Development of a DC Appliance Connector for Telecommunications Equipment

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Abstract - The requirements from applicable international (IEC) and domestic (UL) standards are studied for the making of a DC power inlet connector for telecommunications equipment with rated nominal voltages from 350V to 400V. Product safety issues relating to protection against electric shock and arc flash for 400 VDC power distributions are discussed. The making and breaking characteristics of a 400 VDC electronic load are investigated by live testing. Results of tests conducted on pilot production connectors to verify product safety and function are presented.

1. Introduction

Data and telecommunications centers are major consumers of electrical energy. Yet less than half of this power is delivered to the computing load in a typical data center. The remainder of the power is consumed by power conversion, distribution losses, and cooling.

The lifetime energy costs of operating a server now exceeds its purchase price is some regions. These economics will bring about a significant shift in how we evaluate the capital costs of data centers. The efficiency of the power distribution and emergency power systems will be play a critical role in the return on investment of the data center.

Power distribution in data centers is typically 220 to 480V AC and −48V DC in telecommunications facilities. Higher voltage DC distribution systems present the potential for higher power efficiencies in both types of facilities. Higher voltage DC distribution systems require fewer components than best practice AC distribution systems, offering potential cost and reliability advantages.

Several types of components must be developed for these higher voltage DC distribution systems to become a reality. One of these is the DC Appliance Connector.

The development of the DC Appliance Connector by Anderson Power Products was influenced by 4 factors; making and breaking of the DC arc, existing product safety standards, user safety and general requirements.

II. DC Arcing

It is well known that when a live load is broken across two terminals of a DC circuit, an arc will sustain for a far greater distance than with an AC circuit of comparable voltage. Far less known is the electrical characteristics of making a DC electronic load across two terminals.

Modern electronic devices have a filter capacitor immediately following the power input connector in order to comply with EMI requirements. As the capacitor is connected across the power lines, it behaves similar to a short circuit until charged regardless of whether the electronic device is switched on or off.

The current flowing through a capacitor in a DC circuit can be described as: ic = C dvc/dt. Where C is the capacitance value, dvc is dependent on the input voltage and dt is a function of the time constant of the circuit which is dependent on the source impedance.

The in-rush current into a DC powered electronic device is therefore not related to the steady state load and may be of similar magnitude for a 100-watt or a 2000-watt power supply.

A survey was conducted and it was determined that in most IT equipment this capacitor is 6.8 microFarad or less.

Direct observations of DC power system in-rush current where conducted that show very different results depending on the impedance of the power source.

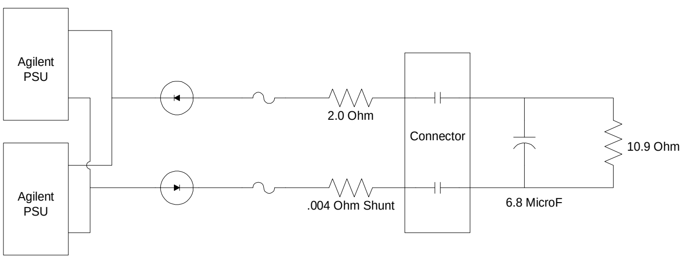

Figure 1

Using the test set up shown in figure 1, in-rush currents of 300 to 400 amps were observed by Anderson Power Products. Similar independent tests conducted by Net Power Systems of Stockholm Sweden produced different results. Peak in-rush currents measured by Net Power Systems were in the 150 to 200 amp range.

However, the power sources used in both these tests where quite different. The Agilent power supplies have low impedance because of their large bulk capacitors. Net Power Systems utilized a battery string as the power source in their tests. The much higher impedance of the battery string limits the in-rush current and is not representative of the true application.

Clearly, a suitable test circuit must eliminate variation in results due to the power source. In addition, we would like to simulate the impedance of the distribution wiring between the source and the load.

Figure 2 depicts a test circuit that uses a large capacitor to simulate the hold up capacitance of 100 Kilo-watt DC power source. The capacitor also eliminates the effects of impedance variation of the test power source. In addition, inductive and resistive elements have been added as described in ETSI EN 300 132-3 to simulate distribution wiring.

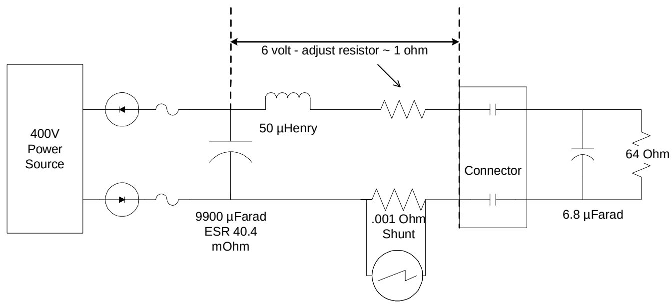

Figure 2

The resultant in-rush current observed was 300 amps as seen in the oscilloscope photograph shown in figure 3. Also seen in is the “making arc” indicated by the presence of voltage across the connector for approximately 7 milliseconds before the contacts engage.

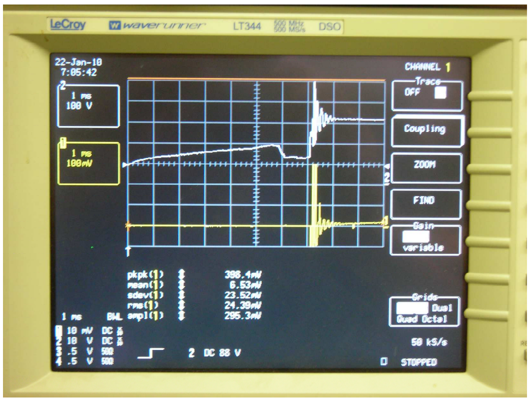

Figure 3

How does this affect the design of our DC Appliance Connector? The connector contacts must be designed in such a manner to provide a sacrificial area of sufficient mass to dissipate the arc energy. This sacrificial area must be away from the surface of electrical engagement when the connectors are fully mated. This will provide an undamaged contact surface for steady state electrical engagement.

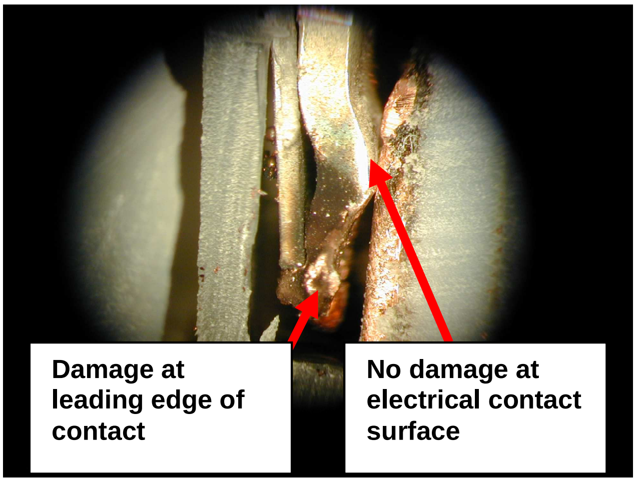

Figure 4

Figure 4 shows the Anderson Power Products connector design after DC arcing tests. The leading surfaces of the contacts show significant arcing damage. However, the surfaces of steady state electrical engagement are completely undamaged.

We experience only minor increases in contact resistance consistent with normal mechanical wear after DC arcing tests. Contacts are silver plated for best resistance to arcing. Tin plating can become molten during DC arcing resulting in "spitting" and/or "welding".

By contrast AC appliance inlet connectors do not have sacrificial contact surfaces. The initial arcing surface and the final electrical contact surface are one and the same. Figure 5 shows an IEC320 plug female contact after DC arcing. The DC arc has burnt a hole completely through the material of the female contact at the electrical contact point.

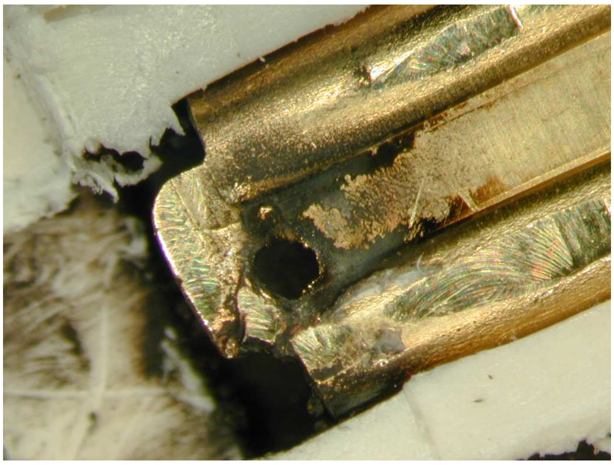

Figure 5

III. Safety Standards

Performance standards used as the design requirements for our 400VDC power inlet connector where developed by a sub-committee of "DC Power Partners" which is an ad-hoc industry group of companies, technical organizations and individuals promoting DC power distribution.

As we are concerned with developing a connector for telecommunications equipment there are a number of product safety standards that must be met. Among them are; ETSI EN 300 132-3 "Power supply interface at the input to telecommunications equipment; Operated by rectified current source, alternating current source or direct current source up to 400 V", IEC 60950 & UL 950 "Information technology equipment – Safety", IEC 61984 "Connectors – Safety requirements and tests" and UL 1977 "Component Connectors for Use in Data, Signal, Control and Power Applications".

We also must review safety standards of general governance such as IEC 60644 "Insulation coordination for equipment within low-voltage systems". Consideration of safety standards for devices of similar usage for AC power distribution such as IEC 60320 "Appliance couplers for household and similar general purposes" may also provide general guidance.

A principal connector design element is the creepage and clearances required for voltage isolation.

We may determine our creepage requirements by referring to Table 4 of IEC 60664. Assuming a 400V nominal working voltage, pollution degree 2 conditions and material group 3 insulation; the creepage requirement for basic insulation is 4.0mm and the requirement for reinforced insulation is double, 8.0mm. This table is harmonized with the creepage tables of IEC 60950, UL 1950, IEC 61984 and exceeds the requirements of UL 1977.

To determine our clearance requirements we must also reference IEC 60664. We will use Table 1 to determine the rated impulse voltage category. In order to use the table we must know the overvoltage category of our equipment. We have chosen overvoltage category II; "energy-consuming equipment to be supplied from the fixed installation. Example; appliances" We can now use table 1 by selecting the voltage category equal to or greater than our nominal voltage, in this case 600 volts and equipment overvoltage category II to find our rated impulse withstand voltage of 4.0KV. Using this figure and assuming a pollution degree 2, we can now reference Table 2 and find our clearance requirement for basic insulation of 3.0mm. IEC 60664 currently specifies that clearance for reinforced insulation shall be taken from the next higher impulse withstand voltage category, 5.0KV that corresponds to a 4.0mm clearance.

Each of the referenced safety specifications requires user protection from hazardous voltages. This can be evaluated by use of a articulated finger probes as specified by IEC and UL. For most connectors the finger probe evaluation is performed on an energized connector in the mated condition. However, for a circuit breaking connector, the finger probe evaluation must also be performed on an energized connector in the un-mated condition. Reinforced insulation requirements must be maintained from the energized circuit to the finger probe.

The connector must function under normal operation without excessive self-heating. For this requirement, we are governed by the contact heating test limit of 45^0C shown in IEC 61984. Temperature limits of IEC 60950 and UL 1950 as well as the temperature rating of UL 1977 would permit higher self-heating temperatures.

Connector heating performance after making and breaking load is of great importance for a DC appliance connector. This is one area where there are significant differences between safety standards. IEC 61984 requires that the connector make and break load at rated current and voltage for the mechanical rating of the connector. UL 1977 requires the connector be evaluated at rated voltage and 150% of rated load for 250 cycles. We must also consider that the connector shall endure the in-rush current of charging a filter capacitor. It is of interest that by developing a connector that can endure the expected 300 amp capacitive in-rush current, the resulting UL connector rating for breaking current exceeds 20 amps.

There are numerous areas of our design such as wire retention and contact retention, where we have adopted industry standard practice.

IV. User Safety

Many user safety requirements are addressed within the governing product safety standards. One additional item of serious safety concern is arc flash.

One way to avoid arc flash is to prevent unintentional un-mating of the connectors. This is accomplished by integrating a simple positive latch into the connector design.

However, intentionally un-mating of the connectors under load will create a DC arc. Electric arcs can create intense heat and produce temperatures as high as 18,000 degrees Centigrade. These temperatures can damage metals, insulating materials and cause severe skin damage.

In the case of our DC Appliance Connector; the voltage and load produce a small, localized DC arc. We can protect the user by designing the plug and receptacle housings in such a manner that during the un-mating of the connectors there is complete overlap of the connector housings until the arc extinguishes. This is easily confirmed by performing current breaking tests in a darkened room and observing the visual presence or lack of an arc flash.

One consideration that may not be obvious to designers unfamiliar with current breaking connectors is that debris from contact plating and insulating materials produced as result of damage from an electric arc leaves conductive deposits on the surfaces of the connector housings. We have found that because of these deposits normal standards for basic insulation may not be adequate to maintain voltage isolation between contacts during and after load breaking tests. To insure that a sustainable arc is not created by this phenomenon, we have used a more conservative creepage distance of > 8.0mm for both basic insulation. We have also performed a dielectric withstand test after breaking tests to validate safe operation.

V. General Requirements

To support a migration from AC to DC power distribution, one attribute that we desire to maintain is the form factor of the connector. DC power systems must be equal to or smaller than its AC connector predecessors.

Our DC Appliance Connector is designed to fit the same sheet metal opening as the IEC320 C14 (10 amp) receptacle. This permits manufacturers to use the same enclosures for DC or AC power supplies. It should be possible to swap an AC power supply for a new DC power supply in an existing telecom device.

In order to achieve the greater creepage and clearance requirements of the 400 volt DC Appliance Connector within the same form factor as the IEC 320 connector a more complex housing geometry with greater length is required.

VI. The Saf-D-Grid Connector

The Saf-D-Grid connector design is shown in figure 6. The form factor similarity to the IEC320 connector is evident. However, the housing geometry necessary to achieve our voltage isolation is more intricate than the simple IEC320 design. The power contacts are not visible as they are well recessed within the housings to achieve arc flash and touch safety. The housings overlap to protect the user from arcing and the positive latch is evident along the top surface of the plug.

Figure 6

Saf-D-Grid connector performance was validated in the UL certified client data test facility of Anderson Power Products. The connector is UL 1977 Recognized and the mating power cords are UL817 Listed.

ELECTRICAL

Voltage
- UL/CSA 600 VDC
- IEC 400 VDC

Current Rating 20 amps

Wire Range (AWG) #14 to #18
(mm²) 1.5 to 2.5

Hot Plug Rated
- 250 cycles 400V @ 400A in-rush
- 250 cycles 400V @ 20A load

Dielectric Withstanding Voltage 3000VDC

Operating Temperature (℃) -20° to 90°
(℉) -4° to 194°

MECHANICAL

Contact Retention (lbf) 20
(N) 89

Latch Retention (lbf) 20
(N) 89

SAFETY

Touch Safe
- Meets protection requirements of IEC and UL articulated finger probes

Arc Flash Shield
- Connector housings shields user until flash has extinguished

Integral Latch
- Prevents unintentional un-mating of connectors which may be under load

Creep & Clearance
- > 8.0mm between live parts of different polarity
- > 8.0mm between live parts and the mating surface or earthing circuit

VII. Standardization Activities

International standards for DC power distribution are under study. The author is active as a contributing expert on these committees.

In January 2008, IEC formed Technical Committee, Working Group 8, TC23WG8, "Electrical Accessories for DC Current". TC23WG8 is developing harmonized specifications for IEC DC electrical accessories standards. The WG has recommended a +/- 190 Volt bus for data center power distribution and has studied the problems of making and breaking DC loads.

IEC also established Strategic Working Group 4, SG4, "LVDC distribution systems up to 1500V DC in relation to energy efficiency" in October 2009. This high-level committee is working to define DC bus voltages and other characteristics for a broad range of applications.

In October 2010, EMerge Alliance announced it would expand its charter from intrinsically safe Class 2 DC power and voltage levels to include higher voltage and power levels practical for building wide power distribution. Many of the companies that make up the DC Power Partners have joined the EMerge Alliance and are leading the development of a 380 VDC power distribution bus standard. A draft standard will made available for member comment in early 2011.

VIII. Conclusion

There are many technical considerations which must be evaluated in the development of a 400 volt DC appliance connector. These technical considerations can be addressed in a new connector design with the equivalent size and safety of existing 250 VAC appliance connectors.