APC

APPLICATION NOTE #53

Using APC InfraStruXure Three Phase Whips and RM PDU's for Nonlinear Loads

By Ryan Hansen

Abstract

Consulting Engineers and customers frequently express concern about the acceptability of three phase, 4-wire whips and rack-mount PDUs that are used to distribute InfraStruXure power in a nonlinear load environment. APC is frequently challenged to supply 200% rated neutral conductors. APC conducted extensive testing and demonstrated beyond any doubt that the whips and rack-mount PDUs can be safely used in the worst nonlinear load environment. This application note describes the test methods and provides the test results that support that conclusion.

Background

In the late 1980's and early 90's the widespread use of switch-mode power supplies in data processing equipment caused a serious situation in "computer rooms" and office environments. Up until that time loads had been pretty linear and the neutral conductor was thought of as a "non-current carrying conductor." Electric codes permitted the neutral wire to be sized to only 25% of the rating for associated current-carrying phase wires. With the advent of nonlinear loads, that all changed. Nonlinear loads create harmonic currents. Triplen harmonics (3rd and odd multiples of the 3rd harmonic) are additive in the neutral. The theoretical maximum neutral current for a 4-wire, 3-phase balanced load is 1.73 times the phase conductor rating. This excess current caused the under-sized neutral wires to get hot, and caused overheating of transformers, lighting ballasts, and junction temperatures. The immediate response by industry and code officials was to require over-sized neutrals on all 4-wire circuits and to derate transformers. This subject is covered in detail in APC White Paper #26 – "Hazards of Harmonics and Neutral Overloads."

In a delta/wye transformer, harmonic currents are trapped in the secondary windings and dissipated as heat. "K-rated" transformers and derating formulae were developed to prevent overheating of transformers. InfraStruXure uses transformers rated specifically for nonlinear loads.

The longer-term response by industry was to create "power factor-corrected" power supplies, largely in response to requirements by European standards. Today more than 90% of the power supplies used in information technology are power factor-corrected. The result is that most loads look "linear" and harmonic currents have disappeared.

Nevertheless, InfraStruXure uses "whips" designed to serve nonlinear loads. By the very nature of derating circuit breakers, fully-sized neutrals already can carry 125% of the maximum current that could be seen on any phase conductor. APC decided to set up some tests to determine how well the neutral conductors could handle excess harmonic currents.

APC Testing

Prior to formal release of the InfraStruXure Type B three phase 4-wire whips to the market the APC Billerica InfraStuXure Ancillary Products Design Team performed exhaustive testing. The goal was to examine the performance of the three phase whip and RM PDU power cord assemblies under a variety of different loading scenario's (See Appendix A Test Data). Also required was testing to satisfy UL/CSA Compliance for Safety (See Appendix B). This testing conclusively proved the safety of the three phase 4-wire + ground whip assembly and RM PDU input cable assembly when used to power nonlinear loads.

The additional testing in Appendix A was performed at the request of APC's Applications Engineering Team. This separate testing was conducted subsequent to the UL/CSA test shown in Appendix B. The intent of this additional testing was to formally document the three-phase whip assembly performance under **three different loading conditions:**

1. 100% nonlinear load on all three phases. Nonlinear was defined as a load of ~132% ITHD with a ~ 0.6 power factor.

2. 100% nonlinear load on two phases and zero load on the third phase. Nonlinear was defined as a load of ~132% ITHD with a ~ 0.6 power factor.

3. 50% nonlinear load + 50% linear load on all three phases. The nonlinear component was defined as a load of ~132% ITHD with a ~ 0.6 power factor. The linear component was pure resistive load with a 1.0 power factor.

This testing reinforced the results of the original UL/CSA testing in Appendix B, i.e., that the components were operating within their specified temperature limits. APC's testing proves that the basic theory about harmonic currents is correct; i.e., the neutral currents can be as high as 1.73 times the phase current. Test #1 shows phase current of ~15.93A, while the neutral current is 27.67A. 27.67/15.93 = 1.7358845. The testing also shows that this condition can only exist when all three phases are equally loaded.

However, even under this load condition, all InfraStruXure three-phase whip and RM PDU power cord components (i.e., cable, plug and connector) operated within their safe UL temperature limits.

Tests 2 and 3 show that any imbalanced loading between the phases or the addition of linear load *reduces* the neutral current. Also note the effect of the addition of linear load to the ITHD % in test #3. This phenomenon of load interaction effects on neutral current in 4-wire circuits is discussed in detail in APC White Paper #38 – "Harmonic Currents in the Data Center: A Case Study"

Conclusion

APC's testing conclusively proves the InfraStruXure three phase 4-wire whips and Rack Mount PDU Power Cords are safe to use at their UL/CSA ratings with single-phase nonlinear loads. Even though nonlinear loads and harmonic neutral currents are relatively rare in today's IT environment, the test results shown in the following appendices demonstrate that InfraStruXure can safely be used in the worst-case applications.

APPENDIX A

InfraStruXure Three Phase Whip Tests

TEST #1 100% Nonlinear (SMPS) load on all phases.
LOAD MEASUREMENTS

	Voltage (Vrms)	Current (Amps)	Power (W)	VA	Power Factor	I THD
Ø1	119	15.94	k1.11	k1.91	0.582	132.2%
Ø2	120	15.93	k1.12	K1.93	0.581	132.3%
Ø3	120	15.71	k1.10	K1.89	0.584	133.8%
N		27.67				

MAXIMUM TEMPERATURE MEASUREMENTS (°C)

Thermocouple # and Location	Line Cord
1. Room Ambient	22.5
2. Neutral wire, copper	59.3
3. Neutral wire, insulation	57.6
4. Outer jacket	55.7
5. Black Ø wire, insulation	57.4
6. Red Ø wire, insulation	55.9
7. Orange Ø wire, insulation	55.8

Thermocouple # and Location	L21-20 Connector
1.Black Ø	45.9
2.Red Ø	41.8
3.Orange Ø	46.2
4.Neutral Ø	59.9
5.Ground	42.2

Thermocouple # and Location	L21-20 Plug
6.Black Ø	45.9
7.Red Ø	44.0
8.Orange Ø	44.3
9.Neutral Ø	58.0
10.Ground	42.5

<u>Runtime</u> (hr:min)4:00

TEST #2 100% Nonlinear (SMPS)load on phases 02 & 03.
LOAD MEASUREMENTS

	Voltage (Vrms)	Current (Amps)	Power (W)	VA	Power Factor	I THD
Ø1	122	-	-	-	-	-
Ø2	120	16.11	k1.13	K1.92	0.585	132.0%
Ø3	120	16.15	k1.13	K1.92	0.584	133.2%
N		22.12				

MAXIMUM TEMPERATURE MEASUREMENTS (°C)

Thermocouple # and Location	Line Cord
1. Room Ambient	24.1
2. Neutral wire, copper	46.4
3. Neutral wire, insulation	45.1
4. Outer jacket	44.4
5. Black Ø wire, insulation	44.7
6. Red Ø wire, insulation	44.5
7. Orange Ø wire, insulation	44.4

Thermocouple # and Location	L21-20 Connector
10.Black Ø	33.2
11.Red Ø	36.4
12.Orange Ø	40.0
13.Neutral Ø	46.9
14.Ground	33.7

Thermocouple # and Location	L21-20 Plug
15.Black Ø	33.4
16.Red Ø	38.1
17.Orange Ø	38.4
18.Neutral Ø	44.8
10.Ground	35.3

<u>Runtime</u> (hr:min) 4:00

TEST #3 50% Nonlinear (SMPS)load + 50% Linear (Resistive)load on all phases.

LOAD MEASUREMENTS

	Voltage (Vrms)	Current (Amps)	Power (W)	VA	Power Factor	I THD
Ø1	118	15.94	k1.64	k1.88	0.870	54.5%
Ø2	120	16.04	k1.67	K1.92	0.872	54.4%
Ø3	119	15.88	k1.65	K1.89	0.869	54.5%
N		22.12				

MAXIMUM TEMPERATURE MEASUREMENTS (°C)

Thermocouple # and Location	Line Cord
1. Room Ambient	25.7
2. Neutral wire, copper	45.2
3. Neutral wire, insulation	44.6
4. Outer jacket	44.6
5. Black Ø wire, insulation	46.2
6. Red Ø wire, insulation	44.5
7. Orange Ø wire, insulation	45.0

Thermocouple # and Location	L21-20 Connector
19.Black Ø	39.4
20.Red Ø	37.4
21.Orange Ø	40.1
22.Neutral Ø	40.6
23.Ground	35.9

Thermocouple # and Location	L21-20 Plug
24.Black Ø	38.9
25.Red Ø	33.8
26.Orange Ø	33.4
27.Neutral Ø	39.3
10.Ground	35.3
Runtime(hr:min)	**4:00**

Appendix B - UL/CSA InfraStruXure Whip Test Report

GENERAL INFORMATION

Test Location: American Power Conversion Corporation
85 Rangeway Road
North Billerica, MA 01862
978-670-2440

Model: Powercord (whip) of InfraStruXure Power Distribution Unit (PSX PDU)

Serial#:

Input Rating: 20 A, 16 steady state

Output Rating:

Product Description: Powercord removed from PDU and loaded with Kepco computer loads with poor power factors (0.68).

Applicant (Program Manager): Bill Ziegler

Regulatory Compliance Engineer: William Burke

Regulatory Compliance Technician: Matt English

Start Date: 3/5/02

Report Issue Date: 3/6/02

Report Number: 02SPE002

Test Setup: 3Ø Powercord wrapped seven times in a coil around a trough to simulate seven whips in a trough. The whip was loaded to 16A/Ø with Kepco computer loads from Ø-N. One Kepco couldn't deliver 16A so two were wired in parallel. The Kepco outputs were loaded with electronic DC loads.

Critical Components:

Comments:

Certification Agency Project Handler: ____

Certification Agency Project Reviewer: ____

Calibration: APC ID #'s of measuring devices used for each test are referenced at the bottom of each data sheet. The list of the lab's test equipment with calibration information is listed at the end of the report.

Applicability of Test Results: The test results in this report apply only to the revision level of the sample tested.

Measurement Accuracy: When test data is within 5% of the pass/fail criteria, the measuring device's instruction manual is referenced to determine the accuracy of the measuring device. If the accuracy of the measuring device is greater than 5%, the test result is either considered to be a failure, or it is to be repeated with a measuring device having a better accuracy range.

Automated Data Collection: When test data is automatically gathered or processed by a computer, the data is verified manually. For example, when temperatures from multiple thermocouples are recorded from an electronic thermometer onto a computer, the accuracy of one component temperature is verified with a hand-held thermal meter.

HEATING (TEMPERATURE RISE)

Test E4: CSA 107.1, Clause 11.3.1; UL 1778, Section 45; EN 60950, Clause 5.1.

Model PSX-PDU 12 AWG Whip was connected to a 120/208 V, 3Ø, 60 Hz source and operated in the modes stated in the table below. Temperatures were monitored until thermal equilibrium. Maximum temperatures obtained during the test were measured by means of 30 AWG, Type K (chromel-alumel) thermocouples placed on the components.

Maximum Measured Temperatures (°C)

Thermocouple # and Location	Normal Mode
1. Room Ambient	24
2. Neutral wire, copper	54
3. Neutral wire, insulation	52
4. Outer jacket	48
5. Black Ø wire, insulation	52
6. Red Ø wire, insulation	48
7. Orange Ø wire, insulation	49
Runtime (hr:min)	**4:00**

Pass/Fail Criteria (excluding abnormal results):

1. XFMR & inductor insulation of products with a specified ambient of 40°C shall be limited to the following temperature rises (measured temp - measured ambient):
   - Class A(105), 50°C; Class B(130), 70°C; Class F(155), 90°C; Class H(180), 115°C.
2. Components such as caps & PC Boards are limited to the component's specified rating minus the difference between the UUT's specified ambient and room ambient.
   - Powercord is rated 90°C. Panelboard is rated 75°C, so powercord is limited to 75°C. Product is rated 40°C, but tested in a 24°C ambient, so powercord is limited to 59°C.
3. External surfaces are limited to the following temperature rises:
   - Carrying handles or knobs: 25 if metal; 35 if non-metallic.
   - Handles or knobs that are contacted but do not involve lifting or carrying:
   - 35 if metal; 45 if glass or porcelain; 60 if plastic or rubber.
   - External surfaces which may be touched:
   - 45 if metal; 55 if glass or porcelain; 70 if plastic or rubber.

Comments:

Equipment ID & Range: 1369

Tested by: Matt English Date Tested: 3/6/02 Report#: 02SPE002

Reviewed by: [P][~~F~~]: William Burke

INPUT CURRENT - 3Ø PDU

Test E5-3: CSA/UL 60950, Clause 1.6.2.

Model PSX-PDU 12 AWG Whip was connected to a 3Ø, 60 Hz source and operated at the voltage and mode of operation listed in the table below. Input current was measured using a True RMS ammeter while operating at max normal load.

Input - Normal Mode

	Voltage (Vrms)	Current (Amps)	Power (kW)	VA	Power Factor	Average Voltage	Average Amps/ Ø	Total Power (kW)
Ø1	119	16.10	1.34	1.91	0.701	208	15.85	3.897
Ø2	121	15.75	1.29	1.90	0.676			
Ø3	120	16.00	1.27	1.92	0.664			

Input Rating: 120/208 V, 3W+N, 20 A, 60 Hz

Pass/Fail Criteria: Measured steady state input current shall not exceed rated input current by more than 10%, when tested at the nominal voltage and under normal load.

Comments:

Equipment ID & Range: 664, 2204, 2205, 2206

Tested by: Matt English Date Tested: 3/6/02 Report#: 02SPE002

Reviewed by: [P][~~F~~]: William Burke Data Sheet Rev 1 (9/18/01)

APC InfraStruXure Equipment Calibration List

APC ID	Type	Manufacturer	Model #	Serial #	Cal. Date	Cal. Due
356	Current Probe Amp.	Tektronix	AM503A	B011415		
411	Current Clamp	Fluke	31/33	5655170	12/18/01	12/18/02
470	Digital Multimeter	Fluke	87	956030123	5/16/02	5/16/03
512	Chatillon	Force Gauge	DFI100	19339	12/26/01	12/26/02
550	Sharp Edge Tester	Tech. Eng. Serv.	SET-50	N/A	12/19/01	12/19/02
664	Power Analyzer	Voltech	PM3000A	6632	9/16/02	9/16/03
731	Thermometer	Stanford Research	SR630	17559	5/16/02	5/16/03
1211	Digital Multimeter	Fluke	45	6608022	9/12/02	9/12/03
1266	Oscilloscope	Tektronix	TDS420A	B022778	12/20/01	12/20/02
1353	Thermometer	Stanford Research	SR630	34148	12/19/01	12/19/02
APC ID	Type	Manufacturer	Model #	Serial #	Cal. Date	Cal.

						Due
1930	Power Analyzer	Valhalla Scientific	2300	40-2441	8/21/01	8/21/02
2161	MilliOhmmeter	Valhalla Scientific	4150ATC	8-4185	8/8/01	8/8/02
2200	Current Probe	Tektronix	A6302	B075985	12/18/01	12/18/02
2204	Current Clamp	Voltech	CL100	3143	12/18/01	12/18/02
2205	Current Clamp	Voltech	CL100	3245	12/18/01	12/18/02
2206	Current Clamp	Voltech	CL100	3247	9/16/02	9/16/03
2207	Current Clamp	Chauvin Arnoux	C103	2385	12/18/01	12/18/02
2208	Current Clamp	Voltech	CL100	3246	2/12/02	2/12/03
3157	Electric Strength	Associated Research	3570D	10743	9/16/02	9/16/03
3158	Thermometer	Agilent	34970A	US37036117	9/16/02	9/16/03
2048	Differential Probe	Tektronix	P5200	B015174	12/19/01	12/19/02
2049	Differential Probe	Tektronix	P5200	B015103	12/19/01	12/19/02
2050	10x Voltage Probe	Tektronix	P6138A	N/A	12/18/01	12/18/02
2051	10x Voltage Probe	Tektronix	P6138A	N/A	12/18/01	12/18/02
2321	Current Clamp	Yokogawa	CL612	75504	12/19/01	12/19/02
3378	Current Clamp	Voltech	CL100	5786	11/28/01	11/28/02
1819	1000x Voltage Probe	Tektronix	P6015A	B036710	11/09/01	11/09/02
1820	1000x Voltage Probe	Tektronix	P6015A	B036711	11/19/01	11/09/02
1788	Oscilloscope	Tektronix	TDS520C	B010530	11/09/01	11/09/02
1369	Thermometer	Stanford Research	SR630	34176	11/27/02	11/27/03
736	Thermometer	Stanford Research	SR630	17574	9/13/02	9/13/03
1993	Current Clamp	Voltech	CL100	2076	12/18/01	12/18/02
2989	Digital Multimeter	Fluke	87	75600972	5/16/02	5/16/03
3572	Power Analyzer	Voltech	PM3000	3572	9/16/02	9/16/03

Uncalibrated Equipment

APC ID	Type	Manufacturer	Model #	Serial #
1530	IEC Test Finger			
1779	Protractor	Dasco Pro	Angle Finder	
2764	Surge Machine	ECAT	E4554	9907204