Server Technology Inc.

Phase Balancing: The Last Few Inches Of a High-Efficiency Power System

White Paper STI-100-009
2010-June-25

Headquarters
Server Technology, Inc.
1040 Sandhill Drive
Reno, NV 89521
United States of America
+001 (775) 284 2000 Tel
+001 (775) 284 2065 Fax
sales@servertech.com
www.servertech.com
www.servertechblog.com

EMEA
Server Technology Intl.
Sienna Court
The Broadway
Maidenhead
Berkshire
SL6 1NJ
United Kingdom
+44 (0) 1628 509053 Tel
+44 (0) 1628 509100 Fax
salesint@servertech.com

APAC
Server Technology, Inc.
37th Floor, Singapore Land Tower
50 Raffles Place
Singapore, 048623
+65 (0) 6829 7008 Tel
+65 (0) 6234 4574 Fax
salesint@servertech.com

Overview

Within enterprise data centers, power used for operating the facility, lighting, running IT loads and cooling is the largest operational expense. Numerous papers and articles have been published by The Green Grid, The Uptime Institute, PG&E, Lawrence Berkeley Laboratories and others discussing ways to measure, monitor and increase efficiencies. This paper discusses the effect on efficiency of load balancing across phases in a 3-phase distribution system.

Though it is well known that an attempt should be made to balance loads in a 3-phase system, losses attributed to the failure to balance are not typically discussed. As amperage delivered to the data center cabinet continues to increase from 30A to 60A to 100A+, losses in the feeder wiring should be considered.

The Math: Joule’s First Law

Joule's first law describes the relationship between the heat generated within and the current flowing through an electrical conductor. It is named for James Prescott Joule who studied the phenomenon in the 1840s. It is expressed as:

$$Q = I^2 \cdot R \cdot t$$

where *Q* is the heat generated by a constant current *I* flowing through a conductor of electrical resistance *R*, for time *t*. When current, resistance and time are expressed in amperes, ohms, and seconds respectively, the unit of *Q* is the joule.

Dividing both sides of the equation by *t* gives:

$$P = I^2 \cdot R$$

where *P* is power in watts. One watt equals one joule per second. For any conductor with a specific known resistance, as the current increases, the power loss through that conductor increases as the square. For instance, a doubling of current will quadruple the power loss and thus heating from that conductor.

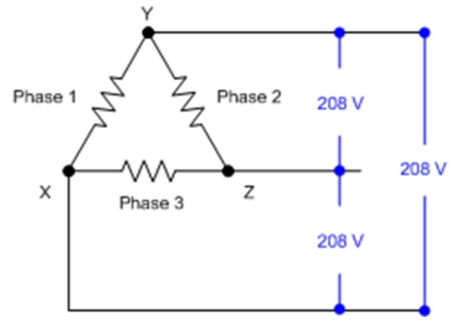
Feeder Cable Resistance

This table provides a quick reference for solid copper wire resistance for a range of gauges.

AWG	Ohms / 1000’			AWG	Ohms / 1000’			AWG	Ohms / 1000’			AWG	Ohms / 1000’		
0	0.1			10	1			20	10			30	100		
1		0.125		11		1.25		21		12.5		31		125	
2			0.16	12			1.6	22			16	32			160
3	0.2			13	2			23	20			33	200		
4		0.25		14		2.5		24		25		34		250	
5			0.32	15			3.2	25			32	35			320
6	0.4			16	4			26	40			36	400		
7		0.5		17		5		27		50		37		500	
8			0.64	18			6.4	28			64	38			640
9	0.8			19	8			29	80			39	800		

Highlighted are 12-gauge which is common for 20A circuits, 10-gauge which is common for 30A circuits, and 6-gauge which is common for 60A circuits. These are rule of thumb values. Slight variation in resistance will be seen due to tolerance in the wire diameter, ambient temperature, insulation, and self-heating effects. These variations can be ignored for this analysis.

Delta Loads



When utilizing a 120/208V 3-phase circuit in North America and applying loads in a delta configuration for 208V, balancing reduces losses in the feeder cables to the distribution point in the cabinet.

Example 1:

A 60A 208V 3-phase circuit is loaded in a delta configuration such that 13A is plugged into each of the three outlet phases: XY, YZ, and ZX. The current on the input lines are calculated using the following equations.

$$X^2 = XY^2 + ZX^2 + XY \cdot ZX$$

$$Y^2 = YZ^2 + XY^2 + YZ \cdot XY$$

$$Z^2 = ZX^2 + YZ^2 + ZX \cdot YZ$$

Thus the current through the *X, Y,* and *Z* input lines equals 22.52A each. Losses can be calculated using Joule's Law.

$$P/R = X^2 + Y^2 + Z^2$$

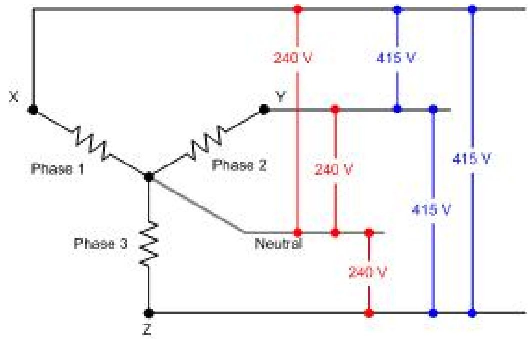
$$P/R = (22.52)^2 + (22.52)^2 + (22.52)^2 = 1521 \text{ watts/ohm } \textbf{or} \text{ 61 watts/100' of cable}$$

Worst case out of balance would be that all 48A are plugged into one of the outlet phases. In this case losses are:

$$P/R = (39)^2 + (39)^2 + (0)^2 = 3042 \text{ watts/ohm } \textbf{or} \text{ 122 watts/100' of cable}$$

This result shows that power loss and heat generated in feeder cables on out-of-balance circuits can be as much as double that of balanced delta loaded circuits.

Wye Loads and Neutral Current



When utilizing a 415V 3-phase circuit in North America or elsewhere around the world and applying loads in a wye configuration for 240V, balancing reduces losses in the feeder cables to the distribution point in the cabinet just as in the case of delta loads. Additionally, with wye loads, the current through the neutral wire should be considered.

Using vector math and assuming the phases are mutually 120° apart, the current *N* through the neutral wire in a 3-phase wye loaded circuit where *X, Y,* and *Z* are the currents through the three input phases is expressed as:

$$N^2 = X^2 + Y^2 + Z^2 - X \cdot Y - Y \cdot Z - Z \cdot X$$

When all three input lines are balanced such that $X = Y = Z$, zero current flows through the neutral wire. Worst case for the amount of current through the neutral wire comes when one or two of the input lines are without load. For instance, if $Y = Z = 0$, then $N = X$; and if $X = Y$ and $Z = 0$, then $N = X = Y$. The neutral current will never exceed the highest input line current.

Current flowing through the neutral wire results in pure loss per Joule's First Law.

Example 2:

A 30A 240/415V 3-phase circuit is loaded in a wye configuration such that 8A is plugged into each of the three outlet phases: XN, YN, and ZN. Simply, the current through each input phase is 8A and the current through the neutral is 0A. Losses are:

$$P/R = X^2 + Y^2 + Z^2 + N^2$$

$$P/R = (8)^2 + (8)^2 + (8)^2 + (0)^2 = 192 \text{ watts/ohm } \textbf{or} \text{ 19 watts/100' of cable}$$

Worst case out of balance would be that all 24A are plugged into one of the outlet phases. In this case losses are:

$$P/R = (24)^2 + (0)^2 + (0)^2 + (24)^2 = 1152 \text{ watts/ohm } \textbf{or} \text{ 115 watts/100' of cable}$$

This result shows that power loss and heat generated in feeder cables on out-of-balance circuits can be as much as 6 times that of balanced wye loaded circuits. In this example, supposing the end user had 100 feeder cables at 100 feet in length each and was paying 10 cents a kilowatt hour, the cost to the facility would be $8410 per year.

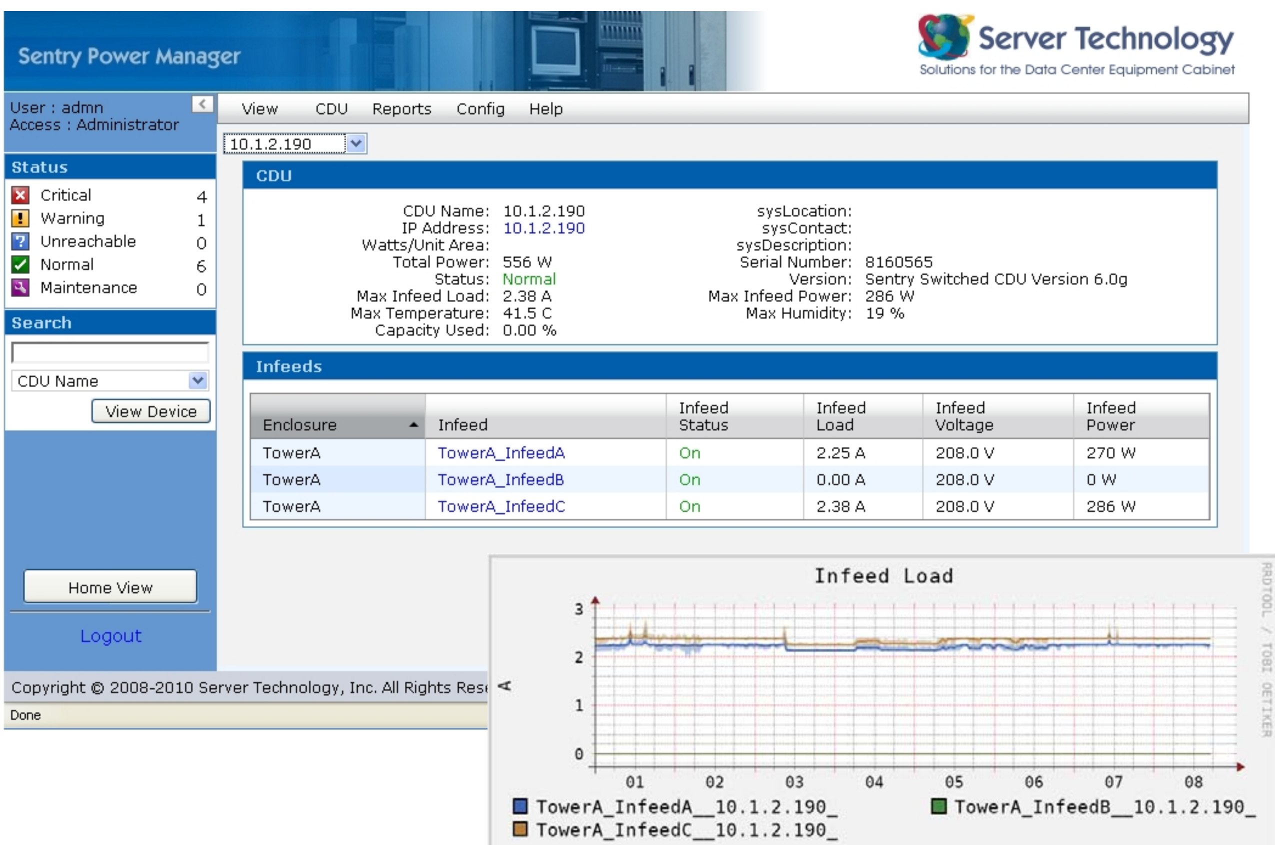
Monitoring Phase Balancing

Server Technology 3-phase Cabinet Power Distribution Units (CDU's) such as the CWG-24VYM311A1 provide three (3) LED digital displays to simultaneously view the amperage flowing through the three input phases. At a glance, a technician can examine their load balancing while installing equipment and during power auditing, even behind a locked cabinet door.

Or, view the loading over the network using the integral web-based GUI and get SNMP alerts and/or email notification of a breach of a user-set balancing tolerance. For instance, an administrator can be notified if one of the input phases is more than 20% higher or lower than the average.

Although it is useful to get spot measurement data of the distributed loads, it is known that that those loads may vary significantly over time due to changes in allocated usage. When that is the case, trending of usage can help an administrator make decisions about how to best improve efficiency.

The Sentry Power Manager by Server Technology provides single point access to all network CDU's for outlet managing, power and environmental monitoring, and alarm/trap handling. By polling and then storing data from the CDU's, it is possible to view the loading over time for the input phases of the CDU's to determine long-term balance conditions.



Summary

With large data centers operating in the tens of megawatts, incremental increases in efficiency translate into appreciable savings. Although the amount of power loss and excess heat due to imbalanced loading is small in comparison with other system inefficiencies, it can be noticeable once all other points have been optimized. Implementing 240/415V power, as discussed in STI white paper Power Efficiency Gains by Deploying 415 VAC Power Distribution in North American Data Centers, goes a long way toward highest efficiency design. But as amperage requirements continue to increase in the data center cabinet, balancing of loads for efficiency becomes more and more important, especially in the wye distribution chain.

A thorough analysis of the load balancing on a cabinet by cabinet basis, with trending of consumption over time is the first step to determine if additional steps should be taken to more optimize the load distribution. As with any potential improvement in the data center, an ROI should be calculated to determine if action is warranted.