Overload Protection in a Dual-Corded Data Center Environment

White Paper 206
Revision 0

by Neil Rasmussen

Executive summary

In a dual-corded environment, the loss of power on one path will cause the load to transfer to the other path, which can create an overload condition on that path. This can lead to a situation where the failure of one path leads to the failure of both paths. This paper explains the problem and how to solve it, and provides a set of rules to ensure that a dual-path environment provides the expected fault tolerance.
The key purpose of a dual-corded or dual-path electrical architecture is to ensure continuity of IT operations during a failure of part of the power distribution system, by providing an alternative power path.

By dual-corded, we mean IT devices that have two separate power inputs, and are designed to continue to operate when one cord loses power.

By dual-path, we mean a power distribution system that supplies a dual-corded IT environment with two separate power paths, such that each IT device receives power from the two separate paths. The two paths may join at some upstream point, which might be at the distribution panel, the UPS output, the switchgear, or the utility mains connection. In some cases, data centers have been constructed where the two paths extend into the mains distribution system and are provided by separate substations or even separate high voltage lines. Most data centers that have a dual-path system extend it up to the facility switchgear, and a standby generator is used to achieve redundancy when there is only a single utility mains feed to the building.

When there is a failure in the distribution system or even in an IT device power supply, a system with dual-corded IT and a dual-path power distribution system is designed to maintain the operation of the IT load. While this is simple in concept, some rules and monitoring must be established to ensure the system operates correctly. This paper first explains how the IT devices behave in this environment, then explains the conditions that must be met to ensure that the expected availability is achieved, and finally provides strategies about how to manage a dual corded environment.

A correctly implemented and verified dual-path power system provides fault tolerance and allows for concurrent maintenance of any point in the power system. This is true even if there are no cross connects between the power paths, and even if one of the paths has no UPS. Many users implement dual-path architecture but do not trust it to work when needed, as evidenced by the use of static transfer switches and cross ties for maintenance. It is a common design practice to ensure power to both paths during many types of failures, even during maintenance. Yet this extra insurance should not be necessary if the dual-path system works correctly to begin with. If a dual-path system is correctly implemented and verified, the system will tolerate the loss of a path without incident, which allows for data center designs that are simpler and less costly.

A dual-corded IT device is assumed to be able to operate correctly when powered from either cord. However, this assumption about the behavior of the devices is not always correct. In a dual-corded IT environment, it is first necessary to establish if the devices truly meet the dual-corded assumption. Over 95% of all dual-corded IT devices typically encountered will correctly operate from a single cord, but this is not 100%. The reasons that there are some devices that do not correctly operate according to the dual-corded assumption include:

- The device specifically implemented dual cords not for redundancy but rather as a means to get more power to the IT device by using multiple power supplies. There are a number of reasons why an IT device might use multiple supplies instead of one larger supply, which include: A) the device was designed to be expandable over time including the ability to add more power, B) the device designers did not want to require a special large power plug, and by using two supplies with conventional plugs they avoided this issue.

- The device has three power cords, and requires two of them to operate correctly. There is no way to plug three cords into two power paths so that the device will survive...
the failure of either path (it might survive the failure of the path with one cord attached, but would not survive the failure of the path with the two cords plugged in).

- The device has implemented dual cords for redundancy under normal configurations, but under full internal IT device configuration the power load is greater than a single supply can provide, so that the dual-cord assumption is only good for lightly configured devices. While this seems to be a design flaw, it has occurred in some networking equipment where some newer plug-in cards did not exist yet at the time of the chassis design. Most vendors in this situation later issued updated power supplies of higher rating, but the burden is on the user to ensure that the configuration meets the dual-corded assumption.
- The device was designed as a dual-corded device, but one power supply has failed in service and that condition has not been noticed or corrected. The device is now behaving as a single-cord device and will drop when the power is lost to that remaining path.
- The device is a dual-corded device but both cords have inadvertently been plugged into the same power path. The device will act normally but will drop when the path feeding the two cords drops. This is a common occurrence, particularly in data centers where there are many different people with rights to access and change equipment.
- The device is not a dual-corded device but is a single-corded device, and has been deployed in a dual-path environment. If dual-corded behavior is needed for this device, it can be achieved by installing a small rack-mount transfer switch for one or a few devices, or, if the single-corded load is large, dual-corded behavior can be obtained by installing a large static switch feeding a special third path to the single-corded racks or zone. For more information see, White Paper 62, Powering Single-Corded Equipment in a Dual Path Environment.

Figure 1
A server that has three power inputs and does not meet the dual-corded assumption.

Two types of devices
Most dual-corded IT devices operate by having the two cords feed separate power supplies or separate groups of power supplies. Within the IT device, the outputs of the power supplies are combined. Under normal operation, the IT load power requirement is shared across the two power supplies (or two banks of power supplies). While this sharing is typically not exactly balanced, each supply (or bank of supplies) typically carries 50% +/- 10% of the load. When the power fails on one path due to failure of the power path or of the IT power supply, the entire IT device load immediately is picked up by the remaining supply. Since the IT device computing power requirement does not change during a power failure, the power path that has not failed will suddenly see its normal 50% share of the IT load power increase to 100%. Furthermore, some IT equipment may speed up fans when a power supply drops out, so the total power requirement of an IT device may actually increase by up to 15% during this event. Therefore, it is reasonable to plan for a 10% increase in load when one path shuts

1 When one power supply drops out, energy used to supply the losses of that supply are eliminated; the increase in the losses of the remaining power supply picking up the load are generally smaller than this, so there actually is a net efficiency increase in the power supply. Therefore, it is possible to observe a total power reduction when one supply drops out. However, in many IT devices the fans speed up on the loss of one supply, which adds power that is much larger than the power supply reduction, so the net is that total power goes up slightly when one supply is lost.
Overload Protection in a Dual-Corded Data Center Environment

Naturally, the power path (and the power supply itself) must be ready to accept this step change in load without malfunction.

However, there is another form of IT load that is less common, that does not “share” its load power across its input cords. In this type of load (which makes up less than 5% of all dual-corded IT devices) the IT device draws all power from one cord under normal operation and switches over to the other cord when the primary input power fails. This “power switch” type of device does provide all the expected redundancy in a dual-corded environment, but has two unusual properties that must be considered during deployment and operation:

- When dual-corded IT devices of the “power share” type are installed, the power on both paths remains evenly balanced as devices are installed. But when IT devices of the “power switch” type are installed, the power will flow depending on which plug is plugged into each path. If the plugs are plugged in randomly, the power should be expected to be roughly balanced between the two paths, but if there is a pattern such as plugging the left cord of the IT device into the left power path, then an imbalance condition can occur where most or even the entire load is on one power path. While the previous discussion explains that the underutilized path will suddenly need to carry the entire IT load if the primary path fails, operators seeing the underutilized path may incorrectly assume that more loads can be placed there, when in fact it must be reserved to ensure system redundancy works correctly. Therefore, existence of the “power switch” type dual-corded IT loads must be correctly recognized and planned for in the design and operation of the data center.

- Dual-corded IT devices of the “power share” type switch over very quickly when there is a failure of one path. The power on the remaining active side increases rapidly (over a few milliseconds) to its new value as it takes on the entire IT device load power. However, IT devices of the “power switch” type behave slightly differently. In these devices, there is a short delay of up to 25 milliseconds before the switch over occurs to the active path. During this short time, the power supplies are unpowered, and must survive on energy stored in capacitors within the power supplies. When the switchover is complete, the power flow must not only power the IT load, but it must recharge the storage capacitors in the power supply. This can result in a brief condition where the load on the active supply jumps to 150% of the IT load requirement or even more for up to 50 milliseconds. If a large number of similar “power switch” type IT devices are installed in the same way, this can actually cause an overload in the upstream supply systems and cause an undesirable breaker trip, creating a load drop. The transient overload is greatly reduced if the “power switch” type devices are installed so that their primary supply cords are not all concentrated on one power path.

To minimize the above problems, it is important to know whether dual-corded devices are of the “power switch” type, and, if so, ensure that they are deliberately installed in an alternating pattern so that the load remains balanced on both power paths (see sidebar).

If an IT device does not meet the dual-corded assumption because it has three power inputs, such as the device shown in Figure 1 above, it can be operated in a dual-corded environment and take advantage of redundant power paths by one of the following techniques:

1) Treat the device as a single-corded device and plug all three cords into a rack-mount transfer switch designed for that purpose.

2) Plug one supply into path A, one into path B, and the third into a rack-mount transfer switch. If there are a number of such devices, they can share an appropriately sized transfer switch.

An example of a 2kW rack-mount transfer switch designed for this purpose is shown in Figure 2 (units of higher capacity are also available).

How do you know if an IT device is of the “power share” type or of the “power switch” type?

The easiest way to do this is to measure the current on each of the power cords using a clamp-on meter and an AC wire splitter. If approximately equal currents are measured on both cords, the device is of the “power share” type.
Efficiency

The question is sometimes raised whether the concentration of loads on one path in a dual-path environment increases or decreases the system energy efficiency, when compared with balancing the load. Analysis shows that for a power system where both paths are of the same design, balancing will increase distribution efficiency, but that the gain is a tiny fraction of a percent\(^3\). Therefore, there is no disadvantage to balancing in this case. However, there are systems where one path has a higher efficiency, for example where one path is UPS protected and the other path is raw utility power. In these cases it is obviously more efficient to concentrate the load on the raw utility path if possible.

Color coding

In a system where there are IT devices that have cords that are supposed to be plugged into either path 1, path 2, or into a transfer switch, it can become difficult to keep track of the various cords and ensure they are wired correctly. This problem can be complicated when the stock cords provided with the IT devices are much longer than required, creating a significant amount of excess cordage within the rack, which can make it very difficult to trace cords to verify that they are correctly connected. To solve this problem, the IT device cords can be replaced with color-coded power cords of the correct length as shown in Figure 3.

To correctly color code IT equipment power cords, three colors are required. In the preferred system of Figure 3, the cords are coded blue = path A, red = path B, and black = single-corded device. Where only one path is UPS protected and the other path is raw utility (sometimes referred to as a Tier 3 power system), the blue path is the UPS path.

\(^3\) The detailed analysis is not provided in this paper.
example in the figure, the single-corded device is fed from the UPS path, but as described previously, it can also be fed from a rack-mount transfer switch (or central static transfer switch), in which case the black IT cord connects to the transfer switch. Note that the use of cords of an appropriate length has made it easier to inspect the power cords and reduced power cord clutter that can block the airflow. Furthermore, in Figure 3 the cords shown are equipped with locking devices so they cannot be pulled out, and have a yellow visual indication that allows personnel to quickly identify any cords that are not fully engaged.

The above discussion leads to a number of simple rules and procedures that need to be followed regarding the deployment of IT devices. These are summarized at the end of this paper. In the next section, we discuss what conditions must be met in the power distribution system to assure redundancy in the dual-path environment.

Given the characteristics of the dual-corded IT load, we can now describe how the power distribution system must be designed and managed to assure that the expected redundancy is achieved.

The key goal in the power distribution system is to ensure that a failure anywhere in one path will not cause the failure of the second path. The fact that a data center is currently operating correctly under normal conditions is no assurance that a power path will operate correctly when the other path fails.

We have already explained that the failure of one path will result in the step increase of the load on the alternate path. The magnitude of this step, and where it occurs, will depend on the nature of the failure in the failed power path. Here are two important examples that bound the scope of the load step:

The failure of a path at the branch circuit to a rack cabinet will typically result in a doubling of the power load on the alternate path circuit to that cabinet. However, upstream breakers supplying multiple PDUs on the remaining path may only see a few percent increase in power.

The failure of a path at the central UPS supplying that path will typically result in a doubling of the power load on every alternate path circuit to every cabinet. In addition, all upstream breakers supplying PDUs on the remaining path will also see a doubling of power.

In all cases, it must be ensured by both design and by operating practices that any failure on one path will not cause an overload condition at any point in the alternate path. While this sounds very complicated, it can be assured by understanding a few simple principles:

- If each path is designed so that at every point it is capable of supplying the entire power requirement of the downstream equipment, then it cannot be overloaded.
- If procedures or systems are implemented to assure that the IT devices are never installed so as to exceed the design values of the distribution system, then no overload will occur.

These simple principles are easy to define in a design, but hard to ensure in a dynamic data center environment. There are generally two ways to implement these principles:

- Do a worst case analysis on every add, move, or change to ensure that no conditions exceed any design value. This requires a lot of information that may be difficult to obtain about the IT devices, requires time and engineering expertise, and can result in a

Note: Non-critical single-corded loads should be plugged into a UPS feed. If this feed fails, it can be manually connected to the remaining feed if necessary. Example loads include KVMs, monitors, etc.
very conservative design where the data center capacity is significantly underutilized. This approach is best used where there is a very large installation of homogeneous IT equipment.

- Implement monitoring of the distribution system and provide data regarding operating safety margins and give warnings when adds, moves, or changes approach the operating limits of the different points of the distribution system. This is the most practical approach in a dynamic data center environment.

To implement a monitoring strategy, each phase of every circuit is monitored to assure that it will not overload in the case of any failure anywhere in the alternate power path. Note that in an ideal dual path environment, the load in any path can at most double for any failure in the alternate path, so this would mean monitoring to assure that no circuit is loaded beyond 50% of the design rating. However, in a practical data center that includes some loads that are of the switch type, and some loads that exhibit increased power consumption when a power supply shuts off, we need to provide an extra margin of safety to assure no circuits overload. Experience shows that monitoring circuits to a practical limit of 40% of the design load is sufficient to assure reliable operation during any path failures. The monitoring system would report overloads so they could be identified during equipment installation or during operation, to allow operators to take action to reduce the load.

In a homogeneous IT environment, where the load is comprised of many of the same IT devices, the monitoring threshold should be established by measuring the behavior of a representative IT device. If the device does not exhibit an increase of power when one path is lost, then the monitoring threshold can be set to 50%. For every 1% increase noted in the power consumption, the monitoring threshold should be reduced by 0.5%. For example, if the IT device load goes to 110% when one cord fails, the monitoring threshold should be set to 45%.

While it seems complicated to implement margin monitoring on hundreds of branch circuits in a data center, this is a standard feature on many rack PDUs and providing reports is an "out of the box function" on some data center infrastructure management (DCIM) solutions, such as those offered by Schneider Electric and others. White Paper 107, *How Data Center Infrastructure Management Software Improves Planning and Cuts Operational Costs*, provides information on how DCIM can help manage adds, moves, and changes.

When such a system is implemented, users can gain enough confidence to depend on the system for concurrent maintenance by allowing one path to go down for a rack, pod, room, or even the whole facility. In fact, if users are not confident in the operation of the system and refuse to depend on it for maintenance and changes, then it is less likely to ever be maintained or tested and consequently is even more likely to fail when a real power outage occurs.

This leads us to the rules regarding the implementation of dual-path redundancy:

**Rule 1**: Verify that the devices installed do correctly operate as dual-corded devices with fail-over capability. If this cannot be assured by the vendor, consider in house testing of devices before deployment.

**Rule 2**: Verify that some system and procedure has been implemented to monitor and correct power supply failures in dual-corded devices. Most IT devices have provision to report this, but often the warnings are not properly monitored or routed to cause a response action.

---

5 Refer to the earlier section “Behavior of the dual-corded device” to review the six ways in which dual-corded devices may not operate as expected.
Rule 3: Institute installation and change control procedures that ensure that the two cords of each dual-corded device are plugged into different power paths. Ensure that the dual cords are connected to the same phase (or phase pair) on each of the two rack PDUs and ideally, the same outlet group on each of the two rack PDUs. Implement color coding of cords and ensure cords are of the appropriate length for the application.

Rule 4: Be aware of single-corded loads in the data center, understand if they are critical, and, where appropriate, provide them with dual-path support through the use of rack-based automatic transfer switches (for targeted devices) or large Static Switches (for clusters or zones of single-cord devices).

Rule 5: Know which devices, if any, are of the “power switch” type configuration and ensure that there is a process to ensure that the primary power inputs of different devices are not concentrated on one power path, but are distributed across the power paths in a balanced manner.

Rule 6: Implement monitoring at each phase of every circuit in the data center and at all levels in the distribution system⁶ to provide data on how close operating currents are to 40% of design level, and to provide warnings when any operating current exceeds 40% of the design level⁷. Check margins before adds, moves, and changes to avoid pushing any operating current above 50% of design rating.

Rule 7: Consider implementation of a verification protocol where racks or groups of racks are periodically inspected for proper cord connections and then tested by individually shutting off each power feed. By testing only a small section of the data center and appropriately selecting the timing of tests, consequences of failure are limited. This practice greatly increases confidence in the dual-path system.

---

⁶ Note that while it is obviously necessary to implement monitoring at final branch circuits, this is not enough to assure reliable operation; it is equally important to monitor feeders and subfeeders to assure they will not overload when a corresponding feeder in the alternate path goes down.

⁷ If the load is known to change significantly during a feed failure or if the dynamic variation of the power consumption of the IT loads with IT workload is significant, then a number less than 40% should be considered, or, alternatively, power capping software should be considered.
This paper explains how dual-corded IT devices function and considerations of how to deploy them in data centers so as to achieve fault tolerance for failures in a power path.

While many devices have multiple power cords, they do not all behave the same way, and not all will actually function correctly when operated from only one power cord. An effective redundant design to achieve fault tolerance requires that each device be assured, by testing or design, to meet the assumed requirement that it can operate on a single cord.

Inevitably some device that is not dual corded will need to be deployed in a dual-path data center, and these can obtain some of the benefits of dual-corded operation by feeding them from a rack-based transfer switch designed for that purpose or, if a large number must be supplied, via a stationary static switch.\(^8\)

The presence of dual-power paths does not ensure redundancy, and the loss of one path can cause an overload and failure in the alternate path, unless the adds, moves, and changes over time have not violated the system design criteria.

The key to ensuring that fault tolerance is achieved is to monitor each phase of every circuit in the data center to assure that none is loaded beyond 40-50%. This monitoring sounds complex due to the number of circuits but is a standard function in some rack PDUs and DCIM software. By following the set of simple rules outlined in this paper, users can assure that a dual-path system achieves the planned degree of redundancy and availability.

---

**About the author**

Neil Rasmussen is a Senior VP of Innovation for Schneider Electric. He establishes the technology direction for the world’s largest R&D budget devoted to power, cooling, and rack infrastructure for critical networks.

Neil holds 25 patents related to high-efficiency and high-density data center power and cooling infrastructure, and has published over 50 white papers related to power and cooling systems, many published in more than 10 languages, most recently with a focus on the improvement of energy efficiency. He is an internationally recognized keynote speaker on the subject of high-efficiency data centers. Neil is currently working to advance the science of high-efficiency, high-density, scalable data center infrastructure solutions and is a principal architect of the APC InfraStruXure system.

Prior to founding APC in 1981, Neil received his bachelors and masters degrees from MIT in electrical engineering, where he did his thesis on the analysis of a 200MW power supply for a tokamak fusion reactor. From 1979 to 1981 he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.

\(^8\) Many rack-based ATS are designed fast enough to sustain the IT load during a switch transition. This is not true for larger centralized ATS, so a faster static type switch is required when a switch supports multiple racks or a zone.
Resources

**Powering Single-Corded Equipment in a Dual Path Environment**  
White Paper 62

**Comparing UPS System Design Configurations**  
White Paper 75

**An Improved Architecture for High-Efficiency, High-Density Data Centers**  
White Paper 126

**How Data Center Infrastructure Management Software Improves Planning and Cuts Operational Costs**  
White Paper 107

**Power and Cooling Capacity Management for Data Centers**  
White Paper 150

Browse all white papers  
whitepapers.apc.com

Contact us

For feedback and comments about the content of this white paper:

Data Center Science Center  
dcsc@schneider-electric.com

If you are a customer and have questions specific to your data center project:

Contact your Schneider Electric representative at  
www.apc.com/support/contact/index.cfm