Circuit Breaker Applications in Data Centers

Retain for future use.

Introduction

Circuit breakers are a key part of the computer power systems in data centers. This bulletin discusses the use of circuit breakers in Power Distribution Units (PDUs) and Remote Power Panels (RPPs) to provide power and protection to the circuits that feed the servers.

Servers handle the data and must function continuously and correctly or the data is compromised and the losses in money and time can be astronomical.

Data center owners and operators are constantly looking for ways to increase productivity by improving uptime and reducing energy costs. Since a good share of the energy costs are directly involved with cooling the white spaces where the servers are operating, thermostat settings are being raised.

White spaces have traditionally been cooled below 72 degrees Fahrenheit. Air conditioning and data center experts are now pushing the temperatures to 80 degrees Fahrenheit or even higher to reduce energy costs.

The increase in white space temperatures are affecting the electrical equipment. Thermal margins of the circuit breakers in the PPUs and RPPs are reduced with the increase in operating temperature.

Another recent design change in data centers that affect the thermal margins of the circuit breakers is the increase in load on each circuit breaker. Previous designs had the circuit breakers loaded at 30–35% during normal operation and 60–70% during single side operation for emergencies, maintenance, etc. Today many newer designs have circuit breakers loaded as high as 40–45% during normal operations and 80–90% during single side operation for emergencies, maintenance, etc.

Issues

- Data center white spaces are getting warmer.
- More servers are being fed from the PDUs and RPPs so the load on each circuit breaker is higher.
- PDUs and RPPs were designed for cooler white spaces with lower loaded percentages. Circuit breaker types and ratings were selected based on these designs.
- Larger transformers are being installed in the PDUs in the same footprints to allow for increased loads which add to the internal temperatures of the PDUs.
- Thermal margins of the circuit breakers in the PPUs and RPPs are reduced with the increase in operating temperature.

Solutions

It makes sense economically and socially to reduce energy costs by doing more with less. It also makes sense that with changes in temperature and loading, reviews of the PDU and RPP designs and circuit breaker selection also need to be done to assure sufficient thermal margin to allow for proper operation at the hotter white space temperatures and higher loads.

See Recommendations below to select the correct circuit breakers and trip systems, best placement of circuit breakers in the PDUs and RPPS, and proper line and load conductor sizing.

Recommendations

Select the Correct Circuit Breakers

Circuit breakers are designed and tested to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. The National Electrical Code (NEC) requires circuit breakers to carry 80% of their amperage rating when installed in an enclosure up to a 40 degrees Celsius ambient temperature.

The NEC and the UL489 Molded Case Circuit Breaker Standard allow 100% rated circuit breakers and equipment. There are specific application guidelines and tests required for the circuit breakers and equipment to apply protection at 100% of the circuit breakers rated current.

Most circuit breakers in PDUs and RPPs use thermal-magnetic (TM) trip systems. TM trip systems are sensitive to ambient temperature changes. TM trip units are calibrated and tested per UL489 at 40 degrees Celsius ambient temperature. Manufacturers publish re-rating factors for temperatures above or below 40 degrees Celsius so that system designers and customers understand how temperatures affect the tripping characteristics of the trip system.

As efficiency efforts continue by increasing the temperatures in white spaces, applying trip units with TM trip systems will have to be a major focus in studying tripping characteristics to assure maximum uptime.

Electronic trip systems are not affected by temperature changes and are much more ambient insensitive than TM trip systems.

Investigations into applying electronic trip circuit breakers must be included in future data center designs and in spare and replacement circuit breaker planning. As future increases in temperature and load are implemented, electronic trip circuit breakers will be much more flexible to assure maximum uptime.

PowerPact J-Frame Circuit Breakers Equipped with Thermal-Magnetic Trip Units

The example shows temperature derating for PowerPact™ J-frame circuit breakers with TM trip units (from the circuit breaker catalog).

A standard-rated PowerPact J-frame circuit breaker with a 250 A TM trip unit would be expected to carry 80% of 250 A = 200 A in a 40 degrees Celsius temperature. If the temperature increases to 50 degrees Celsius, the circuit breaker would carry 80% of 214 A = 171 A.

Table 1 – Temperature Derating for PowerPact J-Frame Trip Unit with Thermal Protection—Long-Time

Temperature[1]		Rating (A) I_n				
°C	°F					
-10	14	221	264	289	330	377
0	32	207	247	273	310	364
10	60	194	230	266	290	330
20	68	180	213	240	270	307
30	86	166	194	220	248	279
40	104	160	176	200	226	260
20	131	131	160	176	193	214
60	140	111	124	161	160	177

1 Shaded areas indicate temperature rerated values, non-shaded areas are standard circuit breaker amperage ratings at 104°F (40°C).

Example of temperature derating for J-frame with Electronic trip unit – from the circuit breaker catalog.

Standard rated J-frame circuit breaker with 250 A electronic trip unit would be expected to carry 80% of 250 A = 200 A up to 50 degrees Celsius temperature. No derating would be needed until the temperature increased to 55 degrees Celsius. (Please note that circuit breakers applied in drawout or Plug-in mounting bases do require a derating above 40 degrees Celsius.)

PowerPact H-, J-, and L-Frame Circuit Breakers Equipped with Electronic Trip Units

Electronic trip units are not affected by variations in temperature. If the trip units are used in high-temperature environments, the Micrologic™ trip unit settings must nevertheless take into account the temperature limits of the circuit beaker.

Changes in temperature do not affect measurements by electronic trip units.

The built-in CT sensors with Rogowski coils measure the current.

The control electronics compare the value of the current to the settings defined for 104 degrees Fahrenheit (40 degrees Celsius).

Because temperature has no effect on the CT measurements, the tripping thresholds do not need to be modified. However, the temperature rise caused by the flow of current combined with the ambient temperature increases the temperature of the device.

To avoid reaching the thermal withstand value it is necessary to limit the current flowing through the device, that is the maximum Ir setting as a function of the temperature.

The table below indicates the maximum long-time (LT) protection setting Ir (A) depending on the ambient temperature

Table 2 – Derating PowerPact J-Frame Circuit Breakers with Micrologic Trip Units

Type of Device	Rating	Temperature						
		104°F (40°C)	113°F (45°C)	122°F (50°C)	131°F (55°C)	140°F (60°C)	149°F (65°C)	58°F (70°C)
Unit Mount	250 A	250	250	250	245	237	230	225
Plug-In or Drawout	250 A	250	246	237	237	226	220	216

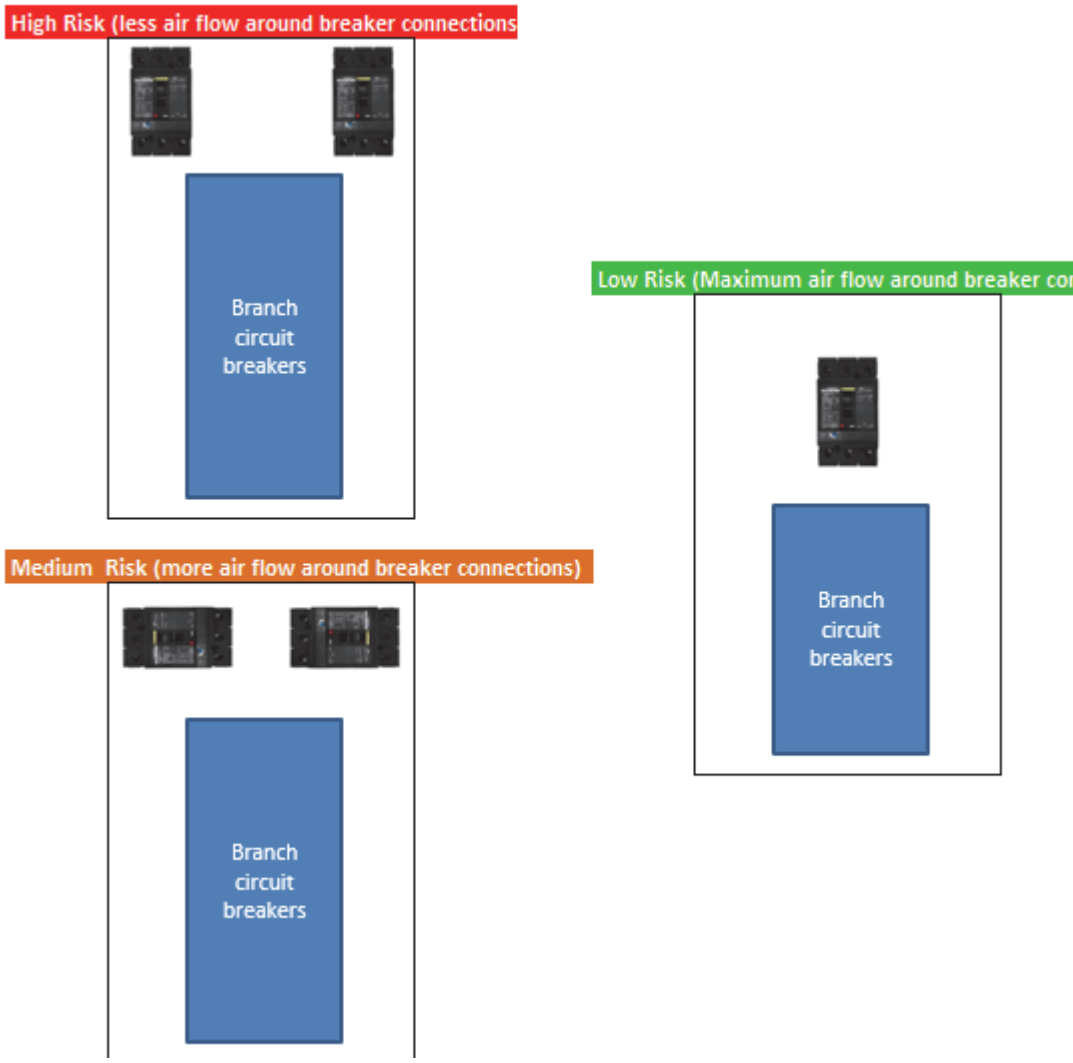
Circuit Breaker Trip System Selection Guidelines

	Good	Circuit Breakers with Thermal-Magnetic Trip Systems Used in many currently designed PDUs and RPPs Very reliable when white space temperature are 68–72°F and the loads during single-sided operation is 75% or less of circuit breaker rating.
	Better	Circuit Breakers with Standard Electronic Trip System Recommended for future PDU and RPP designs for higher white space temperatures and denser loads up to 80% of circuit breaker rating. Electronic trip system is not affected by higher temperatures. Need to make sure temperatures don't exceed the thermal withstands.
	Best	Circuit Breaker with Advanced Electronic Trip System Offer all of the same performance for operations at higher temperatures and loads as standard electronic trip systems. Offer metering and communications for power and energy measurements. Offer temperature monitoring so that problem areas, loose connections, etc. can be identified while they can be resolved quickly and easily.

Circuit Breaker Placement

Circuit breaker placement and orientation inside the PDUs and RPPs can affect the circuit breaker cooling and thermal performance. The following diagrams show how orientation of the circuit breakers affect air flow and thermal performance.

If air flow is limited due to circuit breaker placement or orientation, additional derating may be necessary to assure that the circuit breaker thermal withstand is not exceeded.



Line and Load Conductor Sizing

The NEC and UL489 require specific conductor sizing for circuit breakers. The sizing is based on NEC table 310.15(B)(16) per the 75 degree Celsius temperature rating column. As shown in the table, for 225 A load, the conductor size for the circuit breaker is required to be 4/0. For 250 A, the conductor size is 250 kcmil.

Some PDU and RPP manufactures size conductors per the NEC table 310.15(B)(17) which is for single conductors in open air. This table is used for cable trays, etc. but should not be used for circuit breakers or other equipment products.

NEC Table 310.15 (B)(16) - Multiple Conductors in a Raceway (linked with UL489 standard)

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampaciti
Volts, 60°C Through 90°C (140°F Through 194°F), Not More Th
Earth (Directly Buried), Based on Ambient Temperature of 30°C

Size AWG or kcmil	Temperature Rating of Conductor			
	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Ty
	COPPER			
18**	—	—	14	
16**	—	—	18	
14**	15	20	25	
12**	20	25	30	
10**	30	35	40	
8	40	50	55	
6	55	65	75	
4	70	85	95	
3	85	100	115	
2	95	115	130	
1	110	130	145	
1/0	125	150	170	
2/0	145	175	195	
3/0	165	200	225	
4/0	195	230	260	
250	215	255	290	
300	240	285	320	
350	260	310	350	
400	280	335	380	
500	320	380	430	
600	350	420	475	
700	385	460	520	
750	400	475	535	
800	410	490	555	
900	435	520	585	
1000	455	545	615	
1250	495	590	665	
1500	525	625	705	
1750	545	650	735	
2000	555	665	750	

Wire is 4 sizes too small in some RPP designs - creates high temperature connections.

Correct wire sizes for 225 and 250 A circuit breaker applications

NEC Table 310.15 (B)(17) - Single Conductors in Open Air

Table 310.15(B)(17) (formerly Table 310.17) Allowable Ampacities
2000 Volts in Free Air, Based on Ambient Temperature of 30°C (8

Size AWG or kcmil	Temperature Rating of Conduc			
	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	T
	COPPER			
18	—	—	18	
16	—	—	24	
14**	25	30	35	
12**	30	35	40	
10**	40	50	55	
8	60	70	80	
6	80	95	105	
4	105	125	140	
3	120	145	165	
2	140	170	190	
1	165	195	220	
1/0	195	230	260	
2/0	225	265	300	
3/0	260	310	350	
4/0	300	360	405	
250	340	405	455	
300	375	445	500	
350	420	505	570	
400	455	545	615	
500	515	620	700	
600	575	690	780	
700	630	755	850	
750	655	785	885	
800	680	815	920	
900	730	870	980	
1000	780	935	1055	
1250	890	1065	1200	
1500	980	1175	1325	
1750	1070	1280	1445	
2000	1155	1385	1560	

In fact NEC 110.14 C (1) specifies the use of conductors sized per NEC table 310.15(B)(16): *"...conductor ampacities used in determining equipment termination provisions shall be based on Table 310.15(B)(16) as appropriately modified by 310.15(B)(7)."*

NEC 110.14 C (1)

Wiring terminations of equipment shall be based on 310.15(B)(16) – NOT 310.15(B)(17)

(B) Cooling. Electrical equipment that depends on the natural circulation of air and convection principles for cooling of exposed surfaces shall be installed so that room airflow over such surfaces is not prevented by walls or by adjacent installed equipment. For equipment designed for floor mounting, clearance between top surfaces and adjacent surfaces shall be provided to dissipate rising warm air.

Electrical equipment provided with ventilating openings shall be installed so that walls or other obstructions do not prevent the free circulation of air through the equipment.

110.14 Electrical Connections. Because of different characteristics of dissimilar metals, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be identified for the material of the conductor and

(C) Temperature Limitations. The temperature rating associated with the ampacity of a conductor shall be selected and coordinated so as not to exceed the lowest temperature rating of any connected termination, conductor, or device. Conductors with temperature ratings higher than specified for terminations shall be permitted to be used for ampacity adjustment, correction, or both.

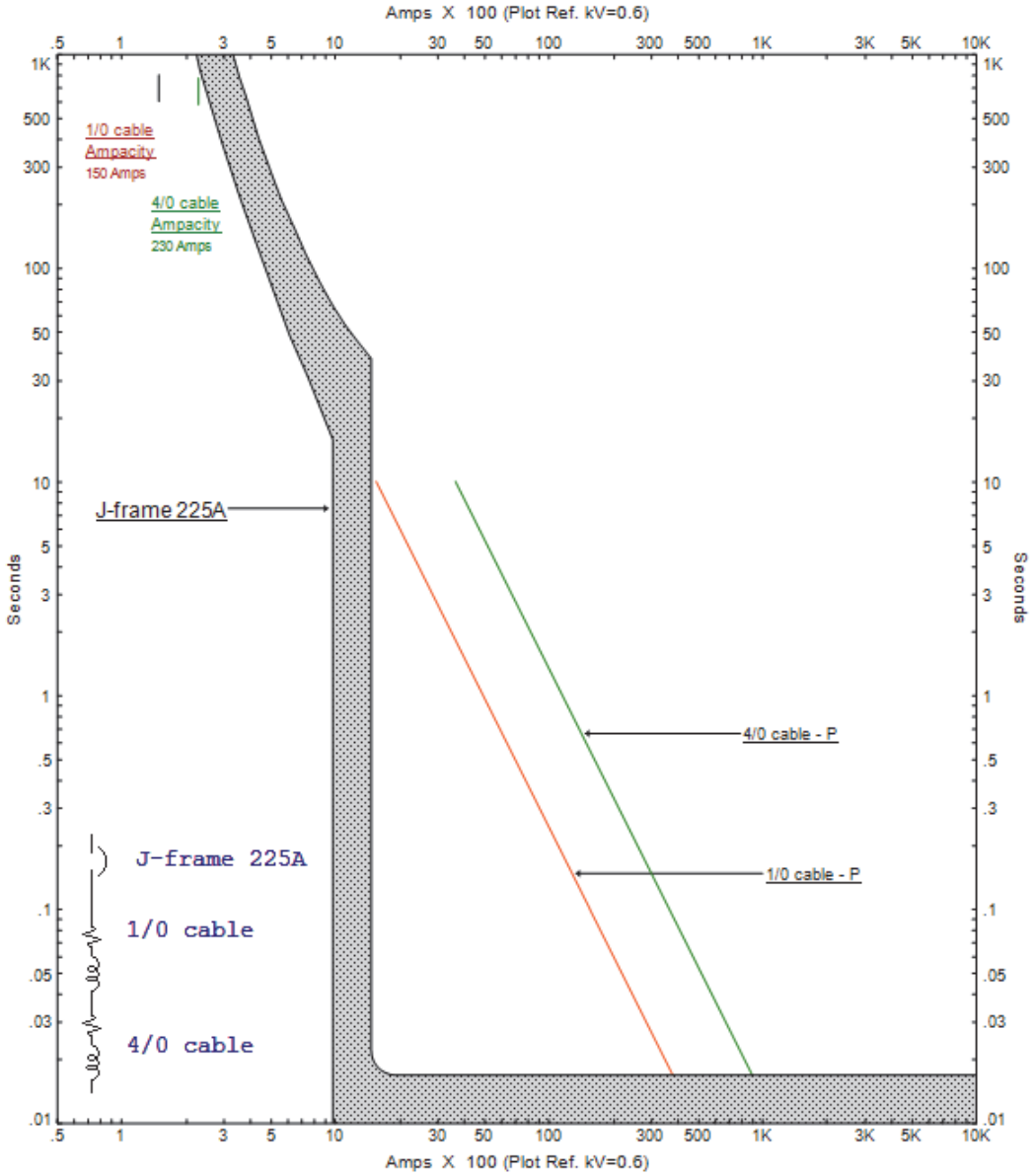
(1) Equipment Provisions. The determination of termination provisions of equipment shall be based on 110.14(C)(1)(a) or (C)(1)(b). Unless the equipment is listed and marked otherwise, conductor ampacities used in determining equipment termination provisions shall be based on Table 310.15(B)(16) as appropriately modified by 310.15(B)(7).

Since circuit breakers are never tested with undersized conductors, circuit breaker performance is unknown and may not trip per the tripping characteristics or may overheat.

The circuit breaker's primary purpose is to protect conductors. The circuit breakers will not protect undersized conductors.

The following cable damage curve shows 1/0 cable sized from the NEC table 310.15(B)(17) – single conductor in open air is 4 wire sizes smaller than required by UL489 and the NEC table 310.15(B)(16) used for equipment which is 4/0 cable protected by a 225A circuit breaker.

The 1/0 cable is not protected from overloads and is designed to carry only 150 A continuously. The 4/0 cable is protected at it's designed capacity of 230 A continuously.



References:

2014 National Electric Code (NFPA 70)

UL 489 Standard for Safety for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures - Twelfth Edition, Dated January 22, 2013

PowerPact H, J, and L-Frame Circuit Breaker Catalog (0611CT1001)

ETAP Version 12.6.0 - Cable Damage Curve

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