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# Utilization of Features and Resources for UPS Systems

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This study is based on double conversion UPS systems. Double conversion UPS units are complex equipment consisting of various electrical devices. UPS manufacturers provide documentation, manuals, and datasheets to cope with the tedious task of its management. However, the lack of standards, confusing terminology and knowledge in different fields of engineering generate difficulties when managing UPS systems in practice. It is the goal of this thesis, to provide guidelines for the management of large scale UPS systems in data centers.

The thesis is the result of the research for double conversion UPS units, Power Xpert 9395P from Eaton and Liebert Trinergy Cube from Vertiv, operating in a large scale data center building. The thesis work includes the analysis of non-sealed lead acid batteries used as energy storage for the UPS system.

The result is an information package that assists technical personnel to familiarize with UPS systems terminology, introduce battery management systems, UPS modes, and other important features of the UPS system as a whole.




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|---|---|
| Keywords | UPS systems, UPS modes, UPS features. |

## Contents

**List of Abbreviations**

UPS: Uninterrupted Power Source (or uninterruptible power supply)

UPM: Uninterruptible Power Module

PSU: Power Supply Unit

SST: Solid State Technology

STS: Static Transfer Switch

ST: Static Switch

IGBT: Insulated-Gate Bipolar Transistor

PCB: Printed Circuit Board

DC: Data Center

PDN: Power Distribution Network.

PWM: Pulse Width Modulation

EMC: Electromagnetic Compatibility

EMI: Electromagnetic Interference

IEC: International Electrotechnical Commission

CB: Circuit Breaker

BMS: Battery Management System

## 1 Introduction

The main function of UPS systems is to supply power continuously to the critical load. This is why UPS stands for uninterruptible power supply. The UPS systems are integrated by various electrical and electronic equipment such as UPS unit, battery banks, power distribution network, control boards, and so on. The main application of UPS systems is supplying constant electrical power to servers in data centers. The servers are the critical load in the UPS system.

Server demand has increased in data centers due to the expansion of internet services such as clouds, root servers, file servers and so on. As consequence, data centers are increasing their volume to support the large amount of servers, while UPS systems are growing to keep pace of higher power demands. On the other hand, the complexity of UPS system makes its management difficult in large scale data centers, due to their large size. UPS systems require theoretical background as well as practical experience in different fields of engineering. In addition, only a few companies manufacture large UPS systems, adding difficulties when finding information related to the topic. Therefore this thesis has the purpose of guiding the reader with the proper utilization of features and resources provided by UPS manufacturers.

The thesis analyzes a double conversion UPS system from a data center park while introducing simple theory and avoiding the reader to get overwhelmed by the amount of information. Besides, plenty of figures and tables have been added to illustrate UPS systems.

The Thesis is divided in three main sections; the first section explains the power distribution network interacting with UPS system, the second section explains double conversion UPS structure and components. Finally, the third section describes the numerous features of UPS units. For simplicity, the thesis work is focused on the features of UPS unit models: Power Xpert 9395P from EATON, and the Liebert Trinergy Cube from Vertiv.

# 2 UPS System

The UPS system analyzed during this thesis work supplies continuous power to the critical load, which are servers located inside a data center. The data center building where the UPS system operates is referred as DC building. The UPS system supplies 1 200 kVA, more information related to data center and its power distribution network can not be shared in this thesis due to proprietary containment belonging to the company managing the data center. Nonetheless, the next sections introduce the main components found in UPS systems in the DC building, such as UPS units, battery banks, bypass connections, critical load, control connections of the UPS units.

The UPS system is large and complex, composed of several components. First, the main components of the UPS system are introduce in the next sections. In later sections, are presented in detailed information related to the operation of the UPS system, internal architecture of the UPS units and the system features. The system features are the main focus of the thesis.

## 2.1 UPS Units

This section identifies the inputs/outputs terminals and the main components of the UPS unit Power Xpert 9395P. The units model Power Xpert are the latest generation of UPS technology from Eaton. [1]

From the exterior the UPS unit consist of four cabinets attached together. Figure 9 shows the purpose of each cabinet and are tagged various components inside unit 9395P, below.

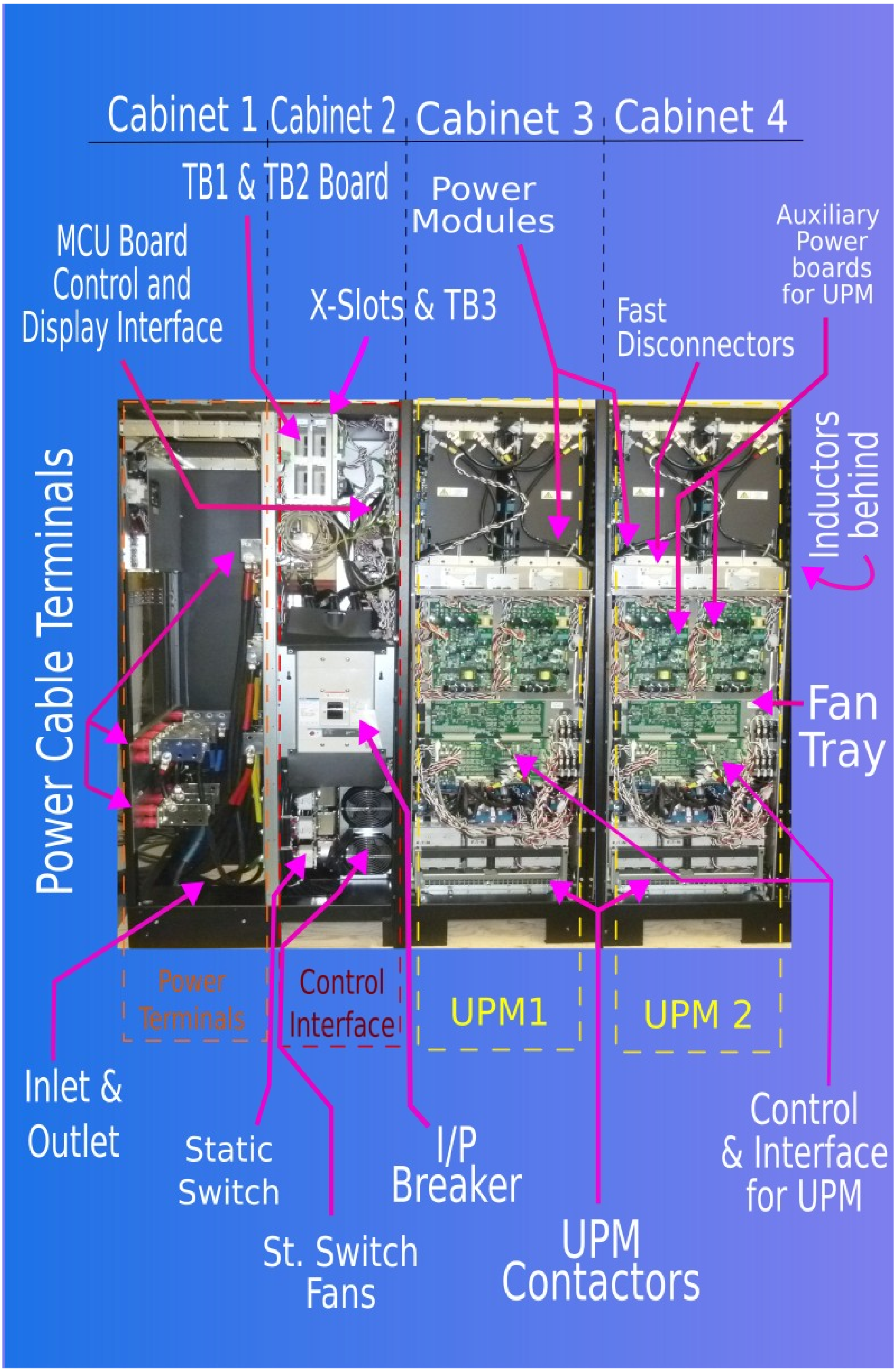


Figure 1. Main components of the UPS unit 9395P sort by cabinets.

The UPS contains various devices including two UPMs, short for uninterruptible power units. The UPMs are modular, which can be replaced while the UPS is operating. The power output for individual UPM is of 300kVA [4]. Single UPMs have the same architecture as conventional double conversion UPS. However to increase the power output the UPS unit possesses two UPMs working in parallel. The UPMs share the static switch, the inlet/outlet cabinet and other devices to reduce volume of the UPS.

Other components such as the terminals blocks that are referred as TB in figure 9. TB are explain in later sections.

## 2.2 Inputs and Output Scheme for UPS

The UPS system analyzed during the thesis work consists of three UPS units working in parallel. Thus, the UPS system possesses a total of six UPMs.

The UPS units are fed from the line supply cabinets as shown in figure 2. The distribution cabinet N04 feeds the rectifier, while distribution cabinet N05 feeds the static switch.

The output cables of individual UPS units 1, 2 and 3 leave the inlet/outlet cabinet and are connect to cabinets N05, N06 and N07 respectively. At this point the necessity of power synchronization by UPS units is evident, because they share the same output which is the common output bus bar.

In addition to the power input and output of the UPS units, the power connections for the direct current which connects the battery bank are necessary. The direct current power cables connects individual UPMs to their respective battery bank through a direct current bus called dc bus; dc stands for direct current. Every connection possess individual fuses to protect the equipment.

Figure 2 shows the power connection scheme of the three UPS units, the connections are tagged according to its purpose.

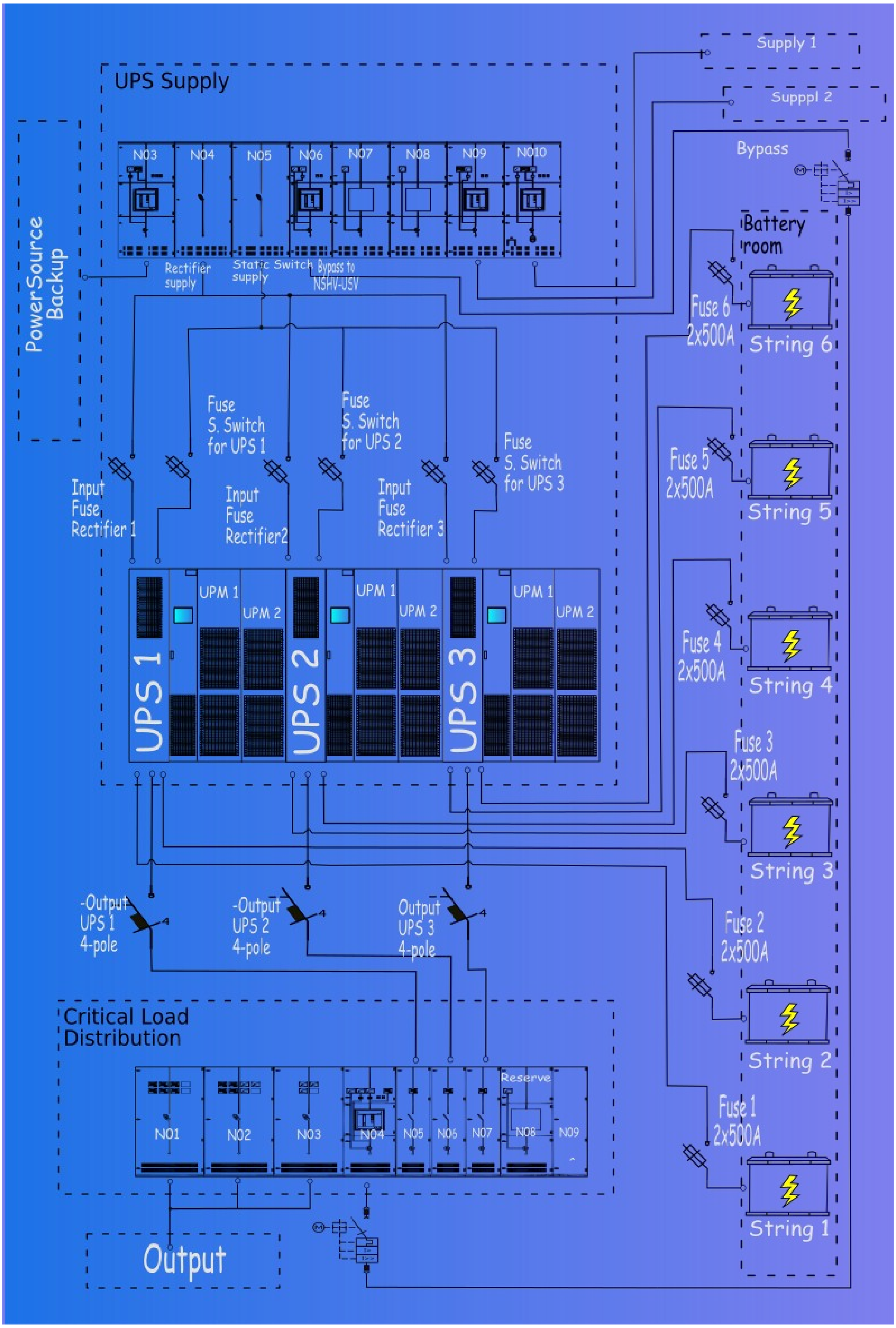


Figure 2. Power connections scheme for UPS units in DC2.

## 2.3 Battery Connections

The battery bank is divided in six battery stings, each string is connected to its correspondent UPM. The string is an arrangement of batteries connected in series with a total of 240 batteries. Figure 3 below shows the battery connections scheme.

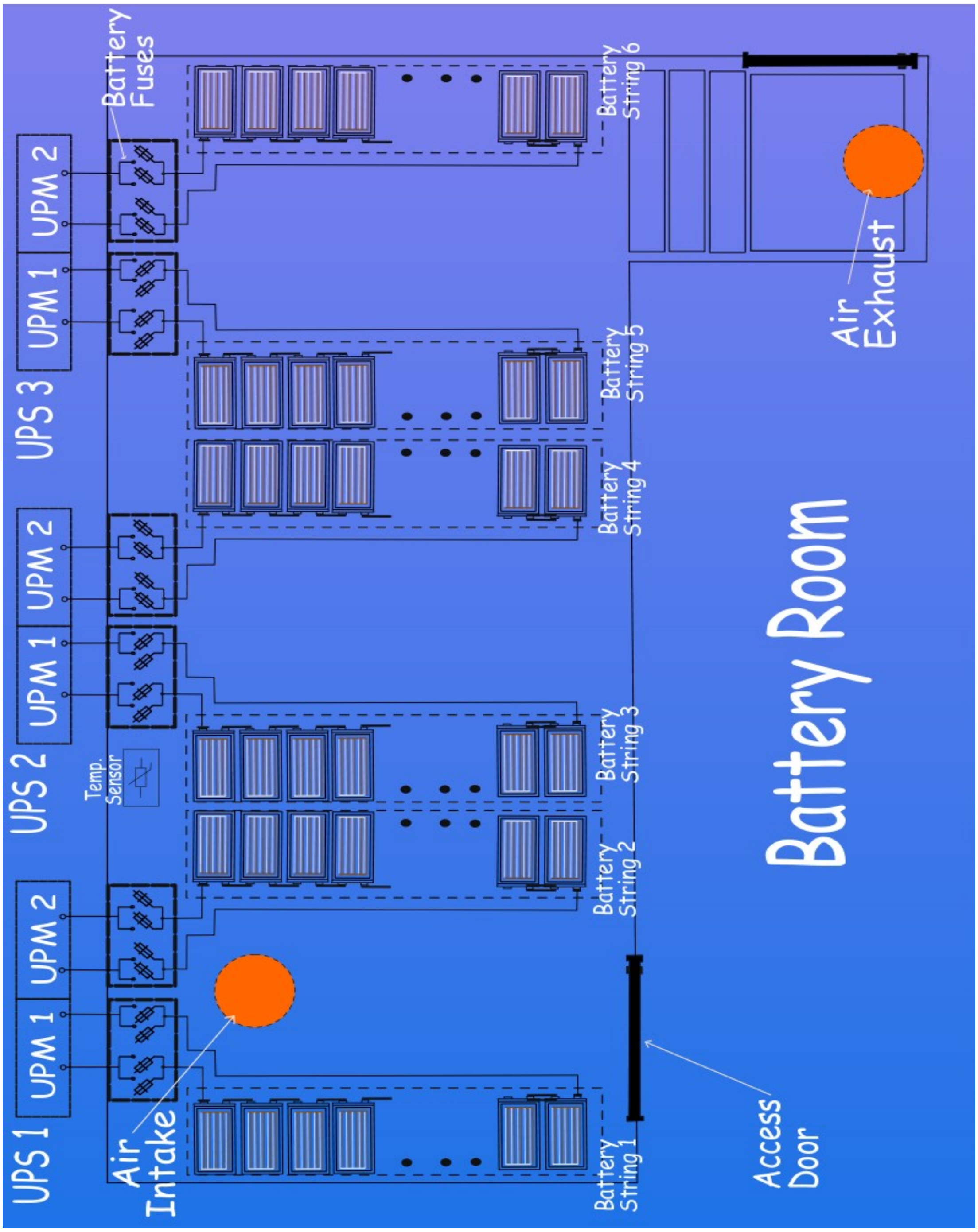


Figure 3. Battery connections scheme in the battery of DC2.

The battery strings are placed in special battery racks inside the battery room. The batteries must be place in proximity of the UPS units to avoid power loss through power cables. The battery model used for the battery string are all the same, which are non-sealed acid batteries. The battery model analyzed during the thesis work is the none sealed lead acid battery model 10 OSP-XC-400 from the manufacturer Hoppecke.

The battery room also possesses an air intake and air exhaust, because non-sealed lead acid batteries require ventilation, shown in figure 3.

## 2.4 Control Connection and Communication

The control and communication connections are external connections added to the UPS units for sending/receiving signals. In the DC building, three UPS units are placed in parallel sharing the same common bus bar for output and input power, as mentioned previously. Therefore, communication between parallel units is crucial for optimal operation and prevention of failures.

The unit 9395P possesses multiple control connections that should get connected to their corresponding terminals in the control cabinet. The terminals are split in four blocks named TB short for terminal blocks. The purpose of each terminal is listed, below:

- **TB1:** is the interface between the shutdown button called EPO. Additionally, TB1 is also the interface for battery connections.

- **TB2:** Is the backup control for parallel operation. Besides, TB2 have two relay connections for general purpose alarm.

- **TB3:** Offer five programmable UPS alarms. The alarms are activated by a remote dry contact closure.

- **TB4:** is a special terminal use to add communication card. The communication card is called x-slot.

Figure 4 below represents the communications connections.

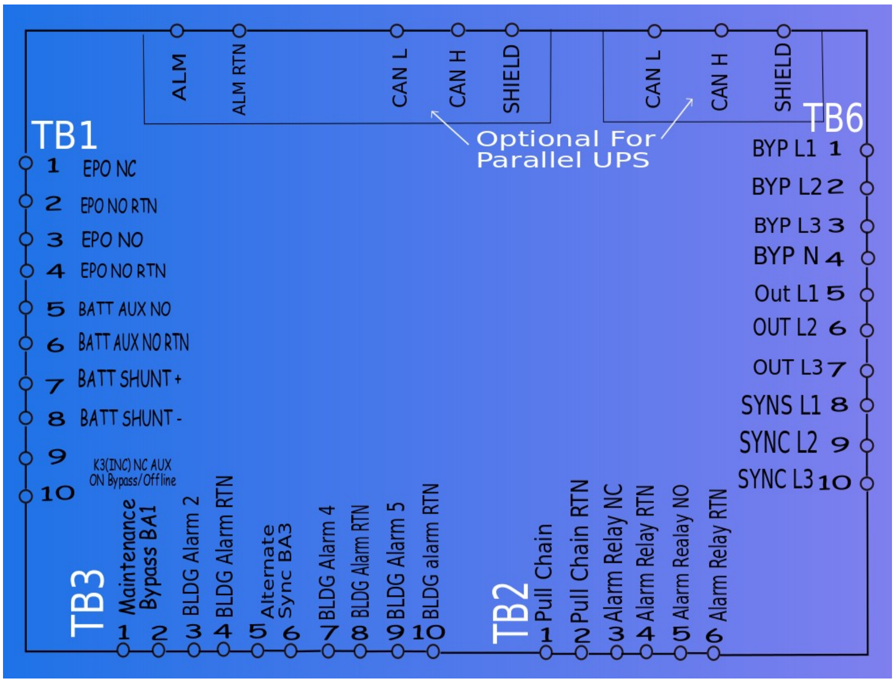


Figure 4. Control connections for the UPS units 9395P.

In addition, it is possible to install a HotSync CAN bridge Card in Unit 9395P as alternative communication bus [4.53].

## 2.5 Bypass

The bypass circuit in electrical power distribution is defined as an alternative power connection which changes the power flow to omit certain device while keeping its load powered. The main component of the bypass equipment is the switch circuit to change the flow of power. Various types of switch exist such as regular mechanical switches, circuit breakers, relay switches and SST switches. SST is short for solid state technology switches. Detailed information about solid state technology for switches are presented in later sections.

The UPS system in the DC building possesses two bypass circuits controlled by circuit breakers. Figure 5 below represents the two main bypass circuits used by the UPS system.

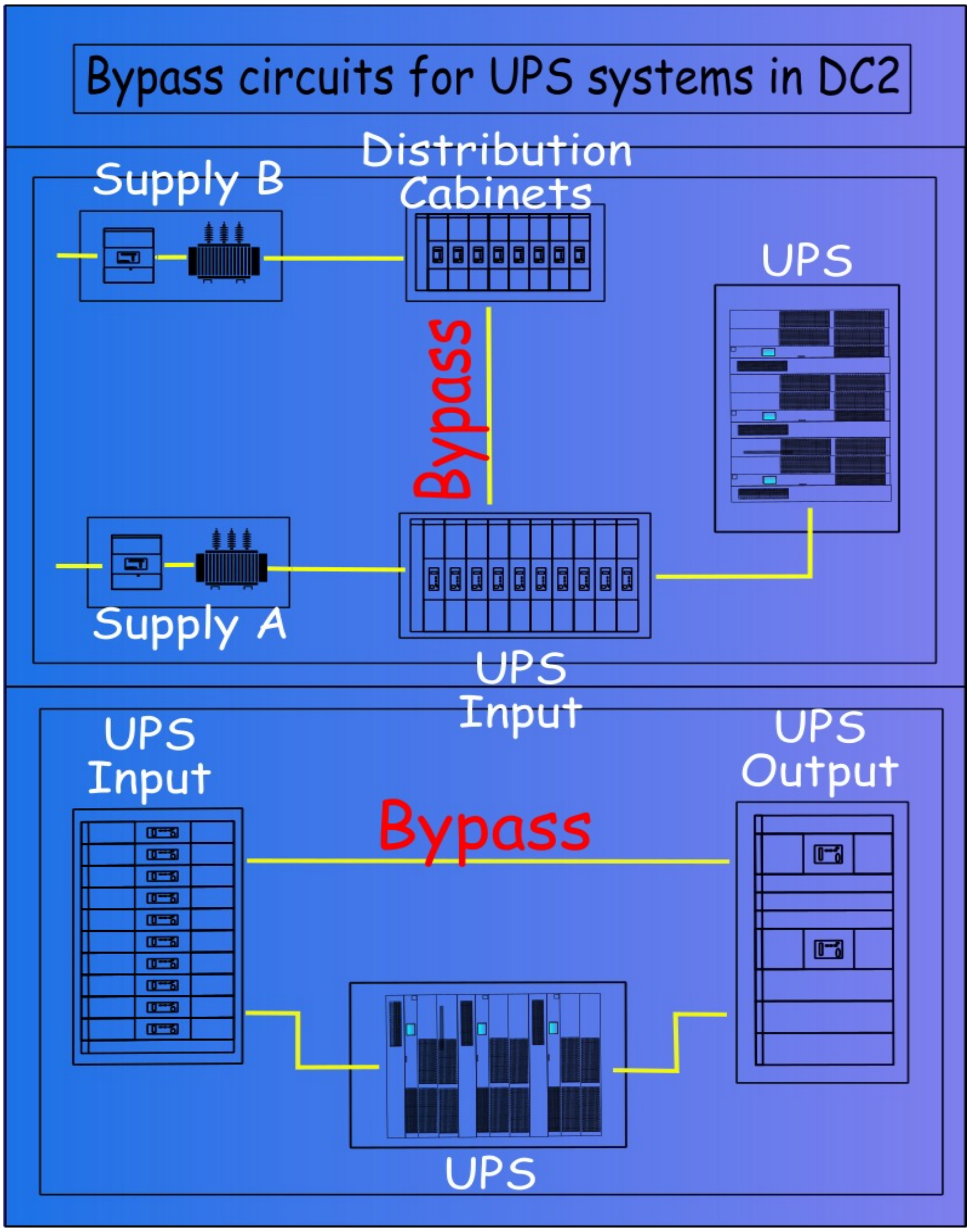


Figure 5. Bypass circuits for the UPS system. The bypass circuit on the top is used to omit the supply from transformer A. The bypass circuit on the bottom is used to omit the UPS units.

The aforementioned bypass controlled by circuit breakers is also referred to as manual bypass because the circuit breakers are controlled manually. Only authorize personal can operate the circuit breakers, or else inappropriate configurations could cause undesired results.

In addition to the manual bypass circuits the UPS system possesses also, two SST switches. SST switches are not controlled manually because they are integrated by power transistors. Power transistors are switches made from silicon and control by electricity. Figure 6 represents the solid state switch bypass connections at DC building.

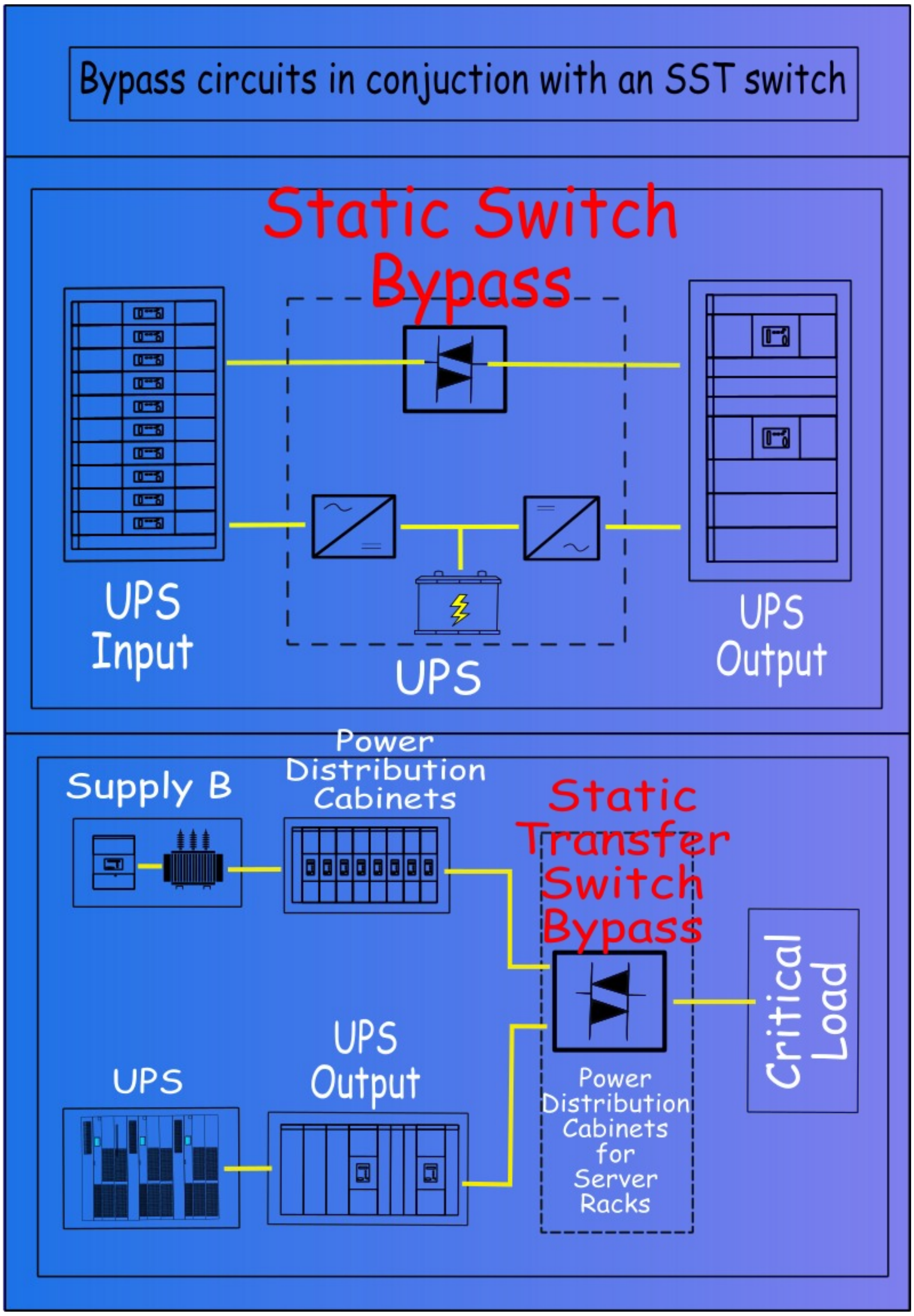


Figure 6. Bypass circuit in conjunction with SST switch. On the top box, the SST switch creates a circuit bypass the UPS units in case of UPS failure. On the bottom box, the SST switch choose between source A and B in case of line failure at PDN A or B.

The two SST switches possess different internal configuration due to their purpose. The SST switch on the left of figure 6, turns OFF or ON when it detects a failure in the UPS components. The solid state switch in unit 9395P goes by the name static switch. The static switch bypass the UPS units in 2 milliseconds. [4] The SST switch shown on the bottom of figure 6, is often called static transfer switch or STS because it swaps (or transfer) the power source of the distribution cabinet for server racks from the UPS to supply B. When the STS swaps the source from UPS to supply B, it implies the load is connected directly to the mains and its power disturbances.

## 2.6 UPS load

Failures in UPS units such as wrong settings, incorrect UPS mode during operation, and other failures cause power blackouts or disturbances which damage the critical load. Failures in UPS systems are translated as costly problems for data centers. [6] Nonetheless, selecting the optimal UPS mode, is translated into power cost saving. To select the proper parameters one must understand the UPS load in the data center.

The UPS load consists of every electrical equipment considered critical to the functionality of the data center infrastructure. The UPS load is often referred to  critical load. The critical load is listed below.

- Dedicated Servers
- Cloud Servers
- Miscellaneous IT-Equipment

The next sections present more details about the critical load type and their optimal operation in conjunction with UPS units.

### 2.6.1 Dedicated Servers

The dedicated servers are the servers rented by customers. The customers customize the components integrating the custom server. The power supply unit or PSU installed on dedicated servers depends on the power consumption of the dedicated servers components.

The PSU used for dedicated servers in the data center building where the UPS 9395P operates is not different from a generic PSU used at home for desktops PCs. Thus, power outages exceeding 20 milliseconds cause an immediate power shutdown of the dedicated servers. In other words, the UPS systems must always be ready to supply power in less than 20 milliseconds or the servers will turn-off.

The PSUs are powered in parallel from distribution cabinets in the servers racks. The non-linear power given by a single PSU is low. However, over 10 000 servers or more are placed in parallel inside a data center, causing a noticeable increase of non-linear behavior. To avoid penalties from the reactive power produced by the critical load, the UPS system must be ready to compensate non-linear loads in addition to power failure.

### 2.6.2 Cloud-Servers

The cloud-servers structure is not very different from the dedicated server.  However, a cloud-server could host hundreds or even thousands of virtual servers at the same time, multiple clients could rent one or more virtual servers on the same cloud server. Cloud-servers are considered power efficient machines because they share their resources between multiple users. In other words, the power efficiency occurs when the client rents a virtual server but does not utilize the resources of the server (inactive user) allowing other active users utilize the same resources from cloud servers on their own virtual servers.

When a cloud servers power is interrupted multiple clients lose connection, impacting more on the power quality of the data center. To avoid power failure, cloud servers possess two or more PSUs to take advantage of redundancy. At the same time, cloud server PSUs are integrated by a higher quality of components than regular PSUs.

The cloud servers in DC building are powerful machines that possess a higher density of components to host as many virtual servers as possible and take advantage of their dual PSUs for redundancy.

Cloud-servers are placed in parallel on server racks as done with dedicated server space inside the DC building. However, the PSU for cloud-server causes less reactant in the UPS system, due to the higher quality of the PSU [8].

### 2.6.3 Miscellaneous IT Equipment

The miscellaneous IT equipment refers to other electrical equipment powered by the UPS. The power consumption of the miscellaneous IT equipment is negligible for analyzing them as part of the critical load, because its power consumption is insignificant compared to the servers described previously.  The miscellaneous IT equipment is integrated by, Ethernet switches, PC peripherals, Wi-Fi hubs, to mention a few.

## 2.7 UPS Measurements

The measurements were taken from individual UPS units. Individual UPS 9395P units possess an interface display, the interface shows measurements taken from its power connections sensors when selected. Figure 7 shows the display panel at UPS units.


Figure 7. Display interface of UPS Unit 2.1.

Table 1 presents general information about the power consumption of the UPS in relation to the real power, apparent power, efficiency and so on. The values in table 1 were copied from the display interface of individual units. The table is divided by power input and power output for units1, 2 and 3 respectively.

Table 1. Measurements taken from display interface at the UPS Unit.

| Power Input | | | | |
|---|---|---|---|---|
| | Apparent Power | Real Power | Power Factor | UPS Efficiency |
| unit 2.1 | 248.4 kVA | 248.0 kW | 0.99 | 95.4% |
| unit 2.2 | 253.3 kVA | 247.8 kW | 0.99 | 95.3% |
| unit 2.3 | 245.3 kVA | 244.8 kW | 0.99 | 95.0% |
| Power Output | | | | |
| | Apparent Power | Real Power | Power Factor | UPS Efficiency |
| unit 2.1 | 257.1 kVA | 236.0 kW | 0.91 | 95.4% |
| unit 2.2 | 258.7 kVA | 238.7 kW | 0.91 | 95.3% |
| unit 2.3 | 253.6 kVA | 233.4 kW | 0.91 | 95.0% |

The voltage and current from batteries were taken from individual UPMs in the same UPS interface. However, the current was not specified because the batteries were fully charged. The battery measurements are shown in table 3, below.

Table 2. Battery Measurements:

| String number | Connected to | Voltage [volts] | Current in Amperes [A] |
|---|---|---|---|
| String 1 | UPM 1 in UPS 2.1 | 537 v | No specify |
| String 2 | UPM 2 in UPS 2.1 | 537 v | No specify |
| String 3 | UPM 1 in UPS 2.2 | 537 v | No specify |
| String 4 | UPM 2 in UPS 2.2 | 537 v | No specify |
| String 5 | UPM 1 in UPS 2.3 | 537 v | No specify |
| String 6 | UPM 2 in UPS 2.3 | 537 v | No specify |

The current values of the battery string vary according to the state of the battery. For instance, when battery strings are low of charge, the current is high to charge them. After the battery is fully charged the current drops near zero which is called a floating charge. The current and voltage parameters for the batteries are set up according to specifications of the battery manufacturer. Battery management is an extensive topic that forms part of UPS systems.

In addition, to internal measurements of the UPS units displayed on the interface, the UPS system monitors the power from the power input and output in the bus bars.  The UPS system monitors the power using a power analyzer model is UMG-604 from the manufacturer Janitza [9].

# 3 The UPS

This section presents more detailed information about the UPS unit. Understanding the UPS units from a practical approach is difficult. Therefore the subject is divided into three sections; The first section explains in short how double conversion technology works, the second section explains the main components of UPS units, and the third section presents the typical resources offered by UPS manufacturers.

First of all, UPSs are defined as a special type of electrical equipment that provides protection against power outages, as well as voltage regulation during power line over-voltage and under-voltage conditions [10]. Often, UPS units also provide protection against other disturbances, such as voltage spikes, line noise, frequency variation and so on. Figure 8 below shows typical power disturbances found in UPS systems.

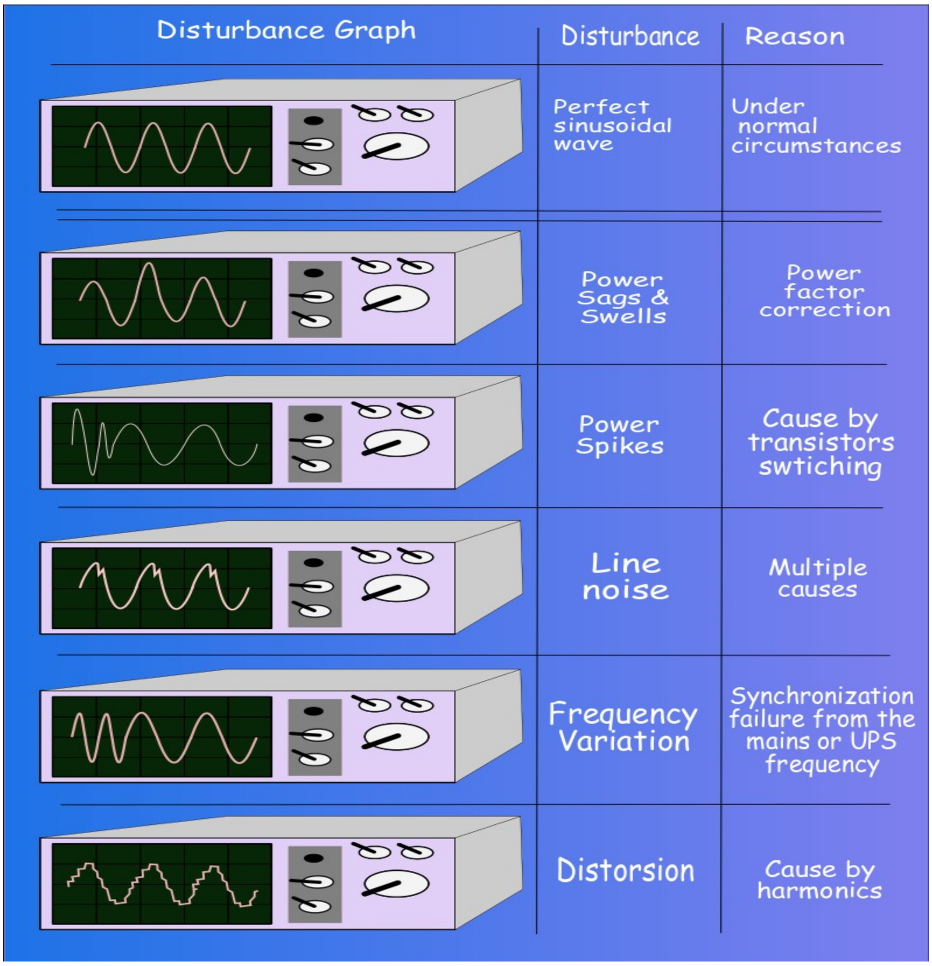


Figure 8. Typical disturbances generated by UPS system.[10]

The internal circuit and the components for the UPS units vary according to manufacturer's choice. The classification of UPS units is wide, nevertheless, five internal architectures stand out in the market for high power. The five architectures are listed below:

- Standby
- Line interactive
- Standby-ferro
- Double conversion on-line
- Delta conversion on-line

In terms of power efficiency, delta conversion UPS units perform better than other UPS architectures by reducing electricity costs. However, double conversion UPS units offer numerous advantages for large scale data centers, making them the standard in the industry. This thesis is focused on double conversion UPS systems.

## 3.1 UPS Operation

This section explains how double conversion UPS systems work in general and highlights their main components.

The common architecture of double conversion systems consists of power conversion from ac power into dc power using a rectifier at the input of UPS. A portion of the dc power is directed towards the battery bank to keep it charged, while the larger part of the dc power is transformed back to ac power using inverters. The output of the inverter supplies power to the critical load. In the case of power outage, the battery bank provides power to the inverter.

In conjunction with the inverter, a power filter is placed in the output to protect the load from disturbances cause during power conversion from the inverter. For additional reliability, the power line itself is used as a backup to the UPS, using another device for fast switching, which transfers the power to mains in case of UPS failure. In other words, the fast switching device is a static state technology switch behaving as a by-pass. The typical block diagram for double conversion UPS units is shown in figure 9.

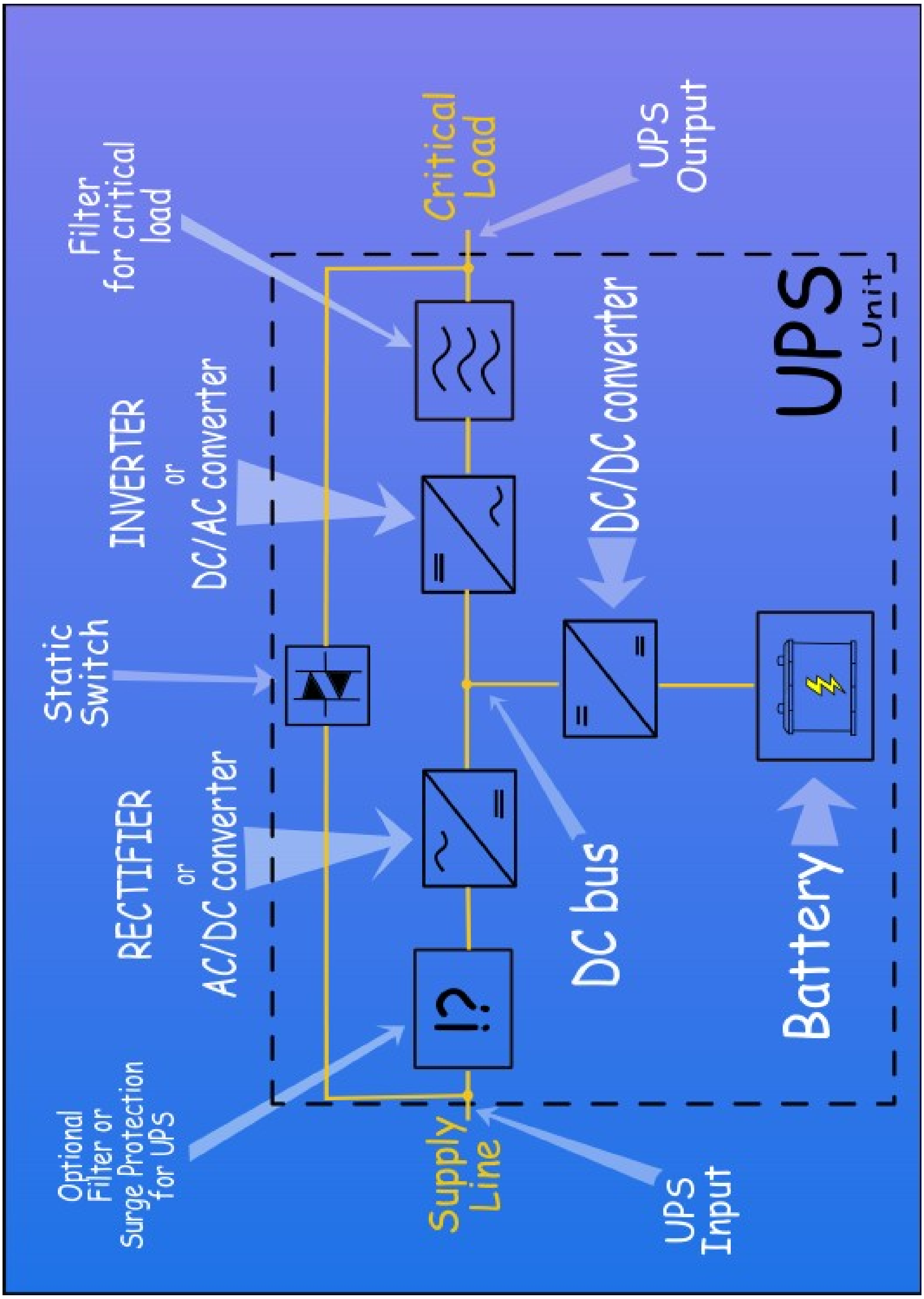


Figure 9. General block diagram for double conversion UPS. [10]

Typically the SST switch is a power transistor such as SCR or GTO technologies, because they can handle high power.

Usually, the UPS units possess additionally components in its circuitry for line disturbances such as surge protectors, filters, circuit breakers, to mention a few. For instance, the circuitry in unit 9395P possesses two filters and various circuit breakers, The filter from the input removes disturbances from the mains, while the filter in the removes disturbances from the UPS power converters. Figure 10 shown the block diagram for unit 9395P.

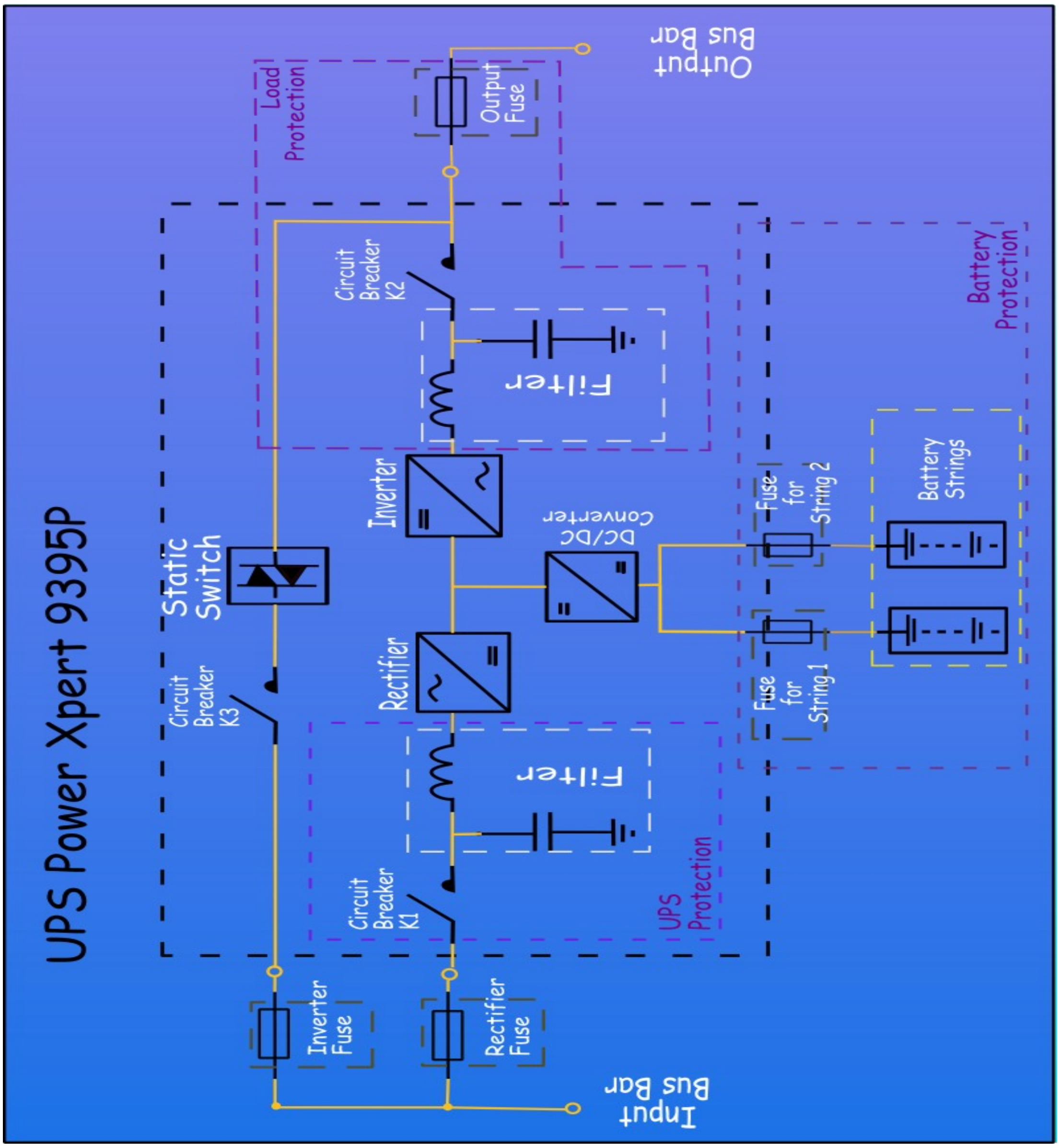


Figure 10. Block diagram for UPS model Power Xpert$^{TM}$ 9395P from EATON.

The filters reduce disturbances by using capacitors and inductors able to tolerate high power. However, the capacitors use for filtering have the disadvantage of having a short service life. High-quality capacitors have an average service life of 10 years. [4]

The circuit breakers employed in unit 9395P accomplish the disconnection of UPS modules for replacement or maintenance, while the input and outputs are energized. In addition, a circuit breaker is added to the static switch to avoid leakage. The leakage is an unwanted behavior caused by the atomic structure found is certain solid-state technologies. To avoid the leakage the circuit breaker is always placed before the solid state switch.

More details about UPS components is presented in the next sections.

### 3.1.1 Control Board

The control unit as its name implies is the circuit board controlling the UPS. Nowadays, UPS units posses multiple control boards with MCUs, short for microcontrollers. The MCU is the brain of the control board. Figure 11 shows control board tasks.

The main control board collects data from the sensors in the power outputs and inputs, and commands the behavior of the main components integrating the UPS unit. In other words, numerous MCUs control the power converters, circuit breaker, static switch, and other components integrating the UPS unit, and all MCUs are controlled by the main MCU. The specific functions of the MCU vary depending on their purpose such as synchronization for parallel UPS units, display interface, switching control, external communication, alarm, main control board and so on.

### 3.1.2 Power Transistors

The field of power electronics describes power transistors as the key device behind power conversion. Power transistors possess fast switching abilities which make them the center in power conversion design. Consequently, the type of power transistor used in power conversion defines the circuitry and technique implemented in the power converter.

Ideally, power transistors behave similarly to regular switches with faster switching capabilities. However, in real life applications power transistors possess leakage current, and have other disadvantages to regular mechanical switches.

UPS manufacturers update their devices with the latest technology used in power conversion. Therefore, understanding the type of power transistor technology proves beneficial when analyzing UPS systems. For instance, UPS unit 9395P utilized IGBT technology for power conversion.[4] Table 3 below, presents common power transistors utilize for UPS units.

Table 3. Power transistors technologies.[13]

| Power Transistor Type | Switching Speed in kilo Hertz | Current Tolerance in amperes | Internal Power loss | Main disadvantage |
|---|---|---|---|---|
| BJT | 10kHz | 750A | Medium | Very inefficient: Switching frequency is low and big power loss |
| MOSFET | 1MHz | 100A | Very low | Low power tolerance input. |
| IGBT | 90kHz | 500A | medium | Slower switching than MOSFET, but tolerates higher currents. |
| GTO | 1kHz | 200A | High | Low switching frequencies. |
| SCR | 1kHz | 3000A | Very High | Slow switching, Cause large disturbance in their output power. |
| MCTs | 50kHZ | 625A | Low | Low reverse voltage tolerance. |

The switching frequency and maximum current tolerance are the key features in power transistors. They determine the performance of the power converter. In table 3 is presented IGBT power transistors as the ideal technology for fast switching, while handling high current in power conversion. [13]

Power transistors such as SCRs and GTO are found in solid state switches, such as static switches and static transfer switches to mention a few.

### 3.1.3 Power Converters

Power conversion is defined in the fields related to electrical engineering as converting electric energy from one form to another form. For instance converting between alternate current (ac) to direct current (dc), or changing the voltage or frequency, or some combination of these. Power conversion is obtained through various types of power converters. For instance, this could be as simple as a transformer changing the voltage of ac power or a complex system such as double conversion UPS unit.

The power converters integrating the UPS system accomplish different purposes, although they work together to warranty a constant supply of power. The main power converters found inside UPS units are listed below:

- The Rectifier: refer as alternate current to direct current converter (AC/DC). The main purpose of the rectifier is supplying power to the inverter in the UPS while keeping the battery bank charge.

- The Inverter: refer as direct current into alternate current converter (or DC/AC).

- DC/DC converter: changes the voltage to a lower or higher level depending on voltage level input and output. DC/DC converter is also referred as step up or step down converter respectively.

A detailed explanation of how electric converters work is not part of the thesis. On the other hand, is important to recognize the technology used during the electrical conversion and identify the components which integrates the electric converter.

For instance, the power converter technology used in the UPS unit 9395P is a pulse-width-modulation technique or just PWM. The PWM allows fast switching control of the power transistors named IGBT used in the rectifier and inverter integrating unit 9395P[4.10]. The PWM technique allows fast switching of IGBTs which improves the shape of the sinusoidal wave at the output of the UPS unit.

Figure 11 illustrates the internal circuitry for double conversion UPS units made from IGBT power transistors. In figure 11 the IGBTs forming part of the rectifier are controlled by the rectifier control board, while the IGBTs forming part of the inverter are controlled by the inverter control board. Both rectifiers and inverters are controlled by the main MCU board, which analyzes the input and output power to achieve smooth conversion. In addition, other devices, such as the surge protection and SST switch are controlled by the main MCU board for  the safety of the power conversion operation.

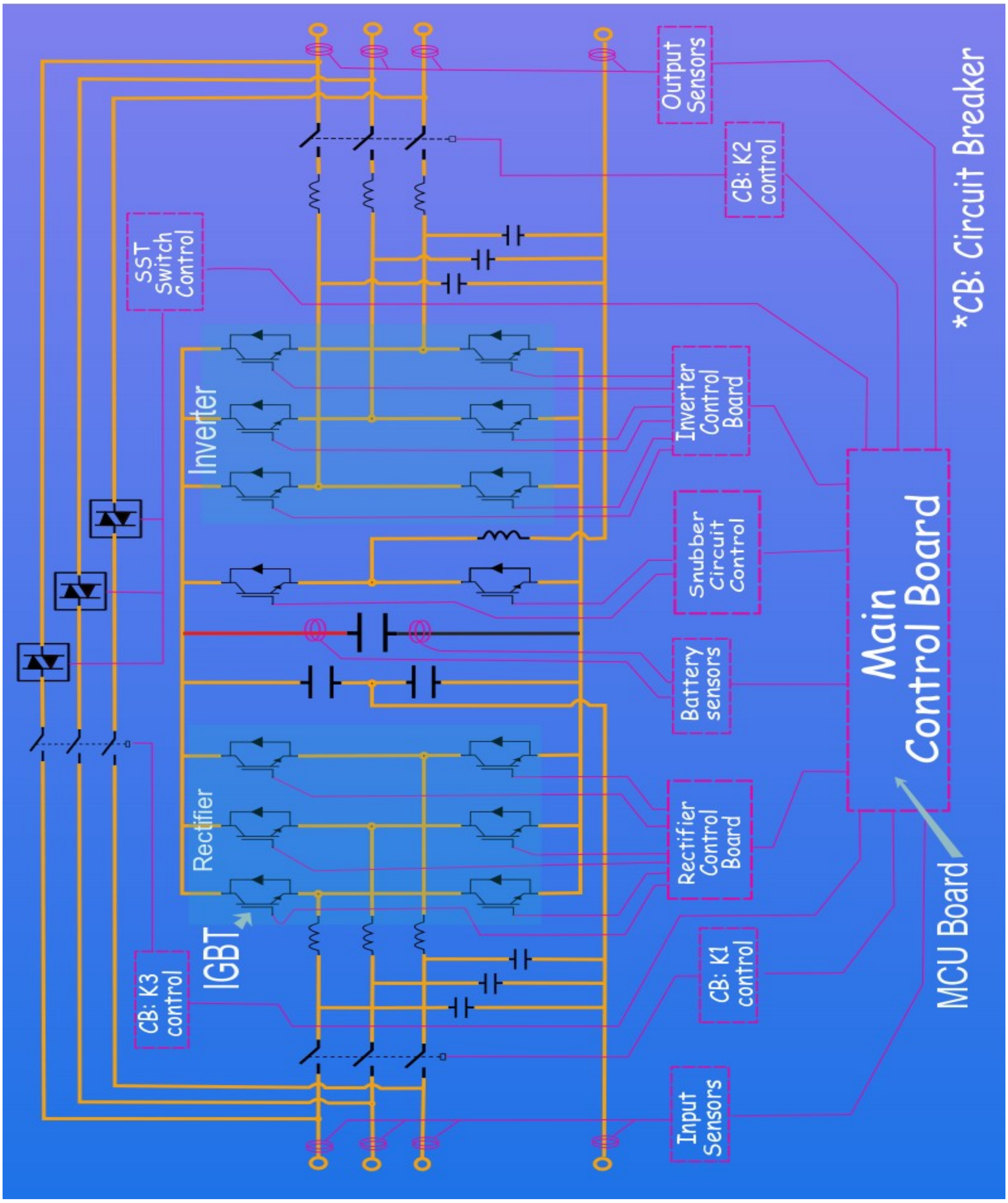


Figure 11.  Internal circuitry for double conversion UPS units. [10]

Unit 9395P has a similar internal circuitry to the circuit shown in figure 11. However, the unit 9395P has two UPSs working in parallel called UPMs.

The advantage of parallel UPMs is the reduction cost and volume by sharing components. Besides is possible to remove the UPM without taking the whole UPS unit. However, having one SST switch per unit bypass both UPMs when only one UPM has failed. The SST leaves the load without protection against power outages and disturbances.

### 3.1.4 Solid State Switches

Solid state technology for switches, is defined in simple words as a special type of switches behaving similarly to regular switches but control electrically using current, voltage or a mix of both in the control terminals. Solid state switches are mounted in electrical circuits in different configurations to obtain different purposes such as static transfer switch circuit, static switch circuits and so on. The fist behaves like a bypass and the second transfers the source of the power from A to B.

The main purpose of solid state switches in UPS systems is the additional reliability to the system. In other words, it provides direct power supply to the load from the mains, by bypassing the UPS itself, or any other electrical equipment for power distribution.

The solid state technology for switches used in UPS systems for large scale data centers differs from conventional power transistors switches by their ability to handle higher currents and voltages. Simply, the solid state switches used in large UPS systems transmit higher electrical power than regular IGBTs or other power transistors. However, current leakage is spectated from the device also, like almost all power transistors.

For instance, the UPS system analyzed in this thesis work possesses double SST switches to warranty continue power supply. One SST switch called static switch opens or closes to bypass the UPS, while the second SST switch called static transfer switch swaps between sources. The double SST switch protection ensure continues power flow. Figure 12 below illustrates the concept of double SST switch protection.

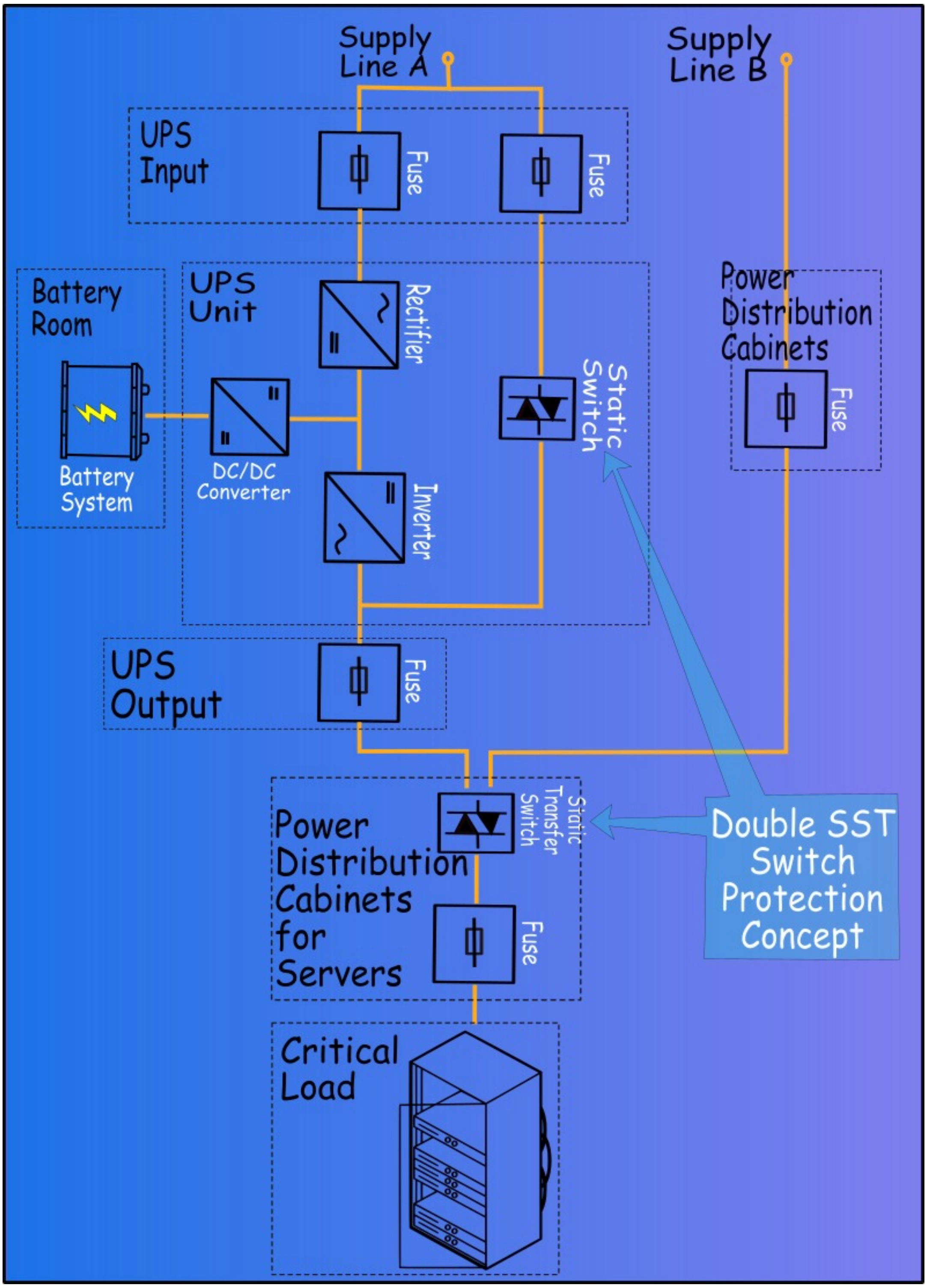


Figure 12. Double SST switch protection concept for the critical load of data centers.

In summary, the SST for switches behaves similarly to conventional mechanical switches, although they switch faster, and are controlled by electric currents and voltages, but possess small power leakage. The main purpose of SST switches in UPS systems is to bypass faulty electrical equipment and ensure the power flow to the critical load.

### 3.1.5 Battery System

The battery provides electricity during a power outage. The battery system is nowadays referred to as an energy storage device because it stores energy in a form different from electricity and releases electricity when required. For instance, regular home batteries utilize chemical reactants to release electricity when the chemical reaction occurs.

UPS systems are able to use various types of energy storage devices. However, lead-acid battery banks are frequently used in conjunction with UPS units, because they offer lower cost and fast current supply without damaging the batteries.

For optimal utilization of energy storage devices in conjunction with UPS units, it is necessary to understand its technical specifications. For instance, the UPS system analyzed possess non-sealed lead-acid batteries, model 10 OSP.XC 400 from the manufacturer Hoppecke.

Table 4 presents the technical specifications for the battery model 10 OSP.XC 400. The specifications are divided into two sets to simplify the specifications, the first set refers to the general features of the battery, while the second set refers to battery recommendation during operation.

Table 4. Specifications, values and descriptions for non-sealed batteries.

| Battery type: 10 OSP.XC 400, 2V,1,27kg/l for individual battery | | |
|---|---|---|
| General Characteristics | | |
| Specifications | Values | Description |
| Delivery | Individual batteries must be inspected by the time of arrival to avoid possible failures. | |

| | | |
|---|---|---|
| Installation | 6 strings with a total of 240 battery packs per string place on special battery racks. | |
| Storage without charging | Should not exceed 3 months period. The period of storage changes according to environment temperature and sun exposure. | |
| Battery Components | 10 positive plates per battery pack | |
| Voltage | 2 volts per battery pack | |
| Ambient temperature for storage | Tolerance range: 0° to 40° Celsius, while 20° Celsius is the optimal temperature. | |
| Electric charge | 440 Ampere-hour per battery pack containing $C_{10}$ | |
| Electrolyte density | 1.27 kg/l | The electrolyte have a total weight of 10.2 kg per battery pack |
| Weight | 34.0 kg | per battery pack |
| Volume | 189x208x420 | Length x Width x Height in millimeters |
| Torque | $20\,N\cdot m$ | Maximum torque for installation. |
| Characteristics for Operation | | |
| Electric charge in Ampere-hour in relation to the load | The energy capacity is 440 amperes per hour, However the critical load could get a maximum of 15 minutes of electric charge. | |
| Energy capacity in Watts | 237.6 kWh | $240\times 2{,}25\times 440 \simeq 237\,600\,\textit{watts per hour}$ found in one battery string |
| Discharge | For C10 the maximum discharge nominal capacity is 440 amperes. | |
| Minimum voltage for battery cell | 1.69 V | If voltage on batteries cells goes under 1.69, they could be destroy and service life is shorten. |
| Maximum voltage per battery cell | 2.4 V | Maximum voltage per battery pack. |
| Ambient temperature | 10°C - 30°C | Operating ideal temperature. Over 55°C is not permissible. |
| Humidity | 85% | Maximum permissible humidity |
| Charging current at 2.4 volts | 40 A - 90 A | Maximum charging current is 10 A – 20 A per 100 Ah. |
| Floating charge | 2.25 V | The floating voltage is 2.25 per battery pack. For the battery string is 537 volts |

The technical specifications are vital to set up the parameters during UPS installation and management.

## 3.2 Resources

The resources presented by UPS unit manufacturers are the technical documents such as manuals, technical specifications, datasheets, FAT and so on. Most of the documentation is mandatory to guide the user. However, documentation from manufacturers is often difficult to comprehend.

In the next sections are presented the most common resources from UPS Units Power Xpert 9395P from Eaton and the UPS unit Liberty Trinergy 2400A from Vertiv.

### 3.2.1 Proper Documentation

This section emphasizes the presentation of documentation provided by UPS manufacturers for installation manuals, technical specifications, FAT and other information necessary for the management of UPS systems.

For instance, one expects to receive proper documentation for expensive equipment in large data centers. This is the case for the unit Power Xpert 9395P which presents extensive and well-detailed information. However, the UPS unit Liebert Trinergy Cube from Vertiv possesses misinformed and confusing terminology in their documentation from personal experience.

The correct management of all electrical equipment related to UPS systems is achieved by using clear and simple guidelines provided by manufacturers documentation.

### 3.2.2 Technical Specifications

The technical specifications are referred to as the set of documents required by the product [14]. The declaration of technical specifications is in accordance with IEC rules.

The main technical specifications for the unit Power Xpert 9395P from Eaton are listed below:

- Model: product type, ratings and technology implemented.

- Mechanical specifications: specify dimensions, weight, UPS entry cable, protection class and superficial aesthetics.

- Environmental specifications: refers to the proper environment for the UPS operation and storage. Characteristics such as acoustic noise, temperature, humidity are provided in addition.

- Efficiency: refers to the electrical power efficiency and heat dissipation from their internal components in relation to the maximum power supply to the load.

- Input specifications: refers to the rated power, number of output phases variation tolerance, rated output frequency, slew rate, power factor, maximum current input.

- Output specifications: refers to the rated power, number of output phases variation tolerance, rated output frequency, slew rate, loaded power factor, overload capability, and so on.

- Bypass Specifications: specifications in relation to the SST switch tolerances.

- Battery Parameters: Battery voltage, charging profile, charging current limit.

The consecutive sections provide additional information about the technical specifications in relation to the optimization of the UPS features for the unit Power Xpert 9395P. The specifications were provided by the manufacturer Eaton brochure and manuals.

### 3.2.3 FAT

FAT stands for factory acceptance testing. In the engineering field, the factory acceptance testing is a test conducted to determine if the requirements of a specification or contract are met, prior to the shipping of the UPS components.

Often technical personnel of the data center participates in the FAT and it is important to understand the specifications in the next sections.

### 3.2.4 Environmental Conditions

Table 5 present the environmental conditions taken from the datasheet specifications for UPS unit Power Xpert 9395P.

Table 5. Environment condition for UPS unit Power Xpert 9395P.

| Item | Value | Description: |
|---|---|---|
| Acoustic Noise | <81dBA at full load.<br><74dBA at 60% load. | The acoustic noise values is taken at 1 m distance from the double conversion UPS unit at 25°C. |
| Storage | From -25°C to +60°C. | Ambient temperature for the storage of the UPS unit with protective package |
| Operating Environment | From 0°C to +40°C. | For active double conversion of the UPS unit. |
| Battery bank | From +20°C to +25°C. | For optimal conjugated work between UPS and battery bank. |
| Relative humid-ity range | From 55 to 95% | Humidity tolerance without condensation allowed. |
| Altitude | 1000 m | Maximum altitude service in meters. |

The humidity and temperature are important factors to take into account the operation of the UPS units in conjunction with the battery system. Typically the battery bank is placed separately from the UPS system because the heat released by UPS units could damage the battery cells.

For instance, the UPS system analyzed during the thesis work possess different rooms for the battery systems and for UPS units to provide optimal environmental conditions for individual devices.

### 3.2.5 Mechanical Specifications

The size matters, especially according to the regulations in Finland. Regulations such as electrical equipment position in relation to emergency exits and fire zones. For instance, under Finnish regulations, there is a minimum distance between the front panel of the UPS cabinets and the exit door in case of an emergency. Table 6 below specifies the mechanical specifications for UPS units 9395P.

Table 6. Mechanical specifications for UPS unit Power Xpert 9395k.

| Item | Value | Description: |
|---|---|---|
| Dimensions | 1890x880x1880 mm | Width x depth x Height specify in millimetres. |
| Weight | 1530 kg | Total weight in kg of the UPS unit not including the shipping package. |
| UPS Degree of Protection | IP 20 | Protection provided against intrusion such as; dust, accidental contact, and water at electrical enclosure. |
| UPS cable entry | Bottom | Cable inlet. |

The mechanical specifications play an important role during the installation and the cooling of the UPS units. For instance, proper distance between the roof and the top panel of the UPS unit allows correct air flow exhaust for the cooling of the power transistors. Besides proper separation between roof and top panels avoids damages caused by the heat released.

Note: Obstructions on the top panel of the UPS unit Power Xpert 9395P and Liebert Trinergy Cube decrease their cooling capabilities, according to their manuals.

### 3.2.6 UPS Input & Output Specifications

The Input specifications, as well as the Output specifications, are vital information for obtaining the maximum efficiency of the UPS units. Tables 7 and 8 present the input and output specifications respectively.

Table 7. Input specifications for UPS unit Power Xpert 9395P.

| Item | Value | Description |
|---|---|---|
| Input voltage | 220/380 V; 230/400 V; 240/415 V. | Line to neutral, line to line voltage ratings |
| Voltage tolerance | 230 V -15%/+15% | For Rectifier |
| | 230 V -10%/+20% | For STS |

| | | |
|---|---|---|
| Power factor | >0,99 | 25% to 100% of load |
| | >0,97 | 10% to 25% of load |
| Input current | 840A | In amperes for the r.m.s value of the 400 line to line. |

Table 8. Output specifications for UPS unit Power Xpert 9395P.

| Item | Value | Description |
|---|---|---|
| Output voltage | 220/380 V; 230/400 V; 240/415 V. | Line to neutral, line to line voltage ratings |
| Variation | < ± 2.5% | Output voltage variation. |
| Harmonic distortion | <2% | Linear load |
| | <5% | Non-linear load |
| Output Power | 600kVA/550W | Maximum power supply by the UPS |
| Frequency | 50 or 60 HZ | Configurable output frequency. |
| Power factor | 0.7 lagging to 0.8 leading | Permitted range |

The power efficiency for the UPS unit is calculated using the formula (1):

$$Efficiency = \frac{(Power\ Output)}{(Power\ Input)} \times 100\,\% \quad (1)$$

The formula is a useful tool for calculating power efficiency with accuracy. Table 9 shows the power efficiency value measured by the manufacturer for reactive loads at different load levels. Additionally, the heat dissipation is presented in table 9 at different load levels.

Table 9. Power Efficiency for UPS for UPS unit Power Xpert 9395P.

| Item | Value | Load percentage from the maximum power supplied by the UPS unit. |
|---|---|---|
| Efficiency in double conversion Rated for linear load. | 95.6% | 100% |
| | 96.0% | 75% |
| | 96.3% | 50% |
| | 95.6% | 25% |
| Heat dissipation | 25.5 kW | 100% |

| | | |
|---|---|---|
| in double conversion in kilowatts | 17.1 kW | 75% |
| | 10.7 kW | 50% |
| | 6.3 kW | 25% |
| | 4,3 kw | No load |

The power efficiency of the UPS unit is increased to near 99% when operating in modes different from the double conversion mode according to the brochure.

### 3.2.7 IEC Regulations

UPS systems are dangerous electrical equipment because the power converters produce electromagnetic interference and inject current harmonics into the electrical utility system due to the fast switching of the power transistors.

Regulations obligate power converters manufacturers to reduce their unwanted harmful signals. This is the case for UPS manufacturers regulated by the IEC, short for International Electrotechnical Commission. IEC rules are only applied to Europe. More information about IEC regulations is accessible from their website. The next table mention some interesting documents about UPS regulations.

Table 10. Regulations for UPS units and its purpose

| Identification | Item | Purpose |
|---|---|---|
| IEC 62040-1:2017 | UPS | Safety requirements |
| IEC 62040-2:2016 | UPS | EMC requirements |
| IEC 62040-3:2011 | UPS | Method of specifying the performance and test requirements |
| IEC 62040-4:2013 | UPS | Environmental aspects - Requirements and reporting |
| IEC 62040-5-3:2016 | UPS | DC output UPS - Performance and test requirements |
| IEC 62310-2:2006 | STS | EMC requirements |

Usually, sales agents advertise their UPS systems as the best in the market. For instance, they claim to posses filters against noise and harmonics. However, all UPS systems have such filters due to regulation in Europe.

Note: The word EMC stands for Electromagnetic Compatibility, is the branch of electrical engineering concerned with the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects [17].

# 4 UPS Features

Understanding the characteristics of UPS units allows performance improvement during operation. The following sections explain in detail the three most important features of the UPS unit Power Xpert 9395P and the UPS unit Liebert Trinergy Cube 2400A. The summery of the UPS features are listed below.

- UPS Modes: operation mode for the UPS unit.
- Battery management: monitoring batteries performance.
- Redundancy: understanding reliability for UPS unit.

In addition extra features for the UPS systems with less importance are presented at the end. Extra UPS features such as parallel UPS unit set up, dust protection, cable management, the service life of components, expectations of the UPS display interference, emergency shutdown button purpose.

## 4.1 UPS Modes

This section presents the operating modes for double conversion UPS units. The UPS operating mode is related to the power flow through the main components of the UPS systems such as rectifier, inverter, battery, and solid state switch explained in previous sections. The regular operating mode for the UPS system is double conversion mode, other modes are the standby mode, Standby mode with an active filter, the battery mode and the parallel optimization mode.

Performance improvement for the UPS is achieved by selecting the most suitable operation mode for the critical load. To select the ideal mode for UPS operation is necessary to understand the advantages and disadvantages of individual UPS modes in relation to the type of critical load and line power input.

For instance, the critical load in the data center analyzed during the thesis work is non-linear with approximately 0.9 power factor measured. In addition, the critical load consists of servers which can not be without power longer than 20 milliseconds to avoid imminent shutdown.

### 4.1.1 Double Conversion Mode:

The double conversion mode is also referred to as regular mode, ON-line mode, VFI mode (VFI stands for voltage frequency independent by IEC standard EN 50091-3). Double conversion mode consists of the active operation of the rectifier, inverter, and battery. Figure 13 below illustrates the double conversion mode.

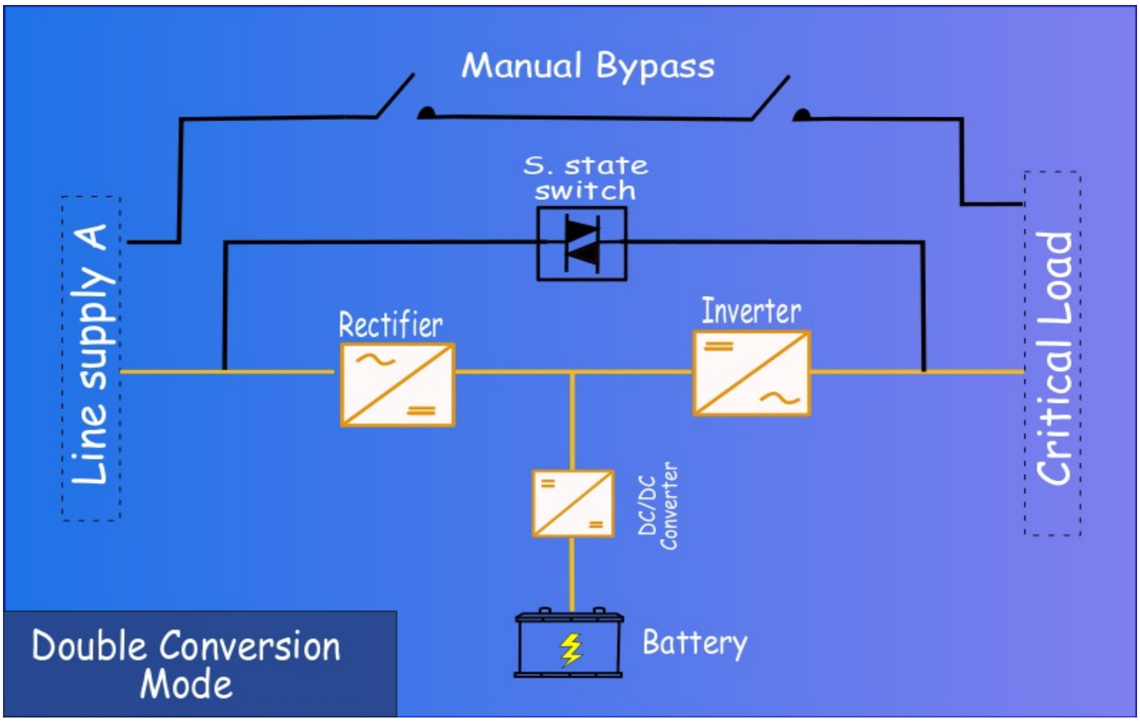


Figure 13. Double conversion mode

Double conversion mode has the main advantage of providing power supply in less than 2 milliseconds when blackouts or power failures occur. Double conversion mode provides better protection against power disturbances than other modes. However, most components in the UPS unit active translating in higher power costs because the UPS unit increases power consumption. [4]

In summary double power conversion mode is the regular mode for the UPS unit which provides the best protection against power disturbances and also provides the fastest supply of power from the battery in case of blackouts. The disadvantage of double conversion mode is the higher power consumption of the UPS unit itself.

### 4.1.2 Standby Mode

Standby mode operation has the main purpose of lowering the power consumption of the UPS by keeping their main components in standby and allowing power flow through the SST switch known as just solid state switch.

Standby mode is also referred to as passive mode. The standby mode has two subcategories with active filters and without any active filter. The active filter is the inverter.

Standby mode without an active filter is referred to as OFF-line mode or VFD mode (VFD stands for voltage frequency dependent by IEC standard EN-64920-3). The standby mode consists of allowing the mains to supply the power via the solid state switch, while the inverter, rectifier and the battery system are inactive or in standby, waiting to supply power for the critical load from the battery when a failure occurs, such as power outages. Figure 14 below illustrates the power flow for standby mode without a filter.

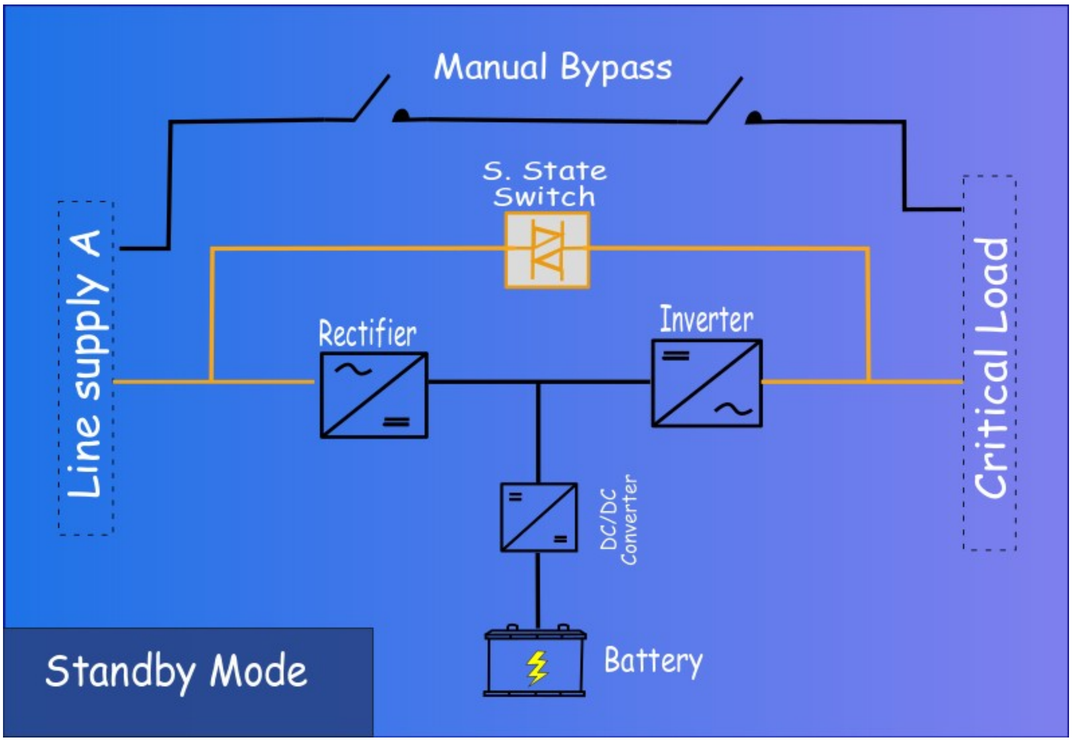


Figure 14. Power flow of Passive Standby Mode or VFD.

The main advantage for standby mode is the lower power consumption in the UPS unit, because the UPS unit has less active components than double conversion mode. However, the critical load is exposed to disturbances from the mains. The switching mode from passive mode without an active filter to battery mode is slower than other modes

UPS manufactures may call the standby mode without filter by other names. For instance, the manufacturer Eaton refers to the standby mode without a filter as ESS mode, ESS is short for energy saver system.

The second subcategory for standby mode is standby mode with an active filter, it consists of keeping the solid state switch operating in conjunction with the inverter to reduce certain disturbances from the mains, because the inverter acts as an active filter. The standby mode with active filter is called VI mode (VI stands for voltage independent by IEC standards). Figure 15 below illustrates the power flow for standby mode with an active filter.

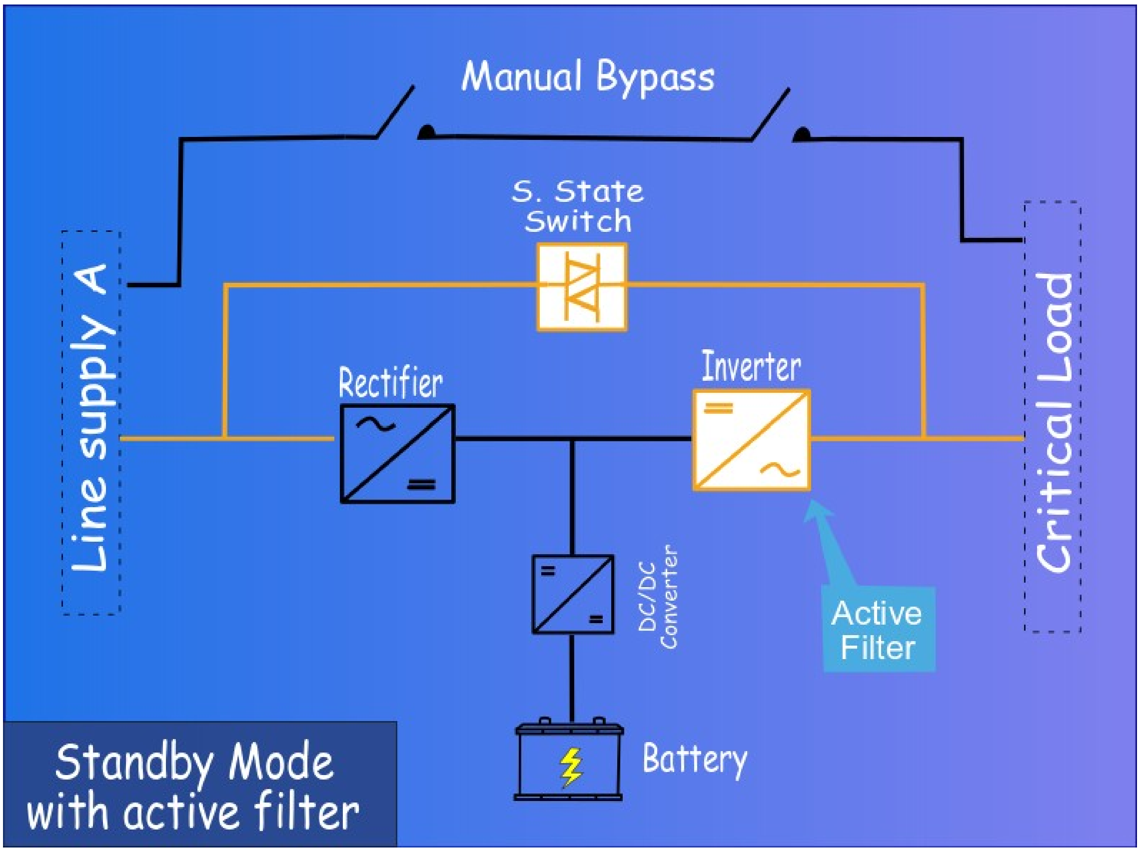


Figure 15. VI mode power flow.

The main difference from both standby modes is with o without an active filter is the inverter becoming the active filter. Keeping the inverters as an active filter reduces some power disturbances which warranties better performance of the critical load but increases the power consumption of the UPS unit. [19][20]

### 4.1.3 Battery Mode

Battery mode is referred to as the utilization of the battery as a supply of electrical power for the critical load. In battery mode, the inverter, the battery and the dc/dc converter are active and working together. The battery mode is enabled when the UPS unit detects a power outage in the supply line. Figure 16 below illustrates the power flow of the battery mode.

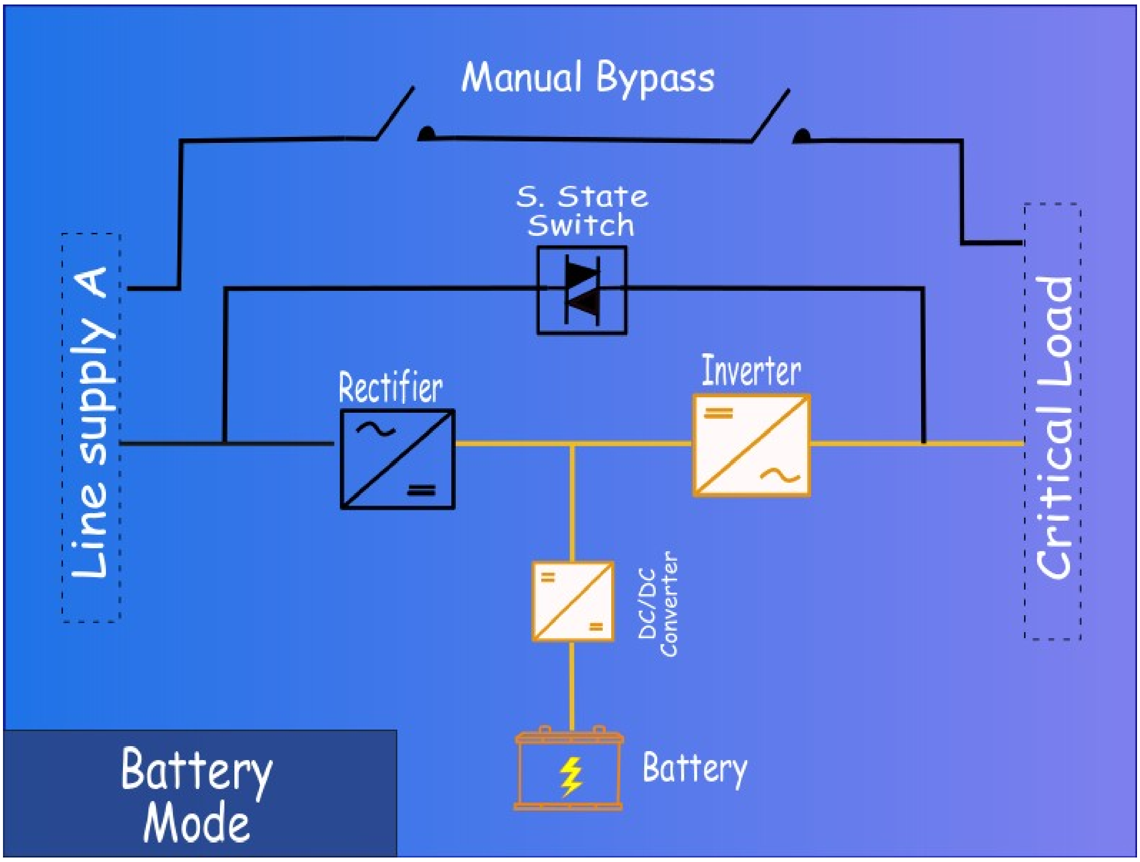


Figure 16. Battery mode during power failure or outage.

Apart from the battery mode explained previously, the UPS units contain other none formal operational modes such as floating charge mode, charging mode, battery test mode and so on which are related to the charging supply of the battery bank. The current supplied to the battery bank depends on the charging required by the battery. The current settings for the charging modes are programmed based on battery specifications.

### 4.1.4 Parallel Mode Optimization:

The parallel mode optimization is a special mode, which enables power efficiency by the UPS units connected in parallel to the same critical load. The parallel mode optimization has other names such as VMMS mode by Eaton or Circular Rotation by Vertiv in units Power Xpert 9395P and Liebert Tinergy Cube respectively.

The power efficiency for parallel mode optimization utilizes the concepts of redundancy and standby mode. In simple words, the parallel mode optimization consists of keeping the necessary modules turn-ON to supply the critical load near 50% of power supply capacity, while the other modules are in standby. By keeping individual UPS units near a 50% load, it obtains the maximum power efficiency of approximately 96.3% described in table 10 for UPS unit 9395P. The inactive or standby modules consume less power decreasing the power consumption of the UPS system. Additionally, the active modules supplying power to the load are swapped with standby modules monthly or weekly for avoiding constant stress in the components of active modules

For instance, the data center analyzed during the thesis work possesses three UPS units, each UPS unit possesses 2 UPMs per unit. In total, the UPS system possesses 6 UPMs, individual UPMs supply 300 kVA. The maximum power supply by the UPS system in parallel connection is 1800 kVA. Meanwhile, the average power consumption by the critical load is approximately 600 kVA. Consequently, it is possible to use four UPMs at 50% of their capacity (4 times 150 kVA) to supply the necessary power for the load while the other two UPMs are in standby mode. The system achieves 96.3% power efficiency for the four UPMs actively supplying power to the load while the two inactive UPMs are consuming minimal amounts of power. Additionally, The inactive UPMs are swapped monthly with two active UPMs. Thus, every uninterruptible power module obtains one month rest after 2 months of constant operation.

## 4.2 Redundancy

Redundancy is defined in electrical engineering as the addition of a component to certain equipment for maintaining continuous supply in case of failure, maintenance or replacement. The type of component added to the system varies. For instance; in UPS units, the redundant component could be an extra: control board, power cable connection, synchronization control, power module, or a UPS unit working in parallel.

In the case of power modules for UPS systems, different formats of redundancy are implemented depending on the numbers of power modules added to warranty continuous supply to the load. The different formats of redundancy are listed in table 11, below.

Table 11. Redundancy formats and descriptions.

| Redundancy Formats | Description |
|---|---|
| Single N | Simply N, represents the amount of power required by the critical load. For, instance the load requires 1500 kVA and one module supplies 300 kVA, then N equals five to supply the total1500 kVA. |
| N+1 | Represents the power required by the critical load plus one module supplying power. For instance, 5 modules supply 1500 kVA, then N +1 equals 1800 kVA or 6 modules in total. |
| N+N | Represents twice the power required by the critical load. For instance, the load N=1500kVA. then N+N =3000 kVA, or 10 modules in total. |
| 2(N+1) | Represents twice the power required by the critical load plus one module. For instance, the load N=1500kVA, then 2(N+1)=3300 kVA, or 11 modules in total. |
| 3N/2 | It is represented by 3 backup systems supplying power for two different loads. |

The reliability of the redundancy format is also referred to as active, passive, or standby. In other words, it is classified by; running, running in the background, or only running when a failure occurs respectively.

The UPS unit 9395P in DC2 building possesses N+1 format, because the three UPS units set in parallel contain six UPMs, even if the critical load requires a maximum of five UPMs. The redundancy for the UPS system in DC2 allows maintenance or replacement of one power module while supplying continues power to the critical load.

The different formats of redundancy are not exclusive of a power module in the UPS system, the formats are used in other types of hardware, software and so on. For instance, the DC2 building possesses the double SST switching concept as shown in figure 12, which could be referred to as redundancy of format 2N.

### 4.3 Battery Management

Battery management is considered by experts as one of the most important features in UPS systems. Battery management consists of numerous procedures to extend the longevity of battery while keeping energy stored in the batteries at its maximum after multiple charging cycles. The battery type dictates the battery management procedure.

For instance the UPS unit 9395P notify battery failures when battery voltage drops under the parameters taken from the battery specification by retrieving the voltage measured between the ends of the battery stings. In simple words, the UPS unit notifies when the battery strings needs maintenance when bizarre voltage readings are measured on battery strings. However, the UPS system does not specify the reason for the irregular behavior, or which individual battery cell is faulty because the measurement is connected in series.

Two procedures are implemented to properly monitor non-sealed lead-acid batteries or other types of chemical batteries.

The first procedure is installing a BMS connected to individual batteries to monitor each cell in the string. BMS is short for the battery management system. The BMS offer optimal charging currents, and balance out the battery charge on individual batteries for the string, maximizing energy capacity and battery life service respectively. The second solution is to perform battery tests by technical personnel on a regular basis. Reliable BMSs, are costly and its price increases at a larger number of batteries, making the second solution feasible.

## 4.4 Extra Features:

The next sections present additional features for UPS systems considered essential depending on the facilities where the UPS units are operating.

### 4.4.1 EPO feature

The EPO feature refers to the emergency shutdown button by UPS manuals from Eaton and Vertiv. The emergency shutdown button as its name implies, the button shutdowns the supply of power to the critical load by turning off the UPS unit or UPS units working in parallel completely including the battery supply. The installation of the EPO button is optional, because it only offers additional safety for the personnel, in case of electrical hazards.

### 4.4.2 Longevity Feature:

The longevity feature is related to the service life of all components integrating the UPS system. During the replacement of failed components or for maintenance in the UPS system, the critical load is left without UPS backup. Consequently, the time of service for the main components integrating the UPS system acknowledges when certain components are prompt to fail and take the necessary precautions.

For instance, the live service for the capacitors and fans integrating the UPS unit Liebert Trinergy Cube is 10 and 7 years respectively.

### 4.4.3 Parallel Feature

The great advantage of double conversion UPS is their ability to be installed in parallel and to supply extra power needed for large critical loads as the ones found in data centers.

Special synchronization controls are necessary to assist parallel units for synchronizing their output power from the inverter. For instance, Eaton is able to set up to eight UPS units in parallel. Parallel units are installed in various forms to achieve additional performance or reliability. The SST switching component found in UPS units could be installed as distributed or non-distributed, meaning one SST switch per UPS unit or one for all parallel units respectively.

Disturbed UPS systems have the advantage of utilizing one common direct current bus bar (or dc bus) for multiple battery strings connected in parallel working as one battery bank. In case one battery string fails the other battery strings connected to common bus bars continue to operate. However, the energy capacity of the remaining battery strings is reduced substantially (less ampere-hour provided by the battery bank).

### 4.4.4 Display Interface

The main benefits of a display interface are reliable access to the settings and the data of the UPS units. Easy access to the settings avoiding mistakes by the user from disconnecting a module by accident, or setting the wrong parameter. Besides, accurate readings from the UPS data are obtained from a reliable interface.

For instance, the UPS unit 9395P in the DC building offers a user-friendly display, with access to multiple measurements. In addition, it is possible to shut down power modules for maintenance by following simple instructions. On the other hand, the UPS Libert Trinergy Cube unit on a different DC building, do not allow access for most settings, making it difficult its maintenance without Vertiv personnel.

### 4.4.5 Alarm Feature

The alarm feature refers to the set of alarms which the UPS units alert when they detect problems.

Different communication protocols can be implemented to set the alarm systems according to the external infrastructure interacting with the UPS unit. In addition, it is possible to set the alarms via SNMP, short for Simple Network Management Protocol.

### 4.4.6 Dust Protection

Over time, dust accumulates on the circuitry, thus reducing their ability to keep the power converters under optimal temperature. For instance, when heat increases on the power transistors its power efficiency diminishes due to the physical and chemical properties of its silicon structure. Heat-sinks and fans are attached to the circuit boards for keeping the power transistors under maximum operating temperatures. However, fans accumulate dust faster on the heat-sink and other circuit boards resulting on a thicker layer of dust which diminishes performance.

Dust filters reduce the accumulation of dust solving the aforementioned problem, playing an important roll in the power efficiency of the UPS unit.

### 4.4.7 Cable Management

The title Cable Management refers to the possibility of running power cables properly though special cable trays and to obtain benefits such as electromagnetic interference reduction, increase heat dissipation, proper installations and improves aesthetics. In addition, proper cable management facilitates maintenance, for instance when connecting or disconnecting equipment integrating the UPS systems such as UPMs.

For instance, in inappropriate power cable connections between cores in unit UPS Liebert Trinergy Cube could block the exhaust airflow for cooling of power converters. [24]

## 2 Conclusions

As a review, the thesis work consisted of a deep analysis of the UPS systems in a data center and various topics were developed with the purpose of guiding personnel through various features and resources for the UPS and external components that form the UPS system.

A deeper understanding of UPS system features and resources allows improvement of the UPS system which was the ultimate goal of the thesis. In other words, the thesis accomplished its main purpose by defining the UPS system, UPS operation, critical load of the UPS system and highlighting features and resources of the UPS system. The thesis work has produced an extensive text with the intention of understanding topics, such as:

- Integration of the UPS system with the power distribution network in a large scale data center.

- Integration of the UPS system with the power distribution network in a large scale data center.
- Understanding the critical load and how it affects performance.
- Presenting useful terminology for the components and understanding its functions in the UPS system.
- Identifying and understanding the resources (documentation) provided by the UPS manufacturer.
- The General Operation of the UPS modes in correlation with the critical load.
- Battery management optimization by setting the appropriate environment for the battery and understanding the operation of the battery and UPS.
- Defining solid-state technology switches and its operation in relation to the UPS system.
- Guide through minor problems in UPS performance such as dust accumulation, cable management and so on called extra UPS features.

Finally, during the analysis of the UPS and the creation of the different topics previously mentioned, brought up new problems and questions. Concluding, the necessity of deeper research focused on two important aspects of the UPS system, which are:

1. Battery Management: Optimal environmental conditions for the batteries while tracking its performance and creating a proper schedule for its maintenance.

2. Accurate measurements of the critical load: Is necessary more knowledge about the effects of the reactance caused by multiple power supplies connected in parallel at large scale data centers to achieve improvement by adding filters or upgrading the PSU with better technologies.

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23 Vertiv, Installation Manual. Liebert Trinergy Cube 2400A, Manual: Revision 2 [1.11.2018]

## UPS Topology

Multiple types of UPS systems exist world wide and there is non-official topology for UPS systems. However five UPS architectures are highlighted for UPS working in data centers with large critical loads,.The five UPS architectures are listed, below:

- Standby.
- Line interactive.
- Standby-ferro.
- Double conversion on-line.
- Delta conversion on-line.

For large scale data centers is recommend a double conversion UPS because they have a better output wave form across all operating modes and better isolation. This can be referred to as computer grade power.

## Lead Acid Battery

The lead-acid battery is the oldest type of rechargeable chemical battery. Lead-acid batteries have low energy density meaning less energy-to-weight ratio and less energy-to-volume ratio. However, lead-acid batteries possess the ability to supply high surge currents. For instance, provide the high current required by automobile starter motors or high power demand of UPS units in large data centers. Another important feature of Lead-acid batteries is the low cost compared to other energy storage devices.

Lead-acid batteries are bulky energy storage devices integrated by negative and positive lead-acid plates, separators for the plates, connectors between plates, terminal connectors, enclosure pack and the electrolyte liquid responsible for the chemical reaction. The lead acid batteries are kept stationary due to their heavy weight on special racks. The battery rack allows easy access to the batteries for replacement and maintenance.

Lead-acid batteries are divided into two subgroups sealed and none-sealed batteries. The main differences are sealed batteries require less maintenance while none-sealed last longer. The maintenance required by none-sealed lead-acid batteries is listed below by period by time.

- Monthly Maintenance: Voltage measurement of individual battery strings and battery cells in float mode. Visual observation for the electrolyte level. Verify temperature and humidity in the battery room is correct.

- Annual Maintenance: Visual check of the screw connectors in case of corrosion. The temperature of individual battery cells and the density of the electrolyte.

**Static Switch Layout for the UPS Unit 9395P 600 kVA.**

The UPS unit 9395P possess two uninterrupted power modules sharing common devices i as shown in the layout, below.