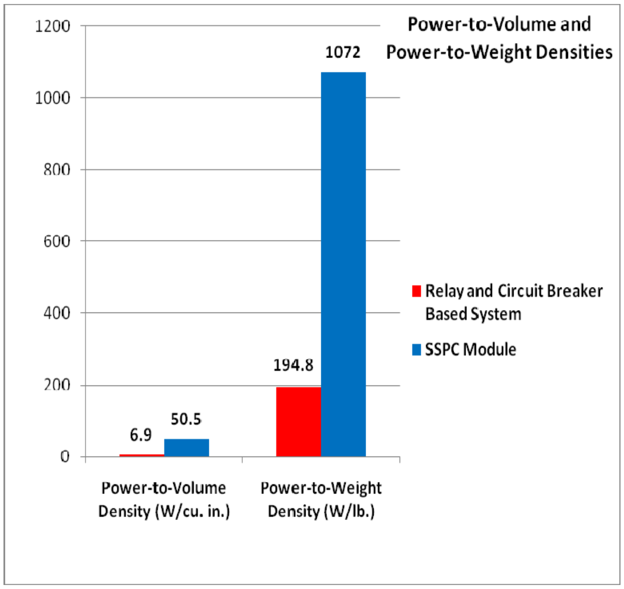

Figure 5. Top-Down, System-Level Comparison: Power to Volume and Weight Densities, Solid State Power Control Module vs. Electromechanical Switching Box.

Table 1. Data for 28 V, 25-amp Relays

28V, 25-amp Relays	Width (in.)	Depth (in.)	Height (in.)	PC Board Real Estate (sq. in.)	Volume (cu. in.)	Weight (lbs.)	Coil Dissipation (watts)	Contact Dissipation (watts)	Total Dissipation (watts)
#1	1.01	0.52	1.00	0.52	0.52	0.10	2.45	N/A (note 1)	6.20
#2	1.71	0.48	1.01	0.82	0.83	0.12	2.45	4.38	6.83
#3	1.72	0.53	1.01	0.90	0.91	0.1	2.45	4.38	6.83
#4	1.53	1.40	1.90	2.14	4.07	0.19	1.44	N/A (note 1)	5.19
#5	2.7	1.39	1.42	3.75	5.33	0.20	0.49	2.50	2.99
AVERAGE	**1.74**	**0.86**	**1.27**	**1.56 (Note 2)**	**2.11 (Note 2)**	**0.14**	**1.86**	**3.75**	**5.60**

Table 2. Data for 28 V, 25-amp Circuit Breakers

28V, 25-amp Circuit Breakers	Width (in.)	Depth (in.)	Height (in.)	PC Board Real Estate (sq. in., Width X Depth)	Volume (cu. in.)	Weight (lbs.)	Power Dissipation (watts)
#1	1.14	0.57	2.53	0.65	1.65	0.09	N/A (note 1)
#2	0.78	0.59	2.09	0.46	0.97	0.05	5
#3	0.70	0.59	2.28	0.41	0.95	0.07	5
#4	1.22	0.45	2.81	0.549	1.54269	0.06	N/A (note 1)
#5	1.64	0.76	2	1.24	2.48	0.15	2.5
AVERAGE	**1.10**	**0.59**	**2.34**	**0.66 (Note 2)**	**1.52 (Note 2)**	**0.08**	**4.17**

Notes:

1. The contact dissipation data for relay #1 and relay #4, and circuit breaker #1 and circuit breaker #4 is not available, For the relays, the average of the other three values of relay contact dissipation was used for computing overall relay dissipation. For the circuit breakers, the missing value was not included in the calculation for average dissipation.
2. For both relays and circuit breakers, the average PC board real estate (sq. in.) and volume (cu. in.) are computed as the average of two different methods:
    a. Using the first method, the average PC board real estate is computed as the average PC board real estate of the five relays or circuit breakers. Similarly, the average volume is computed as the average volume of the five relays or circuit breakers.
    b. Using the second method, the average PC board real estate is computed as the average width for the five relays or circuit breakers times the average depth. Similarly, the average volume is computed as the average width for the five relays or circuit breakers times the average depth times the average height.

For comparing the volume, weight, and power dissipation of solid state and electromechanical switching from a bottom-up component perspective, Tables 1 and 2 provide the weight, volume, and power dissipation of commercially available electromechanical relays and thermal breakers, each from multiple suppliers. These tables include the outline dimensions, weight, and power dissipation for five 28V, 25-amp relays; and five 28V, 25-amp circuit breakers. In addition, they include the computed PC board real estate and volume for these components, along with the computed average values for these parameters.

For relays and circuit breakers, the average real estate per channel = 1.56 + 0.66 = 2.22 sq. in. Assuming that relays and breakers occupy 60% of the total PC board area, the total real estate per channel = 2.22/0.6 = 3.7 sq. in. Using the average circuit breaker height of 2.34 in. and assuming a PC board thickness of 0.093", a top-side clearance of 0.02, and a back-side clearance of 0.25" (similar to a comparable SSPC board assembly), the total assembly height for a relay/breaker board assembly = 2.34 + 0.02 + 0.093 + 0.25 = 2.7 in. The total volume for one channel = (3.7)*(2.7) = 9.99 cu. in., and output power per unit volume = (28)*(25)/(9.99) = 70.1 W/cu. in.

For a 16-channel SSPC board assembly, the board dimensions are 9.2 X 6.3 in., with a maximum component height of 0.54 in., PC board thickness of 0.093", and a back-side clearance of 0.25", for a total height = 0.54 + 0.093 + 0.25 = 0.883”. Total volume for 16 channels = 9.2 X 6.3 X 0.883 = 51.18 cu. in. This translates to 51.18/16 = 3.20 cu. in. per channel. For a 25-amp channel, the output power per unit volume = (28)*(25)/3.20 = 219 W/cu. in.

The weight of a typical bare 9.2 X 6.3, 0.093” thick PC board is 0.55 lbs. For such a board, the weight per unit area = .55/((9.2)*(6.3)) = .0095 lbs/sq. in. For one relay + breaker channel, total real estate per channel = 3.7 sq. in., therefore the PC board weight per channel = (.0095)*(3.7) = 0.035 lbs. Total relay + breaker weight per channel = 0.14 + 0.08 + 0.035 = 0.255 lbs. The output power per weight = (28)*(25)/0.255 = 2745 W/lb.

The weight of a typical 16-channel SSPC board assembly is 1.8 pounds. For a 28 volt, 25-amp SSPC channel, the output power per unit weight = ((28)*(25))/(1.8 /16) = 6222 W/lb.

REDUCED WIRING

For either an aircraft or a ground vehicle, if load switching is performed using crew-accessible circuit breakers requiring manual reset, then these must be located in the vicinity of the pilot or operator. This forces all power wires to be routed both to and from the location of the crew. Since SSPCs can be controlled over a network, their use eliminates the need to run power wires to and from the crew location, thereby saving weight and reducing fuel consumption.

POWER DISSIPATION

SSPCs provide a lower thermal profile than circuit breakers. This is based on the low on-resistance of switching MOSFETs, whose affect can be further reduced by paralleling multiple MOSFETs and/or multiple SSPC channels for switching current to the same load. Further, solid state switching eliminates the power dissipated in the relay coils, solenoids, bimetallic strips, and contact resistances found in circuit breakers and relays. As a result, SSPCs provide a significant advantage in internal power dissipation relative to circuit breakers and relays.

As an example, consider a 28 volt, 25-amp SSPC channel relative to a circuit breaker/relay combination. In each case, assume that the channel is fully loaded.

Referring to Tables 1 and 2, the average power dissipation for a 28V, 25-amp relay + circuit breaker channel = 5.61 + 4.17 = 9.78 watts. For a typical 28V, 25-amp SSPC channel with a voltage drop of 115 mV, the resulting dissipation is 2.875 watts. Further, it is important to note that the SSPC path dissipation includes the RP-26200 PC board traces and connector contacts, while that for the circuit breakers and relays does not.

	Electromechanical Switching	SSPC Module
Voltage	28V	28V
Current	25 A	25 A
Volume	9.99 in^3	3.20 in^3
Weight	0.255 lbs.	0.113 lbs.
Power-to-Volume Density	**70.1 W/in^3**	**219 W/in^3**
Power-to-Weight Density	**2745 W/lb**	**6222 W/lb**

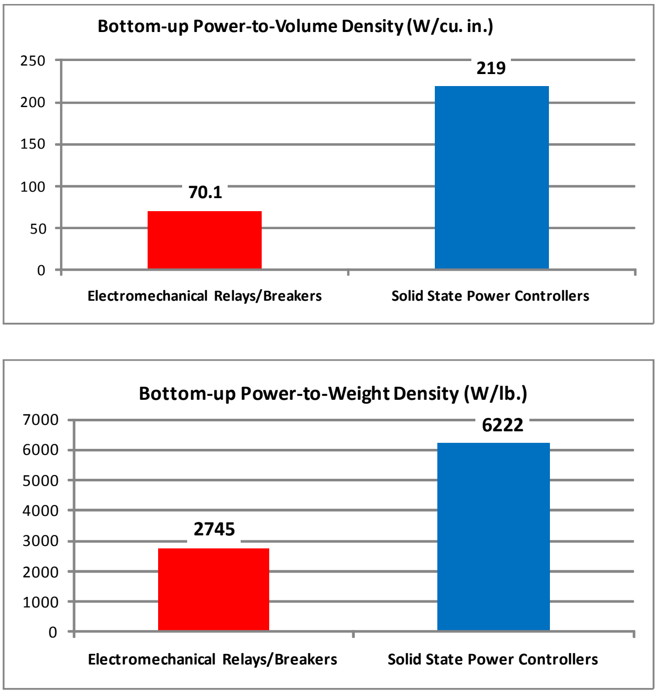

Figure 6. Bottom-Up Comparison: Power-to-Volume and Power-to-Weight Density, SSPC Channel vs. Relay/Breaker Combination.

	Electromechanical Relay + Circuit Breaker	SSPC Channel
Voltage	28V	28V
Channel Current	25A	25A
Relay Coil Dissipation	1.86 W	--
Relay Contacts Dissipation	3.75 W	--
Circuit Breaker Dissipation	4.17 W	--
SSPC Voltage Drop	--	0.115V
Total Channel Power Dissipation	**9.78 W**	**2.875 W**

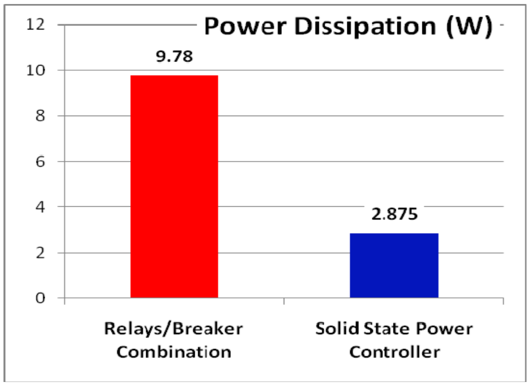

Figure 7. Channel Power Dissipation, SSPC vs. Electromechanical Switching.

RELIABILITY

In terms of reliability, SSPCs provide significant advantages over electromechanical circuit breaker/relay-based power distribution. The MTBF (mean time between failures) of a multi-channel SSPC board is an order of magnitude higher than that of a comparable implementation based on circuit breakers and relays. Since SSPCs have no moving parts, they exhibit a far lower number of failure modes than circuit breakers and relays. Figure 8 shows the internal construction of relays.

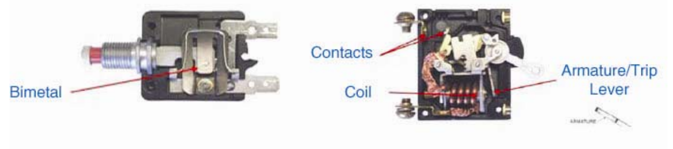

Figure 8. Breaker and Relay Internals

Some of the failure modes specific to electromechanical switching include:

- Contact resistances for relays and circuit breakers are subject to arcing, resulting in oxidation, erosion, and pitting, leading to increased contact resistance.
- The arcing resulting from opening breakers and relays switching into inductive loads can degrade contacts, resulting in contact erosion, and possibly welding. Similarly, contact bounce can affect the operation of loads, and also result in arcing and failures, including contact welding.
- Operation at low load currents can fail to burn off oxidation, resulting in high contact resistance.
- In high-vibration environments, electromechanical switches can chatter, affecting system operation. In addition, vibration can lead to material failure and misalignment.
- The operation of relay and breaker contacts can degrade in salt spray, dusty, or sandy environments.
- Armatures for thermal circuit breakers and relay coils dissipate power, resulting in additional heat and complicating system thermal design.
- Relay coils are subject to long-term damage from humidity, dust, and dirt, resulting in coil wire insulation embrittlement and eventually failures.
- For relays, high on/off cycling rates can lead to wear on moving parts, binding relay armatures, contact erosion, intermittent contact operation, and coil failures.
- Lack of operation can lead to build-up of organic material on relay contacts. For example, there's the possibility that a weapon won't fire due to oxidation or organic material on relay contacts.[1]

For DDC's RP-26200 28 volt, 16-channel SSPC board, the MIL-STD-217 MTBF for a ground mobile environment is estimated as 415,000 hours at 25° C. The MIL-STD-217 failure rate for a comparable electromechanical contactor at 25° C is $1.00\bullet10^{-6}$ events/hour, and for a circuit breaker is $3.3\bullet10^{-6}$ events/hour. The failure rate of the contactor/breaker combination = $1.00\bullet10^{-6} + 3.3\bullet10^{-6} = 4.3\bullet10^{-6}$, or a combined MTBF of 233,000 hours.[2] For 16 contactor/breaker combinations, the MTBF is 233,000/16 ≈15,000 hours. Referring to Figure 9, this provides SSPCs with an MTBF advantage of a factor of about 27.7 to 1 relative to electromechanical relays and breakers. The true advantage for SSPCs is actually somewhat higher than this, since their MTBF includes the failure rates of the SSPCs' processor and control electronics, while for relays and breakers, these are not considered.

	16 Contactors and Circuit Breakers	**DDC RP-26200, 28V 16-channel SSPC Board**
1 contactor/breaker combination	233,000	N/A
16 contactor/breaker combinations	15,000 hrs	**415,000 hrs**

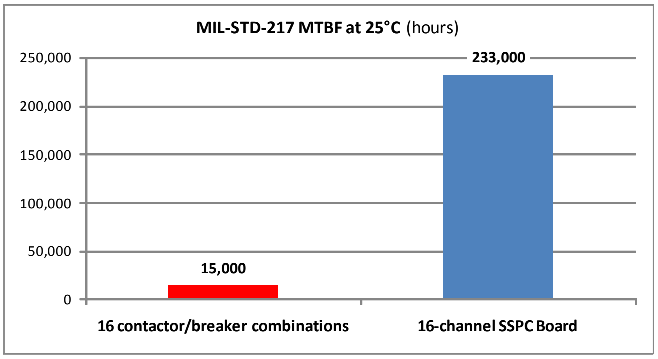

Figure 9. Reliability (MTBF), MIL-STD-217 MTBF for a Ground Mobile Environment at 25°C

SHORT CIRCUIT INSTANT TRIP

The higher reliability of SSPCs relative to switches and breakers provides an improvement in protection and safety. In addition, following the occurrence of short circuit faults, SSPCs will deactivate in approximately 1 mS, while breakers and relays take tens of mS to open. This added delay time can lead to significant damage to wiring and equipment.

From a system reliability standpoint, the use of SSPCs enables automated redundancy. This can entail activating a

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[1] Electric Power Research Institute; Maintenance and Application Guide for Control Relays and Timers Technical Report; December 1993; page 3-7.

[2] Kulkarni, Ashok; A Hidden Reliability Threat in UPS Static Bypass Switches; American Power Conversion; 2006; page 5.

redundant path to a load, or possibly a bus tie to switch the power source to an alternate generator or back-up battery. This allows rapid restoration of power to vehicle and mission-critical loads following failures of generators, wiring, or other power system components.

SYSTEM LIFE CYCLE COST

The use of SSPCs can system life cycle costs based on multiple factors, including:

- The higher reliability of SSPCs relative to electromechanical switching reduces ground vehicle downtime and maintenance costs.
- Based on their lower weight and lower power dissipation, SSPCs provide fuel savings relative to circuit breakers and relays.
- SSPCs, by providing real time feedback to on-board diagnostic computers, can facilitate preventive maintenance by predicting failures in equipment and wiring before they occur. This allows maintenance to be performed during scheduled downtimes, rather than following outright failures.
- Relative to maintainability, multi-channel SSPCs consolidate the functions of many circuit breakers and relays on to highly modular circuit boards. Further, since SSPCs include built-in self-test functionality, their operational health may be interrogated continuously over a bus or network. This design and construction minimizes troubleshooting time and therefore mean-time-to-repair. The increased reliability, coupled with lower repair times serves to increase vehicle availability time and reduce maintenance costs.
- By providing a high degree of flexibility, SSPCs enable a modular and scalable system design. This allows SSPCs to facilitate incremental vehicle upgrades, such as the installation of additional C4I equipment. In large part, this is due to the fact that individual SSPC channels can be re-programmed to accommodate varying loads. Further, it is possible to parallel the outputs from multiple channels in order to support loads requiring higher currents than the capacity of individual channels.
- In addition, the use of multi-channel SSPC assemblies can reduce inventory costs, by allowing the same box, including with *the same internal firmware programming*, to be installed in multiple locations in the same vehicle. This is made feasible by the fact that it's possible to program a multi-channel SSPC with multiple "personalities", the selection of which will be determined by the hardwired bus (e.g., CAN Bus) address for a given location in a vehicle.

LOAD FLEXIBILITY

As platforms evolve to more electrical and electronic operation, there will be increased need to support multiple equipment configurations with varying power requirements. The current ratings for electromechanical relays can vary depending on the type of load. For example, a relay rated for 25 amps for resistive loads may be rated for only 12 amps for inductive loads, 10 amps for motors, and 4 amps for lamps.

By comparison (Figure 10), SSPCs can support the same maximum current rating for all types of loads. In addition, the current ratings for SSPCs are typically programmable over a range of at least ten to one. Further, it's possible to support higher load currents by paralleling the outputs from multiple SSPCs. Based on these factors, SSPCs support greater use flexibility than breakers and relays by allowing rapid re-configuration.

MONITORING AND DIAGNOSTICS

Solid State Power Controllers support multiple aspects of health management for ground vehicle power and wiring systems. These include:

- SSPCs provide autonomous circuit protection for faults such as short circuits and overloads. SSPC trip events may be immediately reported over the board's bus or network interface by means of alarm messages, thus allowing the platform's power management computer to efficiently manage power system redundancies. Alternatively, the power management computer may periodically poll the SSPCs' status over the board's bus or network interface.
- SSPCs can provide high accuracy (±5%) measurements of input and load voltages, and load currents. For detected faults such as under- or over-voltage, under-current, and over-temperature, individual channels may be programmed to either trip immediately, or to issue alarms over the network interface. In the latter case, power management computers can log the faults, and possibly make determinations to deactivate SSPCs, depending on other factors. For example, for certain fault conditions for some platform or mission critical loads, circuit deactivation may not be practical.
- SSPCs monitor input voltages, allowing system computers to track generator and/or battery power quality, along with load currents and total power consumption.

- Based on the status and parametric data provided from SSPCs, power management computers can perform continuous analyses of power system operation. This enables determinations of such faults as loss of, or low or high input voltage; short circuits or open circuits in wires or loads; along with failed SSPCs, with either open or shorted switching MOSFETs.

Data reported from SSPCs can be used for system-level diagnostics and prognostics, enabling predictive, condition-based maintenance, thereby helping to provide improved availability and continued mission readiness. For example, if the system management computer records an increase in the current drawn by a pump, this could point to the need for advance maintenance to repair or replace a failing pump.

	Current Rating by Load Type (A)			
	Resistive	**Inductive**	**Motor**	**Lamp**
25A Relay	25	12	10	4
SSPC Channel, Programmable up to 25A	**25**	**25**	**25**	**25**

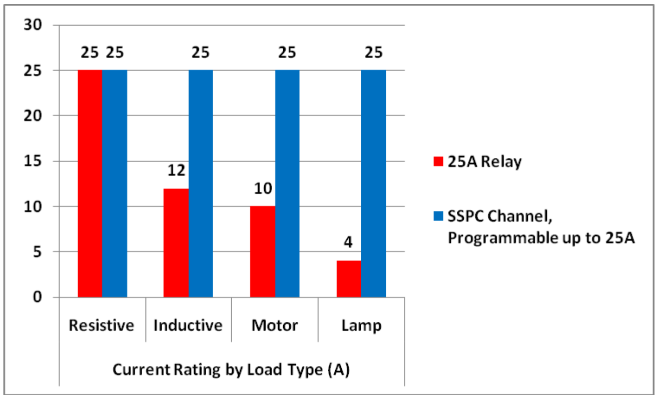

Figure 10. Current Ratings by Load Type, DDC SSPC Channel vs. Electromechanical Relay

SURVIVABILITY AND FAULT TOLERANCE

SSPCs provide many features contributing to the survivability and fault tolerance of vehicle power systems. These include:

- As discussed, SSPCs provide a significant increase in reliability over electromechanical breakers and relays. This contributes substantially to the survivability of ground vehicle power systems.
- For some applications, multiple SSPCs can be cascaded. That is, there will be one or more high-current SSPCs connecting between one of the platform's primary power buses and one or more power distribution centers, each of which contain multi-channel SSPCs. This provides fault containment and system survivability by preventing circuit faults on one load (or its wiring) from propagating to other circuits.
- From a system reliability standpoint, the use of SSPCs allows automated redundancy, enabling the restoration of power to platform and mission-critical loads following failures of generators or other power system elements. This includes load shedding, as a means to automatically, quickly, and reliably turn off non-essential loads in emergency situations.
- SSPCs can provide real time, internal and system-level diagnostics, including:
    - Loss of SSPC input voltage, indicating generator, battery, or wire failures.
    - Tripped SSPCs, indicating short circuit faults in load wires or loads.
    - SSPC output voltage activated, but zero load current, indicating open circuit faults in wiring or loads.
    - SSPC output activated when intended to be off or following a TRIP event, indicating a shorted MOSFET.
    - Low output voltage with SSPC intended to be in ON state, indicating a controller failure or MOSFET failed open.

CONCLUSION

Table 3 provides a comparison between the functionality and performance of SSPCs relative to electromechanical circuit breakers and relays. In part, this comparison is based on DDC's RP-26200 28 volt, 16-channel SSPC board housed in an enclosure, and a comparable system based on electromechanical circuit breakers and relays. It is also based on specification data for commercially available relays and circuit breakers. As can be seen, SSPCs provide a number of functional and performance advantages. These include higher reliability, lower power dissipation, higher power/weight and power/volume densities, improved operation in high vibration environments, faster clearing of short circuit faults, greater use flexibility, reduced EMI, and increased capability for reporting status.

Table 3. Comparison Summary: SSPCs vs. Breakers and Relays

Parameter	Electromechanical Breakers and Relays	SSPCs	SSPC Advantage
MTBF -- 16 channels (hours)	15,000	415,000	Increased platform power availability, reduced maintenance costs.
Switching power dissipation – one 25-amp channel	9.8	2.9	Reduced power losses, smaller thermal profile.
System-Level: Power/ Volume Density – Load watts per cubic inch	6.9	50.5	Frees up space for crew and/or equipment.
Bottom-up : Power/ Volume Density – Load watts per cubic inch	70	219	
System-Level Power/Weight Density – Load watts per pound	194.8	1072	Reduced weight translates to fuel savings.
Bottom-up Power/Weight Density – Load watts per pound	2745	6222	
Operation in high vibration environments.	Contacts can chatter, resulting in voltage outages and spikes.	Solid state switching ensures continuity of power to loads.	Improved quality and availability of power to loads.
Time to clear short circuit faults.	Tens of mS.	Approximately 1 mS.	Fast clearing of short circuits prevents damage to wiring, equipment, and vehicles.
Flexibility	Trip current is fixed. Maximum current varies depending on load type.	10:1 Programmable rated current. The maximum current is the same for all load types. Multiple SSPCs may be paralleled.	Power distribution equipment may be re-programmed for varying load scenarios.
EMI	Abrupt switching of load currents.	Controlled rise and fall times.	Reduced surge currents for switching into inductive or lamp loads. Reduced inductive spikes for power turn-off.
Status reporting.	None or minimal.	Report status, voltages, currents, and temperatures.	Provide inputs to system computers for prognostics, diagnostics, and improved system maintenance.

REFERENCES:

1. Electric Power Research Institute; Maintenance and Application Guide for Control Relays and Timers Technical Report; December 1993.
2. Kulkarni, Ashok; A Hidden Reliability Threat in UPS Static Bypass Switches; American Power Conversion; 2006.