Static bypass in modular uninterruptible power supplies - central or distributed. Comparative analysis.

UPS architecture with central (centralized) and distributed (decentralized) static bypass

All industrial on-line uninterruptible power supplies contain static and manual (service) bypass. The static bypass (SB) is a high-speed static switch made on the basis of bidirectional thyristors. As is well known, static bypass protects critical equipment (equipment requiring stable power supply) and the UPS itself in the event of various emergency situations, for example, in the event of a malfunction of the UPS itself or in the event of an overload in the output of the UPS. Modular UPSs are no exception and also have these devices. A typical modular system is a rack in which power modules are mounted. If a manual bypass is generally central, then a static bypass in modular systems is distributed (Decentralized Bypass Architecture) or central (Centralized Bypass Architecture). In systems with a centralized architecture, static bypass is performed as a separate CSB module (Central Static Bypass), which is installed in a rack with power modules 1 - 10 (Fig. 1). In distributed systems, a static bypass (SB) is installed into each power module (Figure .2).

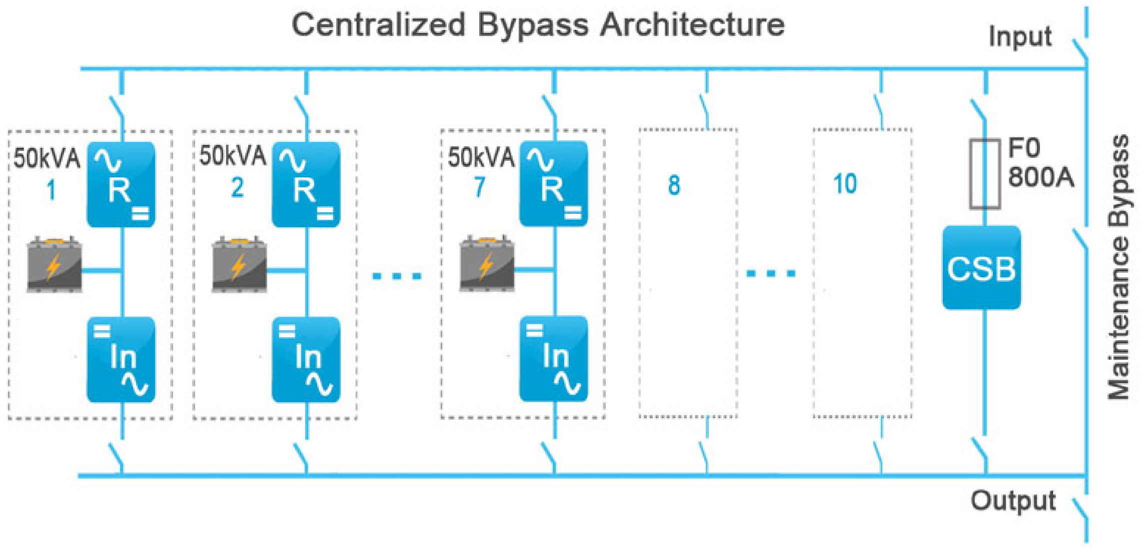

Fig.1. Sample of UPS rack with centralized static bypass architecture

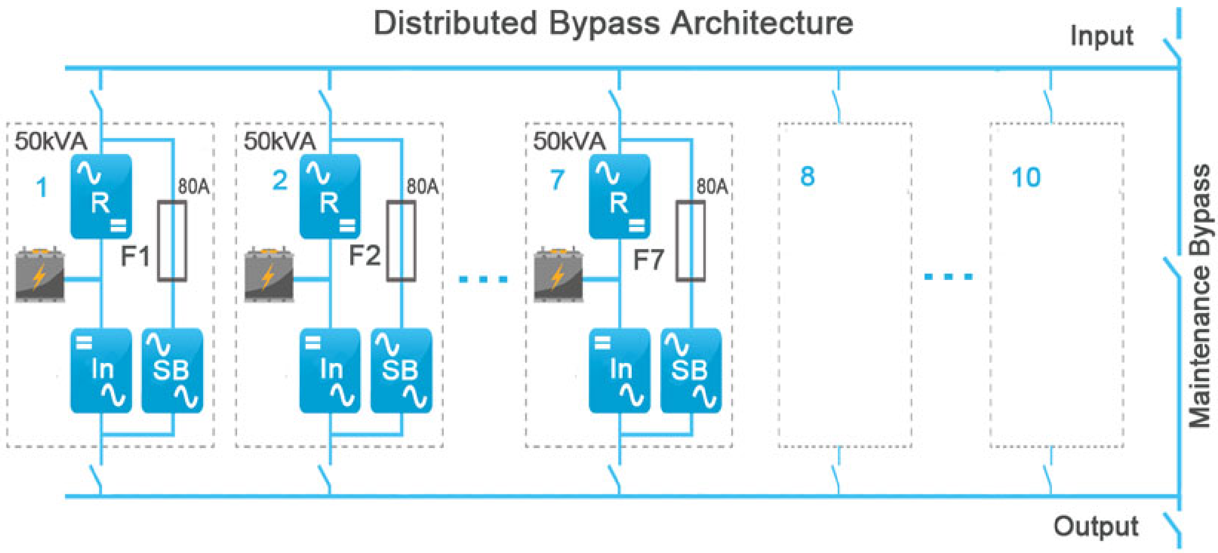

Fig.2. Sample of UPS rack with distributed static bypass architecture

In addition to architectural differences, there is another significant difference between the central and distributed bypass.

The power of the central bypass corresponds to the power of the entire UPS rack. In the example in fig. 1 central bypass is rated at 500 kVA and protected by a 800A 3-phase fuse. The power of the distributed bypass corresponds to the power of the power module in which it is installed. In the example in fig. 2 distributed bypass designed for power 50 kVA and protected by a 3-phase fuse 80A.

Initial conditions when comparing UPS with central and distributed bypasses

Let us analyze the operation of 2 modular uninterruptible power systems with different static bypass architecture in various emergencies. In order to correctly compare both systems, it is necessary to initially set these systems to the same initial conditions:

1. Both UPSs are N + 1 redundant modular systems. All power modules are installed in one rack. The rack should have free slots for installing additional power modules in order to further increase power. The UPS must be connected to the mains in such a way that with a further increase of the load, the user would not have to change the power cablings and change the protection devices (PD). In other words, the user installs power electrical cables and installs protection devices based on the maximum possible power of the connected UPS.

2. Comparison of 2 systems will be carried out on a specific example. The number of power modules is selected based on the fact that the load power = 300 kVA and it is necessary to ensure redundancy N + 1. The UPS rack must be able to increase the load power up to 450 kVA with the same N + 1 redundancy.

The possibility of increasing the UPS power in the future is the main advantage of the modular UPS. Therefore, in practice, the vast majority of modular UPSs operate with free slots, so that there is a possibility of increasing the UPS power in the future.

In accordance with these conditions, the UPS rack has:
- 10 slots for installation of 10 power modules 50kVA each.
- 7 power modules 50kVA (1-7). They provide N + 1 redundancy at 300 kVA load.
- 3 empty slots (8-10). In the future, it will be possible to install 3 power modules of 50 kVA to increase the system capacity to 450 kVA with N + 1 redundancy (Fig. 1.2)

3. In the UPS rack with a distributed static bypass architecture, 7 power modules (1–7) are installed, each of which contains its own static bypass, designed for a 50 kVA power module (Fig. 2). The UPS rack with centralized static bypass architecture also contains 7 power modules (1-7) without static bypass + Central Static Bypass Module (CSB), designed for a maximum rack power of 500 kVA (Fig. 1). Manufacturers of systems with a central bypass complete their racks with a central bypass module designed for the maximum power of the entire rack, since it is extremely unreasonable to increase the rack power by adding new power modules with replacement of the Central Static Bypass Module by more powerful bypass module.

4. We assume that the user, in order to protect his equipment, installed in all the rooms the protection devices (PD) designed for the maximum power of the installed equipment with a small power margin and 50 ms response time. The power margin of protection devices is necessary,

because the load is usually not a constant and during operation may decrease or increase depending on the mode of operation. Protection devices trigger in 50 ms after an overload, i.e. after the load power exceeds the throughput of the protection device.

5. Static bypasses in the both UPS are protected by fuses F0 ... F7 (Figure 1.2). We assume that all static bypasses in both UPS systems have protection fuses of the same speed - at a 10-fold increase in current from the nominal value, the fuses burn out in 20 ms. This condition corresponds to the class T of slow fuses.

Static bypass fuses in a system with distributed bypass with 50 kVA modules have a rating of 80A (Fig. 2). To calculate the burnout time of the fuse, we use the known fuse protection parameter , which is constant over a wide range of currents and is calculated using the formula $I^2 * t$, where I - is the current passing through the fuse (A), t - is the time during which the fuse blows (s) . This formula is valid for currents above the fuse rating. At currents less than or equal to the nominal value of the fuse, the fuse does not burn out and the burnout time = infinity. As a result, we obtain that the fuse protection parameter of the 80A fuse is $(10 * 80)^2 * 0.02 = 12800 A^2 s$.

In a system with a central bypass, the static bypass fuse F0 (Fig. 1) has a rating of 800A and its fuse protection parameter is $(10 * 800)^2 * 0.02 = 1280000 A^2 s$, respectively. Thus, knowing the current passing through the thyristor during an overload, we can calculate the fuse blow time and, accordingly, determine the time when the UPS output voltage turns off.

6. In all calculations we will assume that the manufacturer of the UPS with the distributed static bypass managed to solve the problem of the equal current sharing in the static bypass circuits. In other words, the thyristors have the same internal resistance, the delay time of switching of all the thyristors is the same, and the fuses have the same burnout time when overloaded. In addition, to simplify the calculations, we will assume that the load and the overload are evenly distributed in phases.

7. We assume that the critical load connected to the UPS is 300 kVA, located in three rooms 1-3 (Fig. 3). Each room is equipped with the protection devices PD-1, PD-2, PD-3, which trigger in case of an overload in 50 ms. We also assume that the UPS switches to bypass when the load per 1 module exceeds 110% of its rated power, i.e. when the load power reaches 55 kVA per module.

For brevity, we will call UPS with central bypass - UPS1, UPS with distributed bypass - UPS2.

Note

The actual technical characteristics of the bypass fuses and protection devices may differ significantly from those specified in clauses 5 and 7. For example, an actual 80A fuse can start melting at currents > 100A and not at currents > 80A, as indicated in condition 5. Real protection devices in practice, they also cannot have a constant response time, as indicated in condition 7. The response time depends on the type of protection device used, on the overload current, and on many other parameters. Simplification of technical characteristics is used to simplify calculations, so that it is possible, without delving into complex calculations, to compare two uninterruptible power systems in different situations.

Having detailed technical characteristics of real bypass fuses and protection devices, the user can independently assess the capabilities of his equipment in specific operating conditions.

Comparison of the overload capacity of the UPS with the central and distributed static bypass

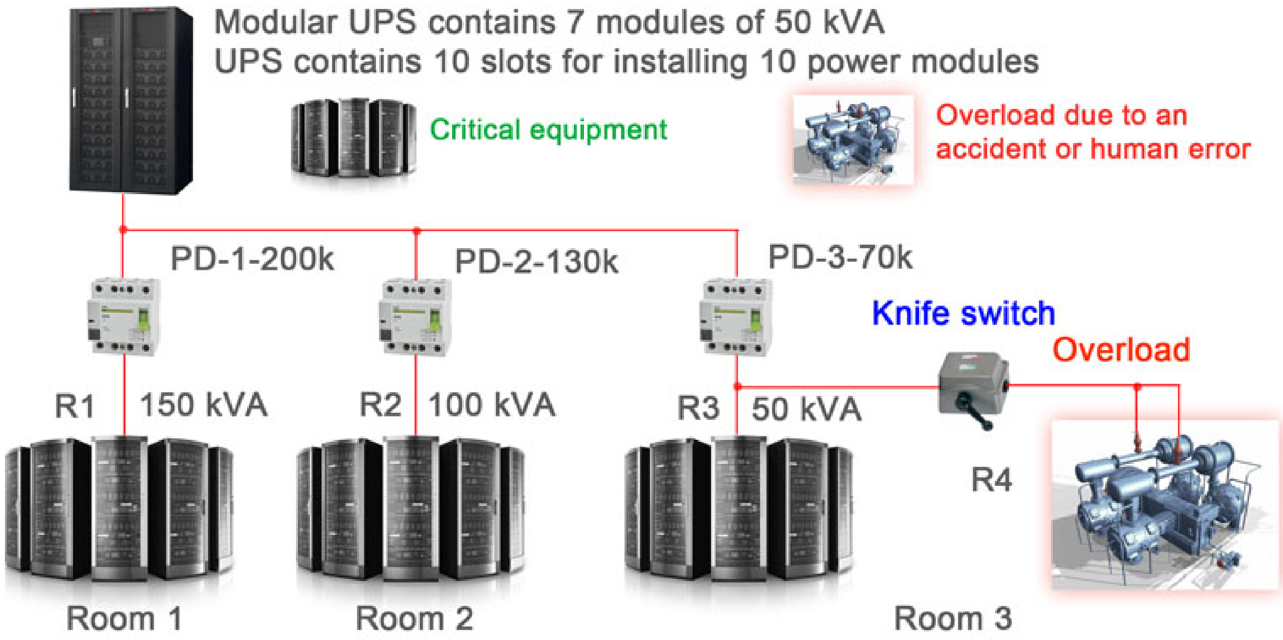

Fig. 3. An example of connecting the critical load to the UPS, where overload may occur. Protection devices are designed for load power with a margin of about 30%. Redundancy mode N+1. Overload occurs in the room 3.

Consider various situations that differ in the amount of the load connected to a UPS with a central and distributed bypass.

Situation 1

Regular situation, no overload. Total load = 150 + 100 + 50 = 300 kVA. The load on each module is 300/7 = 42.9 kVA. Both systems operate on-line and provide N + 1 redundancy.

This situation is displayed in the following table:

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	300 000	300 000	Total load = 150 + 100 + 50 = 300 kVA
Load on 1 module, VA	42 857	42 857	Load per module = 300/7 = 42.857 kVA. No overload

Power Module Overload Ratio	0.86	0.86	The ratio of the actual load on the module to its rated power is 42857/50000 = 0.86. Power modules are not overloaded.
Bypass Current, A	0	0	Bypass off
Bypass Current Increase Factor	0	0	No bypass current
Bypass fuse blow time, ms	∞	∞	The fuses do not activate.
Bypass Fuse Status	OK	OK	
UPS mode	on-line	on-line	N + 1 Redundancy

Situation 2

Suppose that an accident has occurred in room 3. An additional load R4 90 kVA is connected to the existing load R3 50 kVA (Fig. 3). The total load on the UPS has increased to 150 + 100 + 50 + 90 = 390 kVA.

In accordance with the initial conditions, the protection device PD-3 must disconnect the load R3 + R4 in room 3 in 50 ms. If static bypass fuses blow before 50 ms, PD-3 does not trigger and the entire critical load of user R1, R2, R3 is powered off.

UPS status:

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A²s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	390 000	390 000	Total load on UPS = 150 + 100 + 50 + 90 = 390 kVA
Load on 1 module, VA	55 714	55 714	Load per module in both UPS > 55 kVA
Power Module Overload Ratio	1.11	1.11	Overload factor on module 1.11 > 1.1 - the bypass turns on in both UPS
Bypass Current, A	565	81	The current in the bypass circuit of UPS1 and UPS2 is calculated by the formula: I1 = 390000 / (230 * 3) - the power of the entire load in UPS1 is taken into account I2 = 55714 / (230 * 3) - power per module in UPS2 is taken into account

Bypass Current Increase Factor	0.71	1.01	The central bypass fuse of the UPS1 is 71% loaded, the fuse does not melt. The current in the distributed bypass circuits of UPS2 exceeds the nominal value by 1.01 times, therefore, according to the initial condition 5, the process of fuses melting begins.
Bypass fuse blow time, ms	∞	1 963	The estimated time of complete melting of the UPS2 fuses is $12800/81^2 = 1963$ ms (see initial condition 5). Since the response time of the PD-3 = 50 ms < the melting time of the bypass fuses 1963 ms, the PD-3 triggers, the entire load in room 3 is turned off, and the process of bypass fuses melting stops.
Bypass Fuse Status	OK	OK	The central bypass fuse of UPS1 remains intact. The fuses in the distributed bypass circuits of UPS2 remain intact, although the melting process was initiated.
Load during the overload	bypassed	bypassed	Protection Device PD-3 shuts off the entire load in the room 3.
UPS mode after overload removal	on-line without interruption	on-line without interruption	After disconnecting the load in room 3, both UPS switch to on-line mode. As the load decreases, N + 1 redundancy mode is restored.

Because of the accident in room 3, the protection device PD-3 trigges before the bypass fuses blow out. Static bypasses fulfilled their function - protection of critical loads against overload. Part of the critical load located in room 3 turns off. However, the equipment in rooms 1, 2 continues to operate without interruption.

In situation 2, it can be noted that even at relatively small overloads (R4 = 90 kVA), the fuses in the distributed bypass of UPS2 begin to melt, and the process of their melting stops at the tripping moment of the PD - 3.

Situation 3

Suppose that a more powerful accident occurs in room 3: an overload of R4 = 2150 kVA was connected. Accordingly, the total load on the UPS has increased to 150 + 100 + 50 + 2150 = 2450 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	

Total load on rack, VA	2 450 000	2 450 000	Total load = 150 + 100 + 50 + 2150 = 2450 kVA
Load on 1 module, VA	350 000	350 000	Big overload
Power Module Overload Ratio	7	7	7-fold overload of power modules, both UPS switch to static bypass
Bypass Current, A	3 551	507	
Bypass Current Increase Factor	4.44	6.34	The currents in the bypass circuits exceed the rated value of their fuses. The melting process starts in all fuses.
Bypass fuse blow time, ms	101.53	49.75	The fuse in UPS1 does not blow, because its estimated melting time = 101.53 ms > 50 ms (the response time of PD-3). The protection device PD-3 triggers before the central bypass fuse blows out. The fuses in UPS2 burn out because their burning time = 49.75 < 50 ms. The protection device in the room 3 does not have enough time to trigger. UPS2 turns off, all the critical load in all rooms 1-3 is turned off.
Bypass Fuse Status	OK	burned out	The fuse in UPS1 does not burn out. All fuses 7x3 = 21 pcs. in UPS2 in all power modules with distributed bypass burn out.
Load during the overload	bypassed	load off	UPS1 continues to power the load through the central bypass. UPS2 stops powering the load.
UPS mode after overload removal	on-line without interruption	UPS off, all load off	Bypass of UPS1 withstands overload. After disconnecting the overload in the room 3 by PD - 3, UPS1 goes into on-line mode and continues to supply the load in rooms 1, 2 without interruption. The equipment stops operating only in the room 3 where the overload has occurred. Bypass of UPS2 does not withstand overload. All bypass fuses in all power modules burn out. UPS2 turns off all critical loads R1, R2, R3! Before starting up the UPS2, it is necessary to manually disconnect the overload in room 3 and replace all static bypass fuses 7x3 = 21pcs. in all 7 power modules.

Here it is necessary to pay attention to the fact that in UPS2 all the fuses of the distributed bypass blow out in all 7 power modules. The user needs to know that the fact that the bypass fuse has blown does not mean that the cause of the overload has been removed. If the user replaces all the fuses and tries to restart UPS2 again, then all the fuses will blow out again, because the cause of the overload has not been eliminated and PD-3 did not trigger. Therefore, before restarting UPS2, it is imperative to find the cause of the overload and eliminate it, for example, open the blue knife switch in the room 3 (Fig. 3).

Situation 4

Suppose that an even more powerful accident occurs in room 3: an overload of R4 = 3200 kVA is connected. Accordingly, the total load on the UPS increases to 150 + 100 + 50 + 3200 = 3500 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	3 500 000	3 500 000	Total load = 150 + 100 + 50 + 3200 = 3500 kVA.
Load on 1 module, VA	500 000	500 000	Big overload
Power Module Overload Ratio	10.00	10.00	10-fold overload of power modules, both UPS switch to static bypass
Bypass Current, A	5 072	725	
Bypass Current Increase Factor	6.34	9.06	The currents in the bypass circuits exceed the rated value of their fuses. The melting process starts in all bypass fuses in both UPS.
Bypass fuse blow time, ms	49.75	24.38	Static bypass fuses in both UPS burn out, because the time of their combustion is less than the response time of the PD-3 protection device (50ms). In UPS1 1x3 = 3 central bypass fuses burn out. In UPS2 7x3 = 21 distributed bypass fuses located in 7 power modules burn out.
Bypass Fuse Status	burned out	burned out	A static bypass fuse blow out in both UPS. Protection device PD-3 does not trigger, because bypass fuses burn out before PD-3 has triggered.
Load during the overload	all load off	all load off	
UPS mode after overload removal	UPS off, all load off	UPS off, all load off	Both UPSs do not withstand the overload and disconnect all user's equipment R1, R2, R3! To start up the UPS, user has to: 1. de-energize the overload in the room 3 (turn off the blue knife switch). 2. replace bypass fuses: in UPS1 - 3 fuses in the central static bypass module in UPS2 - 21 fuses in all 7 power modules

Assessing situations 3 and 4, we can conclude that UPS1 with a central bypass withstands a 10-fold overload, UPS2 with a distributed bypass withstands a 7-fold overload. A significant gain in overload capacity of UPS1 was ensured by the using of a central static bypass module, which is designed for total power of the UPS 500 kVA.

Calculations were given for the protection devices with a response time of 50 ms. Using of the slower protection devices reduces the overload capacity of both UPS. For example, in case of using of protection devices with a response time of 200 ms, UPS2 disconnects the entire load at overload R4 = 930 kVA (overload factor = 3.51), and UPS1 at overload R4 = 1450 kVA (overload factor = 5).

Thus, the overload capacity of UPS1 with a central bypass is substantially higher than the overload capacity of UPS2 with a distributed bypass.

Overload capacity of UPS with central and distributed bypass during external overload

Overloading can occur not only in the output of the protection devices. Consider the case when an overload occurs between the output of the UPS and the input of protection devices. This overload is very dangerous for a critical load, because it turns off the entire critical load in all rooms (Fig. 4).

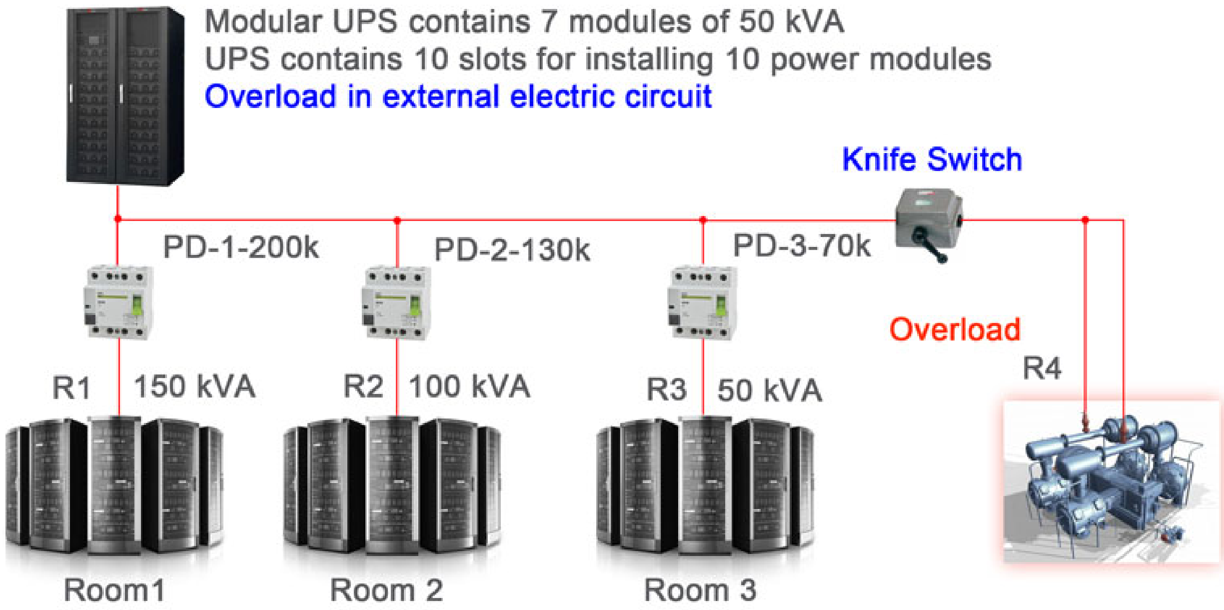

Fig. 4. External overload occurs between the UPS output and protection device's inputs. Redundancy mode N+1

Situation 5

Consider the situation when external overload R4 = 87 kVA is connected (Fig. 4)

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	

Total load on rack, VA	387 000	387 000	Total load = 150 + 100 + 50 + 87 = 387 kVA
Load on 1 module, VA	55 286	55 286	Overload
Power Module Overload Ratio	1.11	1.11	Overload factor 1.11 > 1.1, both UPS switch to static bypass
Bypass Current, A	560.87	80.12	
Bypass Current Increase Factor	0.70	1.002	The current in the bypass circuit of the UPS1 is less than the nominal value, the fuse does not melt. The current in the distributed bypass circuit of UPS2 exceeds the rated value of its fuses. The fuses start to melt.
Bypass fuse blow time, ms	∞	1 993	The central bypass fuse in UPS1 does not burn out. All distributed bypass fuses in UPS2 burn out for 2 s. If during this time overload R4 does not disappear, then UPS2 turns off, and the entire critical load in all rooms 1, 2, 3 is turned off.
Bypass Fuse Status	OK	burned out	The fuse in UPS1 does not burn out. All fuses 7x3 = 21 pcs. in UPS2 in all power modules with a distributed bypass melt down.
Load during the overload	bypassed	switched off	UPS1 continues to power the load through the central bypass. UPS2 stops powering the load.
UPS mode after overload removal	on-line without interruption	UPS off, all load off	Bypass of UPS1 withstands overload. After the external overload R4 is disappeared, UPS1 goes into on-line mode and continues to supply without interruption the entire critical load in rooms 1, 2, 3. Bypass of UPS2 does not withstand overload. All bypass fuses in all power modules burn out. UPS2 turns off all the user's loads R1, R2, R3! To start UPS2, it is necessary to disconnect the overload R4 manually and replace all static bypass fuses 7x3 = 21pcs. in the all 7 power modules.

Situation 6

Consider the situation when external overload R4 = 253 kVA is connected (Fig. 4)

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	

Total load on rack, VA	553 000	553 000	Total load = 150 + 100 + 50 + 253 = 553 kVA
Load on 1 module, VA	79 000	79 000	Overload
Power Module Overload Ratio	1.58	1.58	Overload factor 1.58 > 1.1, both UPS switch to static bypass
Bypass Current, A	801	114	
Bypass Current Increase Factor	1.002	1.43	The currents in the bypass circuits of both UPS exceed the rated value of their fuses. The fuses start to melt.
Bypass fuse blow time, ms	1 993	976	The central bypass fuse in UPS1 burns out for about 2 s. All distributed bypass fuses in UPS2 burn out for about 1 s.
Bypass Fuse Status	burned out	burned out	
Load during overload	load off	load off	Both UPSs shut off all critical load.
UPS mode after overload removal	UPS off, all load off	UPS off, all load off	Both UPSs do not withstand the overload and disconnect all user equipment R1, R2, R3! To start up the UPS, user has to: 1. in manual mode, turn off the overload in the room 3 (turn off the blue knife switch). 2. replace bypass fuses: in UPS1 - 3 fuses in the central static bypass module in UPS2 - 21 fuses in all 7 power modules

The external overload is much more dangerous than the internal overload even at the N + 1 redundancy, because the entire critical load is disconnected at relatively small overloads: in UPS2 with distributed bypass, the entire critical load is disconnected at 87 kVA overload, and in UPS1 with central bypass at 253 kVA overload. Here we also see a significantly higher reliability of UPS1 with a central bypass.

The effect of external overload can occur not only when an overload occurs between the UPS and protection devices (Fig. 4). This effect can occur even when an overload occurs in the rooms with installed protection devices. This effect is especially pronounced when the UPS operates in non-redundant mode, i.e. when the load power corresponds to the total power of the UPS. Consider the occurrence of this effect in the following examples.

UPS overload capability with central and distributed bypass in non-redundant mode. Internal Lock Current Protection (ILCP). Energy Traps.

Many users believe that the operation of a modular UPS in non-redundant mode (N + 0) does not represent a great danger and is quite acceptable. They think - there is no overload, so everything is fine. And if an overload occurs, the user thinks that the UPS will switch to a static bypass and while the UPS is on the bypass, the user can quickly find the cause of the overload, quickly eliminate it, punish the guilty persons and everything will continue to operate without any negative consequences. However, this is a big mistake. Consider the operation of the UPS without redundancy in more detail.

It should also not be forgotten that any modular UPS operating in N + 1 redundancy mode always unintentionally to the user can go into N + 0 non-redundancy mode. For example, if the power consumption of the load increased during operation . Therefore, the user is very useful to know what potential threats arise in this case.

Suppose that a user has installed a load of 150, 100, 100 kVA in rooms 1, 2, 3 (Figure 5). There may occur at least 3 unpleasant situations.

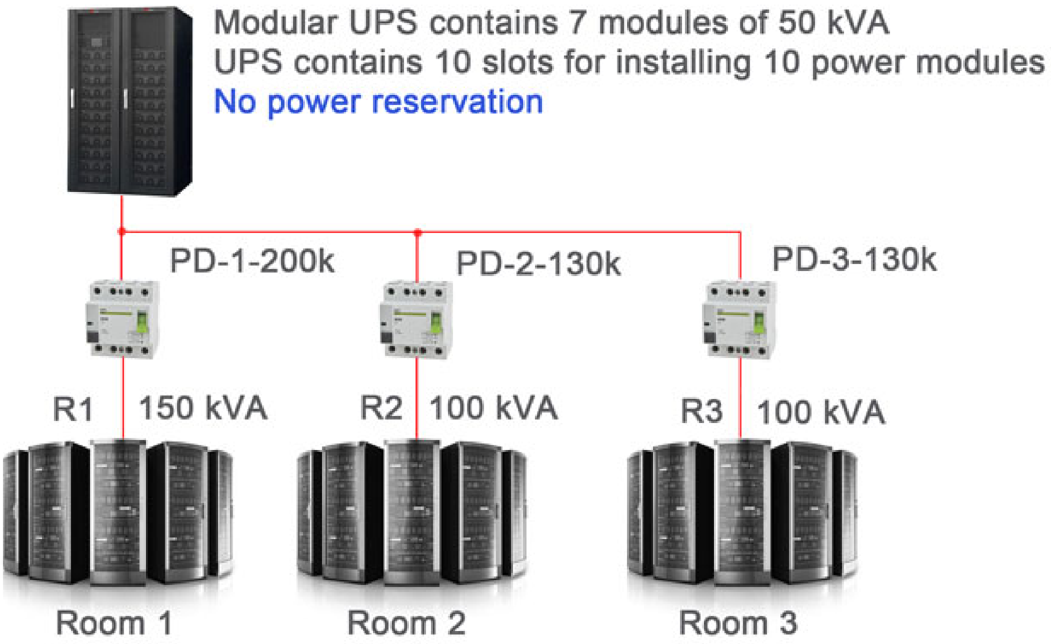

Fig.5. An example of modular UPS operation in non-redundancy mode. The total power of the UPS 7x50 = 350 kVA corresponds to the power of the load 150 + 100 + 100 = 350 kVA.

Situation 7

With the load indicated in fig. 5 The UPS is 100% loaded. Usually, the power consumed by the load is non-constant and can change its value during operation. The load can either increase or decrease. For this reason, the rated currents of the protection devices are selected with a small margin. In our example, the power margin of the protection devices is about 30%. The load changes in rooms 1-3 are random, but there is a possibility that the load power in all three rooms may increase at the same time. Suppose that at some point in time the power consumption in rooms 1, 2, 3 became respectively, 170, 110, 110 kVA. Protection devices at such values of the load do not trigger and remain on - for them there is no overload.

The state of the two UPSs is summarized in the table:

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	7	7	
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	

Bypass Fuse Protection Parameter, A^2s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	390 000	390 000	Total load = 170 + 110 + 110 = 390 kVA
Load on 1 module, VA	55 714	55 714	Load per module = 390/7 = 55.7 > 55 kVA. Inverters overloaded
Power Module Overload Ratio	1.11	1.11	1.11 > 1.1 - the bypass turns on in both UPS
Bypass Current, A	565	81	
Bypass Current Increase Factor	0.71	1.01	The central bypass of UPS1 is loaded by 71% - the fuses do not start melting. The distributed bypass of UPS2 is loaded by 101% - the process of the bypass fuses melting begins.
Bypass fuse blow time, ms	∞	1 963	The central bypass fuse of the UPS1 does not burn out. The estimated time of blowing out of the fuses in UPS2 with distributed bypass is about 2 s. If during this time the total power of the load does not decrease, then all the fuses of the distributed bypass of UPS2 blow.
Bypass Fuse Status	OK	burned out	The central bypass fuse of the UPS1 does not burn out. All fuses of the distributed bypass of UPS2 burn out within 2 seconds.
Load during overload	bypassed	switched off	Because of the insignificant simultaneous increase in power of all the loads, both UPSs transfer to static bypass. The central bypass fuse in UPS1 does not burn, the load continues to be fed through the static bypass. In case the duration of the overload lasts more than 2 s., all fuses of the distributed bypass of UPS2 in the amount of 3x7 = 21 pcs. burn out.
UPS operation mode after overload	on-line without interruption	UPS off, all load off	UPS1 switches to bypass during overload. After the total power of the load has decreased, the UPS1 transfers to on-line mode without interrupting the power supply to the load. UPS2 during an overload shuts off all critical load in all rooms 1, 2, 3. All distributed bypass fuses in all UPS2 power modules - 21 pcs. burn out.

This example shows that the even a small increase of power of the load (20 + 10 + 10 = 40 kVA) in UPS2 with distributed bypass in non-redundancy mode can have disastrous consequences for the user, while UPS with a central bypass successfully copes with this overload. The occurrence of such a situation can be very rare, for example, once a year, but a very unpleasant event for the user, when the entire critical load is unpredictably turned off. In addition, those responsible for such a situation is very difficult to find. It seems that there was no overload - the protection devices did not trigger, but the entire critical load in all rooms was turned off!

UPS1 with a central bypass during an overload switches to a static bypass, its fuses do not blow, and after reducing the load power UPS1 restores the on-line mode. The user will not even notice that something potentially very dangerous has happened.

The situation when the occurring overload in the rooms with protection devices does not make triggering of the protection devices, but causes the power off of the entire user's load - a fairly common phenomenon and is called Internal Lock Current Protection (ILCP). UPS2 with distributed bypass in our example falls into the so-called Energy Trap.

It should be noted here that UPS1 with the central bypass in our case (Fig. 5) cannot get into the situation of internal blocking of current protection. Even if the load power in all rooms 1, 2, 3 grows to the rated values of protection devices 200 + 130 + 130 = 460 kVA, the current increase factor in the bypass circuit will reach 667/800 = 0.83. The central bypass fuse does not burn out and UPS1 returns to on-line mode without interrupting the load power after the overload has disappeared.

With a load of > 460 kVA, the protection devices start to respond to overload and the overload capacity of the UPS2 increases substantially (see situation 3, 4).

Considering this situation, it can be seen that the overload capability of UPS2 with distributed bypass in non-redundancy mode N + 0 can significantly decrease (from the value 7 (N + 1, situation 3) to the value 1.11 (N + 0, situation 7)), while the overload capability of UPS1 with a central bypass does not change (value is 10 in N + 1 and N + 0 modes (situation 4)).

Consider another situation in which the load power remains unchanged 150 + 100 + 100 = 350 kVA (Fig. 5), but unpleasant changes occur in the UPS itself.

Situation 8

The following unpleasant, but quite probable event occurs - one power module fails, and it is automatically disconnected from the entire system. The same situation occurs if someone from the service personnel accidentally or faultily turns off the power module. Or, for example, in the case when smoke went out of the module, the operator most likely turns off this power module. As a result, only 6 working power modules remain in the UPS. The total load 150 + 100 + 100 = 350 kVA remains unchanged.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of modules in the rack	6	6	The number of working modules decreased by 1 and became equal to 6
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass fuse protection parameter, A^2 s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	350 000	350 000	Total load = 150 + 100 + 100 = 350 kVA
Load on 1 module, VA	58 333	58 333	Load per module = 350/6 = 58.333 kVA Load per power module > 55 kVA. Inverters overloaded.
Power Module Overload Ratio	1.17	1.17	1.17 > 1.1 - bypasses turn on

Bypass Current, A	507	85	
Bypass Current Increase Factor	0.63	1.06	The central bypass of the UPS1 is 63% loaded - the fuses do not melt. The distributed bypass of the UPS2 is 106% loaded - the process of bypass fuses melting begins
Bypass fuse blow time, ms	∞	1 791	
Bypass Fuse Status	OK	burned out	The central bypass fuse of UPS1 does not burn out. All fuses of the distributed bypass of UPS2 burn out within 1.8 s.
Load after disconnecting one power module	bypassed	UPS off, all load off	In both cases, shutting down one power module makes transferring the UPS to bypass mode. In UPS1, the central static bypass is 63% loaded, so the UPS continues to power the load. The user has the opportunity to replace the faulty module and return the system to on-line mode. In UPS2, all static bypass fuses in all modules 3x6 = 18 pcs. burn out. The UPS2 shuts down, all the critical load in all rooms is turned off!

UPS1 with central bypass is much more reliable in operation. Its overload capacity does not depend on the number of modules installed in the rack. Even if only one power module remains in the rack, UPS1 with central bypass switches to bypass and the load does not shut down. The user will always have some time to eliminate the malfunction. For example, if one module was mistakenly turned off by an operator, it can be turned on again or faulty module can be replaced.

UPS2 with distributed bypass is very sensitive to the failure or shutdown of even one power module. When UPS2 is in non-redundancy mode, the shutting down only one module shuts down the entire UPS and powers off all the critical load.

Therefore, UPS with distributed bypass can only safely operate in N + X redundancy mode, where X > 0. Operation of uninterrupted power supply systems with distributed bypass without redundancy (X = 0) is extremely dangerous! The user risks even with a slight overload (situation 7), or turning off just one power module (situation 8) to shut off the entire critical load!

It should be noted here that generally power modules with a built-in bypass are not fully switched off when an internal fault occurs. Usually the static bypass as far as possible remains activated and, in the event of an inner failure in the module, it switches on synchronously with other distributed static bypasses. Therefore, situation 8 in UPS2 with distributed bypass occurs when a fault in the power module affects the operation of the static bypass. For example, in the event of a malfunction in the control board of the power module.

Situation 9

The situation when UPS1, UPS2 operate in non-redundancy mode (N + 0, Fig. 5). The total load on the UPS 150 + 100 + 100 = 350 kVA.

There are such cases, when in the event of an overload UPS2 with distributed bypass switches to bypass. All fuses in all modules blow out, load is disconnected (for example, as in situation 3). After elimination of the overload, the UPS can start in on-line mode by oneself . After the voltage appears, the user naturally turns on all critical equipment and waits for service engineers to arrive so that they can replace bypass fuses that have blown. In the event of the fuse holders are located on the module's front panel, the process of replacing the fuses is easy and can be done even by the user. Their replacement can be made on-line. However, in some cases, one or more power modules may continue to signal a malfunction of the bypass line, for example, due to a malfunction in the control board that could suffer due to high overload currents passing through the power module. In this case, the power module cannot be switched to a static bypass. Fig.6 shows the case where the display panel of the power module shows that the module is working in on-line mode and that the bypass line is not available, although the bypass fuses were replaced after overload. Attempting to transfer the UPS to a static bypass may cause the critical load to power off.

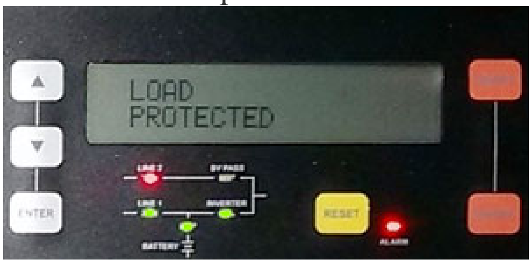

Fig. 6. The indication of the power module with a built-in static bypass indicates that the power module is working in on-line mode, but bypass line is not available.

If a similar malfunction occurs in UPS1 with a central bypass, the service engineer can in on-line mode, remove the central bypass module, correct the fault and install the central bypass module back into the UPS rack. Thus, in UPS1 with a central bypass in case of non-redundancy mode, it is possible to troubleshoot the static bypass in on-line mode without shutting down the critical load.

In UPS2 with distributed bypass in non-redundancy mode, it is impossible to repair the static bypass in on-line mode, because if one power module is removed from the rack, then the UPS powers off the entire load. It is also not possible to transfer the UPS to a mechanical bypass without interrupting the power supply of the critical load. Thus, overloading of UPS2 with a distributed bypass may result in the need to shut down the critical load twice. The first time when the overload itself occurs, the second time to troubleshoot a static bypass.

This example shows that the installation of a static bypass into a separate central bypass module (Fig. 1) has significant advantages over the distributed bypass architecture, where the static bypass is built in the power modules (Fig. 2). Removing the power module from UPS with a distributed bypass inevitably leads to a reduction in the total power of the UPS and at the same time a decrease in its overload capacity. Installing the fuse holders on the front panel of the power module only partially solves the problem of the integrated bypass. Troubleshooting in the control board is only possible after removing the power module from the UPS rack.

Control of static bypass in both UPS with central and distributed bypass has a distributed architecture. In both systems, static bypass control commands come from a power module that performs the function of a master. In the remaining slave modules of UPS with distributed bypass, as in the central bypass module, only executive functions are implemented. Only the gain of the control signals from the master module is performed. Thus, the central bypass module does not contain a bypass control circuit — only a signal's amplifier. Control circuit of the central bypass is distributed in the power modules and has the same redundancy as in the UPS with a distributed bypass. In the central bypass module, only the signal amplifiers and the bypass diagnostic circuits are installed. In the central bypass module the signal amplifier, as a rule, is duplicated to improve reliability and eliminate a single point of failure. The thyristor element itself can be made on the basis of one powerful thyristor or several low-power parallel thyristors. To increase the reliability of the central bypass, if thyristor of required power is available, it is better to use one powerful thyristor instead of several low-power parallel thyristors. In this case, the problem of equal current sharing between the thyristors disappears. However, in some cases, the manufacturer may use several parallel thyristors to remove a single point of failure. The power of the central bypass module corresponds to the power of the UPS with the maximum possible number of power modules.

Potential risks during maintenance of modular UPSs with central and distributed bypass

Consider another important aspect in the operation of the modular UPS - the operating reliability of UPS1 and UPS2 during maintenance, when service engineers have to remove the module from the rack for its maintenance, and during this time, the UPS continues to operate on the remaining modules. To ensure UPS operation in on-line mode during maintenance, the number of power modules must provide N + 1 redundancy mode. The duration of the UPS maintenance, when one of the modules is extracted from the rack for its maintenance, ranges from 30 minutes to several hours, depending on the number of modules in the UPS. After removing one power module, the UPS operates in non-redundant mode N + 0. During the maintenance, such unpleasant events may also occur as an overload of the UPS or failure of any remaining module in the UPS rack. We must not forget that when the power module is removed from the rack, the load on the other modules increases.

Assume that the user has a critical load installed in three rooms and is equal to 150 + 100 + 50 = 300 kVA, respectively. The user provided N + 1 redundancy mode - installed 7 power modules of 50 kVA. The total power of the UPS = 7x50 = 350 kVA. Protection devices in the rooms are respectively equal to 200 kVA, 130 kVA, 130 kVA. In our example, in room 3 a protection device PD-3 has power protection of 130 kVA, so that in the future there is possibility to increase the power of critical equipment to 100 kVA (Fig. 7). We deliberately created such a situation, that in general is quite likely, but it allows us to analyze again the effect of internal blocking of current protection, which was described in details in situation 7.

In addition, situations where the power of protection devices significantly exceeds the power of the connected load are quite common.

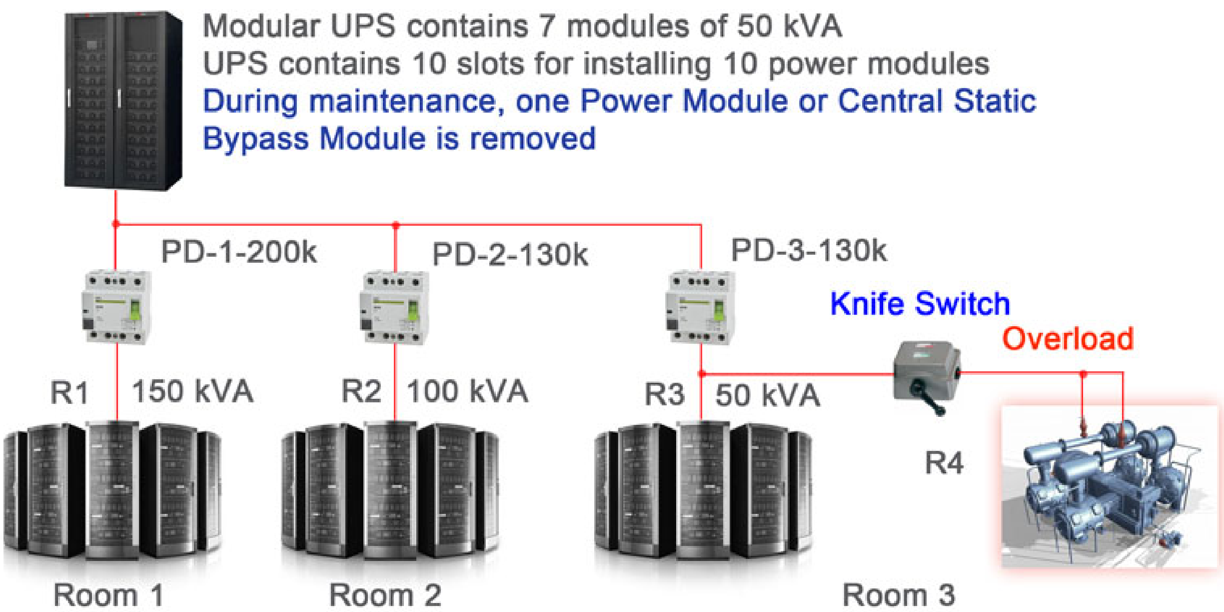

Fig. 7. UPS operation during maintenance.

Situation 10

The status of UPS1 and UPS2 before maintenance:

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	7	7	7 power modules provide N + 1 redundancy
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass fuse protection parameter, A^2 s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	300 000	300 000	Total load = 150 + 100 + 50 = 300 kVA
Load on 1 module, VA	42 857	42 857	
Power Module Overload Ratio	0.86	0.86	Power modules loaded at 86%, no overload
Bypass Current, A	0	0	Static bypass off
Bypass Current Increase Factor	0	0	
Bypass fuse blow time, ms	∞	∞	
Bypass Fuse Status	OK	OK	
UPS operation mode	on-line	on-line	N + 1 Redundancy

Both UPSs operate on-line with N + 1 redundancy.

Maintenance: the power module is removed in UPS1 and UPS2

Consider a situation when one power module is removed from the rack for maintenance.

Situation 11

UPS1 and UPS2 operate without one power module, which is removed from the rack for maintenance.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	6	6	After removing one power module in both UPS, 6 power modules remain.
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass fuse protection parameter, A^2 s	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	300 000	300 000	Total load = 150 + 100 + 50 = 300 kVA
Load on 1 module, VA	50 000	50 000	
Power Module Overload Ratio	1.00	1.00	Power modules are 100% loaded, no overload

Bypass Current, A	0	0	Static bypass off
Bypass Current Increase Factor	0	0	
Bypass fuse blow time, ms	∞	∞	
Bypass Fuse Status	OK	OK	
UPS operation mode during maintenance	on-line	on-line	Both UPSs continue to operate on-line, but there is no redundancy.

After extracting one power module for maintenance, both UPS systems continue to operate in on-line mode.

Situation 12

During maintenance one power module was removed in both UPS.

Suppose that in room 3 during maintenance, an additional load R4 = 32 kVA is connected. This is a not a big additional load. It may occur due to a change in the mode of operation of critical equipment or because of any malfunction in the equipment. The total power load in room 3 become equal to 50 + 32 = 82 kVA. The protection device PD-3 is designed for a power of 130 kVA, and therefore it does not trigger. The total load on the UPS becomes equal to 150 + 100 + 50 + 32 = 332 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	6	6	1 power module in UPS1,2 is removed
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	332 000	332 000	After connecting the additional load R4 = 32 kVA, the total load on the UPS become equal to 150 + 100 + 50 + 32 = 332 kVA
Load on 1 module, VA	55 333	55 333	Load per module > 55 kVA, power modules are overloaded
Power Module Overload Ratio	1.11	1.11	1.11 > 1.1 - the inverters are turned off, the UPS switches to bypass
Bypass Current, A	481.16	80.19	In both UPS the static bypass turns on and the overload current flows through bypass.
Bypass Current Increase Factor	0.60	1.0024	In UPS1, the static bypass is loaded at 60% - bypass fuse does not melt. In UPS2, the static bypass is loaded > 100% - bypass fuses start to melt.
Bypass fuse blow time, ms	∞	1 990	In UPS1, the bypass fuse does not melt and the static bypass provides power to the critical load. In UPS2, all bypass fuses in all power modules begin to melt and burn out in 2 s.

Bypass Fuse Status	OK	burned out	
UPS operation mode during maintenance when an overload occurs	load bypassed	UPS off, all load off	In UPS1, the bypass fuse does not melt and critical load is powered through the static bypass. In UPS2, all bypass fuses in all power modules blow out. The entire load is powered off.
UPS operation mode during maintenance after overload disappeared	on-line without interruption	UPS off, all load off	UPS1 returns to on-line mode after an overload. UPS2 disconnects the entire critical load of the user.

Connecting a relatively small additional load of 32 kVA in room 3 during maintenance of the power module resulted in the turning on of static bypasses in both UPS.

During this overload UPS1 continues to feed the critical load through the central static bypass and the user has time to resolve the emergency in two ways - 1) eliminate the overload 2) reinstall removed from the rack power module.

At the same overload 32 kVA in UPS2, all static bypass fuses in all 6 power modules burn out, and the entire critical load in all rooms 1-3 is shut off. UPS2 with distributed bypass, as in the situation 7, again falls into the Energy Trap. Internal Lock Current Protection (ILCP) occurs. This example vividly demonstrates the vulnerability of UPS2 with a distributed bypass, when relatively small overloading in one of the rooms with the protection device installed can lead to a fatal consequences - shutting down the entire critical load in all the rooms.

With an increase of the overload R4 up to 80 kVA, situation 12 remains unchanged. UPS1 continues to supply the load through the central static bypass, and UPS2 disconnects the entire critical load. With a further increase of overload in room 3 (R4 > 80 kVA), the total load in room 3 becomes > 130 kVA, which leads to the activation of the protection device PD-3 with response time of 50 ms. Protection device PD-3 disconnects the critical load in the room 3. UPS2 goes out of the Energy Trap, and its overload capability increases.

Situation 13

During maintenance, one power module is removed in both UPS. Additional load R4 = 1790 kVA. The total load on the UPS 150 + 100 + 50 + 1790 = 2090 kVA

During an overload when R4 is greater than 80 kVA up to 1790 kVA, the protection device PD-3 triggers and powers off load in room 3. The estimated burnout time of the bypass fuses in UPS1 and UPS2 is > 50 ms.

UPS2 quits of the Energy Trap and its bypass withstands overload up tu R4 = 1790 kVA. During overload, UPS1,2 transfer to bypass, their fuses do not blow, protection device PD-3 triggers in 50 ms. The load in room 3 is turned off, and after that UPS1, 2 go to on-line mode.

Situation 14

During maintenance, one power module is removed in both UPS. Additional load R4 = 1800 kVA is connected. The total load on the UPS 150 + 100 + 50 + 1800 = 2100 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	6	6	1 power module removed from UPS1,2
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	2 100 000	2 100 000	After connecting additional load R4 = 1800 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 1800 = 2100 kVA
Load on 1 module, VA	350 000	350 000	Load per module > 55 kVA, power modules overloaded
Power Module Overload Ratio	7.00	7.00	Power Module Overload Ratio > 1.1 - the inverters turn off, the UPSs switch to bypass
Bypass Current, A	3 043	507	In both UPS, the static bypass turns on and the overload current flows through it.
Bypass Current Increase Factor	3.80	6.34	In both UPS the static bypass is loaded > 100% - the bypass fuses start to melt
Bypass fuse blow time, ms	138.19	49.75	In UPS1, the bypass fuse does not blow out. Estimated melting time > 50 ms. In UPS2, all bypass fuses in all power modules melt down. The protection device PD-3 does not trigger.
Bypass Fuse Status	OK	burned out	
UPS operation mode during overload	load bypassed	all load off	In UPS1, the bypass fuse does not have enough time to melt down, and the critical load is fed through a static bypass. In UPS2, all bypass fuses in all power modules blow out.
UPS operation mode after an overload	on-line without interruption	UPS off, all load off	In UPS1, static bypass withstands an overload. The load in room 3 is disconnected. After disconnecting load in room 3 UPS1 transfers to on-line mode. In UPS2, all bypass fuses in all 6 power modules burn out. All load in all rooms is disconnected.

In case of overloads R4 > 1800 kVA, UPS2 with distributed bypass disconnects the entire critical load. All bypass fuses 3x6 = 18 pcs. burn out.

UPS1 with central bypass withstands overload. Only the critical load in room 3 where the overload has occurred is powered off.

Situation 15

During maintenance, one power module is removed in both UPS. Additional load R4 = 3200 kVA is connected. The total load on the UPS 150 + 100 + 50 + 3200 = 3500 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	6	6	1 power module is removed in UPS1,2
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	3 500 000	3 500 000	After connecting the additional load R4 = 3200 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 3200 = 3500 kVA
Load on 1 module, VA	583 333	583 333	Load per module > 55 kVA, power modules are overloaded
Power Module Overload Ratio	11.67	11.67	Power Module Overload Ratio > 1.1 - the inverters turn off, the UPSs switch to bypass.
Bypass Current, A	5 072	845	In both UPS, the static bypass turns on and the overload current flows through it.
Bypass Current Increase Factor	6.34	10.57	In both UPS the static bypass is loaded > 100% - the bypass fuses start melting
Bypass fuse blow time, ms	49.75	17.91	In both UPS fuse blowout time < 50 ms. All bypass fuses melt down.
Bypass Fuse Status	burned out	burned out	In UPS1, 1x3 = 3 bypass fuses blow out. In UPS2, 6x3 = 18 bypass fuses blow out. The protection device PD-3 does not trigger.
UPS operation mode during overload	all load off	all load off	
UPS operation mode after an overload	UPS off, all load off	UPS off, all load off	In UPS1 and UPS2, all bypass fuses burn out. All load in all rooms is disconnected.

In case of overloads R4 > 3200 kVA, both UPS1 and UPS2 do not withstand the overload and disconnect the entire critical user's load in all rooms.

This case also shows that during carrying out maintenance of power modules, the overload capacity of the UPS with central bypass is significantly higher than the overload capacity of the UPS with distributed bypass and therefore the probability of disconnecting the critical load during maintenance in UPS1 with a central bypass is lower than in UPS2 with a distributed bypass.

Maintenance: the central static bypass module is removed in UPS1, the power module is removed in UPS2

In UPS1 with a central bypass, in addition to the power modules, there is also a central static bypass module, which also needs to be serviced periodically - i.e. it must be removed from the rack for a while. It should be borne in mind, that the maintenance of the static bypass module can be carried out much less frequently than the maintenance of power modules, since it is usually in the off state (it turns on only during overloads), its cooling fans almost never turn on and there is no need for frequent cleaning internal components from dust. In addition, the duration of the maintenance of the central bypass module due to its simplicity is much less than the duration of maintenance of the power module. Approximately, it can be argued, that the maintenance of a power module takes 30 - 40 minutes, the maintenance of a central bypass module takes 10 - 15 minutes. Moreover, the central bypass module is only one, but the total number of power modules more then one and can reach, for example, more than 10. In addition, the power modules it is recommended to service 1-2 times a year, the central static bypass module it is enough to service once every 5 - 7 years.

Let's compare the operation of UPS1 and UPS2, when one power module is removed from UPS2 for maintenance, and the central static bypass module is removed from UPS1. During maintenance, the same overload occurs as in situation 12 - an additional load is connected in the room 3 R4 = 32 kVA.

Situation 16

In UPS1, during maintenance, the central static bypass module is removed, and in UPS2, the power module is removed. During maintenance, an additional load R4 = 32 kVA is connected in room 3. The total load in room 3 becomes equal to 50 + 32 = 82 kVA. The protection device PD-3 is designed for a power of 130 kVA, therefore it does not trigger. The total load on the UPS becomes equal to 150 + 100 + 50 + 32 = 332 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	7	6	The central static bypass module is removed in UPS1 for maintenance, 7 power modules remain in the rack. One power module is removed in UPS2, 6 power modules remain in the rack
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	332 000	332 000	After connecting the additional load R4 = 32 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 32 = 332 kVA.
Load on 1 module, VA	47 429	55 333	In UPS1, the load per module is < 55 kVA, the power modules are not overloaded. In UPS2, the load per module is > 55 kVA, the power modules are overloaded.

Power Module Overload Ratio	0.95	1.11	In UPS1, the overload factor of the power modules is < 1.1, therefore the UPS continues to operate in on-line mode. In UPS2, the overload factor of power modules > 1.1, therefore inverters turn off, the UPS switches to bypass.
Bypass Current, A	no bypass	80.19	UPS1 continues to operate in on-line mode. In UPS2, the static bypass turns on and the overload current flows through it.
Bypass Current Increase Factor	no bypass	1.0024	In UPS2, the static bypass is loaded > 100% - the bypass fuses start to melt.
Bypass fuse blow time, ms	no bypass	1 990	In UPS2, all the bypass fuses in all power modules start to melt and burn out after 2 s.
Bypass Fuse Status	no bypass	burned out	
UPS operation mode during maintenance	on-line	UPS off, all load off	UPS1 continues to operate in on-line mode. In UPS2, all bypass fuses in all 6 power modules burn out. Entire the load is disconnected.

In situation 16, during maintenance, UPS1 with a central bypass, despite overload, continues to supply the entire critical load in on-line mode, and UPS2 with a distributed bypass is turned off. All loads in all rooms are powered off, all the static bypass fuses in all remaining 6 power modules burn out. Situation 16 does not change for the larger overload values up to the value of R4 = 80 kVA. UPS1 continues to operate in on-line mode, but UPS2 turns off and powers off all critical loads. In the whole range of overloads R4 from 32 to 80 kVA, UPS2 with distributed bypass is not able to power user's critical load. Power of the built-in static bypasses is not enough to power the critical load.

UPS2, as in the situation 12, again falls into the Energy Trap, when a relatively small overload in one of the rooms causes a disconnection of the entire critical load in all rooms.

When the overload value R4 in the room 3 becomes more than 80 kVA, the protection device PD-3 starts to respond to overload. Consider this situation.

Situation 17

In UPS1, the central static bypass module is removed for maintenance, and a power module is removed in UPS2. During maintenance, an additional load R4 = 81 kVA is connected in room 3. The total power of the load in room 3 became equal to 50 + 81 = 131 kVA. The protection device PD-3, designed for a power of 130 kVA, triggers in 50 ms. The total load on UPS has become equal to 150 + 100 + 50 + 81 = 381 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	7	6	The central static bypass module is removed in UPS1 for maintenance, 7 power modules remain in the rack. One power module is removed in UPS2, 6 power modules remain in the rack
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	

Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	381 000	381 000	After connecting the additional load R4 = 81 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 81 = 381 kVA
Load on 1 module, VA	54 429	63 500	In UPS1, the load per module is < 55 kVA, the power modules are not overloaded. In UPS2, the load per module is > 55 kVA, the power modules are overloaded.
Power Module Overload Ratio	1.09	1.27	In UPS1, the overload factor of the power modules is < 1.1 - the UPS continues to operate in on-line mode. In UPS2, the overload factor of the power modules > 1.1 - the inverters turn off, the UPS switches to bypass
Bypass Current, A	no bypass	92.03	UPS1 continues to operate in on-line mode. UPS2 turns on the static bypass and an overload current flows through it.
Bypass Current Increase Factor	no bypass	1.1504	In UPS2, static bypass is loaded > 100% - bypass fuses start to melt
Bypass fuse blow time, ms	no bypass	1 511	The estimated melting time of the fuses in UPS2 > 50 ms, the protection device PD-3 triggers first, static bypass fuses in UPS2 do not burn out.
Bypass Fuse Status	no bypass	OK	
UPS operating mode before PD-3 is triggered	on-line	load powered by static bypass	UPS1 continues to operate in on-line mode. UPS2 switches to bypass. The bypass fuses do not blow.
UPS operating mode after PD-3 is triggered	on-line	on-line without interruption	UPS1 continues to work in on-line mode. After PD-3 has triggered, UPS2 returns to on-line mode. In both cases, the critical load in room 3 is off, the load in rooms 1 and 2 continues to be on.

In situation 17, both UPS withstand overload R4 = 81 kVA, however, the critical load in room 3 is turned off - the protection device PD-3 was activated. This situation remains unchanged with a further increase in power of the overload of R4 up to 85 kVA.

Here we have an interesting effect. In case of overload > 80 kVA, UPS2 with distributed bypass goes out of the Energy Trap zone: its fuses do not blow and the load is disconnected only in the room 3 by PD-3.

Situation 18

In UPS1, the central static bypass module is removed for maintenance, and a power module was removed in UPS2. During maintenance, an additional load R4 = 86 kVA was connected in room 3. The total power of the load in room 3 became equal to 50 + 86 = 136 kVA. The total load on the UPS became equal to 150 + 100 + 50 + 86 = 386 kVA. The protection device PD-3 triggers in 50 ms.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	7	6	In UPS1, the central static bypass module is removed for maintenance, 7 power modules remain in the rack. One power module is removed in UPS2, 6 power modules remain in the rack.
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	386 000	386 000	After connecting the additional load R4 = 86 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 86 = 386 kVA
Load on 1 module, VA	55 143	64 333	In UPS1 and UPS2, the load per module > 55 kVA, the power modules are overloaded.
Power Module Overload Ratio	1.1029	1.29	In UPS1 and UPS2, the overload factor of power modules > 1.1 - in both UPS, the inverters turn off. UPS1 disconnects the load, because static bypass module is removed for maintenance and therefore is not available. UPS2 switches to static bypass.
Bypass Current, A	no bypass	93.24	In UPS1, the inverters turn off, the load is powered off. In UPS2, the static bypass turns on and the overload current flows through it.
Bypass Current Increase Factor	no bypass	1.1655	In UPS2, static bypass is loaded > 100% - bypass fuses start to melt
Bypass fuse blow time, ms	no bypass	1 472	The estimated melting time of the fuses in UPS2 > 50 ms, the protection device PD-3 activates, the static bypass fuses in UPS2 do not blow
Bypass Fuse Status	no bypass	OK	
UPS operating mode before PD-3 is triggered	load off	load powered by static bypass	In UPS1, inverters are off, load is off. UPS2 switches to bypass. The bypass fuses do not blow.
UPS operating mode after PD-3 is triggered	load off, PD-3 does not trigger	on-line without interruption	UPS1 turns off, all the load is powered off. After the PD-3 triggers, UPS2 returns to on-line mode without interrupting the power supply to the load. The load in room 3 disconnects.

During an overload of R4 = 86 kVA, UPS1 powers off the entire load, because the UPS does not had the ability to turn on the static bypass which is removed for its maintenance.

UPS2 with overload R4 = 86 kVA switches to static bypass. After actuation of the protection device PD-3 UPS2 restores operation in on-line mode without interrupting of power in the UPS output. In this situation, the static bypass has fulfilled its function - provided a continuous power supply to the load in room 1 and 2 when an overload occurred in room 3. The load in room 3 is turned off.

Situation 18 does not change with overload values R4 up to 1790 kVA. At the value of an overload R4 ≥ 1800 kVA, the static bypass fuses of UPS2 burn out before the protection device PD-3 is activated, all the load is powered off. Consider this situation in more details.

Situation 19

In UPS1, the central static bypass module is removed for maintenance, and one power module is removed in UPS2. During maintenance , an additional load R4 = 1800 kVA was connected in room 3. The total load on the UPS has become equal to 150 + 100 + 50 + 1800 = 2100 kVA.

Name	UPS1 - centralized bypass	UPS2 - distributed bypass	Comment
Number of power modules	7	6	In UPS1, the central static bypass module is removed for maintenance, 7 power modules remain in the rack. One power module is removed in UPS2, 6 power modules remain in the rack
The total number of slots in the rack	10	10	
Bypass fuse, A	800	80	
Bypass Fuse Protection Parameter	1 280 000	12 800	
Output voltage, V	230	230	
Total load on rack, VA	2 100 000	2 100 000	After connecting additional load R4 = 1800 kVA, the total load on the UPS becomes equal to 150 + 100 + 50 + 1800 = 2100 kVA
Load on 1 module, VA	300 000	350 000	In UPS1 and UPS2, the load per module > 55 kVA, the power modules are overloaded
Power Module Overload Ratio	6.00	7.00	In UPS1 and UPS2, the overload factor of power modules > 1.1 In both UPS, the inverters turn off. UPS1 disconnects the load immediately, because static bypass module is removed for its maintenance. UPS2 switches to static bypass.
Bypass Current, A	no bypass	507.25	Inverters in UPS1 turn off, there is no bypass, and the load is disconnected. In UPS2, the static bypass turns on and the overload current flows through it.
Bypass Current Increase Factor	no bypass	6.34	In UPS2, static bypass is loaded > 100% - bypass fuses start to melt
Bypass fuse blow time, ms	no bypass	49.75	The melting time of the bypass fuses in UPS2 < 50 ms, all the fuses of the static bypass of UPS2 burn out, the protection device PD-3 does not have enough time to trigger.

Bypass Fuse Status	no bypass	burned out	
UPS operation mode during overload	UPS off, load off	UPS off, load off	In UPS1, the inverters turn off, the entire critical load is turned off, PD-3 does not trigger. UPS2 switches to bypass. For time < 50 ms, all static bypass fuses in all power modules in the amount of 3x6 = 18 pcs. burn out. All the load is disconnected. PD-3 does not trigger.

With loads of more than 2100 kVA, all fuses in all power modules of the distributed bypass in UPS2 burn out, the entire load is disconnected.

For a more visual representation, all the results of the analysis of situations 11–19 arising from the maintenance of UPS at various overloads are summarized in Tables 1 and 2:

Table 1. During maintenance, in UPS1 and UPS2 one power module is removed (a rather frequent situation 1-2 times a year)

	Total load on UPS including overload R1 + R2 + R3 + R4, kVA				
UPS maintenance type	0-331 S.11	332 - 380 Situation 12	381 - 2090 Situation 13	2100 - 3490 Situation 14	> 3500 Situation 15
UPS1 with central bypass. One power module is under maintenance.	on-line	all the load is powered by static bypass	on-line without interruption, PD-3 triggers, the load in room 3 is off	on-line without interruption, PD-3 triggers, the load in room 3 is off	UPS off, all load off
UPS2 with distributed bypass. One power module is under maintenance.	on-line	UPS2 off, the entire load off. UPS2 falls into the Energy Trap	on-line without interruption, PD-3 triggers, the load in room 3 is off	UPS is turned off, the entire load is disconnected, PD-3 does not trigger	UPS off, all load off

During maintenance of power modules, UPS1 with a central bypass is significantly more resistant to overloads than UPS2 with a distributed bypass. UPS1 with a central bypass provides reliable power to the critical load up to overloads R4 = 3200 kVA, while UPS2 with a distributed bypass can disconnect the entire critical user load even when overloading R4 = 32 kVA. The difference is 100 times! Systems with a distributed bypass during their maintenance, when the power module is removed, are very sensitive to overloads and usually in the event of even a small overload can disconnect the entire critical load of the user.

Such a low reliability of UPS2 with distributed bypass is due to the fact that while the power module is removing from the rack along with the module, a part of the static bypass is also removing. Static bypass is distributed in all power modules. For this reason, the overload capacity of UPS2 decreases accordingly.

Table 2. During maintenance, central bypass module is removed in UPS1, and one power module is removed in UPS2 (rather rare situation for the central bypass module - 1 time in 5-7 years)

	Total load on UPS including overload R1 + R2 + R3 + R4, kVA				
UPS maintenance type	0-331	332 - 380 Situation 16	381 - 385 Situation 17	386 - 2090 Situation 18	> 2100 Situation 19
UPS1 with central bypass. Central bypass module is under maintenance.	on-line	on-line	on-line without interruption, PD-3 triggers, the load in room 3 is off	UPS off, all load off	UPS off, all load off
UPS2 with distributed bypass. The power module is under maintenance.	on-line	UPS2 off, the entire load off. UPS2 falls into the Energy Trap	on-line without interruption, PD-3 triggers, the load in room 3 is off	on-line without interruption, PD-3 triggers, the load in room 3 is off	UPS off, all load off

During maintenance of the central bypass module, the overload capacity of UPS1 is significantly reduced. But it should be remembered here that the static bypass module usually does not require maintenance, because it is idle in normal operation of the UPS, the current does not flow through it, the cooling fans are turned off. The static bypass module switches on only at times of overload and, as a rule, for a short time. In addition, the duration of maintenance of a central static bypass module, due to its simplicity, is much less than the duration of maintenance of the several power modules.

The operation of UPS1 and UPS2 during the maintenance at different overloads was described above in details in situations 11 - 19.

Consequences of the failure of one of the modules in the UPS rack during maintenance of UPS

During the maintenance of any module, which is removed from the rack, another unpleasant situation can occur. Any of the power modules or central static bypass module, which remain in the UPS rack, can fail. Failure of the power module in the UPS rack during maintenance of the power module is quite likely, since when one power module is removed from the UPS rack, the load on the remaining modules increases. Failure of the central bypass module is very unlikely, since it remains unloaded.

Failure of the power module in UPS1 with a central bypass during maintenance causes the load to transfer to the central static bypass. In this situation, it is possible to reinstall the extracted module in order to return the UPS to on-line mode.

In UPS2 with distributed bypass, a similar fault results in either disconnecting the entire load or switching UPS2 to a static bypass. It depends on the type of fault in the power module. The risk of disconnecting the entire load is much higher than that of UPS1 with a central bypass.

Failure of the central bypass module during maintenance of the power module in UPS2 does not change the UPS operation mode. It continues to operate in on-line mode. In such a situation, it is possible to reinstall the extracted power module in order to increase the redundancy level to N + 1 and thereafter it is possible to extract the central bypass module for its repair. All these operations are carried out in on-line mode without shutting down the user's critical load. In addition, the probability of failure of the central bypass while it is not operating is negligible. Its overload capacity and, accordingly, reliability are significantly higher than distributed bypasses. To repair any static bypass built into the power module, it is necessary to remove the power module itself from the UPS rack. This action reduces the full power of the UPS. The load on each remaining in the rack power module increases, and the risk of shutting down the critical load increases. Repair of the central bypass does not require the removal of any power modules. The total power of the UPS and the load on each power modules does not change. With the extracted central bypass module, UPS continues to operate in N + 1 redundancy mode.

Conclusions:

The overload capacity of a system with a central bypass is always higher than the overload capacity of a system with a distributed bypass. The overload capacity of both systems are equalized only when the UPS2 rack with a distributed bypass is fully equipped with all power modules.

UPS2 with distributed bypass is more vulnerable to overloads, and its operation is especially dangerous for critical loads when it is operating in non-redundancy mode. Even a slight increase in the load power (40 kVA, situation 7), or the malfunction of one power module (situation 8) leads to the entire critical load shutdown. UPS2 with distributed bypass easily falls into Energy Traps (situation 7), and repair of power modules sometimes requires switching off the critical load (situation 9). In non-redundancy mode, a modular system with distributed bypass is even less reliable than a standalone UPS, which, in the event of a fault in the UPS itself, switches to a static bypass without any problems.

UPS1 with a central bypass do not have such a problems, since the overload capacity of the central bypass does not depend on the number of modules installed in the system and corresponds to the maximum power of the UPS. In UPS1 with a central bypass, any number of power modules can be removed from the UPS rack for repair or maintenance without transferring the UPS to a manual bypass.

Similar problems arise during UPS maintenance when one power module is extracted from the system (situation 11 - 19). Even a slight overload in UPS2 with distributed bypass (for example, 32 kVA - situation 12) during maintenance can lead to the fatal consequences for the entire user's load. At the same time, UPS1 with a central bypass during the maintenance copes with very large overloads (for example, up to 3200 kVA - situation 15).

When the power module is removed in UPS1 with a central bypass, the overload capacity of the UPS1 does not change, and when the power module is removed from UPS2 with a distributed bypass, its overload capacity decreases proportionally.

If there is any malfunction in any power module (for example, failure occurs in inverter, charger, control board, etc.), then for its repair it must be removed from the UPS rack.

In UPS1 with a central bypass, removing a faulty module is not a problem, even if there is no redundancy. UPS1 after removing the power module from the rack continues to operate in on-line mode, or switches to a static bypass. Ooverload capacity of UPS1 remains unchanged.

In UPS2 with distributed bypass, a faulty module can only be safely removed if the UPS2 has a reservation at least N + 1. If there is no reservation, then the module can be removed from the rack only after transferring UPS2 to a mechanical bypass. Nevertheless, this opportunity is not always available (see situation 9) and depends on the type of a fault in the power module.

In all situations when an overload occurs in UPS2 with distributed bypass (see situations 3–8), all static bypass fuses in all power modules blow out. The situation when static bypass fuses blow out only in one power module is excluded, because the currents in the all static bypasses are evenly distributed. Therefore, when UPS systems with distributed bypass is used, the user must have in stock a full set of bypass fuses for all power modules. For example, for a system with seven modules user has to have 3x7 = 21 fuses. In fact, here we have a single point of failure, "spread" across all power modules. All distributed static bypass fuses always burn at the same time! Here we have only an imitation of the absence of a single point of failure.

The absence of a single point of failure implies that one element of the system can fail and the system can continue to operate on the remaining elements. And if all these elements fail at the same time, then all of them together form a single point of failure.

For the system with a central static bypass, it is enough to have 1x3 = 3 fuses in stock. Replacing them is much faster and easier than replacing all fuses in all power modules in a distributed bypass system. And moreover, the probability of burnout of the fuses of the distributed static bypass is higher than that of the central bypass because of the lower overload capacity.

In the central static bypass module, the static bypass thyristor itself can also be produced in the form of several parallel-connected thyristors with their own fuses, but this action does not turn the central bypass into a module without a single point of failure. The separation and distribution of these thyristors in the power modules does not increase the reliability of the entire system, but only creates additional difficulties during its maintenance and repair. Failure of a power module with a built-in static bypass or removing it from the system for repair or maintenance reduces the overload capacity of the entire system. The static bypass, which determines the overload capacity of the system, serves as a "lifeline for a drowning person".

Installing fuse holders on the front panel of power modules in systems with distributed bypass is an indirect recognition by the manufacturer in weakness of distributed architecture. Situations with blown bypass fuses in all modules do not happen often, but sometimes they happens. Imagine the procedure of changing all the fuses, if they are installed inside the power modules. And if there is no redundancy, such a replacement can only be carried out with the power interruption of the critical load or its partial shutdown. Static bypass fuses in UPS2 with distributed bypass do not burn out one at a time — they burn out simultaneously in all power modules.

Since the static bypass in UPS2 with distributed bypass is installed inside the power module, when an overload occurs, the overload current flows directly through the power module, creating a powerful impulse noise inside the power module. There is a growing threat in the stable operation of the power module during an overload. For example, false transistor switching of invertor can occur. And the erroneous switching of the inverter's transistors when the UPS operates in bypass mode is 100% death for inverter (at least its fuses) and, accordingly, of the entire power module.

The central bypass is installed to a separate bypass line (Bypass), and during an overload, the overload current is switched to that separate line. All power modules and their control circuits connected to the main line (Mains / Rectifier) operate under more favorable conditions, since the source of powerful impulse noise - the overload current is diverted to a separate Bypass line. In particular, the connectors on the rear panel of the power modules will not be subject to destruction (burning), the central processor of the power module will correctly handle the emergency situation, and the IGBT transistors in inverters will not be mistakenly turned on.

In UPS2 with distributed bypass, static bypasses are connected in parallel, and here we have the classical parallel circuit design of semiconductor switches, in which there is no active current control circuit on each switch. A circuit consisting of several parallel-connected low-power semiconductor switches is less reliable than a circuit consisting of one powerful switch, even if the total power is the same. One powerful switch is always more reliable than several parallel-connected low-power switches. Reliable operation of parallel-connected semiconductor switches is possible only if there is a current control circuit in each switch. Such a control circuit is easy to implement when using transistors and it is impossible to implement if thyristors are used as switches. With parallel connection of thyristor switches, it is possible to use only reactive current limiters (inductors). This leads to a decrease in the rate of rise of current at the output of the UPS when the thyristors turn on. And in turn, it creates an additional drop in output voltage of the UPS when switching to a static bypass and can lead to a power failure of the critical load at the moment of overload.

In order to ensure maximum overload capacity of a distributed bypass system, all thyristors must have a minimum spread of such parameters as the conductance and the response time. All bypass fuses must have a minimum spread of the fuse protection parameter I^2t, which determines the moment at which the fuse blows out when an overload current flows. The problem of harmonization of the listed characteristics is especially acute when a new power module is purchased several years after the installing of the UPS itself, in which the thyristors and fuses could be exposed to the high temperature when overloaded during equipment operation.

In on-line mode, static bypasses do not operate - no current flows through them. For static bypass, on-line mode is in fact an idle mode. The static bypass turns on only during overload mode of the power modules and its reliability primarily depends not on the number of static bypasses installed, but on the current increase factor in the bypass circuit, which for systems with a central bypass is less than in distributed bypass systems in all discussed the situations (3-15).

In modular UPS, in contrast to a monoblock UPS, the static bypass does not turn on when the UPS fails. In the event of a power module failure, in a system with N + X redundancy, the faulty power module shuts down, and the system continues to operate in on-line mode using the healthy power modules. Static bypass activates only when overload occurs in power modules. That is, while in monoblock systems the static bypass performs two functions: protection against UPS malfunction and overload protection, then in modular systems only one function is - the overload protection. The function of protecting the critical load from internal malfunction of the UPS has been transferred to the structural organization of the UPS - a modular system design.

Additional documentation	Size	Language
Fuse Principles		Russian
Guaranteed overcurrent rupture		Russian
About UPS bypass		Russian
Master Static Bypass	347 KB	Russian
Static Bypass Vertiv	396 KB	English
Fuse-links / fuses	1.18 MB	Russian
Time-current characteristics of switches and fuses		Russian