PILLER
Power Systems

Isolated-Parallel UPS Configuration

White Paper No. 051

Nothing protects quite like Piller

www.piller.com

Isolated-Parallel UPS Configuration

Frank Herbener, Piller Group GmbH, Frank.Herbener@Piller.com, Germany

Abstract

A new distribution topology for Uninterruptible Power Supplies (UPS), called Isolated-Parallel-System (IP-System), combines the advantages of some of the most popular system designs while eliminating their main limitations and drawbacks. This paper explains the function of an IP-System, the implementation of Diesel engines, the UPS topologies and the kinds of energy storage devices, which are the most suitable for this application. It also shows why an IP-System can be seen as a green alternative to existing UPS scheme topologies. A short summary of experiences with the first big installation and about projects planned for the future shows the flexibility and the performance of IP-Systems.

1 Introduction

Power critical facilities are tending to be larger and have an increasing amount of critical load, requiring more and more highly reliable electrical power.

Direct paralleling of UPS (see **Figure 1**) is a frequently used method to increase the available output power and to provide redundancy. A simple constellation to achieve high levels of output availability is an N+x parallel redundant configuration, whereby N stands for the number of UPS needed to supply the load and x stands for the number of redundant units.

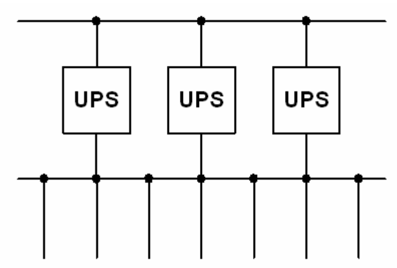

Figure 1 Parallel UPS Configuration

Due to the fact that many units are supplying the same output paralleling bus the parallel redundant scheme is limited to around 5…6 MVA at low voltages and is difficult to concurrently maintain. Even though simple N+x redundancy achieves high levels of output availability, a failure on the common output bus will surely affect the loads.

PILLER
Power Systems

To avoid this single point of failure a possible solution is to use a 2nd output bus. To achieve full redundancy between these two output busses, the system needs to be realized in a way, that each output bus is able to supply the full load. Therefore this system (N+N) redundant configuration, shown in **Figure 2**, needs twice as many units to supply the load. As a result of this, many of the units are only partially loaded and are not operated under their optimum efficiency conditions. So this system will not be the 1st choice if a green UPS scheme topology is the primary consideration, but should still be considered because of its extremely high reliability. Like the parallel redundant scheme, it too is limited in scale at low voltages.

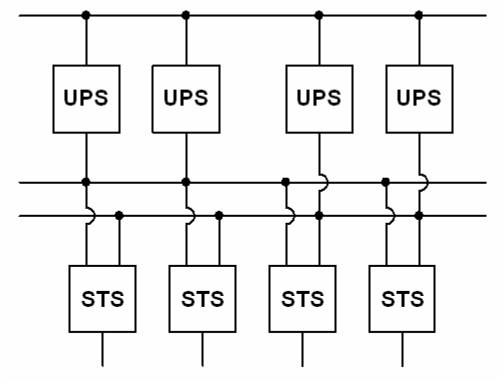

Figure 2 System redundant UPS Configuration with Static Transfer Switches (STS)

Another possibility to avoid the common output bus is to abandon paralleling of UPS. This results in the so called isolated redundant configuration, which is shown in **Figure 3**. In this configuration each UPS supplies its dedicated load while one or more redundant UPS are running in standby, ready to supply the load if one or more of the supplying UPS fail.

The isolated redundant and the system redundant configuration both utilize additional equipment like essential load sharing management and static transfer switches for single corded loads to switch to the alternative power source in case of an UPS failure.

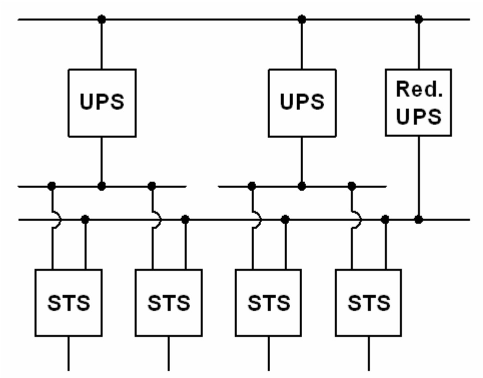

Figure 3 Isolated redundant UPS Configuration with Static Transfer Switches (STS)

A disadvantage of the Isolated-Redundant configuration is the inability of automatic load sharing between the modules and the fact that one or more UPS are running in idle mode without load. In combination with Diesel engines this results in engines running in idle mode during mains failure, which, if done for several hours, has a negative influence on the engines performance.

In the year 2005 the idea of a new system configuration was born, called Isolated-Parallel-System (IP-System). The overall design goal of this new configuration was to avoid the disadvantages of the conventional UPS configurations described above and to merge their advantages into a highly reliable system topology. This topology allows repeated paralleling of UPS modules with the benefit of automatic load sharing and high operating efficiency, while ensuring sufficient fault isolation between the individual units.

2 IP-System Configuration

The initial idea of an IP-System – described in [1] – used a ring bus structure to interconnect the individual UPS modules via isolation chokes in between each UPS module.

Based on this idea a team of engineers working for different companies [5] developed the final star bus structure, which later on was realized in the first customer application.

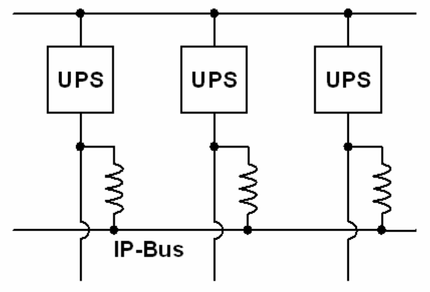

Figure 4 Basic IP-System

In such an IP-System (see **Figure 4**), each UPS is connected to a common bus (IP-Bus) by a 3-phase choke (IP-Choke), designed to limit fault currents to an acceptable level but provide sufficient load sharing at the same time. Each load is related to an individual UPS and is directly connected to the UPS's output.

Due to its load sharing capability an IP-System is typically designed in an N+x redundant configuration. Reducing the number of redundant units to a minimum while keeping the operating point of the UPS at a high level on the efficiency curve, makes the IP-System an ecological power supply for green data centers or other energy efficient facilities.

Load sharing

In normal operation each load is supplied from the mains via its associated UPS. In the case that the UPS's are equally loaded there is no power transferred through the IP-Chokes. Each unit independently regulates the voltage on its output bus and because of the IP-Chokes, there is no reactive current control necessary to inhibit the exchange of reactive power between the UPS modules.

In an unbalanced load condition each UPS still feeds its dedicated load, but the units with resistive loads greater than the average load of the system receive additional active power from the lower loaded UPS via the IP-Bus (see **Figure 5**). It is the combination of the relative phase angles of the UPS output busses and the impedance of the IP-Choke that controls the power flow and that defines the ability of natural load sharing among the UPS modules without the necessity of active load sharing controls.

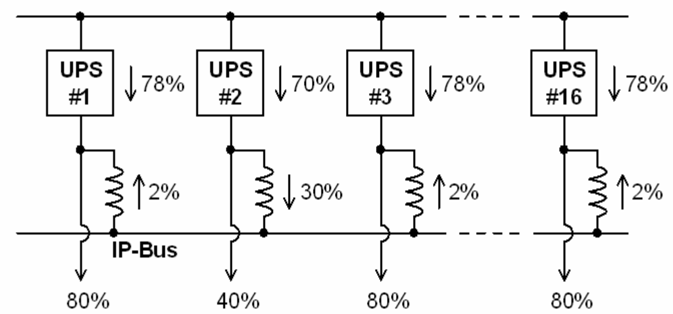

Figure 5 Example of Load Sharing in an IP-System consisting of 16 UPS Modules

The load dependent phase angle between utility and the output of the UPS is the essential factor regarding the natural load sharing capabilities: If there would be no phase angle each UPS output bus would always be synchronous with the mains. With every UPS output in synchronism and the other side of the IP-Choke connected together via the IP-Bus, there could be no phase angle across the IP-Choke and hence no active power flow. So only a phase angle naturally generated in correlation to the load level of the UPS provides the ability of natural load sharing among the UPS modules. A suitable UPS topology to achieve this load dependent phase angle in a natural way is a rotary UPS with an internal coupling choke as shown in **Figure 9**.

The influence of the IP-Choke should also be considered regarding the load sharing capability: With all UPS modules having the same output voltage, the impedance of the IP-Choke inhibits the exchange of reactive current between the units, so that reactive power control is not necessary. The fact that the IP-Chokes also impede the flow of active power between the UPS modules can easily be accepted regarding their ability to effectively limit fault currents within the system.

Looking at the mechanisms of natural load sharing in an IP-System, it is obvious that a direct connection between any location downstream of the UPS and the mains would significantly disturb the system. This connection would eliminate the phase angle between mains and load so that the loads of the whole IP-System would be supplied by that bypass via the IP-Bus, slightly limited by the IP-Chokes only. So before switching a UPS to bypass it definitely needs to be disconnected from the IP-Bus first to avoid this overload situation.

But an IP-System would not really be an advantage compared to existing system topologies if there would be no alternatives to this kind of bypass operation.

So if the traditional bypass operation is not allowed in an IP-System, what will happen in case of a sudden shutdown of a UPS Module? To say 'absolutely nothing' would be slightly exaggerated, but 'almost nothing' is quite close to what really happens.

Supposing that any power flow from a single UPS would immediately be stopped for what ever reason, the associated load is still connected to the IP-Bus via the IP-Choke, which now works as a redundant power source. So the load will automatically be supplied from the IP-Bus without interruption. In this mode each of the remaining UPS Modules equally feeds power into the IP-Bus, like it is shown in **Figure 6**.

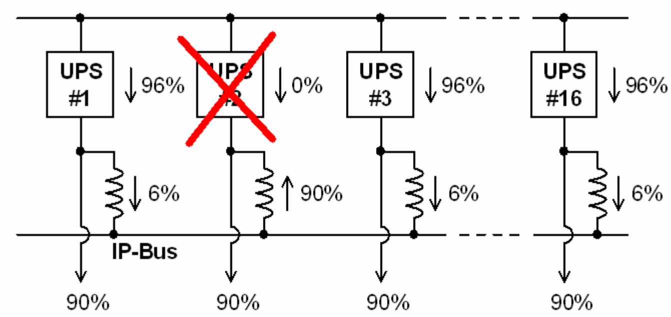

Figure 6 Example of redundant load supply in an IP-System in case one UPS failed.

Because the affected load is now fed through the IP-Chokes and the voltage regulation of the associated UPS is missing there is a voltage drop on the load bus that needs to be considered. Depending on the power factor of the load and the design of the IP-Chokes this voltage drop can be limited to less than 10% of the nominal voltage, so that there is no risk for the load [3].

Up to this point the power flow to the load is ensured by the system design only and there is no switching activity necessary to maintain supply to the load.

The voltage drop across the IP-Choke can be eliminated by connecting the load directly to the IP-Bus. **Figure 7** shows an IP-System, in which the IP-Bus is extended to a ring, still being the center of a star configuration. The additional part of the IP-Bus is called IP-Return-Bus and can be used as a bypass source for the loads, allowing maintenance at the UPS and the IP-Choke while the affected load is supplied by the remaining UPS in a safe manner. A pair of switches on the load side allows to shift the loads between the UPS output and the IP-Return-Bus without interruption and enables the isolation of the UPS from the IP-System under controlled conditions.

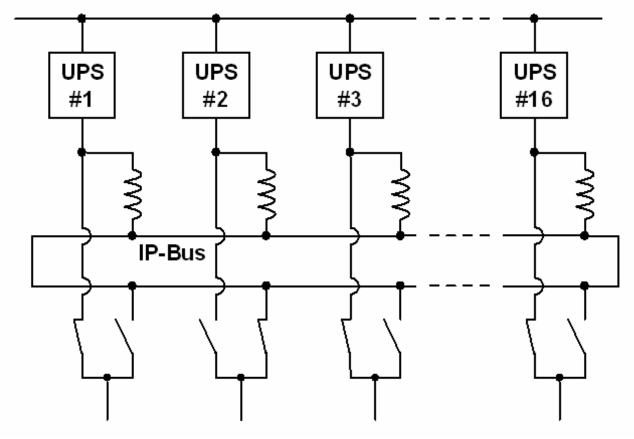

Figure 7 IP-System with the load of UPS #2 directly supplied from the IP-Return-Bus

Fault isolation

Regarding the fault isolation two different fault locations should be taken into consideration: a) the IP-Bus itself and b) the load distribution downstream of each UPS

a) A fault on the IP-Bus is the most critical because it results in the highest local fault currents. The fault is parallel-fed by each UPS connected to the IP-Bus, limited by the subtransient reactance of the UPS combined with the impedance of the IP-Choke. This means that the effect on the individual UPS outputs is minimized and the focal point remaining is the fault withstand of the IP ring itself. The resulting maximum fault current on the IP-Bus is the relevant factor setting the lower limit for the impedance of the IP-Choke.

b) A fault on the load side of a UPS is mostly fed by the associated UPS, limited by its subtransient reactance only. An additional current from each of the non affected UPS is fed into the fault, too. But because of the fact that there are two IP-Chokes effectively in series between the fault and each of the non affected UPS this current contribution is much smaller than the fault current driven by the UPS which has a direct connection to the fault. As a result of this, the disturbance at the non affected loads is very low and the voltage securely stays within the safe region of the ITIC-Curve [3]. This fault isolation effect in combination with the high fault current capability of rotary UPS ensures fast clearing of the fault while effectively limiting the repercussions of the fault on the non affected loads. **Figure 8** shows an example of a fault current distribution in case of a downstream short circuit.

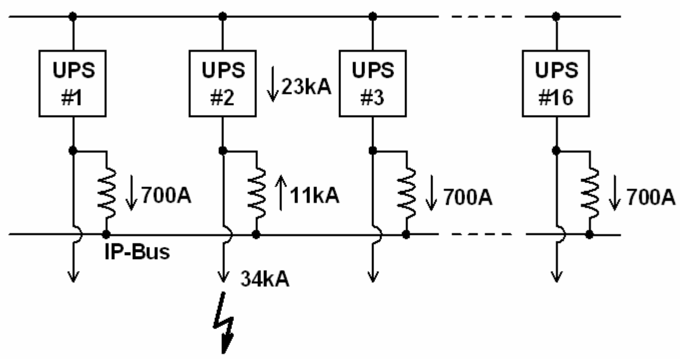

Figure 8 Example of a fault current distribution in an IP-System in case of a short circuit on the load side of UPS #2

UPS-System

Each individual UPS-System consists of the following main components: A UPS with its energy storage device, the IP-Choke for downstream paralleling of the UPS systems and the breakers necessary to operate the system. **Figure 9** shows an UPS-System utilizing a Rotary-UPS.

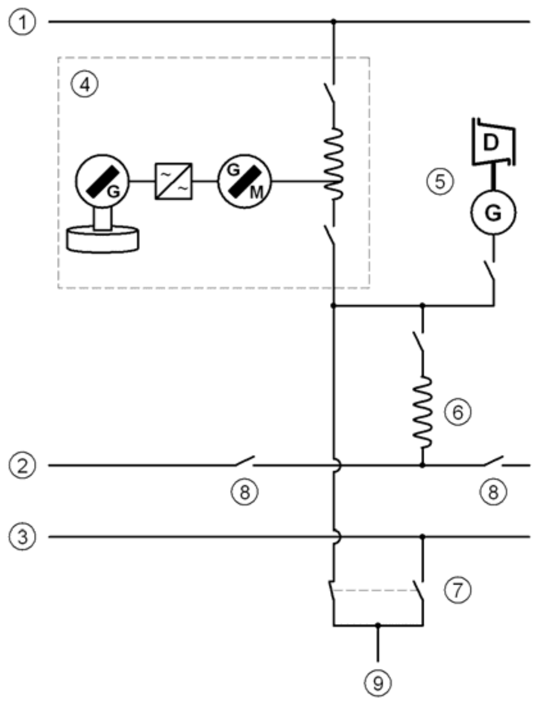

Figure 9 Example of an UPS-System utilizing a Piller UNIBLOCK T Rotary-UPS

1 Utility

2 IP-Bus

3 IP-Return-Bus

4 Rotary-UPS with flywheel energy storage

5 Diesel-Generator for long term mains interruptions (optional)

6 IP-Choke (with IP-Choke-Breaker)

7 Bypass Transfer Breaker Pair

8 IP Isolation breakers

9 Load

The IP-System is not naturally restricted to a special UPS topology, but to get the most benefit out of the IP-Structure the use of rotary UPS with an internal coupling choke is mandatory. It is the high fault current capability combined with natural load sharing that makes this kind of UPS the best choice for an IP-System. For long term mains interruptions, Diesel-Rotary-UPS's

(DRUPS) are a good solution. Alternatively rotary UPS combined with external Diesel-Generators connected to the UPS output bus are also applicable

Even though a UPS in an IP-System can theoretically be equipped with any kind of energy store, for stability reasons a bidirectional operating energy storage device like an electrically coupled flywheel should be preferred. If the UPS-System is not able to give out and absorb power equally (e.g. battery or induction coupling) the system is likely to exhibit lower stability under transient conditions.

Control

The regulation of voltage, power and frequency plus any synchronization is done by the controls inside the individual UPS module. The UPS also controls the UPS related breakers and is able to synchronize itself to different sources.

Each UPS-System is controlled by a separate system control PLC, which operates the system related breakers and initializes synchronization processes if necessary.

The front end of the System Control is a mimic panel that visualizes the status and allows operation of the system. There are several measurement devices integrated in the System-Control, used to monitor the voltages, the power flow and the phase angles in the system. The System Control PLC also remotely controls the UPS regarding all operations that are necessary for proper system integration but without affecting its basic functionality. If there is a separate Diesel-Generator integrated in the UPS system, it is also controlled by the System-Control including its synchronization to different sources. A digital communication interface allows the integration of the System Control in a Building Management System (BMS).

Another PLC, which is called Master Control PLC, is used to control the IP-System in total. Because of its central functionality it consists of two redundant PLCs, each communicating with the System PLCs using a redundant digital communication bus. The Master Control collects the measurement data from the System PLCs and continuously compares the total load with the capacity available from the UPS. Signals generated from this comparison are sent back to the System-Controls giving them the ability to react on any overload situation in the correct way. The Master Control also controls the mains return procedure of the UPS systems to ensure a smooth load transfer of the IP-System to utility.

An overview of the control structure is shown in **Figure 10**.

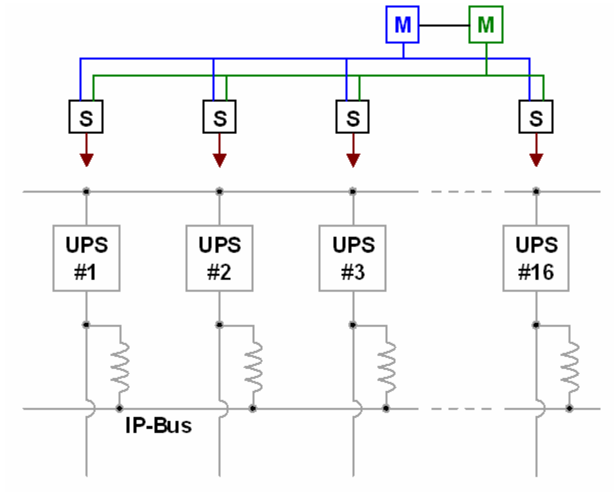

Figure 10 Control Structure of an IP-System showing the arrangement of System-Control (S) and Master-Control (M) related to the UPS-Systems including the redundant communication lines

Additional pilot wires interconnecting the System-Controls allow safe system operation in the improbable case that both Master Controls fail.

Modes of operation

In mains operation each UPS is connected to the mains supplying its assigned load with active and reactive power. The UPS output bus is connected to the IP-Bus via the IP-Choke, enabling independent voltage regulation of the single unit in combination with natural load sharing with the other units. The energy storage devices are fully charged and the Diesel engines are switched off.

In case of a mains failure each UPS automatically disconnects from the mains and the load is initially supplied from the energy storage device of the UPS. From this moment on the load sharing between the units is done by a droop-function based on a power-frequency-characteristic which is implemented in each UPS. Due to the fact that this function is implemented in each UPS there is no load sharing related communication required between the units. After the Diesel engines are started and engaged the loads are automatically transferred from the UPS energy storage device to the Diesel engine, so the energy storage can be recharged and is then available for further use.

To achieve proper load sharing also in Diesel operation each Diesel Engine is controlled by its UPS, independent of whether the engine is mechanically coupled to the generator of the UPS (DRUPS) or an external Diesel-Generator (standby) is used. This kind of engine integration makes the Diesel engine part of the UPS so the combination of UPS and Diesel engine can be considered to be one system. A special regulator structure inside the UPS in combination with the bi-directional energy storage device allows active frequency and phase stabilization while keeping the load supplied from the Diesel engine.

The retransfer of the system to utility is controlled by the master control. After a predefined mains settling time and after all energy storage devices are recharged, the master control individually allows each UPS-System to return to mains operation. This allows a smooth mains return of the whole system in a timely manner and avoids severe load steps on the utility.

The synchronization to the mains is done by using a common synchronization voltage, taken from the main power feeder of the whole system. Using this synchronization voltage as the preferred source besides the individual mains feeder to each single UPS ensures proper synchronization even if for some of the UPS-System the mains voltage is not available.

After the whole system is synchronized and the first UPS-System is reconnected to utility, the load sharing of those UPS-Systems that are still in Diesel operation can not be done by the regular droop function any more, because the system is now locked to the utility's frequency. A new fixed frequency load sharing regulation needed to be invented, that allowed the load sharing between all of the UPS-Systems while some are in mains and others are in Diesel operation. This new regulation scheme, invented and patented by Piller Group GmbH, is called Delta-Droop-Control (DD-Control) and allows proper load sharing in this specific situation without relying on load sharing communication between the UPS modules. DD-Control is based on the physical behavior of the single IP-System and allows each unit to regulate its output power individually without the need of a central control device.

With the implementation of DD-Control into the UPS Modules, all UPS-Systems can be reconnected to utility step by step until the whole IP-System is in mains operation once more. This removes another problem in large scale systems: that of step-load re-transfer to utility after mains failure.

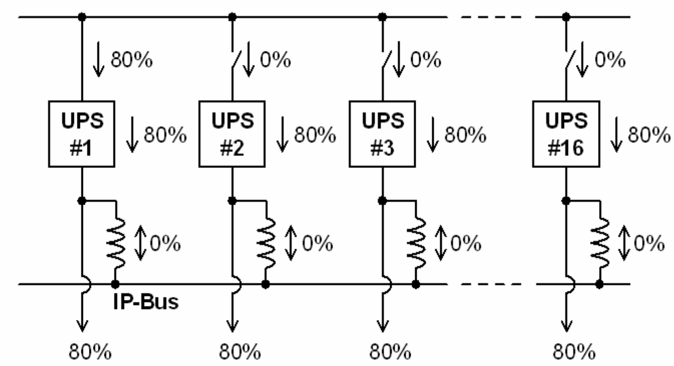

Figure 11 Example of the load flow in an IP-System with UPS #1 already connected to utility while units #2…#16 are still in Diesel-Operation using DD-Control for load sharing

Stability

After the idea of an IP-System was born and the design work started, stability of the system was a major concern. A system based on a network of big interconnecting chokes always has the tendency towards oscillation, especially if rapid changes in the power distribution caused by load steps, Diesel starts and mains outages need to be considered.

Any load step on a single unit in the system will at first change the phase angle between the mains and the load bus of the affected UPS, and will then be transferred through the IP-Chokes to the other UPS until a new operating point for the whole system is found. To effectively damp oscillations during this process the transmission of the load change needs to be done in a smooth way, allowing the system to find its new operating point without overshooting. To ensure effective damping independently of the polarity of the load change, a UPS with a storage device that allows bi-directional full power transfer should be used.

The exceptional stability of an IP-System using UPS with bi-directional energy storage was first simulated by a comprehensive Stability Analyses [4] and later on proved during commissioning of the first customer installation.

Maintainability

The ability to switch the load from a UPS-System to the IP-Return-Bus in combination with an N+x redundant system configuration allows maintenance of a UPS-System while its load is supplied by the remaining UPS in a safe manner.

Additional breakers in the IP-Bus on both sides of the connections of the IP-Chokes – as shown in **Figure 9** – enable partial segmentation of the IP-Bus which additionally allows maintenance on the IP-Choke and the bus-work itself. During maintenance, the IP-System remains fully functional using the IP-Return-Bus as alternative path to the cut out segment.

With DD-Control implemented it is also possible to do maintenance at the input feeder of a UPS-System while only the affected UPS is running in Diesel operation and the rest of the system remains connected to utility.

Summarizing the above mentioned functionality, the IP-System is probably the simplest (high reliability) system to concurrently maintain. All the other solutions with similar maintainability (System, Isolated and Distributed redundant), have far greater complexity of infrastructure, leading to more maintenance and increased risk during such operations.

Efficiency

High efficiency can be obtained with such a high reliability system because of the ability to achieve the fault tolerance of system redundancy without the penalty of low operating efficiencies. A 20MW IP-System design can run with modules that are 94% loaded and yet, offer a reliability that is similar to the system redundant scheme, which has a maximum module loading of just 50%. That can be translated in to a difference in UPS electrical efficiency of 3 or 4%. That means a potential waste of energy of about 5…7 GWh per year, resulting in additional operating costs of $750,000 (ignoring additional cooling costs).

So additionally to the other advantages an IP-System offers a green solution, well suited to the economical demands of a modern data center or industrial facility.

3 Projects

The first Isolated-Parallel-System was realized in 2007 for a data center in Ashburn VA, supplying a critical load of 36MW in total. It consists of two IP-Busses, each equipped with 16 UPS Piller UNIBLOCK UBT 1670kVA with flywheel energy storage in a 14+2 configuration. Each of the UPS is backed up by a Diesel-Generator with 2810kVA, which can be connected to the UPS load bus and which is able to supply both the critical and the essential loads.

Since the success of this first installation, three more data centers have been commissioned, of which the first phase of one is complete (a further 20MWatts) as of today.

There are future projects planned to be done in medium voltage to achieve higher output power than is possible in low voltage solutions. One of these projects will consist of 9 Piller UNIBLOCK UBTD 2500kVA single output Diesel Rotary UPS with flywheel energy storage.

Also a configuration combining the benefits of the IP-System with the energy efficiency of natural gas engines is considered and actually planned by consulting engineers. The total power rating of this IP-System is planned to be over 35MW.

4 Conclusion

The Isolated-Parallel-System provides an exceptional method of combining the features found in Isolated-Redundant and Parallel-Redundant UPS configurations: shared redundancy among UPS Modules and output bus fault isolation in a large, multiple output, paralleled UPS-System. What also distinguishes the IP-System is the excellent maintainability and the outstanding fault tolerance, ensuring a highly reliable and robust power distribution for various power critical applications. Coupled with flywheel energy storage and the ability to configure a massive UPS system of up to 20 MW in low voltage, the IP-System is particularly suited in applications where minimizing space and maximizing return on investment are high priorities. Reducing the number of redundant units to the minimum and avoiding units running in standby makes the IP-System a green solution and a good choice, if an environmental friendly and ecological power supply is desired.

References

[1] Mike Mosman, Iso-Parallel Rotary UPS Configuration,
7x24exchange, 2005 Fall Conf.,
http://www.7x24exchange.org/downloads/7x24Newslink_Fall05.pdf

[2] Mike Mosman, An Isolated-Parallel UPS System for a large Data Center,
7x24exchange, 2007 Fall Conf.,
http://www.7x24exchange.org/downloads/7x24Newslink_Fall07.pdf

[3] Information Technology Industry Council, http://www.itic.org/clientuploads/Oct2000Curve.pdf

[4] Ralf Briest, Kevin Collins, Hilmar Darrelmann, Mike Mosman
Load Sharing and Stability Analyses of Iso-Parallel UPS Systems
PCIM Europe 2007

[5] List of IP-Participants in alphabetical order:
Robert Baldwin, Piller Power Systems Inc.
Ralf Briest, dbr-consult
Kevin Collins, Piller Power Systems Inc.
Hilmar Darrelmann, dbr-consult
Frank Herbener, Piller Group GmbH
Mike Mosman, CCG Facilities Integration Inc.
Orleff Poeschel, Piller Group GmbH

Frank Herbener, Piller Group GmbH,

Frank.Herbener@Piller.com, Germany

PILLER
Power Systems