PILLER
Power Systems

Isolated-Parallel UPS Configuration

Nothing protects quite like Piller

www.piller.com

Abstract

The isolated-parallel UPS configuration has become well established in the marketplace as a system solution for medium-sized and large computer centers. It enables huge savings to be made in UPS units and therefore contributes to an improvement in the efficiency of the overall system. At the same time, the reliability of isolated-parallel systems (IP systems) is comparable to the most reliable Tier 4 system configurations. This white paper deals with the operating principles of IP systems, the integration of Diesel engines, the UPS topologies and the types of energy storage devices that are suitable for this application. Then follows an overview of project-specific designs which illustrates the flexibility and performance of IP systems.

1 Paralleling and Redundancy

1.1 N+x redundant configuration

Direct paralleling of UPS systems – see Figure 1 – is a commonly used method for increasing the available output power and for providing redundancy. A simple arrangement for safeguarding the power supply is an N+x redundant-parallel configuration, with N denoting the number of UPS units needed to supply the load, and x representing the number of redundant units.

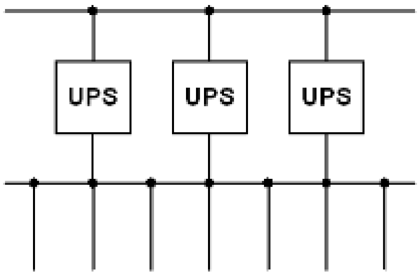

Figure 1 *Parallel UPS configuration*

Since in this configuration several units are supplying the same paralleling bus, the redundant-parallel scheme is limited to around 5 to 6 MVA at low voltages and is virtually impossible to maintain during operation. Even though the simple N+x redundancy ensures high availability, it is highly probable that a failure of the common bus – or even in the downstream load distribution – will cause an interruption of the supply to the loads.

PILLER Power Systems

Even though paralleling has largely served its time for achieving redundancy, it is still used in conjunction with other redundancy concepts, increasing single string capacity to supply large data halls when smaller UPS units are used. Nonetheless, the above also remains valid for such kind of paralleling UPS. And even if integrated into some higher level redundancy concept, paralleling without additional redundant UPS is subject to fail on any components failure.

1.2 N+N redundant configuration

To avoid this "single point of failure" a second bus can be added to the system, so that each load can be supplied with power from either bus. In order to achieve full redundancy, each of the two busses must be able to supply the entire load. Therefore such N+N redundant system configuration, shown in **Figure 2**, needs twice as many UPS as would be necessary to supply the load. And since each N units in such system are operated in parallel they are subject of what is mentioned in the previous chapter 1.1, leading to even more installed units to achieve at least some level of redundancy in each supply path and to not fall back to a single supply path on each single components' failure or during maintenance.

As a result, in normal operation the UPS are loaded below 50% and are not operated at optimum efficiency. Such a system will therefore not be the first choice if an energy efficient UPS solution is preferred, and also its sustainability can be questioned as redundancy is built on using twice the number of components, including batteries. Nevertheless, because of its extremely high reliability it is the most popular, but not only, supply scheme for UPTIME® Tier IV certified data centres.

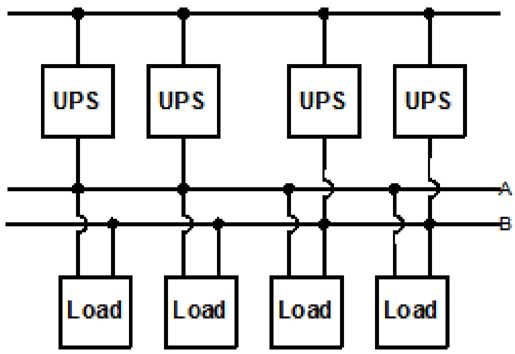

Figure 2 *System-redundant UPS configuration (N+N)*

1.3 Isolated redundant configuration

Another way of avoiding the central bus being a SPOF (Single Point Of Failure) is to abandon paralleling of UPS units. One way to achieve this is the so-called isolated-redundant configuration, shown in **Figure 3**. In this configuration each UPS supplies its dedicated load while one or more redundant UPS units are running in standby mode, ready to supply the load if one of the UPS units fails.

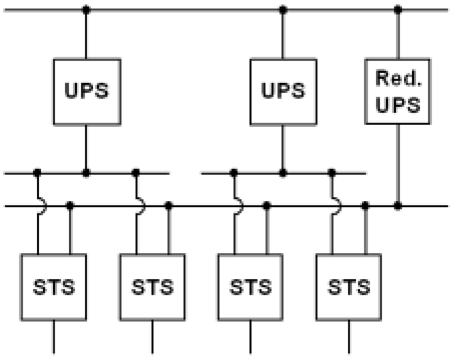

Figure 3 *Isolated-redundant UPS configuration with static transfer switches (STS)*

A disadvantage of the isolated-redundant configuration is that there is no option for automatic load sharing between modules and the fact that one or more UPS units are running in idle mode, i.e. without supplying any load. When combined with Diesel engines, this results in engines running in idle mode during power system failures, which reduces engine performance once this occurs over several hours. And while maintenance is done on the redundant unit the entire redundant path isn't available.

Additionally the isolated-redundant configuration requires extra equipment like static transfer switches or similar to switch to the alternate power source in the event of failure.

1.4 Distributed redundant configuration

The distributed redundant configuration can be seen as the simplest way to achieve redundancy and is a popular solution for Uptime® Tier III certified data centres. Since each supply line is isolated from the others such system additionally comes along with a high level of reliability. In the case that dual corded loads are used such system doesn't necessarily require additional switching elements like STS.

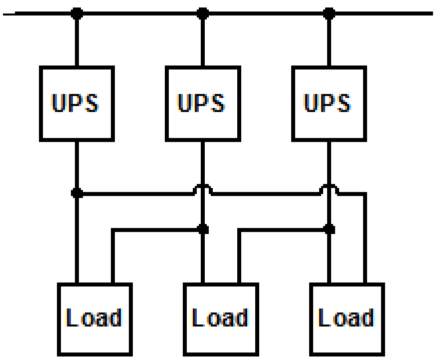

Figure 4 *Basic distributed-redundant UPS configuration*

In the example shown in **Figure 4** each UPS can be loaded up 66% in normal operation, which is better than in an N+N configuration, but still not the best. In case of a UPS failure or a short circuit on a supply line the loads are automatically supplied by the remaining UPS based on their dual corded power supplies.

During maintenance, in which one UPS has to be shut down, one entire supply path will be shut down with it, so that the loads will partially be supplied by one line (A or B) only. This can be seen as a major drawback of such supply system.

1.5 IP-System configuration

In 2005, the idea of a new system configuration was born – the so-called Isolated-Parallel System (IP-System). The basic development goal of this new configuration was to avoid the disadvantages of the conventional UPS configurations described above and to combine their advantages in a new highly-reliable system topology. This topology allows repeated paralleling of UPS modules combined with automatic load sharing and high efficiency while ensuring fault isolation between the load buses of the individual units.

In an IP-System (see **Figure 5**) each UPS is connected to a common bus (IP-Bus) via a choke (IP-Choke). The loads are primarily supplied from their related UPS units. The task of the IP-Choke is to reduce fault currents to an acceptable level – namely to isolate the UPS with its loads from the IP-Bus – while allowing adequate load sharing among the UPS units.

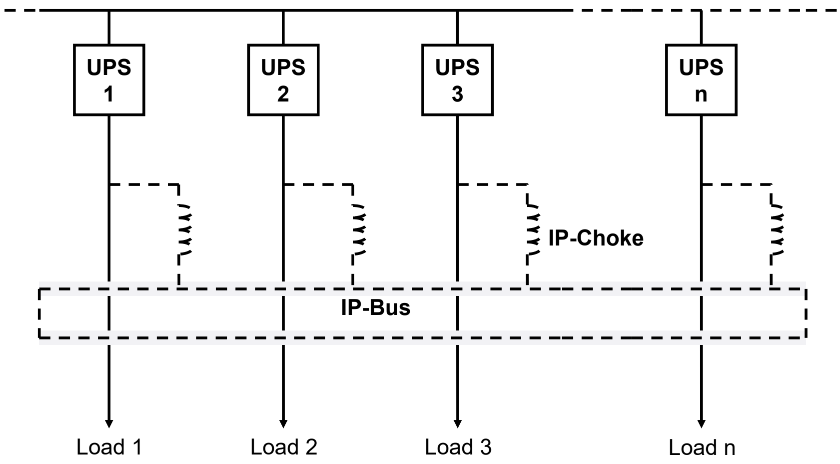

Figure 5 *Basic design of an IP-System*

This load sharing enables the IP-System to be designed as a simple N+x redundant configuration.

With the number of redundant units x being reduced to a minimum costs for redundant units are minimized, too, coming along with significant space saving in the building. Since in this case each UPS unit is run at a high-efficiency operating point IP-Systems represent one of the most energy-saving power supply systems for data centres that doesn't rely on sacrificing the reliability of the power supply, but increases it instead.

Comparing the requirements for e.g. 6 data halls each consuming 2 MW of power, an N+N redundant scheme utilizes 12 or even 14 UPS (2x(N+1)) with 2 MW each, an IP-System only 7 (N+1), while coming along with the same level of reliability. Using large single block UPS like the Piller UNIBLOCK does even avoid any (internal) paralleling to realize a single 2 MW supply source, which simplifies the entire system while increasing reliability.

Closing the IP-Bus to a ring creates additional flexibility regarding concurrent maintainability concurrent expansion of the IP-Bus.

Separate Diesel generators integrated in the IP-System, like it is shown in **Figure 11**, offer an even higher level of maintainability and reliability during maintenance and in failure situations. In a similar way such system allows the integration of any alternative long term energy sources.

Due to the isolating characteristic of the IP-Chokes the general power limit for a single supply system in low voltage is moved from roughly 5 MW in a parallel system to up to 20MW in an IP-System, a power concentration that can normally only be achieved by high voltage installations with all the drawbacks regarding size and costs coming along with it.

2 Characteristics of an IP-System

2.1 Operating modes

In the power grid mode each UPS is connected to the power grid and supplies active and reactive power to its dedicated load. At the output side the UPS is connected via the IP-Choke to the IP-Bus, which enables independent control of the output voltage while sharing active power with the other UPS units (dotted lines in **Figure 6**). The energy storage devices are fully charged and the Diesel engine is switched off.

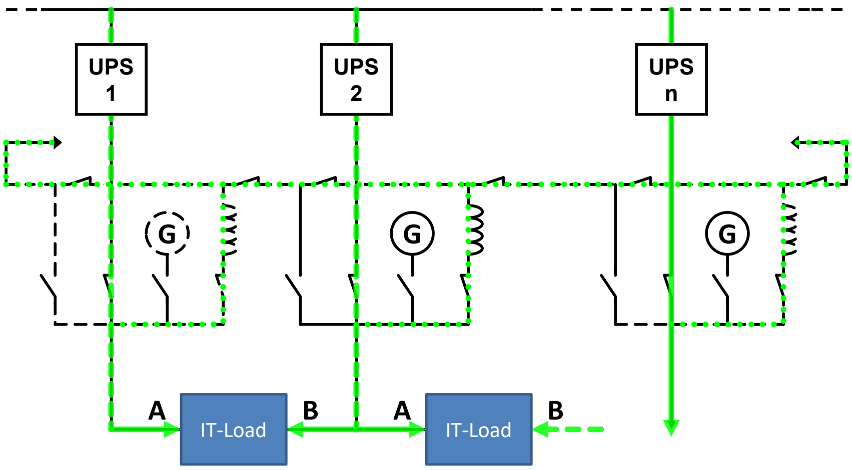

Figure 6 *Example of an IP-System in grid mode*

In the event of a power failure, each UPS automatically isolates itself from the power grid and for the time being the load is supplied by the energy storage device of the UPS. From this moment on, the load sharing between the UPS units is controlled by a droop function, which is based on a power/frequency characteristic implemented in each UPS. Because the same characteristic is present in each UPS, no communication regarding the load sharing is required between the individual systems. After the Diesel engines are started, the supply to the load is automatically transferred from the energy storage device of each UPS to its assigned Diesel engine, so that all energy storage devices can be recharged and become fully available again.

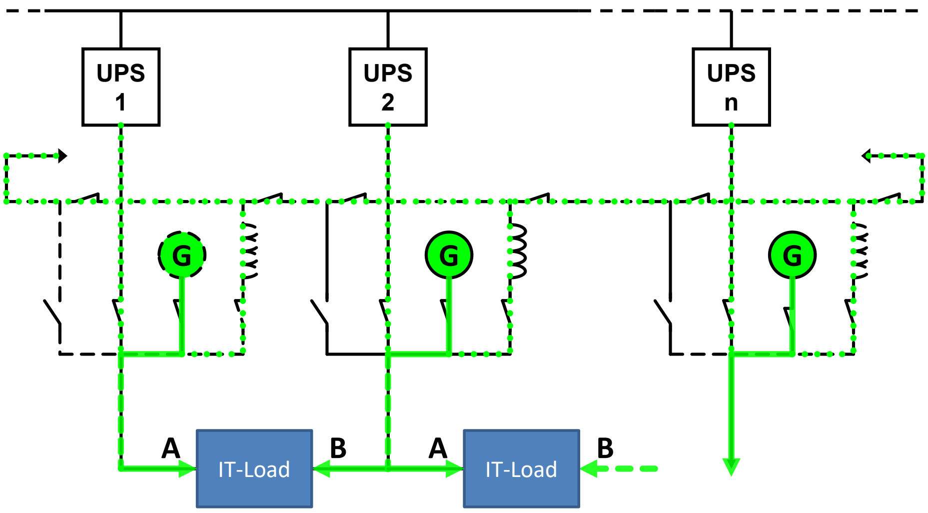

Figure 7 *Example of an IP-System with external Diesel generators in Diesel mode during a utility outage*

To ensure load sharing also in the Diesel mode, each Diesel engine is controlled by the associated UPS via its internal droop function, irrespective of whether the Diesel engine is an integral part of the UPS or an external Diesel generator is used. From a control point of view any Diesel engine can be seen as an integral part of the UPS system and the combination of UPS and Diesel generator can be considered as one unit. A special control structure in the UPS enables active frequency and phase stabilization, which is also effective in the Diesel mode. Whilst the system performs adequately with batteries, there are some improvements coming along with the utilisation of flywheel energy storage.

The restoration of the power supply to the individual UPS systems is verified by the IP-Master-Control. Following a predefined utility stabilization period and after all energy storage devices have been recharged, the IP-Master-Control ensures that the UPS systems are restored in sequence to the power grid mode. This procedure enables high-power IP-Systems to be switched back to the supply system, without causing sudden, excessive load fluctuations in the power grid.

Synchronization to the power grid uses a common synchronization voltage, which is obtained centrally from the main incoming supply. The shared use of this synchronization voltage as the preferred source, as well as the line voltage at each individual UPS as redundancy, ensures uniform synchronization of all systems, even if the line voltage may not be available to some UPS systems.

As soon as the first UPS system is reconnected to the grid, the load sharing between the UPS systems which are still partially in the Diesel mode, can no longer be realized via the regular droop function because the system is now limited to the constant frequency of the power grid. Therefore, a new control method for load sharing had to be developed when operating at a fixed frequency. This new control, which was developed and patented by Piller Group GmbH, is called Delta Droop Control (DD-Control) and enables load sharing in mixed grid and Diesel mode, without the UPS systems having to communicate with each other regarding the load sharing. DD-Control is based on the phase angle between utility and the IP-Bus being measured in each individual IP-System. The knowledge of this phase angle enables each UPS unit in Diesel mode to adjust its power output being the same as of the units in grid mode, without the need for a central control unit.

The DD-Control function is mandatory to reconnect large systems to utility without relying on communication lines between the individual UPS.

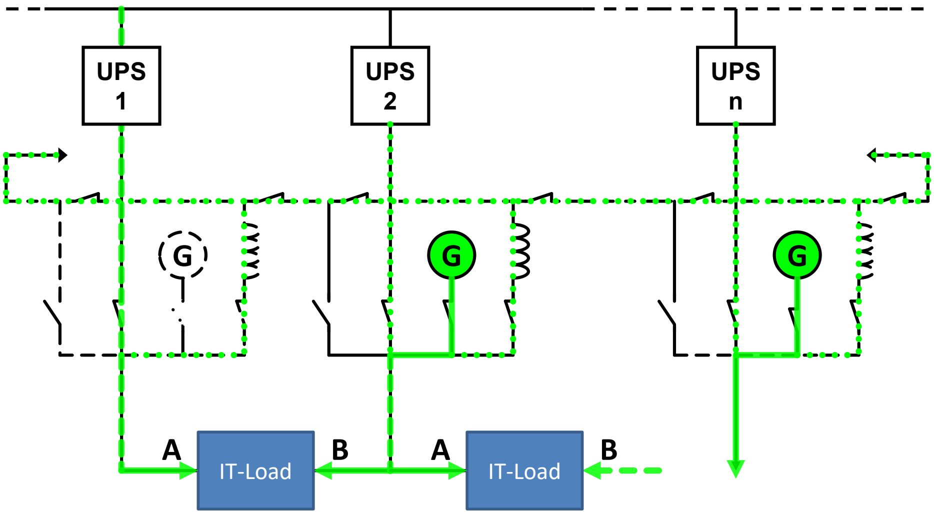

Figure 8 Example of an IP-System returning to grid mode, with UPS #1 is connected to the grid already, while the other units are still in Diesel mode and their load sharing is controlled by the DD control function.

2.2 Maintainability

An IP-System offers outstanding maintainability, proven in data centres with UPTIME® Tier III and Tier IV certification. Assuming at least N+1 redundancy, a UPS can be taken off-line at any time without sacrificing the load; like it is shown in **Figure 9**.

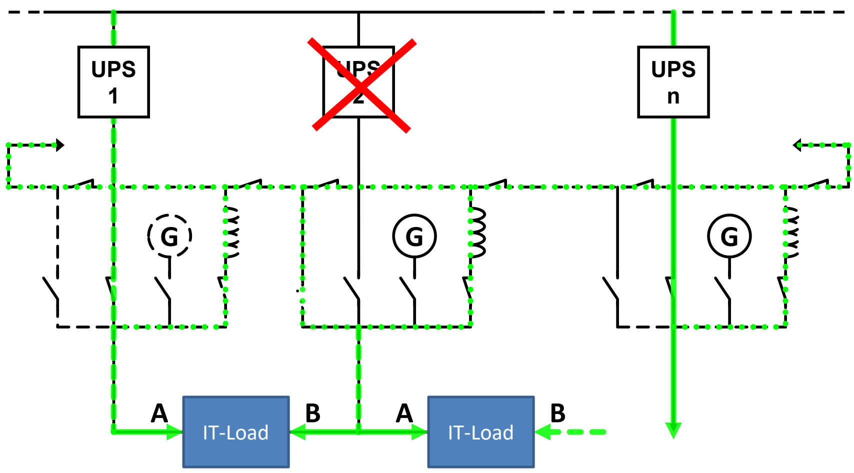

Figure 9 *Concurrent maintainability on a UPS without interrupting any supply path to the loads.*

Besides the fact that no distribution path needs to be interrupted by this procedure, it is even possible to restore the redundancy lost by the shutdown of one UPS, if the system is equipped with separate Diesel-Generators. In such situation like it is shown in **Figure 10**, with one UPS is shut down, the load sharing of the assigned Diesel Generator is controlled by the Piller IP-System-Controller, containing the same load sharing algorithms, as there are Droop and Delta Droop control, like the UPS.

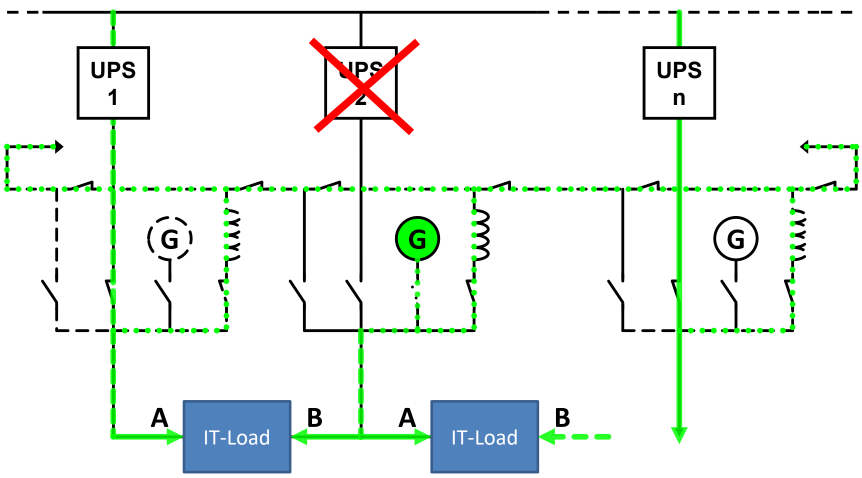

Figure 10 *Keeping system redundancy by starting the assigned Diesel-Generator of the maintained UPS.*

The breakers used for fault isolation in the IP-Bus can be used to isolate bus segments for maintenance while keeping the remaining IP-Bus fully functional because of its ring design. Maintenance on the IP-Choke can be done similarly.

By utilizing DD-Control it is also possible to carry out maintenance on a single incoming feeder of a UPS system, having the affected UPS running in Diesel mode and the remaining UPS units staying in grid mode.

Summarizing the above-mentioned functions, the IP-System is probably the simplest system topology that, combined with maximum reliability, can be maintained during operation while all loads kept being supplied by two power distribution strings. All other solutions with similar maintainability (system redundancy, isolated redundancy and distributed redundancy) have either a far more complex infrastructure or will lose a distribution path during maintenance, which is always subject of an increased risk for the affected loads.

Additionally the Piller IP-Controls offer an outstanding operability and give the data centre operator all necessary information to perform such operations without putting the critical loads at risk. (see chapter 2.4).

2.3 UPS system

An IP-System consists of a number of UPS systems. Such a UPS system comprises the following main components: a UPS with an energy storage device, an IP-Choke for linking the UPS unit to the IP-Bus and the breakers necessary for the safe and reliable operation of the system. **Figure 11** shows a system utilizing a UPS with separate Diesel generators.

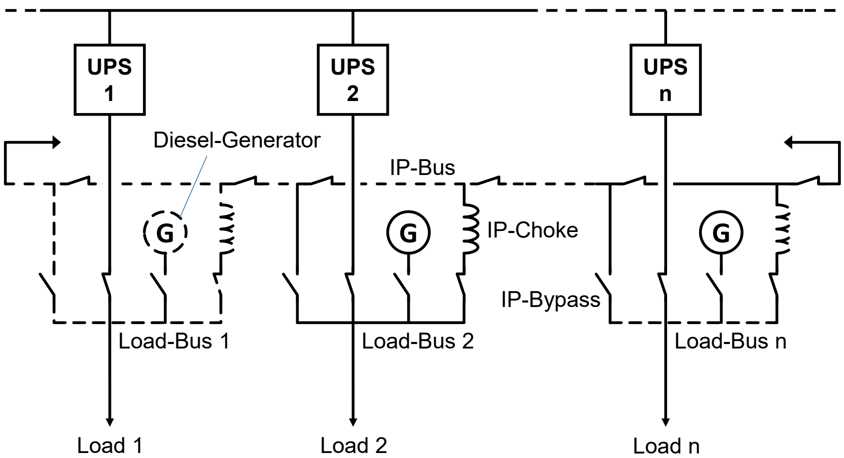

Figure 11 *Typical IP-System utilizing a UPS in combination with a separate Diesel generator.*

An IP-System is not limited to one special type of UPS installation. If, however, it is desirable to make optimum use of the advantages of such a system, then single block UPS containing an electric machine with internal coupling choke is mandatory. Its high short-circuit capacity and its natural load sharing makes this type of UPS the best choice for an IP-System. Even though UPS with integrated Diesel engines can be used, it is beneficial if UPS combined with external Diesel generators connected to the UPS output can be employed. Such combination comes along with a surplus of functionality and flexibility regarding failure handling and maintenance.

Even though a UPS in an IP-System can be equipped with any kind of energy storage device, a bidirectional-operating energy storage device, such as an electrically-coupled flywheel allows for some improvements regarding reliability and frequency response. In this regard, a system with its energy storage being able to supply and to absorb power in the same manner, is superior to systems based on batteries or mechanically coupled flywheels.

2.4 Controls

The control of voltage, current and frequency, plus all synchronization operations are realized by the controllers in the respective UPS unit. The UPS also controls its associated breakers and ideally, if required, should also be able to synchronize itself to other voltage systems, such as the IP-Bus, for example.

A so-called IP-System-Control is assigned to each UPS system. This is the central unit for operating and monitoring the UPS system.

A mimic diagram visualizes the status of the UPS system and also enables safe operation of the system and its breakers. It is located at the front end of each IP-System-Control. Additionally the IP-System-Control monitors all essential voltages, currents, phase angles and performance data of the associated UPS system. Signal lines between the IP-System-Control and the UPS enable the functions of the UPS needed for system integration to be controlled, but without impairing the basic functionality of the individual UPS units. If required, the control of a separate Diesel generator integrated in the system, as well as its synchronization, can be realized by the IP-System-Control. A digital communications interface allows easy integration of the IP-System-Control in a building management system (BMS).

Another PLC, the so-called IP-Master-Control, serves as primary control and monitoring for the entire IP-System. Because of its central function, it consists of two redundant controls which communicate with the IP-System-Control via a redundant digital communications bus.

The IP-Master-Control collects the measurement data from the IP-System-Control and continuously compares the system utilization with the available UPS capacity. The data resulting from this comparison are sent back to the IP-System-Control which, on the basis of these data, is able to react with the correct measures to a possible overload situation or to the failure of one UPS. The IP-Master-Control also controls the restoration of the power supply for the individual UPS systems and therefore enables a controlled transfer of the load of the IP-System to the utility power grid. **Figure 12** shows the arrangement of controls of an IP-System.

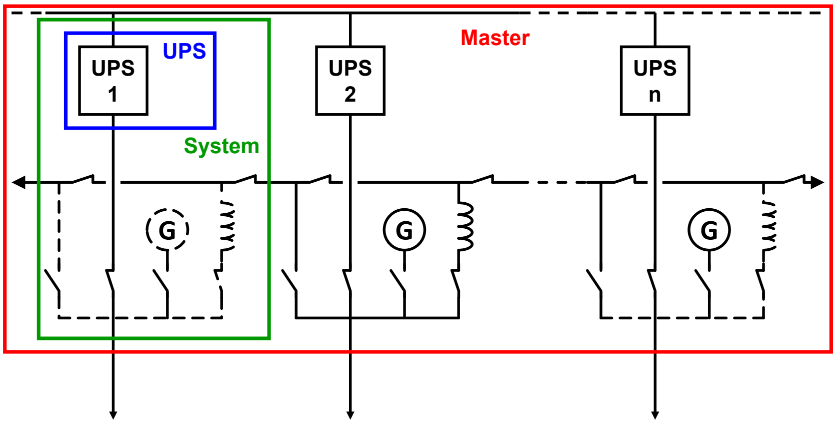

Figure 12 *IP-Controls: arrangement of IP-Master-Control (M), the IP-System-Control (S) and the UPS as the kernel of the entire system.*

Additional control cables which interconnect the individual IP-System-Controls, enable the exchange of all the most important signals, even in the unlikely event of simultaneous failure of both IP-Master-Control. An IP-System can therefore be safely operated without an IP-Master-Control and with little restriction of its functionality.

2.5 Load sharing

In normal operation each load is supplied from the power grid via the associated UPS. Where the UPS units are equally loaded, no power is transferred through the IP-Chokes. Each UPS unit independently regulates its output voltage to the specified nominal value. Any voltage differences are absorbed by the IP-Chokes so that, even in the absence of reactive current control, no reactive current is exchanged between the UPS units.

In an uneven load distribution, each UPS still predominantly feeds its dedicated load. Loads which are greater than the average load of the system receive additional active power from the UPS with the lower load via the IP-Bus (see **Figure 13**). The power flow and the natural load sharing among the UPS units is determined by the combination of the phase angles between the respective UPS output buses and the impedances of the IP-Chokes.

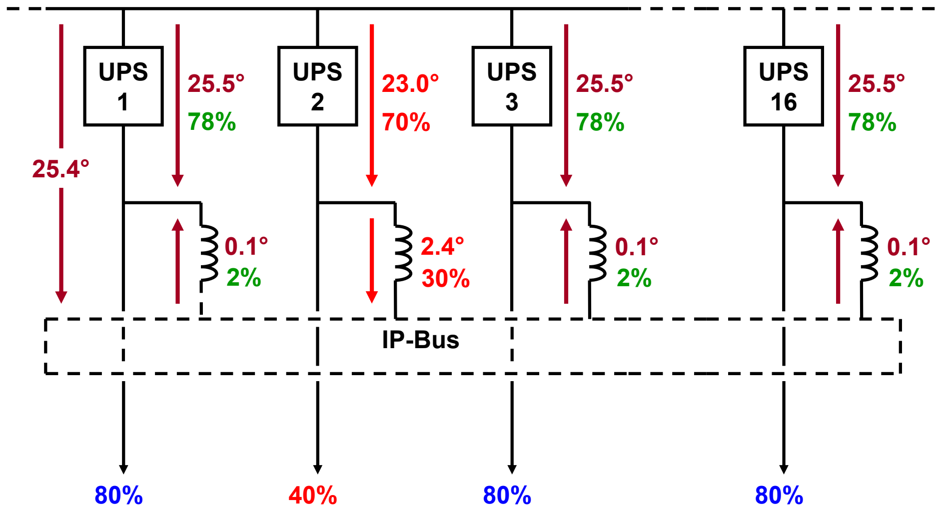

Figure 13 *Natural Load Sharing in an IP-System under unbalanced load conditions*

The load-dependent phase angle at the UPS unit between the supply system and the UPS output is the main factor with regard to natural load sharing. Different phase angles between the UPS outputs due to differing loads, result in active power flow thru the IP-Chokes located between the units. This active power is directed so that it flows from the unit with the lower load with a small phase angle to the unit with the higher load with the greater phase angle and consequently ensures load equalization between the units. Therefore no active load equalization control is necessary during power grid operation. The only suitable UPS topology to achieve this kind of natural load sharing driven by load-dependent phase angles is a rotary UPS with an internal coupling choke, as shown in **Figure 11**.

2.6 Short-circuit response

The main reason for using IP topology is that possible short circuits due to the use of IP-Chokes have little or no effect on the loads. In spite of this, also in an IP-System short circuits must be isolated as quickly as possible, both to meet the safety requirements and to keep disturbances of the power supply to the loads within the limits given by the ITI Curve.

In the event of a short circuit at the load – shown in **Figure 14** – the effects on the whole system are relatively small, since two IP-Chokes are always connected in series between the short-circuit and the remaining loads. With suitably designed IP-Chokes the dynamic voltage sag at the unaffected loads is way below 10% of the nominal voltage.

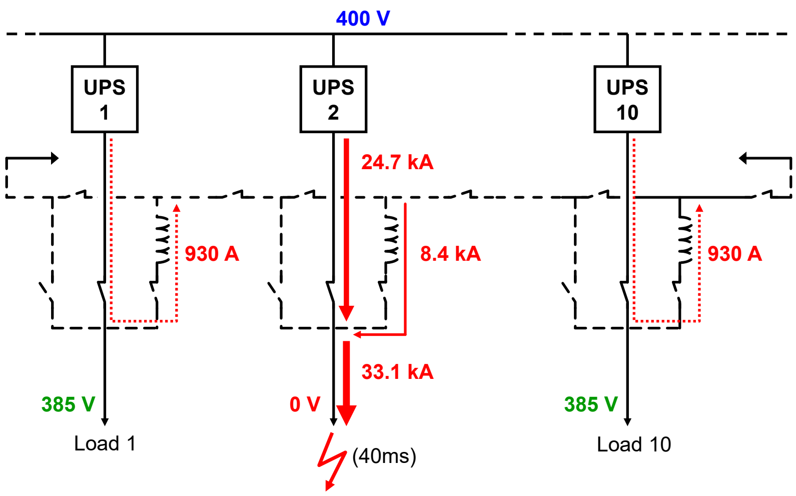

Figure 14 *Example of a fault circuit distribution in an IP-System with a short circuit on the load side of UPS #2. In this case, the voltage drop at the loads not directly affected is only 4% of the nominal voltage.*

The IP-Bus is the central element of an IP-System. A short-circuit on the IP-Bus has repercussions for all UPS units and their loads connected to them and is therefore a particularly critical event for the entire system.

Compared to a short circuit in the load distribution system, in the event of a short-circuit on the IP-Bus; which is shown in **Figure 15**, only one IP-Choke is located in each case between the short-circuit and the UPS output or the load. As a result, in this case the voltage sag at the loads is much larger than the voltage sag in the case of a short circuit in a load distribution system.

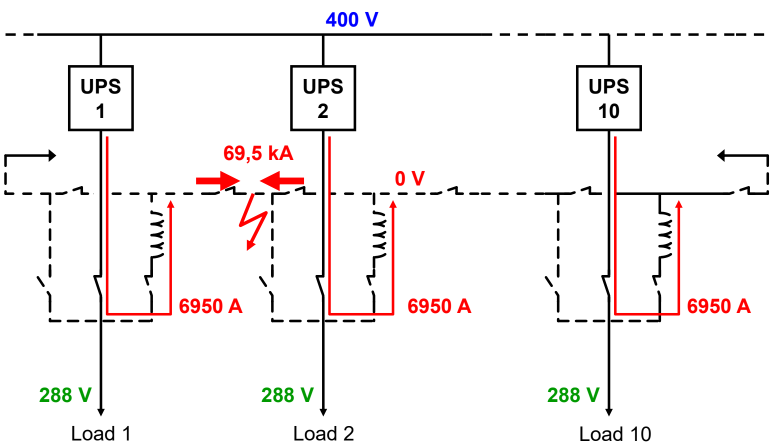

Figure 15 *Example of fault circuit distribution in an IP-System with a short circuit directly on the IP-Bus.*

Utilizing a UPS with a high short circuit contribution, the initial voltage sag at the load is limited to a value below 30%. For sensitive computer power supplies, according to the ITIC curve such a voltage sag is permissible for a maximum period of 500 ms.
A protection concept which is specially tailored to the requirements of the IP-System enables a short-circuit on the IP-Bus to be selectively isolated within 70 ms and at the same time enables the section of the IP-System that is not directly affected to remain fully operational.

Although this involves a less serious short-circuit for the loads, these numbers make it clear that it is advisable to take measures by which a possible short-circuit on the IP-Bus can be largely eliminated. The use of busbar systems, for example, which because of their compact construction are well-suited to isolating the IP-Bus from external effects, can contribute to a short-circuit-proof design. An essentially simple design using components with the lowest possible interference susceptibility, such as outgoing circuits and switch connections, likewise contributes to the prevention of possible short-circuits.

3 Projects

The first isolated-parallel system was developed in 2007 for a data centre in Ashburn, Virginia, [2]. It supplies a total load of 36 MW. The installation consists of two separate IP-Systems, each equipped with 16 Piller UNIBLOCK UBT 1670 kVA UPS units with flywheel energy storage devices in a 14+2 redundant configuration. Each UPS is backed up by a separate 2810 kVA Diesel generator, which is connected to the load bus downstream of the UPS and is able to supply critical as well as general loads.

Since that time the number of data centres relying on Piller IP-Systems has increased to over 75, distributed around 12 countries and with a combined power exceeding 700MW. In addition, a considerable number of these data centres are certified according to UPTIME® Tier III and Tier IV (design and construction), LEED or USGBC green.

All of these systems are built with highly resilient, Piller designed and manufactured UPS and control. The actual combined and continuous operating hours since commissioning are well into the millions without any impact to the critical loads they protect.

4 Conclusion

Isolated Parallel System uniquely enables the advantages of combining isolated-redundant and parallel-redundant UPS configurations. It enables distributed redundancy between the UPS units with simultaneous decoupling of the respective load buses and therefore the simple design of large, parallel UPS systems with several outputs. What also distinguishes the IP-System from other systems are the outstanding maintainability and the unique fault tolerance, which ensure an extremely reliable and robust power supply for high-availability data centres. Due to the ability to use either batteries or flywheel energy storage devices and the possibility of realizing large UPS systems of up to 20 MW in low-voltage technology, the IP-System is particularly suited to applications in which minimizing space requirement and maximizing return on capital are of the highest priority. By reducing the redundant UPS units including their energy storage to a minimum and avoiding systems operated in at low power or even in standby mode, in addition to an extremely environmental friendly and sustainable solution the IP-System is an excellent choice when a safe and ecologically acceptable power supply is demanded.

References

[1] Mike Mosman, Iso-Parallel Rotary UPS Configuration, 7x24exchange, 2005 Fall Conf., http://www.7x24exchange.org/downloads/7x24_fall_05_newslink.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] Published by Information Technology Industry Council, revised 2000

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

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

White Paper No. 0051-2 / Feb. 2020

PILLER
Power Systems