EMGT 835: Engineering Management
Field Project

# Upgrading Data Centers' Electrical Systems: Selecting the Best Electrical Design Configuration for Existing Data Centers

By

Richard T Lienou

Spring Semester, 2012

An EMGT Field Project report submitted to the Engineering Management Program
and the Faculty of the Graduate School of The University of Kansas
in partial fulfillment of the requirements for the degree of
Master's of Science

Tom H. Bowlin
Tom Bowlin
Committee Chairperson

Terence D. Flanagan
Committee Member

Daniel L. Schmidt
Daniel Schmidt
Committee Member

Date accepted: 4/12/12

## ACKNOWLEDGEMENTS

Firstly, I would like to thank my lovely wife, Tcheula, and my sons, Ronel, and Uriel, for being patient, understanding and supportive while I have strived to obtain an Engineering Management master's degree. Sorry for not spending enough time with you; I hope that this accomplishment will be worth the sacrifice.

Secondly, I would like to thank all the people I interviewed for giving me the opportunity to learn from the information they shared with me.

Thirdly, I would like to thank my company, Black & Veatch Corporation, for the financial support provided to help me complete the Engineering Management program.

Last, but not least, I would like to thank all my teachers and my committee members Dr. Tom Bowlin, Terry Flanagan, and Daniel Schmidt for their assistance in helping me to complete not only this field project but also this program.

# EXECUTIVE SUMMARY

The increasing amount of data processed by companies and institutions as a result of the Internet boom has stretched most existing data centers to their limits. Today more people than ever own cell phones, watch videos on mobile devices and make all kinds of online transactions. All the data necessary to make all of these activities possible are processed and stored on servers and computers housed in data centers around the world. Data processed and stored in these servers and computers are accessed 24/7 and as a result, most are required to be operational all the time.

In order for these servers to be continuously operational, data centers' electrical systems need to be very reliable. However, because most existing data centers are decades old, the reliability of their electrical systems are not adequate unless they are upgraded and well maintained. The high cost of power has also increased the need to make data centers' electrical systems more efficient. In general, before any upgrade is made, data center managers evaluate their existing electrical systems to identify the needs of their data centers and develop the best plan to upgrade these electrical systems.

A data center electrical system can be an "N", "N+1", "2N", "2(N+1)" configuration or a variation of these configurations. An N electrical system configuration has just one distribution pathway with no extra capacity and an N+1 electrical system configuration also has just one distribution pathway but with some extra capacity in the UPS subsystem and the backup generator subsystem. Two distribution pathways exist for 2N and 2(N+1) configuration. The level of upgrade done on an existing electrical system generally depends on the type of configuration and equipment of the data center.

This report looks into some of the considerations necessary to select the best electrical design configuration for existing data centers. Specifically, the report identifies what can be done to make some existing data centers' electrical systems more reliable, more efficient and easier to maintain.

# TABLE OF CONTENTS

## LIST OF FIGURES

**LIST OF TABLES**

# CHAPTER 1 - INTRODUCTION

The digital revolution has created an environment in which a large amount of information is processed by servers and computers. The large amount of information processed is necessary for large businesses to run and is generally stored and maintained in data centers. Many companies and organizations will not be able to serve their customers, collaborate with partners, or perform basic business functions if they are not able to properly manage information.

A data center is a facility that hosts IT equipment such as servers and computers that are generally used to process all type of information for businesses. These data centers have become a critical component in all types of businesses (Baggini and Granziero 2011). This is because, for example, more people than ever now own cell phones and computers that they use for all sorts of applications such as watching videos, working online, making calls, and sending text messages. Data making these activities possible are also stored and processed in servers located in data centers.

## Background

A typical data center's electrical system configuration can be divided into several subsystems:

- The utility feeds subsystem, which includes the incoming power to the data center and the utility transformers.
- The backup generators subsystem, which includes the generators and generator Switchgear(s).
- The main switchgears and auxiliary loads subsystem.

- The Uninterruptible Power Supply (UPS) subsystem, which includes the UPS modules, batteries, maintenance bypass panels and UPS output switchboards.
- The Power Distribution Units (PDU) subsystem, which includes the PDUs and the Remote Power Panels (RPP).
- The computers/servers subsystem.

Google is one of the largest owners and operators of data centers in the world. Google data centers around the world continuously draw about 260 million watts of electricity (Glanz 2011). Because of the amount and importance of data processed in data centers, the servers and computers are expected to be available almost all the time. A data center's electrical system is one of the key systems critical for the operation of these servers and computers. The electrical system needs to be designed such that power is continuously available for the data center critical loads. This paper will only focus on the electrical system because without electrical power, none of the important systems that are necessary for servers and computers to be available, such as the Heating, Ventilation and Air Conditioning (HVAC) units, will be operational.

Data centers rely heavily on the continuous supply of electrical power and any electrical problem can easily cause serious damage to the servers and computers. Power issues increasingly cause serious concerns because many data centers are more than two decades old and power failures are very costly. As a result, data centers' electrical systems are receiving more attention than ever before.

The digital revolution has increased the need for more powerful servers and more capacity, which in turn have increased the need for more reliable electrical systems and more electrical capacity. Most existing data centers' electrical systems need to be upgraded to meet the ever-increasing demand from servers. Energy usage at data centers doubled between 2000 and 2006 and was expected to double again by 2011 (Silicon Valley Leadership Group 2008). Forty-four times more data will be processed by the year 2020 compared to 2011 (Crouch 2011). This anticipated growth, the risks associated with the growth and a high availability expectation have put enormous pressure on data center owners to upgrade their facilities' electrical systems in order to meet the demands and needs of their customers.

The ultimate goal for any data center is to be available 24/7. This means that even when utility power is not available, the data center is still expected to operate. Backup generation built into the electrical systems needs to be always ready to support critical loads and single points of failure have to be eliminated. A single point of failure on an electrical system is "an element of the electrical distribution system that at some point will cause downtime, if a means to bypass it is not developed in the system" (McCarthy and Avelar 2011, 3). One of the main goals of any data center electrical system design is to eliminate as many single points of failure as possible. This is why many upgrades done on data centers' electrical systems involve actions to eliminate single points of failure. Furthermore, data center electrical system upgrades are necessary because of outdated electrical systems, insufficient capacity and the need for more reliable and easily maintainable electrical systems.

## Research Objectives

Once the decision has been made to upgrade a data center, an engineering firm is generally hired to develop and propose design options. Over the years, engineers have developed many types of electrical design configurations for data centers with the most common being N, N + 1, 2N and 2(N+1) configurations. Many variations of these configurations exist.

There are many factors that affect the design configuration choice when upgrading data centers' electrical systems. The objective of this research paper is to analyze a data center electrical system upgrade process and make recommendations on what is necessary to have the best data center electrical design configuration.

The expected outcome from this research is to have a better understanding of the driving forces behind the need to upgrade a data center electrical system and the reasons for the selection of different electrical design configurations. Another expectation is to be more knowledgeable about electrical system problems encountered at data center facilities and the possible solutions to these problems.

# CHAPTER 2 - LITERATURE REVIEW

Most data centers that host companies' and organizations' servers are decades old and their electrical systems do not meet some of the reliability, efficiency and design configuration requirements that customers expect today. As a result, all subsystems of the electrical system should be evaluated not only to identify if an upgrade is needed but also to determine what needs to be done to satisfy any design configuration that the data center manager has planned for the facility. Any upgrade project should have at least one of the following goals: making the electrical system more reliable, more available, more efficient, or increasing the capacity. The literature review will discuss the need for an upgrade, the electrical design configurations, the electrical system reliability and system efficiency.

## Need for Upgrade

There are many reasons why some existing data centers need to be upgraded besides their age. The report "Data Center Energy Forecast" presented by the Silicon Valley Leadership Group in July 29, 2008 examined a report presented to Congress in 2007 by the Environment Protection Agency (EPA) on Server Data Center Energy Efficiency. The EPA report estimated a rapid growth of energy usage by data centers based on current trends. Because data centers consume too much power and to reduce their environmental impact, recommendations were made on how to slow down the rapid growth without affecting the services provided. The Silicon Valley Leadership Group report looked at how many companies implemented the EPA recommendations and what results were obtained. The report concluded that data centers were on track to meet the

EPA's best case scenarios of reducing electricity usage by about 50% by 2011 as a result of following the EPA recommendations. The problem with this conclusion was that the data centers studied were not representative of the industry because they were operated by major companies such as Oracle and Sun Microsystems. These companies manufacture servers and can afford to spend substantial amount of money to build top of the line data centers to showcase their products to potential customers or enhance their image (show how green they are). These data centers were more efficient than most data centers in the industry. In reality, even with the late 2000s recession, data centers' energy usage in the U.S. grew by about 36% between 2005 and 2010 (Markoff 2011). Regardless of the amount of energy consumption, most in the industry will agree that the majority of data centers' electrical systems need to be upgraded to improve reliability, efficiency, maintainability or capacity.

Before any upgrade is possible, data centers' facility managers assess their facility power to determine the electrical power capacity needed to support any anticipated growth. The technical paper "Calculating Total Power Requirements for Data Centers" by Sawyer discusses needs assessment at data centers. The author is right that any initiative to upgrade a data center electrical system must start with an assessment of the system. The assessment will allow a better understanding of future capacity needs.

In addition, the technical paper "Data Center Infrastructure Resource Guide" by ANIXER, a world's leading supplier of data center products, discusses the recent increase in data center activities that has contributed to the urgent need to upgrade many data centers' electrical systems because of the increase in power consumption by data centers. For example, data centers power consumption doubled between 1998 and 2003 and doubled again between 2003 and 2006 (Anixer 2008). The need to upgrade data centers or build new ones is even more urgent when future growth projections are considered.

## Electrical Design Configurations

When an existing data center's electrical system is in need of an upgrade, the upgrade performed on the electrical system might not be exactly what is needed because of some constraints and limitations associated with existing equipment and the data center. Generally, the best electrical design configuration will be customized for the existing site based on the cost of the upgrade, how easy it will be to add or change equipment, the space available for new equipment and the extent to which engineers and owners can agree on a design.

It is very important for owners and designers to know what options are available to them when upgrading an electrical system. The technical paper "Planning and Design for a Data Centre Electrical Power Infrastructure: Distribution, UPS, Safety and Savings" by Baggini and Granziero covers all the major electrical topics engineers need to address when designing a data center electrical system. According to the authors, the main aspects that must be taken into account when designing a data center electrical system are the reliability and maintainability of the power supply. The selection of the power distribution and UPS configurations are very important because the UPS subsystem is one of the most critical pieces of the electrical system. Although Baggini and Granziero believe it is not necessary to provide redundancy to components with high reliability compared to other components, in fact it is the cost of downtime that mainly drives the degree of redundancy built into data centers' electrical systems.

Complementing the technical paper mentioned above, the technical paper "Comparing UPS System Design Configurations" by McCarthy and Avelar gives a detailed comparison of the main electrical design configurations for data centers and discusses how to choose the best one. The problem with the discussion in this paper is that the authors assume that a new electrical system is being built and no mention is made of some of the difficulties encountered with existing systems. As we will see later in this paper, choosing the right configuration when upgrading a data center electrical system depends partly on the type of existing equipment.

## Electrical System Reliability

Most data center managers and engineers that Black & Veatch's engineers interacted with over the years said that the most important requirement of the data centers under their control is those data centers' reliability.

Therefore, it is no surprise that 7x24 Exchange, the leading knowledge group for those who design, build and maintains mission-critical facilities, organizes at least one forum each year about the reliability of mission critical facilities. During fall 2011 forum, Fairfax, the president of MTechnology talked about some of the hidden threats to mission-critical facilities' reliability. He also discussed some of the most common problems encountered and how to limit or fix them. His suggestion that engine reliability and aging would improve if the maximum backup generator time to pick up critical loads increased from the common practice of 10 seconds to the 25-30 second range is debatable. Backup generators typically used in data centers' electrical systems are specifically built for data centers and similar critical facilities such as hospitals. They are designed to start and pick up loads within 10 seconds. Therefore, increasing this time will not necessarily improve the life and reliability of the generator. Besides, life safety loads are required to be picked up by emergency generators within 10 seconds (NFPA 110 2010) and most data centers have their life safety loads and critical loads on the same backup generator system. If the life safety loads are not connected to the same backup generator system as the critical loads, then increasing the pickup time beyond 10 seconds will surely not have a negative impact on the generator.

Standby power is a critical part of the data center electrical system. It is responsible for powering servers if the utility power is off for more than a few seconds. In his 2011 article “Maximizing the Reliability of Standby Power Used in Mission-Critical Application” published in the 7x24 Exchange International magazine, Dauffenbach discusses standby generator reliability. According to Dauffenbach, to maximize reliability, facility managers need to understand and consider the critical factors that go into specifying, installing and maintaining a standby power system. This is absolutely true because the better a data center manager knows his/her equipment, the better it will be taken care of, the better it will operate and the longer it will last.

Expensive upgrades are not the only solutions to data centers’ electrical systems reliability problems. Simple steps such as regular maintenance, when performed correctly, substantially improve the reliability of data centers’ electrical systems. Because of the high expectations on data centers to be reliable, data center managers generally develop excessive maintenance plans for some major equipment. The problem with excessive maintenance plans is that they actually reduce the reliability of the data center electrical system. This is because maintenance can cause new problems such as a leaving a generator output breaker in the test position, dropping tools in live equipment and accidentally removing/returning equipment from/to service (Fairfax 2011). The risk of power failure during maintenance is high, partly because of human error blamed on fatigue. Most routine maintenances are performed late in the night.

## Electrical System Efficiency

When upgrading a data center electrical system, designers not only try to make the system more reliable by modifying the existing electrical system configuration and replacing equipment that has reached its end of life, they also try to make the data center more energy efficient. In a world dominated by the green movement, devices are being built to be more efficient and consume less energy than ever before. The book *Grow a Greener Data Center* by Alger discusses some of the reasons to go green such as growing power demand, capacity gains and monetary benefits. A data center can not be green without been efficient. The efficiency information in this book is very important when selecting the best design configuration for an existing data center's electrical system. In this industry, going green is almost certain to be a good decision in the long term because it will eventually save money and reduce the data center's environmental impact.

The single piece of equipment in a data center with the most opportunity for efficiency gain is the UPS because UPS efficiency is greatly affected by the amount of load supported by the UPS. For the same percentage of full load, a newer UPS can easily be five percent more efficiency. This is why most technical papers and magazines articles about data center electrical system efficiency focus on UPS modules. The technical paper "High Performance Data Centers: A Design Guidelines Sourcebook" produced by Pacific Gas and Electric Company in January 2006 provides a viable alternative to inefficient equipment in data centers including UPSs. The paper discusses how existing power supplies at data centers can be used efficiently and what to consider when replacing an existing UPS with a new and more efficient one. While the paper provides many efficient design suggestions that will be beneficial in a wide variety of data center design situations, no design guide can offer a universally correct way to design a data center. Selecting the most efficient UPS system that meets the data center's needs will save money on operating cost. However, it is not easy to calculate the saving and the return on investment (ROI).

Other relevant literature discussing topics found in this paper include "Build the Best Data Center Facility for Your Business" by Alger, "National Survey on Data Center Outages" by the Ponemon Institute, "Battery Technology for Data Centers and Network Rooms: Battery Options" by APC and "Human Error in the Data Center" by Hughes.

# CHAPTER 3- RESEARCH PROCEDURE

The research technique consisted of searching reliable online sources and KU library databases to identify relevant reading materials such as “Build the Best Data Center Facility for Your Business” and *Grow a Greener Data Center* by Alger. Other reading materials included Data Center Management journals and magazines, non-confidential company’s resources and many technical papers. One of the most important parts of this research work was interviewing at least one data center manager as well as data center design experts. Some of the questions asked during the interviews can be seen in Appendix B.

Upgrading data centers’ electrical systems consist of replacing or modifying some subsystems to improve the electrical systems’ reliability, efficiency, capacity or maintainability. In order to select the best electrical design configuration for existing data centers, typical designs for subsystems will be considered and some of the ways to upgrade them will be evaluated in light of our goal of making the overall system more reliable and efficient with more capacity. While analyzing these subsystems, the different reasons why some people prefer certain approaches to others will also be investigated.

In addition to the technical papers, data center magazines, books and company documents evaluated for this research paper, two data center designer experts and a data center manager were interviewed. Both of the data center experts have had at least thirty years of experience designing data center electrical systems, and the data center manager is in charge of all the data centers owned or operated by one of the largest U.S. telecom companies. The interviews took place in the interviewees’ offices in Overland Park, Kansas and Lee’s Summit, Missouri. Five interview requests were made but only three interviews were possible. The two interview requests that were turned down were turned down by engineers working in data centers. These engineers did not receive the permission from their supervisors to be interviewed for this research paper. The purpose of the interviews was to fully understand some of the topics covered in this paper and verify some of the findings in the literature.

In the early stage of the field project, a plan of completion of the field project was developed to keep track of any progress made and meet important deadlines. Most of the research materials were then collected and divided into four main areas of focus, which included documents evaluated to discuss the need for upgrade, the electrical design configuration, the electrical system reliability and the electrical system efficiency. By the time that most of the research materials were collected, it was obvious that some claims or findings needed to be verified. Therefore, some people were contacted, and interview requests were made. As mentioned above, three people were interviewed. While developing the report, the four main areas of focus were applied to most of the data centers' electrical subsystems studied and some of the information collected from the interviews was inserted into the report. Because not enough interviews were made, the decision was then taken to create a recommended consideration table to complement the interviews to meet the report originality requirement.

# CHAPTER 4- ELECTRICAL SYSTEM UPGRADES

One of the most challenging tasks when upgrading a data center electrical system is to decide on the electrical configuration to adopt. The assumption here is that the upgrade is a major one requiring the existing electrical configuration to be modified. Selecting a design configuration is such a challenge because the main design configurations used in the industry are constantly changing to meet data centers' demands. However, despite what the data centers' needs are, some design considerations must be made before those needs can be taken care off.

## Making the Decision to Upgrade

Any data center electrical system must be reliable to the satisfaction of the data center manager and the clients using the servers housed in the data center. It is safe to assume that the reliability of a data center comes primarily from the strength of the data center's electrical infrastructure because the greater its source of power, both primary and backup, the more reliable the servers (Alger 2007). The above statement is of little importance unless the entire electrical system is given the same high level of attention. In other words, all subsystems need to be evaluated. Figure 1 shows the typical subsystems of a data center electrical system.

An overall evaluation of the electrical system should include finding the threats to the system by relying on professional examination and not general perceptions. For example, building redundancy into the electrical system and testing the critical equipment of the system will extend the life of critical equipment, save money and improve the reliability of the system only if it is done right and at the right frequency. Too much redundancy or excessive testing could actually reduce reliability. When threats are found, simple investigations can sometimes reveal that most threats can easily be eliminated with a well defined maintenance plan.

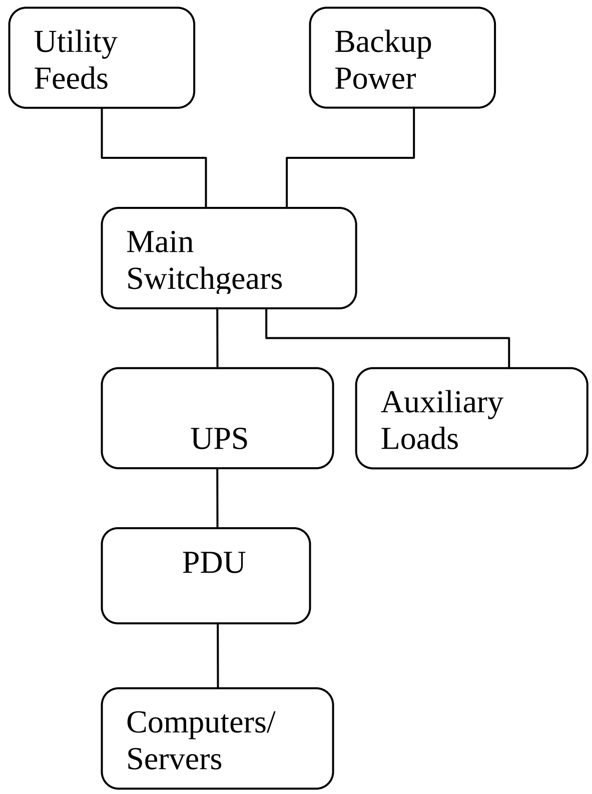



**Figure 1 - Block diagram of a typical data center electrical system**

Before any major upgrade can be made, the data center manager should have a good knowledge of the capacity available and the needs of his/her data center. This is very important in deciding on upgrades because it allows the data center manager to develop plans based on factors such as current and future needs. One way to easily track critical loads and capacity in a data center is by using a spreadsheet like the sample in Figure 2, which can easily be created with the help of other data centers' critical power requirement calculation tools.

| DATA CENTER "A" | Generator Capacity (KW) | | | UPS Capacity (KW) | | | Cooling Capacity (Tons) | | | PDU Capacity (KW) | | | | HVAC Capacity (KW) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Supply | Demand | Availability | Supply | Demand | Availability | Supply | Demand | Availability | PDU Room Supply kW | PDU UPS Allocation kW | PDU Demand kW | PDU Availability kW | HVAC Supply kW | HVAC Demand kW | HVAC Availability kW |
| AREA 1 | 2250 | 1803 | 447 | 1100 | 870 | 230 | 452 | 247 | 205 | 720 | 438 | 332 | 106 | 591 | 332 | 259 |
| AREA 2 | | | | | | | | | | 360 | 262 | 208 | 54 | 337 | 208 | 203 |
| AREA 3 | | | | | | | | | | 115 | 85 | 65 | 20 | 112 | 65 | 47 |
| AREA 4 | | | | | | | | | | 240 | 172 | 148 | 24 | 225 | 148 | 77 |
| AREA 5 | | | | | | | | | | 115 | 110 | 104 | 6 | 281 | 104 | 177 |
| AREA 6 | | | | | | | | | | 60 | 33 | 20 | 13 | 47 | 20 | 27 |

**Figure 2 - Sample data center load tracking spreadsheet**

## Different Electrical System Configurations

There are many data center electrical system design configurations available today. However, most of these design configurations are just variations of the main design configurations, which are N, N+1, 2N and 2(N+1).

### N Design configuration

An N design configuration is the simplest design configuration for a data center electrical system. This system is designed to meet the critical loads need of the data center without any redundancy built into the system. In other words, if the critical loads require 500KVA of UPS power and the system has only one 500KVA PDU module, then this is an N design configuration. This design configuration generally has one utility feed, one generator, one utility switchgear, one UPS module, one PDU and computer loads as shown in Figure 3.

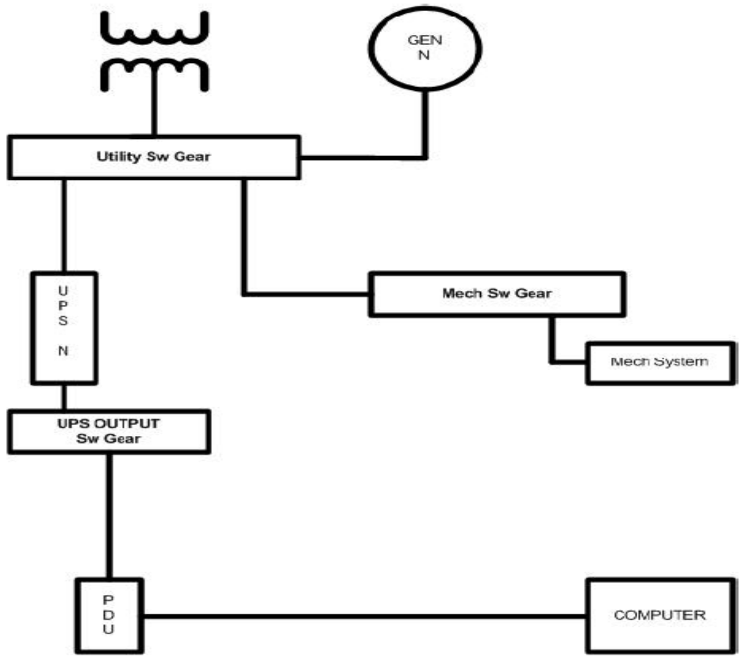



**Figure 3 – Data center N electrical system design configuration (Turner IV, Seader, Renaud, and Brill, 2008)**

One important observation to make from Figure 3 is that none of the critical components in the system has redundancy. For example, if the UPS module fails, the critical loads will not have power or if the generator fails while the data center is in backup mode, power to the data center will be lost. If an electrical design configuration has even only one critical component with no redundancy or no extra capacity built into it, the design is considered an N design configuration. This electrical design configuration has a single path, meaning that the failure of, or maintenance to, a panel or feeder will cause partial or total interruption of operations at the data center (Telecommunications industry association 2005). One disadvantage of an N design configuration is that the “lack of redundancy limits the load’s protection against UPS failures” (McCarthy and Avelar 2011, 6). Also, many single points of failure mean that the system can only be as reliable as its weakest link (McCarthy and Avelar 2011).

## N+1 Design configuration

An N+1 design configuration is an N design configuration with some redundancies or spare capacities built into the design. For example, if a data center has three 2500 KVA generators for backup power but only two are needed to support the data center's critical loads, then the generator subsystem is N+1. This means that there is one spare generator in case one of the two needed generators fails. If the generator system has four 2500 KVA generators but only two are needed to support the critical loads, then the generator system is N+2. Thus, an N+1 design configuration should have the spare capacity or redundancy in the electrical pathway, which includes the utility feed, the generator, the UPS subsystem, the distribution system and all distribution feeders (Telecommunications industry association 2005). Figure 4 shows a block diagram of a typical "N+1" data center electrical design configuration.

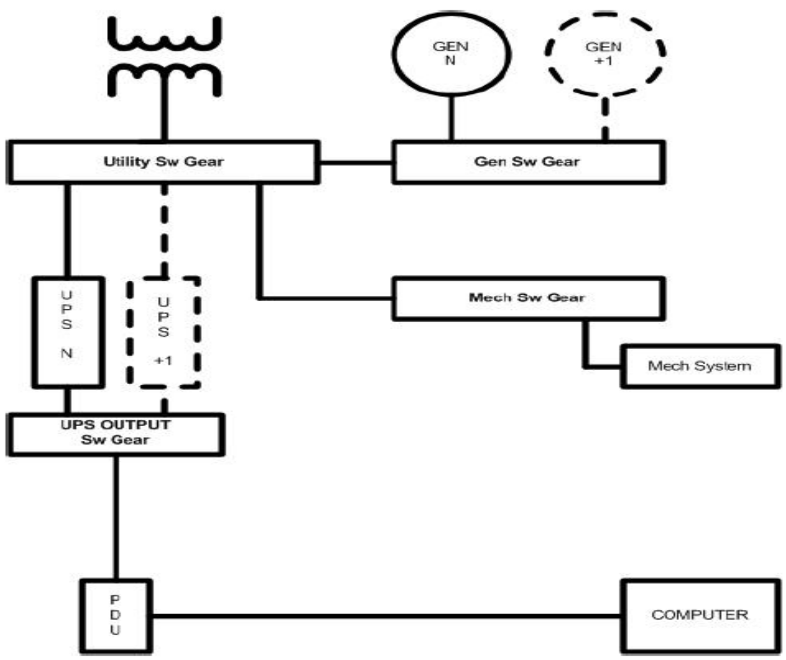



**Figure 4 – Data center N+1 electrical system design configuration (Turner IV et al., 2008)**

One advantage of an N+1 design configuration is the opportunity of the data center capacity to grow if needed. For example, if the critical loads grow, one additional UPS module and generator of the same size as the existing ones can be added.

**2N and 2(N+1) Design configurations**

The ultimate goal of most major data center managers today is to have a 2N or a 2(N+1) electrical design configuration. This is because 2N and 2(N+1) electrical design configurations are the most reliable design configurations in the data center industry. During an interview with Jimmy Hasegawa, principal data center engineer of all the data center facilities for one of the largest telecommunication companies in the U.S., he mentioned that everything been equal, he would like his data centers' electrical systems to be 2N configuration with 2N+1 UPS redundancy. A 2N electrical design configuration can be described as two independent N electrical design configurations used to power the same critical loads. The two N configurations are redundant to each other and each is capable of powering all the critical loads in the data center in case the other one is not available. Each of the two N configurations can only be loaded to about 40-45% of its capacity so that the combined loads can be supported by one side. An example of a typical 2N electrical design configuration can be seen in Figure 5. The only difference between a 2N and a 2(N+ 1) design configuration is that the latter has extra capacity built into each of the two distributions paths of the configuration. For example, each distribution pathway will have an extra generator and an extra UPS module.

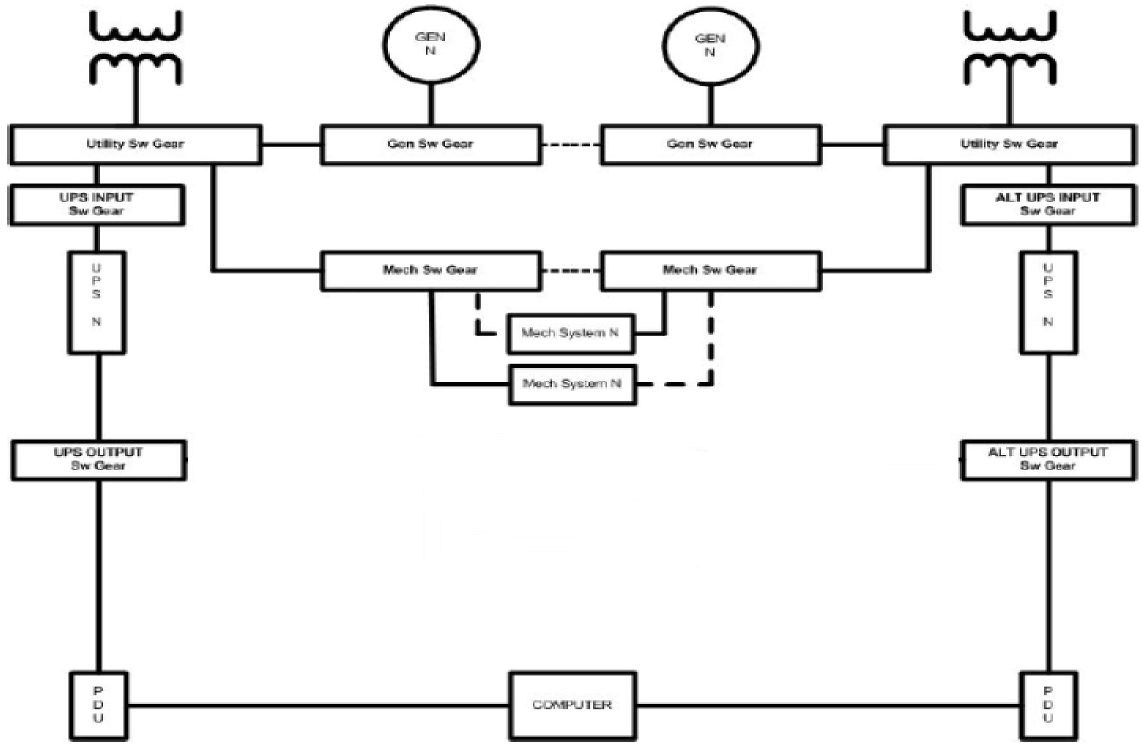



**Figure 5 – Data center 2N electrical system design configuration (Turner IV et al., 2008)**

## Design Considerations

Power availability and reliability are some of the most important challenges facing data centers today. With the increase power density per rack as a result of limited space and increased data processed by servers, conventional data centers are running out of power capacity. Because a large number of computers and servers are concentrated in existing data centers to maximize the use of the space available, the cost of downtime has substantially increased. Single points of failure and electrical system management are now more of concern to data center managers than in the past.

Two critical power issues encountered in data centers are the reliability of the electrical supply and whether the utility grid can supply the required availability. Typical data centers handle power interruptions to external power supply using combinations of UPS and backup generators. An analysis of data centers' outages points to UPS as the most common cause of unplanned outages. Three of the top four causes of data center outages are related to UPS failures (Ponemon Institute 2010). Backup generator failures are next in line in terms of importance. Thus, when there is a need to upgrade an existing data center electrical system, the different subsystems need to be analyzed while focusing on the most vulnerable and critical ones that comprise the UPS and backup generator.

**Utility feed**

The utility feed is the primary source of power for all data centers that do not have self generation capacity (produce their own electricity). Very few data center facilities generate their own power because of the high cost associated with building a generation plant. Thus, most data centers rely on the power provided by the local utility company. The quality and reliability of the power from the utility companies in the U.S. are very good compared to the rest of the world but not good enough to meet data centers' needs. Therefore, the first consideration to analyze when upgrading a data center electrical system is the utility feed.

It is recommended that data centers have two power feeds from independent power substations such that if for some reason one substation is not available, power can still be provided to the data center through the alternate power feed. At least one of the two power feeds should be underground to limit the exposure from natural disasters such as tornados that can easily damage overhead power lines. An underground alternate utility feed was recently installed at a large data center in the Kansas City area to meet the data center's continuous reliability need. Previously, only one overhead utility feed was available for this data center. The cost of installing the underground feed was justified by the possible high cost of downtime in case of failure of the overhead feed.

A few months after the alternate utility feed was installed, a surge arrestor failure in the overhead utility feed switchgear caused the data center to lose its main power feed. The data center had to rely on the newly installed feed for many days while the surge arrestor was being replaced. If the alternate feed was not available, the data center would have been powered by the backup generators for several days assuming that the generators would operate normally. However, the data center’s manager has concerns with the reliability of backup generators. A few months earlier, some generators had failed to start upon request of the data center. Thus, this large data center’s manager experience suggests it is crucial for data centers to have two utility power feeds each with transformers sized appropriately to support the entire data center loads.

Each utility power feed should have a separate main switchgear and the two switchgears tied together with a least one tie breaker to provide redundancy (see sample of a detailed electrical one line in Appendix A). Every data center has auxiliary loads such as HVAC that keep the data centers at the right temperature. Depending on the existing design, redundant panels or switchboards feeding the auxiliary loads should be provided. Each panel or switchboard should only support a portion of the auxiliary loads inversely proportional to the number of panels or switchboards. For example, in a data center with four auxiliary load panels, each panel should only support one quarter on the auxiliary loads. This way if one panel fails, only one quarter of the auxiliary loads will be without power. If for example it is not possible to have multiple panels or switchboards for auxiliary loads, then it is crucial to modify the existing panel or replace it with a double ended one. A double ended panel is a panel with two main breakers that allow the panel to be fed from two different sources (one main source and one alternate source).

**Backup power**

When the main power source of a data center fails, the UPS provides emergency power to the critical loads using batteries connected to the UPS system. The emergency power provided by the UPS only lasts for few seconds until the backup generators are running and ready to power the critical loads. Backup generators will support the critical loads until the main power returns. As a precaution, the UPS batteries are sized to provide emergency power for up to fifteen minutes at most data centers. It can sometimes take days for the main power to return if for example there is a natural disaster. The data center backup generator subsystem must be very reliable during this period, otherwise any problem can cause a complete power loss.

Generator system losses can be reduced by upgrading existing systems that do not meet needed reliability requirements. If for example the generator configuration of an existing data center is an N configuration, it is recommended that the system be upgraded to at least an N+1 configuration. The extra generator will provide backup capacity to the emergency system in case one generator fails to start or does not operate normally. Backup subsystems without extra generator capacity are generally connected to the main electrical system via Automatic Transfer Switches (ATS), but for an N+1 configuration, a generator's switchgear is better and will eliminate single point of failure at the ATS. A 2N or 2(N+1) generator's configuration requires at least two generator switchgears. Since most major upgrades take years and are done in different phases, it is a good practice to always have the end in mind when upgrading any electrical system. Otherwise, valuable capital can be wasted on upgrades that will not be in line with the final design configuration for the data center a few years later. For example, if the data center manager's plan is to have a 2(N+1) configuration, then any upgrade should be in line with the manager's plan with provision for any future growth included. The detailed, data center electrical system one-line (part 1) in Appendix A shows provision for two future generators. For maximum reliability, the generators used should be specifically designed for power generation application and not just adapted from other applications (Dauffenbach 2011). This is because other applications for generators such as in residential use will not be good for data centers. They are less reliable.

**Uninterruptible power supply**

Whether the power is from the utility or backup generators, it goes through the UPS to get to the critical loads. The only time that power gets to the critical loads without going through the UPS is when the UPS fails or is being maintained. The role of the UPS is not just to temporarily provide power to critical loads while the backup generators start, but also to filter the power from the utility and generators. Many people in the industry believe that the UPS subsystem is the most important part or the heart of any data center electrical system. Lud Funke, a senior electrical engineer at Black & Veatch with over thirty years of experience designing data center electrical systems, is one of them. However, some people like Dan Rogge, another senior electrical engineer at Black & Veatch, believe that the UPS subsystem is just one of the most important components of the electrical system. One thing that everybody in the industry can agree on is that the UPS subsystem gets the most attention. After all, "the most frequently cited root causes of data center outages are: UPS battery failure (65 percent), UPS capacity exceeded (53 percent), accidental Emergency Power Off/human error (51 percent) and UPS equipment failure (49 percent)" (Ponemon Institute 2010). Most of the upgrades to UPS systems in data centers are performed to increase their capacity, make them more reliable and improve their efficiency.

Once data center managers determine that more UPS capacity is needed, the size of any new UPS will depend largely on what the data center already contains. For example, if the data center currently has three 500 KVA UPS modules in parallel on a distribution path, it will only make sense to add one or more 500KVA UPS module(s) because the UPS modules work together and are supposed to have the ability to be loaded at the same level or have the same amount of spared capacity. Figure 7 in Appendix A shows an example of a data center's electrical one line with four UPS modules of the same size on each distribution path. The sample electrical one line is from a project recently completed. The fourth UPS module was added to increase the UPS capacity and maintain the N+1 UPS configuration on each distribution path (2(N+1) overall UPS configuration, but only N+1 configuration for the entire electrical system because the backup generator subsystem is N+1 configuration). A UPS output switchboard was also added to improve the maintainability and reliability of the UPS subsystem. Previously, each UPS system only had a UPS output bus with no output breakers, making the UPS modules vulnerable in case of a fault on the output buses.

Any work done on an existing data center electrical system should be seen as an opportunity to make the system more efficient. This is even truer for the UPS subsystem because it is the system with the most cost saving opportunity associated with making the system more efficient and reliable. With technology breakthroughs in recent years, data center owners or operators can save a substantial amount of money in the long run by just installing the top-of-the-line energy efficient UPS modules available today. For double conversion UPS modules, which are the most commonly used in data centers today, efficiency ranges between 80% and 95% for UPS loaded between 15% and 100% capacity (see Figure 6). “By simply selecting a 5% higher efficiency model of UPS, the saving can be over $38,000 per year in a 15,000 square foot data center, with no discernable impact on the data center’s operation beyond the energy savings” (Pacific Gas and Electric Company 2006).

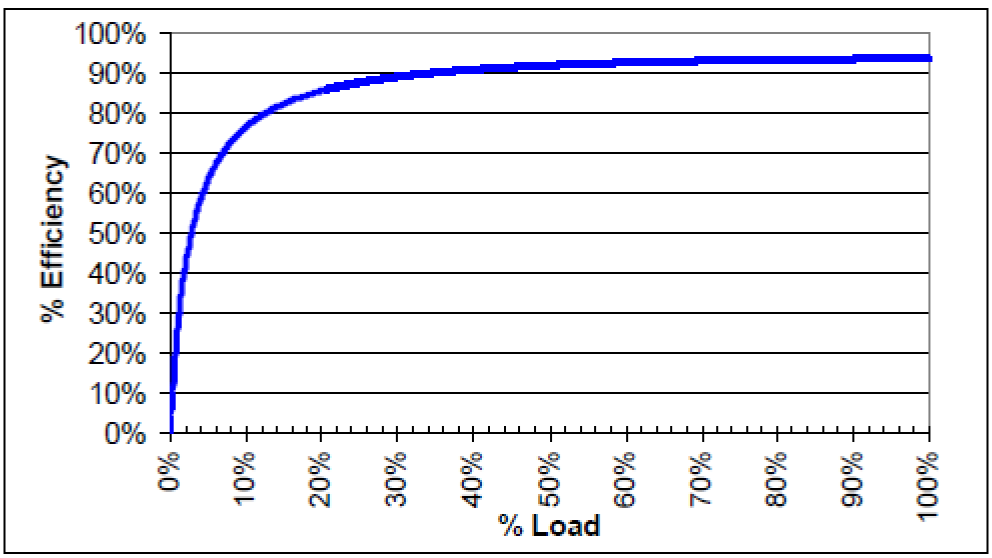



**Figure 6 - UPS efficiency curve (Sawyer, 2006)**

According to Dan Rogge, another way to get better efficiency out of the UPS and a data center electrical system in general is by setting up the UPS subsystem such that in normal operation, critical load power does not flow through the UPS as is the case in most existing data centers. With this type of set up, called a line reactive system, critical loads will be switched to UPS only when a power failure occurs, eliminating most of the losses (about 8%) resulting from double conversion in most UPSs. This is possible because most data center servers and equipment available today can operate through significant power disruptions such as undervoltage and overvoltage (Pacific Gas and Electric Company 2006).

It is very difficult to convince data center managers to consider line reactive systems when upgrading their electrical systems, however, because these systems are not widely used. There are some minor risks associated with reactive systems and they are different from what data center managers are used to. The solution to data center managers' concern with line reactive systems is to upgrade UPS modules with software such as Eaton's Energy Saver System (ESS), which manages UPS operations. This software allows the UPS to operate as it would in a line reactive system without the risk associated with line reactive systems because the software monitors the power from the utility. "When utility power is within normal tolerances, the UPS delivers power with 99% efficiency," without the double conversion mode and "when the utility power falls outside acceptable limits for IT equipment, the UPS seamlessly switches to double conversion mode" (Eaton 2009a).

For data center managers, it does not matter how efficient their data center's UPS subsystem is if it is not in operation. Considering that UPS battery failures cause the most outages in data centers, it is not only essential to maintain and replace batteries when they are due for maintenance or replacement but it is also essential to have the right type of battery to meet the data center's needs. If existing batteries are Valve Regulated (VRLA) type and reliability is a concern for the data center, then the batteries need to be upgraded with wet cell batteries, which are more reliable than VRLA batteries. Wet cell batteries have a very long life (15-20 years), are difficult to install and maintain and need to be in a separate battery room. As for the VRLA batteries, they will last 3 to 10 years, cost less and are easy to install and maintain (American Power Conversion 2005). Although the wet cell batteries are more expensive to install and maintain compared to the VRLA batteries, the reliability gain is worth the extra cost for most data centers.

**Power distribution unit**

Some data centers that are decades old do not use power distribution units. Standard floor standing PDUs receive 480V power and step it down to 208V to feed servers and computers. These units also have Static Transfer Switches and panels with breakers. Most PDUs built today are very reliable and can be used "to monitor power consumption and quality, manage and plan power needs, and react quickly to any potential problems down to the branch circuit level" (Eaton 2009). Installing PDUs in data centers that do not currently use them or upgrading with new PDUs will not only increase the reliability of the electrical system but it will also allow data center managers to easily track power usages in their data centers.

Another advantage of using PDUs is that they can be easily relocated to another area of the data center during upgrades or consolidations. Figure 8 in Appendix A shows a data center's electrical one line with PDUs. In data centers with at least two separate distribution paths, it is recommended that PDUs be fed from a separate path to provide power redundancy. If floor space is a problem when planning to add or replace PDUs, then data center managers should consider using rack mounted PDUs. Rack mounted PDUs are smaller, more efficient and can be mounted right next to servers or in some cases in the same enclosure as the servers. In large data centers, using rack mounted

PDUs can save a lot of money and cables since there is no need to run multiple lengthy cables to the servers.

**Servers/computers**

Servers/computers are the bulk of critical loads in a typical data center. The majority of servers/computers in data centers today have two power cords: one main power cord and one alternate power cord. These cords are plugged into separate remote power panels from separate distribution paths to provide power redundancy to servers/computers. It is still common to see servers/computers with only one power cord in some old data centers. In this case, if these one cord servers/computers are critical and cannot be turned off, then data center managers need to migrate the loads to other servers/computers and replace the single cord servers/computers with double cords servers/computers because single power cord servers/computers have single points of failure at their power cord.

## Choosing the Right Design Configuration

Before a decision is made on upgrading a data center design configuration, some considerations have to be taken into account to better develop a robust plan that technically and financially makes sense and can be implemented easily.

**Cost of downtime**

What is the revenue per minute from running the data center? In other words, how much money does the data center and its clients make per minute? The answer to this question greatly influences the discussion to spend money to make a data center's electrical system more reliable. For reliability upgrades, the estimated cost of the project should be compared to the cost of downtime to determine if it makes sense financially in the short or long term to move forward with the project. Another thing to consider is the effect of the project cost on future business. For example, data center managers who rent or lease space to outside clients should ask themselves if the lease or rental cost will increase as a result of the upgrade. If the answer is yes, they should make sure that their clients will not have any problem paying more for the better service. There should be a positive return on investment for every expenditure made on upgrades.

**Risk tolerance**

How will the data center handle a major power failure? Does the data center have a history of failures or has it been free of major failures? Companies that are sensitive to risks for any reason are more likely to initiate and approve a project to improve reliability and maintainability.

**Availability/Reliability**

Is the data center a 24/7 data center? Can the data center afford to be shut down for maintenance? If the answer to the first question is yes and no for the second, then upgrades to improve or add redundancy in the electrical system or eliminate single points of failure should be approved. These upgrades will more likely add value to the data center.

**Space**

Is space available for new equipment? Most major electrical system upgrades require additional space. For example, installing a new UPS module to increase capacity will require not only additional space for the module but an even bigger space for the

UPS batteries. The lack of space greatly affects the design configuration upgrade of many data centers.

**Maintainability**

At some point in time, any piece of equipment will have to be maintained. It is very important to have an electrical system design such that equipment is easy to maintain or requires less maintenance. In data centers, the percentage of reported failures attributed to human error is more than 60% (Hughes 2012). It is important to identify areas of the electrical system where maintenance can be improved.

Before data center electrical systems can be upgraded, data center managers should take the necessary steps to analyze their electrical systems to identify their data center's needs. Based on the findings from the analysis, a design configuration plan should be developed such that if followed, any upgrades will be in line with the plan. This plan should take into account future growth and include actions to save money whether in the short or long term. Whether the ultimate design configuration plan is an N+1 or 2(N+1), the decision to move forward should be made after evaluating the business, financial and technical aspects of the plan. A data center sensitive to risk may require some degree of redundancy in its key subsystem and have an N+1 configuration, while one that is both sensitive to risk and has more critical loads requires a 2(N+1) configuration (Sawyer 2004).

## Summary and Conclusion

The ultimate goal of any data center is to be available and reliable. The distinction between reliability and availability is slight but important, although many people use these terms interchangeably. The reliability of a system is the probability that it will operate as intended for a given interval of time whereas the availability is the time that the system is operational (Fairfax, Dowling and Healey 2004). The most common approach in the industry to eliminate threats to data center operations is to build redundancy into the electrical system such that no single problem can easily cause power failures. All data center electrical system upgrades “should aim to achieve the ideal balance between technical and financial considerations; this implies that redundancy, in principle, must not be applied indiscriminately, on the contrary it must be carefully evaluated” (Baggini and Granziero, 2010). However, in reality, not all redundancies contribute equally to reliability. For instance, a redundant backup generator, with a 1% failure to start per demand, will contribute far more to reliability than a redundant transformer, whose failure rate is so low that the money spent on a redundant unit can be better spent elsewhere (Fairfax, Dowling and Healey 2004). Excessive redundancy in the electrical system should be avoided because it can lead to excessive maintenance (the system now has more equipment). Yet a well developed maintenance plan will always save money and reduce human errors while increasing reliability. To reduce human error in his data centers, Jimmy Hasegawa has developed a risk cause analysis plan and adopted design approaches that among many things reduce the possibility of human error and facilitate maintenance.

Whether data center managers are upgrading the electrical system of an existing data center or building a new data center, the electrical system of the data center should be expected to keep servers and networking devices operational regardless of external conditions (Alger 2007). When upgrading a data center electrical system, it is very important to develop a plan that if implemented at some point in time, will maximize the reliability and capacity of the different subsystems or the whole data center electrical system. With this mind, some recommended considerations for data center electrical system upgrades are listed in table 1. These recommendations were derived from all the documents and reports read while working on this research topic.

Table 1. Recommended design criteria for data center electrical system configuration

| Item | Recommendation |
|---|---|
| Utility power feeds | 2N utility power feeds (redundant utility power feeds from separate sources). |
| Utility transformers | 2N utility transformers (redundant utility transformers, each capable of supporting all the data center loads). |
| Utility switchgears | 2N utility switchgears (redundant double ended utility switchgears with tie breakers). |
| Backup generator systems | 2(N+1) generator system with 72-hour fuel supply (each distribution pathway has a generator switchgear with one extra generator). |
| UPS systems | - 2(N+1) UPS system.<br>- Separate UPS rooms for each distribution pathway's UPS.<br>- Redundant UPS output switchgears.<br>- No UPS normally loaded at more than 45%.<br>- Install UPS modules with better efficiency than existing ones.<br>- Wet-cell UPS batteries in separate rooms. |
| Distribution systems | - 2N distribution systems (redundant distribution pathways).<br>- Redundant auxiliary loads' panels/switchboards. |
| Power distribution units | Redundant PDUs with static transfer switches. |
| Servers/Computers | All servers and computers (critical loads) should have two power cords. |

# CHAPTER 5 - SUGGESTIONS FOR ADDITIONAL WORK

In analyzing the different data centers' electrical system design configurations, we have focused on the theoretical analysis of the different subsystems. A suggestion for additional work would be to calculate the availability and reliability of data centers' electrical systems and to mathematically analyze the impact of different subsystems' upgrade options on the overall electrical system reliability and availability. Such analysis could play an important role in deciding which subsystem to implement in an upgrade based on their overall impact.

Currently, the majority of data centers in the industry rely on the local utility company for their main source of power. It is possible for some data centers to generate their own power at the site and have more control over their power needs. Some very large data centers are already doing this. When does it make sense for a data center to self generates the power it needs? What are the advantages and disadvantages of self power generation for a data center? Answering these questions could be the subject of another research work.

Computers and servers in data centers use DC power. The AC power provided to servers and computers from wall outlets is immediately converted to DC power for all internal operations. Some people in the industry are advocating for DC power distribution systems in data centers. As a matter of fact, some new, very creative and energy efficient data centers already have DC distribution systems. Analyzing the reliability of DC power distribution system would be a good research subject.

# Appendix A – Sample data center electrical one line diagrams

## Figure 7 – Data center electrical system one-line (part 1)

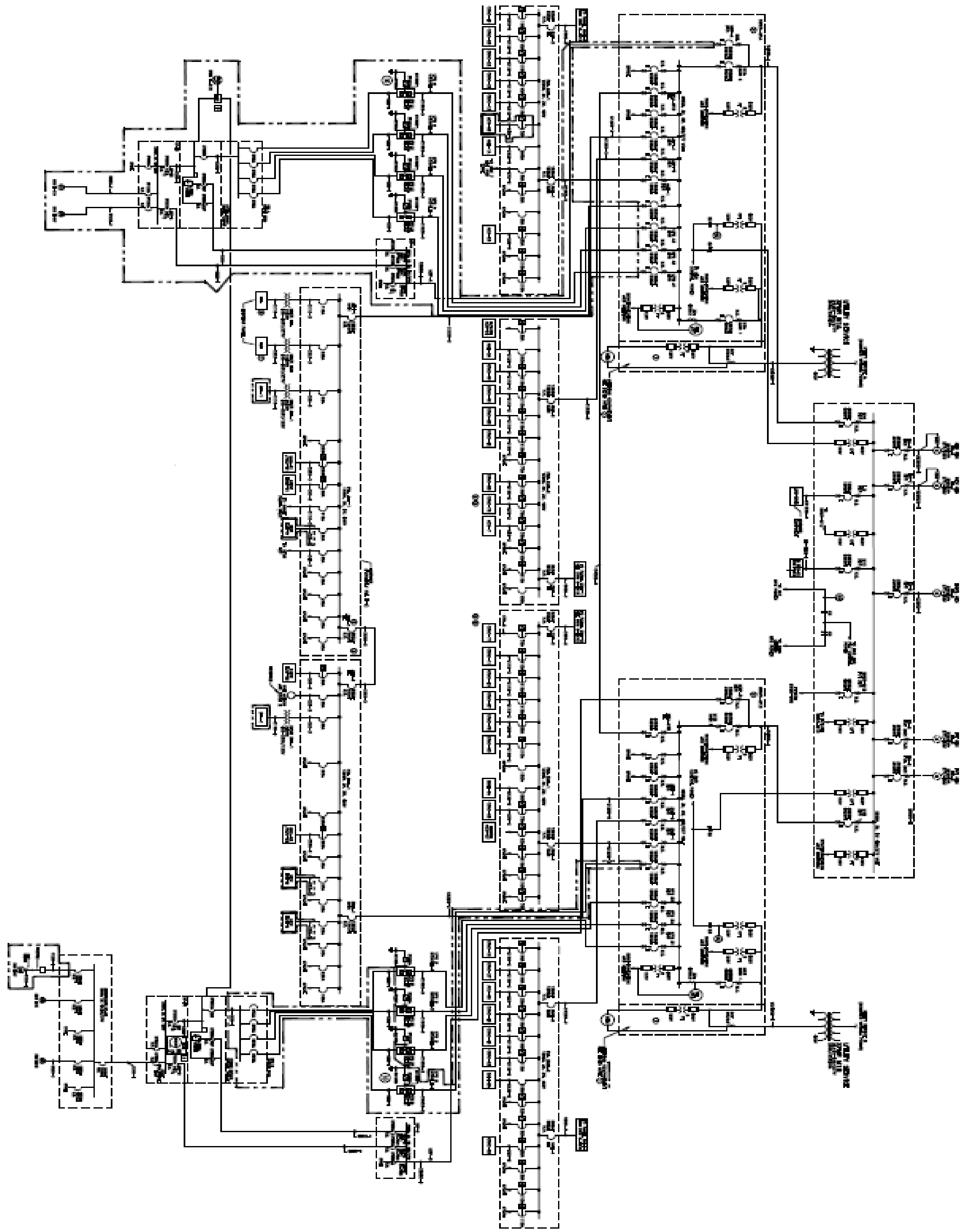
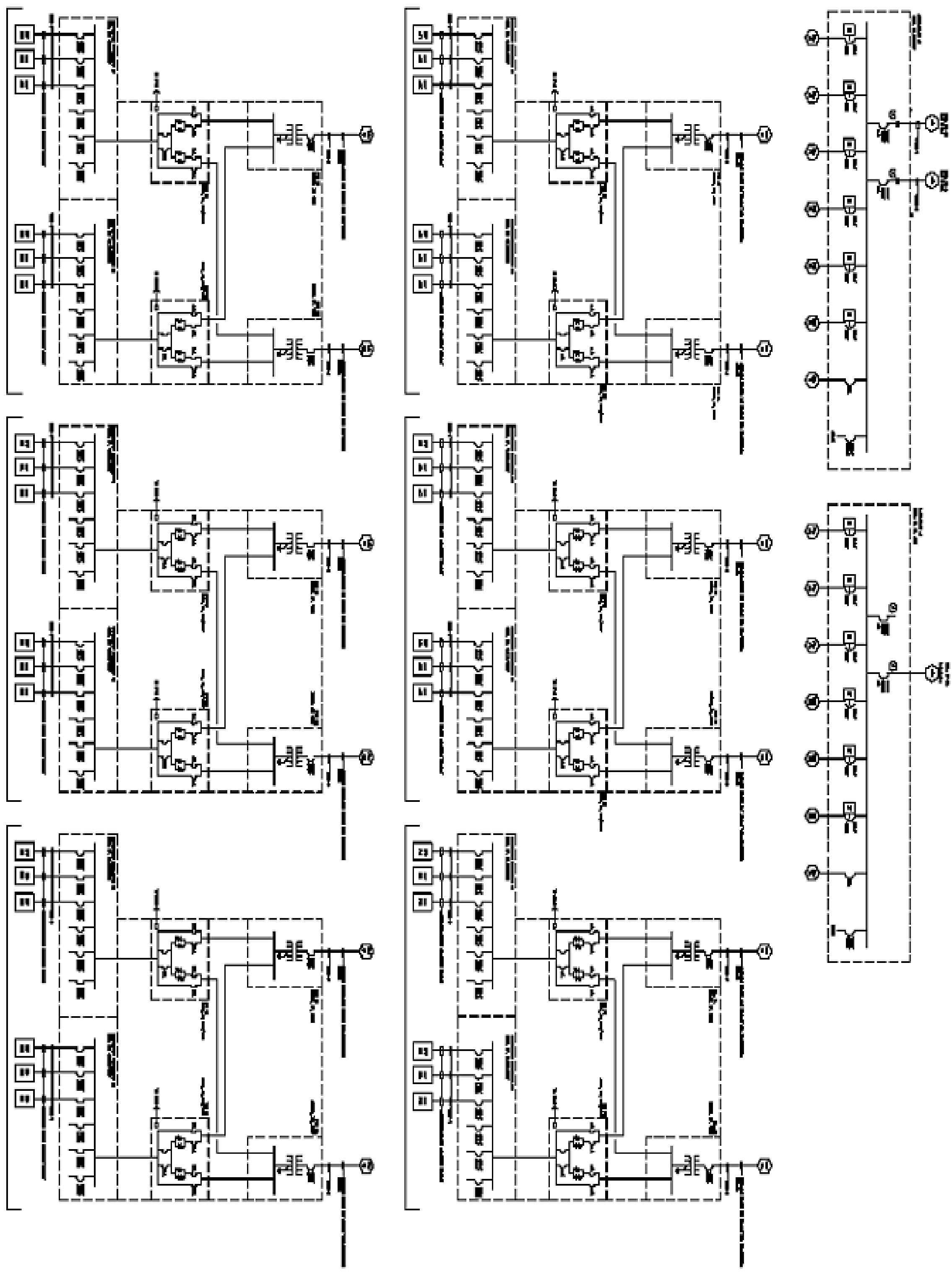


**Figure 8 – Data center electrical system one-line (part 2)**



## Appendix B - Sample Interview Questions

1. What is (are) the reason(s) for requiring the generator set to start in 10 seconds?
2. Increasing the maximum generator set start time to 25-30 seconds will improve the reliability and the life of the generator set. Would you consider setting the generator(s) at a data center to start within this time frame? Why, or why not?
3. What major equipment is more likely to fail in a data center?
4. What are the main causes of power failure in a data center?
5. What would be the most cost effective UPS system configuration, if constraints to implement it such as space, cost, etc. were not a consideration?
6. Do you have enough electric power capacity to sustain growth in the near future?
7. What is more important to you: having enough capacity for anticipated future growth or having a more reliable electrical system?
8. Which factor most influences your decision to upgrade your data center's electrical system: the cost of power failure to your company and its clients or the need to guarantee your clients access to their data anytime?
9. What do you consider to be the weakest link in your data center's electrical system in terms of reliability?
10. What do you consider to be the weakest link in your data center's electrical system in terms of capacity?
11. How important is the ease of maintenance to you when purchasing new equipment or upgrading your data center's electrical system?
12. What steps have you taken to address the important problem of power failures caused by human error?

13. What is the most critical component/sub system of a data center electrical system?

## References

Alger, Douglas. 2007. *Build the best data center facility for your business: A comprehensive guide to designing and operating reliable server environments.* Indianapolis: Cisco Press.

American Power Conversion. 2005. Battery technology for data centers and network rooms: Battery options. White paper, 30, rev 10.

Anixer. 2008. Data center infrastructure resource guide. http://www.anixter.com/AXECOM/AXEDocLib.nsf/%28UnID%29/F9F7765DAF87FF1B86257383004E9C5F/$file/Data_Center_Guide.pdf (accessed January 21, 2012).

Baggini, Angelo, and Matteo Graziero. 2011. Planning and design for a data centre electrical power infrastructure: Distribution, UPS, safety and savings. White paper. SOCOMEC, February. http://www.socomec.co.in/webdav/site/Socomec/shared/INDIA/UPS/News/SOCOMEC%20White%20paper%20for%20planning%20a%20DATA%20CENTRE%20Electrical%20infrastructure.pdf (accessed January 21, 2012).

Crouch, Bobby. 2011. Bracing for tomorrow's data growth Can you say "Zettabyte?". Data Center Management, May/June 2011

Dauffenbach, Michael. 2011. Maximizing the reliability of standby power used in mission-critical applications. 7X24 Exchange International, The end-to-end reliability forum, fall 2011.

Eaton. 2009. Power distribution unit. http://corepowerinc.com/specsheets/PDU.pdf (accessed February 25, 2012).

Eaton. 2009a. Green without compromise, with the industry's most efficient UPS. http://www.google.com/#hl=en&output=search&sclient=psy-ab&q=Green+without+compromise%2C+with+the+industry%E2%80%99s+most+efficient+UPS.&pbx=1&oq=Green+without+compromise%2C+with+the+industry%E2%80%99s+most+efficient+UPS.&aq=f&aqi=&aql=&gs_sm=3&gs_upl=688l688l0l1046l1l1l0l0l0l0l0l0ll0l0&gs_l=hp.3...688l688l0l1047l1l1l0l0l0l0l0l0ll0l0&bav=on.2,or.r_gc.r_pw.r_qf.,cf.osb&fp=9699b23bffa1b841&biw=1230&bih=757 (accessed March 1, 2012).

Fairfax, Steve. 2011. Hidden threats to data center reliability. Paper presented at the 7x24 Exchange International, The end-to-end reliability forum November 13–16, in Phoenix, Arizona.

Fairfax, Steve, Neal Dowling, and Dan Healey. 2004. Reliability analysis of the APC InfraStrucXure Power System. Schneider Electric. White paper, 111, rev 1. http://www.apcmedia.com/salestools/VAVR-5W5PF5_R1_EN.pdf (accessed February12, 2012).

Glanz, James. 2011. Google details, and defends, its use of electricity. *The New York Times*, September 8. http://www.nytimes.com/2011/09/09/technology/google-details-and-defends-its-use-of-electricity.html (accessed February 27, 2012).

Hughes, Jim. Human error in the data center. Danaher Power Solution.

Markoff, John. 2011. Data centers' power use less than was expected. *The New York Times*, July 31. http://www.nytimes.com/2011/08/01/technology/data-centers-using-less-power-than-forecast-report-says.html (accessed February 27, 2012).

McCarthy, Kevin, and Victor Avelar. Comparing UPS system design configurations White paper, 75, rev 3, Schneider Electric. http://www.apcmedia.com/salestools/SADE-5TPL8X_R3_EN.pdf (accessed January 28, 2012).

NFPA 110. 2010. Standard for emergency and standby power systems. http://specs4.ihserc.com/DocViewFrame.aspx?sess=709804442&prod=SPECS4&docid=QAUCOCAAAAAAAAAA (accessed February 10, 2012)

Pacific Gas and Electric Company. 2006. High performance data centers: A design guidelines sourcebook. Technical Paper, January. http://hightech.lbl.gov/documents/data_centers/06_datacenters-pge.pdf (accessed February 27, 2012).

Ponemon Institute. 2010. National survey on data center outages. September 30. http://shared.liebert.com/SharedDocuments/LiebertFiles/SL-24655-R09-10_Rev1-print.pdf (accessed March 1, 2012).

Sawyer, Richard. Calculating total power requirements for data center. White paper, 3. APC. http://phys-ds.physics.lsa.umich.edu/docushare/dsweb/Get/Document-2449/Calculating%20Total%20Power%20Requirements%20for%20Data%20Centers.pdf (accessed December 20, 2011).

Sawyer, Richard. 2006. Marking large UPS systems more efficient. White paper, 108. APC. http://www.visiondataspaces.com/PDFs/White_Papers/Making%20Large%20UPS%20Systems%20More%20Efficient%20-%20WhitePapaer108.pdf (accessed February 18, 2012).

Silicon Valley Leadership Group. 2008. Data center energy forecast final report. July 29. http://www.nwcouncil.org/results.htm?cx=015128466893257307228%3Agl6cicv0g4e&cof=FORID%3A11&ie=UTF8&q=Data+Center+Energy+Forecast+Report&sa=search (accessed November 26, 2011)

TIA-942. Telecommunications infrastructure standard for data centers. http://specs4.ihserc.com/DocViewFrame.aspx?sess=709804442&prod=SPECS4&docid=EULSHBAAAAAAAAAA (accessed February 24, 2012)

Turner IV, W. Pitt, John H. Seader, Vince Renaud, and Kenneth G. Brill. n.d. Tier classifications define site infrastructure performance. White paper. Uptime Institute. http://www.greenserverroom.org/Tier%20Classifications%20Define%20Site%20Infrastructure.pdf (accessed December 14, 2011).