



ARE MODULAR UPS SYSTEMS REALLY MORE RELIABLE?

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Uninterruptible Power Supplies (UPS)

UPSs are designed to protect critical loads from electrical disturbances that commonly occur in mains supplies: Voltage variations (overvoltages, undervoltages, surges), slow or transient frequency variations, power outages and micro power outages (blackouts), voltage sags, voltage spikes, harmonics, high-frequency noise and voltage flickers

The product standard for UPSs (EN 62040) defines the different types of UPS, among which the VFI (on-line, double-conversion) stands out for generating an output waveform for the load with voltage and frequency that are independent from the primary mains supply. From a qualitative point of view, this type of UPS has the best performance because it isolates the load from all types of mains disturbances by generating a new waveform, firstly converting the AC voltage from the primary supply into DC voltage and then regenerating a waveform that is completely free of disturbances for the critical loads. Although this topology is the highest quality, it is also the least efficient given that energy has to flow through two full power converters in series with loss of stored energy in both converters.

Evolution of VFI UPSs

Since efficiency has traditionally been the main weakness of this type of UPS, manufacturers have put considerable effort into developing converter architecture to improve efficiency and capabilities. This has resulted in a move away from initial 6 and 12 thyristor pulse rectifiers to active PWM rectifiers and from ferro-resonant inverters or PWM with low frequency transformer to the current multi-level transformerless inverters. This has enabled efficiency to improve from around 88% to the current 96%-97%. Having not yet reached peak efficiency in the studies performed to date, a substantial improvement in efficiency at topological level seems unlikely although there could evidently be improvements with the use of new semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) or new magnetic materials once their current prohibitively high cost falls.

N+1 parallel UPSs – guaranteed supply for critical applications

Once the highest possible efficiency to date is achieved (96%-97% with multi-level switching technology) and pending the incorporation of new devices to improve this figure, it will be possible to greatly increase system availability ($A = \text{MTBF}/(\text{MTTR} + \text{MTBF})$) using N+1 parallel UPSs with "N" being the number of UPSs necessary to supply power to the load and "1" being a UPS used as redundant backup. This will make it possible to achieve availability of 5 nines ($A \geq 0.99999\%$), equivalent to 5 minutes of unavailability in one year, or 6 nines ($A \geq 0.999999\%$), equivalent to 30 seconds of unavailability in one year, which, ultimately, would improve the reliability of the Data Center (DC from now on) and TCO with respect to the Data Center's energy consumption.

Likewise, with parallel technology, it is possible to obtain a high Tier Certification (Tier III or IV) - a classification published by the Uptime Institute and entitled "Data Centre Site Infrastructure Tier Standard: Topology", according to which facilities classified as Tier III or IV are those that guarantee the best levels of reliability and availability, not only for the strict specification of the UPSs used but also for the complete design of the DC environment, cooling system and electrical distribution to the critical loads.

The concept of UPS modularity

The concept of UPS modularity is difficult to confine to a particular format. UPS modularity can be expressed in many ways:

· Modularity in power

This consists of a UPS whose architecture diagram includes some common parts and other parts (power modules) that are repeated from one module to a total number of modules to cover the power required by the application.

The common parts are usually those that do not handle power, such as UPS operation control and management electronics, hardware featuring a communication interface with the outside world (serial and parallel communications, CAN, USB, TCP-IP, relay interfaces and digital inputs and outputs, etc.), common battery banks (with or without battery chargers), EMI input/output filters, input/output/battery terminals and enclosures or containers (cabinet or box depending on maximum power) for locating the maximum number of modules.

The non-common parts are the different power modules that enable the setting up of a device with the required power and redundancy. Different modules with a certain power are connected in parallel so that the total power of the System is the sum of the powers of all of the connected modules.

As can be seen in this structure, there are non-redundant elements that can cause a system failure if they fail. Power modules, however, are redundant elements, meaning that, if one fails, the system still works with the other modules that may provide less power than before. With due over-sizing and depending on it, the system can become tolerant to the failure of one or more power modules.

· Modularity in functional power

This structure is similar to the previous one in the sense that there continues to be common and non-common parts. Focusing on the latter, the power block of a double-conversion VFI UPS usually consists of a series of power converters, which are listed below:

- PFC rectifier
- Inverter
- Battery charger
- Static switch module

In case of "Modularity in Power", as described in the previous section, these power converters all together are considered as a power module. Another kind of modularity can also be defined based on considering each converter as a parallelable module in itself, resulting in an even more flexible system than the previous one since the power and redundancy of each converter could be separately sized. For instance, it would be possible to size a UPS with more rectifier converters and chargers if oversizing of the battery charge was required or with more inverters if more transient power at output was needed.

- Full modularity

This type of modularity is based on considering each module as a complete UPS with the only common parts being auxiliary not so critical parts like the cabinet or box, the connections upstream of the UPS's input and downstream of the UPS's output, the battery connections, the communication interface with the outside world and the monitoring system.

These systems have two variants with their advantages and disadvantages:

Modular system with distributed static bypass switch (SBS): Each module incorporates its own static switch system to switch its inverter output to the mains. As it is a distributed system, there must be full synchronization between modules to ensure that all of the modules switch at the same time.

Modular system with centralized static bypass switch: In this case, the inverter to mains static transfer system is unique and therefore one of the common elements of the UPS.

There is debate today as to which of these two options offers the better reliability and availability. Distributed bypass systems have the advantage that the bypass is redundant and therefore cease to be a critical point. In addition, the criteria for sizing the bypass's maximum power and current are usually much more generous than those for sizing inverters, which benefits availability in the event of failure of one of the bypass modules. One drawback is that the control, like the power of the bypass, is distributed and this fact can hinder the making of decisions about the right moment to perform the switching from inverter to bypass or from bypass to inverter. The decision must be synchronous for all modules connected in parallel and this makes the management of the distributed bypass difficult.

In systems with a centralized bypass, inverter to bypass or bypass to inverter switching operations are much easier because there is only one bypass power module - a fact that makes the module a non-redundant critical point.

A third compromise solution between the two systems is a centralized bypass with 1+1 redundancy. Some manufacturers have introduced this third option but it could be attributed to the advantages and disadvantages of the two previous options.

Modular UPSs (Full modularity)

The modular UPSs described above are usually arranged on a horizontal rack inside a cabinet and have a certain maximum power capacity. The modular structure of UPSs provides a number of important advantages especially in DC applications:

- 1) Small footprint: UPSs take up very little surface space
- 2) High reliability: as they can be configured as N+m units and the level of redundancy for each DC (or other application), depending on their criticality, can be selected.
- 3) High availability: equally reliable as a conventional UPS, it is possible to achieve availability (A) of 5 or 6 nines, simply considering the very low MTTR of the modular systems together with the selection of the proper level of redundancy.

- 4) System efficiency can be optimised in two ways:
- a. Improvement of the module's energy efficiency. The design of a single module (or a small number of types of module) makes it easier to optimize power converters and achieve maximum efficiency by selecting the most efficient topology and the components with less energy loss for each module.
 - b. Intelligent modular system management: Given that a module achieves maximum energy efficiency at around 75% of the load and taking into account the redundant topology of the system and the temporal variability of the load, it is possible to apply criteria to manage the global system so that the only modules that work are those that are necessary for the load connected at the time and function with a level of power that optimizes module efficiency. In addition, it is possible to apply cycling criteria to equalize the operating time of all of the system's modules and thereby optimize their reliability and that of the complete system or stand-by criteria in which are functionally turned off and in reserve, and waiting to be used to enhance the availability of the system.
- 5) Scalability: The possibility of adapting the power of the system in accordance with the future development and growth of the DC is, without doubt, one of the biggest advantages of modularity over fixed power solutions.
- 6) Adaptability to the power: The modular solution will obviously vary depending on the power. The basic difference in the configuration of the modular system is the power of each module. Possibilities therefore exist for systems consisting of 30-40kVA modules for medium power UPSs or 50-100-200kVA modules for large UPS systems.
- 7) Adaptation to DC Tier levels. The modular solution is fully compatible with the highest standards of Tier classification as defined by the Uptime Institute.
- 8) Improved Total Cost of Ownership (TCO). This can be achieved by improving Operating Expenses (OPEX) by increasing the module efficiency and an intelligent overall system management. Another important aspect is the reduction of Capital Expenditure (CAPEX) mainly because the manufacture of large numbers of identical modules enables the development of an economy of scale which improves the manufacturing costs of UPSs.

Reliability (MTBF) and availability (A) of the different types of UPS

The main goal of implementing a UPS system is to improve the reliability of energy within the limits of current technology. The ultimate objective is to isolate it from any disturbance in the mains power supply.

The first UPSs, in the 1960s, consisted of a rectifier, battery and inverter, and they were designed to stabilize output power and continue to support the load without interruption in the event of failure of the mains supply. The reliability of this simple UPS chain depended on the reliability of two of the three critical elements that were in series: inverter and DC bus from the batteries. A failure in either of them resulted in an immediate load blackout.

In the early 1970s, the static bypass switch (SBS) was introduced to enable load transfer without interruption to the backup power grid in the event of inverter failure or overload. This backup power supply, although much less reliable than UPSs, serves as a source of emergency power in the event of a failure of the inverter or DC bus (batteries), allowing continuity of power supply to the load while the fault is fixed.

This new architecture substantially improves overall reliability as it no longer depends mainly on the reliability of the inverter + DC bus chain. The availability of the new UPSs with Static Sypass depended on the quality of the mains (MTBF_M), the UPS's repair time (MTTR_UPS) and the reliability of the static switch (MTBF_BYP).

However, in recent years the rise of cloud storage, as well as the need to keep large amounts of data backed up in large server infrastructures (DC), has meant that much higher levels of reliability are required in security systems in which UPSs are found. Very critical loads cannot rely on a power supply configuration with a single UPS with static bypass. The need for UPSs with parallel redundant configurations (n + 1) is becoming essential. The main argument for choosing a particular type of UPS must be to safeguard, in the best way possible, the integrity of such large amounts of information. What is required then is a comparative study of Reliability (MTBF)/Availability (A) between the different types of UPS in order to make the right decision. A comparison of the reliability of various UPS configurations must be based on reliable figures in accordance with standard MIL-HDBK-217F (Notice 2, 1995).

The failure rate of a converter is defined as:

$$\lambda_{[conv]} = 1 / \text{MTBF}[conv]$$

Availability (A) is defined as:

$$A = \frac{\text{MTBF}[SAI]}{\text{MTBF}[SAI] + \text{MTTR}[SAI]}$$

· Single UPS without static bypass switch (BYP)

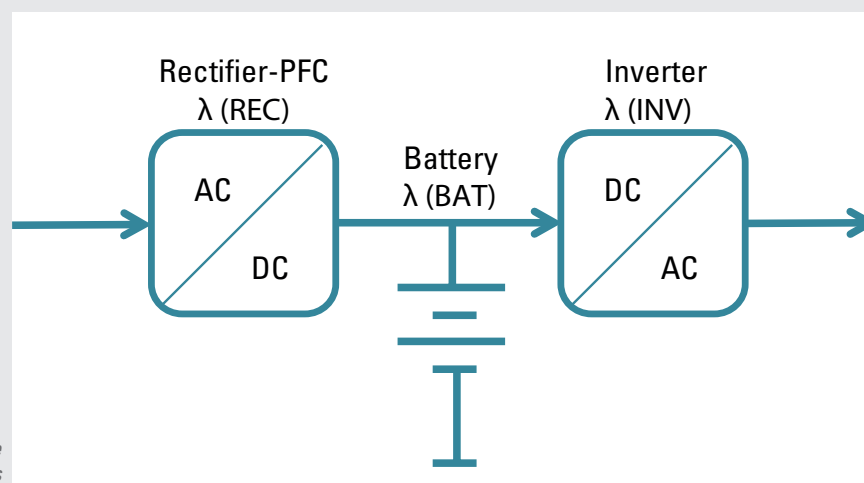


Fig 1. Block diagram (with failure rate) of a UPS without bypass

The reliability of a single UPS without bypass depends on the reliability of the rectifier, battery and inverter (see Figure 1). In this system, in the event of inverter, DC bus (batteries) or rectifier failure over a long period of time (more than the system's backup), there would be a zero at output.

Calculation of MTBF (MTBF_[UPS])

Where:

MTBF_[UPS] is mean time between failures of the unit without static bypass

$\lambda_{[UPS]}$ is the failure rate of a single unit without static bypass switch

$\lambda_{[RECT]}$ is the failure rate of the rectifier

$\lambda_{[BAT]}$ is the failure rate of the DC bus, including the connection with the battery

$\lambda_{[INV]}$ is the failure rate of the inverter

$$MTBF_{[UPS]} = 1 / \lambda_{[UPS]}$$

$$\lambda_{[SAI]} = \lambda_{[RECT]} + \lambda_{[BAT]} + \lambda_{[INV]}$$

Supposing the following indicative figures:

$$\lambda_{[RECT]} = 20 \text{ per million hours}$$

$$\lambda_{[BAT]} = 10 \text{ per million hours}$$

$$\lambda_{[INV]} = 20 \text{ per million hours}$$

The MTBF_[UPS] for a UPS system without static bypass switch would be about 20,000 hours.

· Single UPSs with Static Bypass switch

The reliability of a single UPS can be significantly increased by introducing a redundant power supply and connecting it to the main UPS power supply by means of a static bypass transfer switch (Figure 2). For example, in the event of an inverter failure, instead of the load crashing, it would be transferred from the inverter to the mains without interruption.

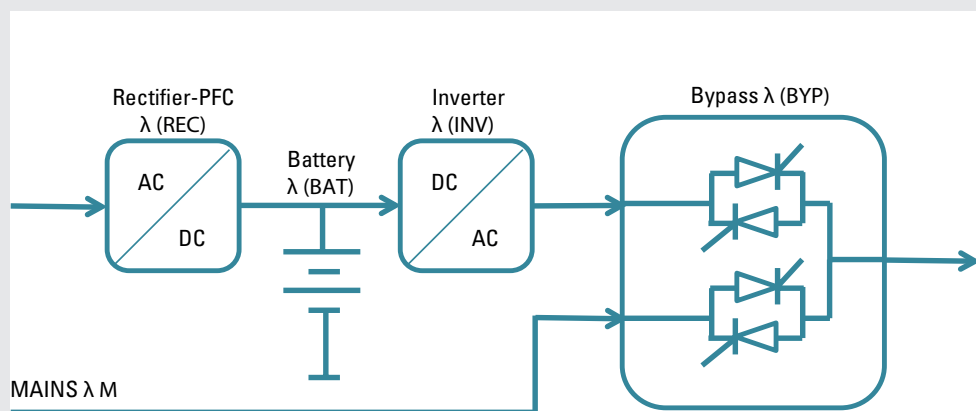


Fig 2. Block diagram (with failure rate) of a UPS with bypass

Calculation of MTBF (MTBF_[UPS + BYP])

Where:

MTBF_[UPS + BYP] is the mean time between failures of the UPS with static bypass switch

MTBF_[M] is the mean time between failures of the mains

λ _[UPS] is the failure rate of a single unit without static bypass switch

λ _[UPS + BYP] is the failure rate of a single UPS with static bypass switch

λ _[M] is the failure rate of the mains

λ _[UPS]/ λ _[M] is the failure rate of a single unit without static bypass switch in parallel with the failure rate of the mains

λ _[BYP] is the failure rate of the static bypass, power or control switch

MTTR_[BYP] is the mean time to repair of the static bypass switch

MTTR_[M] is the mean time to repair of the mains

MTTR_[UPS] is the mean time to repair of a single UPS with static bypass switch

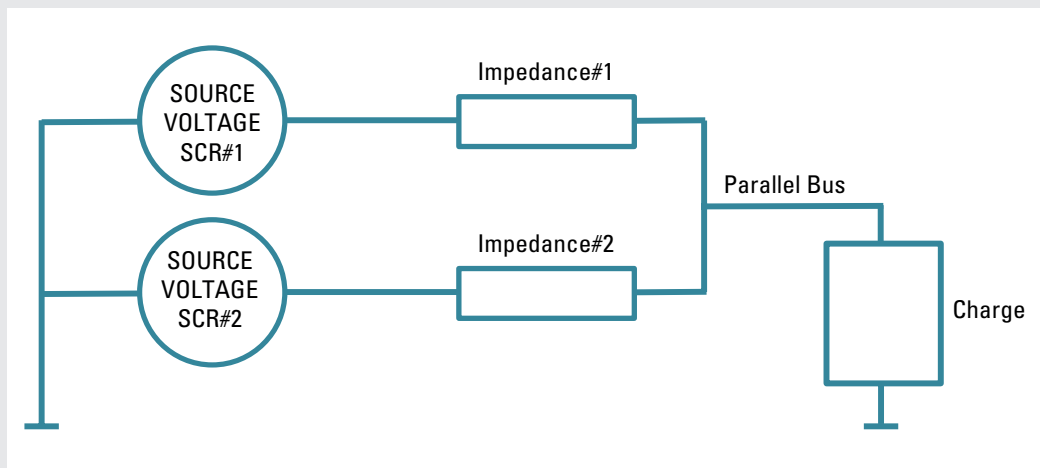


Fig 3. Voltage sources in parallel

Figure 3 shows how the failure rate of a parallel system would be calculated in a system with two voltage sources connected in parallel (SCR#1 and SCR#2):

$$\begin{aligned}\lambda_{[\text{parallel}]} &= \lambda_{[\text{SRC}\#1]} / \lambda_{[\text{SRC}\#2]} = \\ &= \lambda_{[\text{SRC}\#1]} \times \lambda_{[\text{SRC}\#2]} \times (\text{MTTR}_{[\text{SRC}\#1]} + \text{MTTR}_{[\text{SRC}\#2]}) \quad (1)\end{aligned}$$

Applying expression (1) if the UPS has a Static Bypass:

$$\begin{aligned}\lambda_{[\text{UPS+BYP}]} &= \lambda_{[\text{UPS}]} / \lambda_{[\text{M}]} + \lambda_{[\text{BYP}]} = \\ &= (\lambda_{\text{UPS}} \times \lambda_{\text{M}} \times (\text{MTTR}_{[\text{UPS}]} + \text{MTTR}_{[\text{M}]}) + \lambda_{\text{BYP}} \quad (2)\end{aligned}$$

$$\text{MTBF}_{[\text{UPS+BYP}]} = 1 / \lambda_{[\text{UPS+BYP}]} \quad (3)$$

To the statistical failure analysis figures used above:

$$\lambda_{[\text{RECT}]} = 20 \text{ per million hours}$$

$$\lambda_{[\text{BATT}]} = 10 \text{ per million hours}$$

$$\lambda_{[\text{INV}]} = 20 \text{ per million hours}$$

According to last calculation of the MTBF of the UPS without SBS:

$$\text{MTBF}_{[\text{UPS}]} = 20,000 \text{ hours}$$

Other statistical data can also be added, for example:

$$\lambda_{[\text{BYP}]} = 2 / 1,000,000 = 0.000002 \text{ hours}$$

$$\text{MTBF}_{[\text{M}]} = 50 \text{ hours (this figure represents a "good quality" mains supply)}$$

$$\text{MTTR}_{[\text{UPS}]} = 6 \text{ hours (MTTR of one Standalone, non-modular UPS)}$$

$$\text{MTTR}_{[\text{M}]} = 0.1 \text{ hours.}$$

Using this data in expression (2):

$$\begin{aligned}\lambda_{[\text{UPS + BYP}]} &= ((1/20,000) \times (1/50) \times (6 + 0.1)) + (2/1,000,000) = \\ &= (0.00005 \times 0.02 \times 6.1) + 0.000002 = 0.0000081\end{aligned}$$

$$\text{MTBF}_{[\text{UPS + BYP}]} = 1 / (\lambda_{[\text{UPS + BYP}]}) = 1 / 0.0000081 = 123,456 \text{ h}$$

Expressions (2) and (3) show that the reliability of one UPS with static bypass switch (MTBF_[UPS + BYP]) depends on the following parameters: the reliability of the UPS and mains (λ_{UPS} , λ_{M}), the MTTR of the UPS and mains and the reliability of the static bypass switch (λ_{BYP}).

· Redundant UPS in parallel with Static Bypass switch

The reliability of a single UPS can be significantly increased by introducing a redundant configuration (Figure 4).

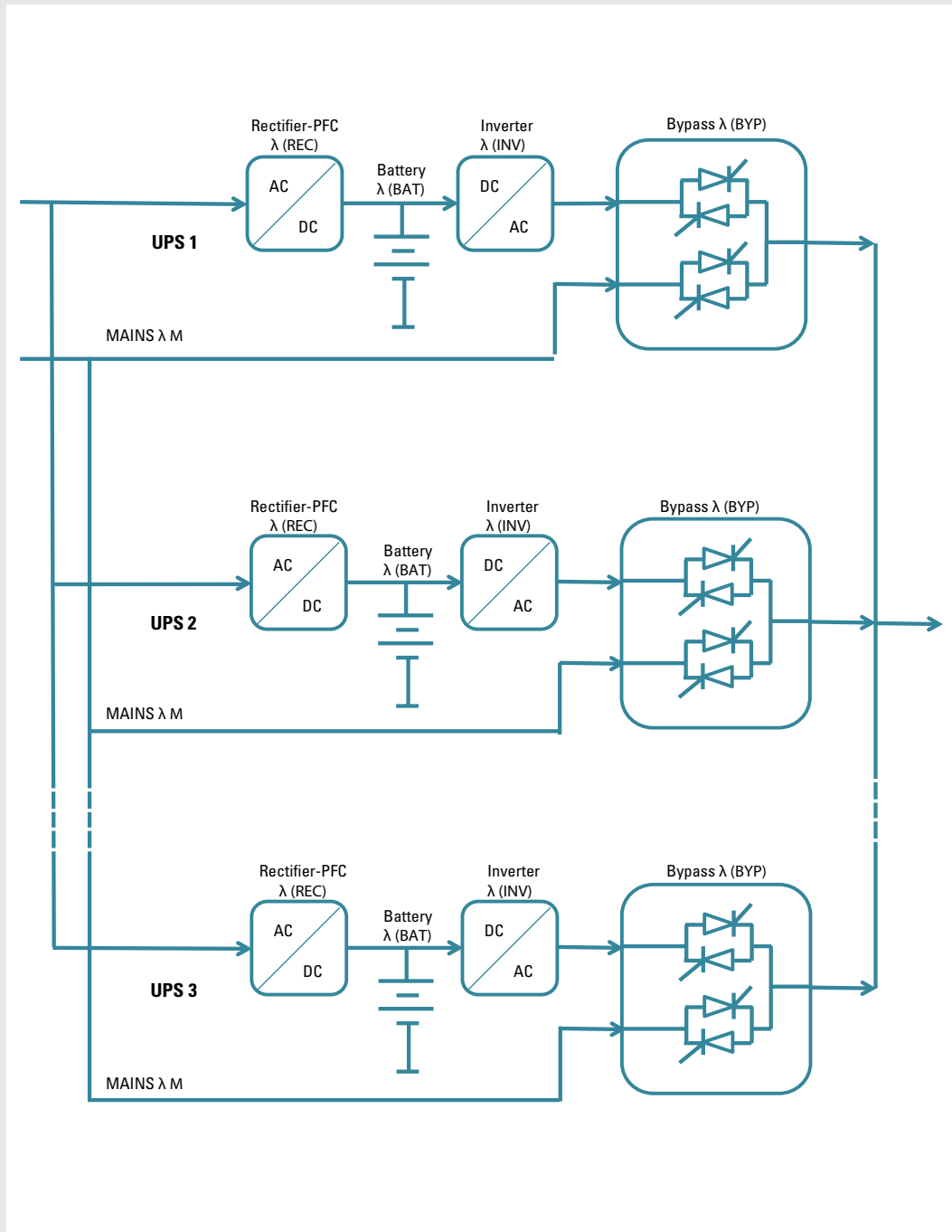


Fig 4. Block diagram (with failure rate) of an N+1 system

Calculation of MTBF for a parallel redundant UPS system (n+1) (MTBF__[(n+1)UPS+BYP])

Failure rate:

$$\begin{aligned} \lambda_{[(n+1)UPS+BYP]} &= (\lambda_{[UPS1]}/\lambda_{[UPS2]} \dots \dots \dots / \lambda_{[UPS(n+1)]}) + \\ &+ (n+1) \times \lambda_{[PBUS]} \\ &+ (\lambda_{[BYP1]}/\lambda_{[BYP2]} \dots \dots \dots / \lambda_{[BYP(n+1)]}) \\ &\simeq (n+1) \times \lambda_{[PBUS]} \end{aligned}$$

Reliability:

$$MTBF_{[(n+1)UPS+BYP]} = 1/\lambda_{[(n+1)UPS+BYP]}$$

Availability:

$$A_{[(n+1)UPS+BYP]} = \frac{MTBF_{[(n+1)UPS+BYP]}}{MTBF_{[(n+1)UPS+BYP]} + MTTR_{[UPS]}}$$

The reliability of a parallel redundant UPS (n + 1) largely depends on the failure rate of the parallel bus, which is the most critical failure point. Parallel redundant UPS chains, static bypass switches and their control electronics, and mains voltage are all redundant elements and therefore have a negligible impact on overall reliability.

Configuration	λ (per million hours)	MTBF	MTTR	A
(1+1)	0,8	1.250.000	12	0,9999904 (5 nines)
(2+1)	1,2	833.000	18	0,9999978 (5 nines)
(3+1)	1,6	625.000	24	0,9999616 (4 nines)
(4+1)	2	500.000	30	0,99994 (4 nines)
(5+1)	2,4	416.666	36	0,999913 (4 nines)

Table 1. MTBF, MTTR, λ and A values for different n+1 configurations

The above table is based on the following figures:

MTBF_[M] = 50 hours, this figure represents a “good quality” mains supply

$\lambda_{[PBUS]}$ = 0.4 per million hours.

Developing the calculations for n=1, n=2 and n=3, we have the following:

$$\begin{aligned}\lambda_{(n+1)UPS+BYP} &= (\lambda_{UPS1}/\lambda_{UPS2} \dots \dots \dots / \lambda_{UPS(n+1)}) + \\ &+ (n+1) \times \lambda_{PBUS} \\ &+ (\lambda_{BYP1}/\lambda_{BYP2} \dots \dots \dots / \lambda_{BYP(n+1)}) \\ &\simeq (n+1) \times \lambda_{PBUS}\end{aligned}$$

Failure rate and MTBF

Because the term $(\lambda_{UPS1}/\lambda_{UPS2} \dots \dots \dots / \lambda_{UPS(n+1)})$ supposing n=2 \rightarrow

$$\begin{aligned}&= (\lambda_{UPS1} \times \lambda_{UPS2} \times \lambda_{UPS3}) \times (MTTR_{UPS1} + MTTR_{UPS2} + MTTR_{UPS3}) = \\ &= (1/20.000) \times (1/20.000) \times (1/20.000) \times (3 \times 6) = 0,00005 \times 0,00005 \times 0,00005 \times 18 = 2,25 \exp -12\end{aligned}$$

For n=3 $\rightarrow 1,5 \exp -16$

For n=4 $\rightarrow 9,38 \exp -21$

Very low failure rate figures

And the term $(\lambda_{BYP1}/\lambda_{BYP2} \dots \dots \dots / \lambda_{BYP(n+1)})$ supposing n=2 \rightarrow

$$\begin{aligned}&= (\lambda_{BYP1} \times \lambda_{BYP2} \times \lambda_{BYP3}) \times (MTTR_{BYP1} + MTTR_{BYP2} + MTTR_{BYP3}) = \\ &= ((2/1.000.000) \times (2/1.000.000) \times (2/1.000.000)) \times (3 \times 6) = 1,4 \exp -16\end{aligned}$$

An even smaller figure.

The formula is therefore summarised as $\lambda_{(n+1)UPS+BYP} = (n+1) \times \lambda_{PBUS} = (n+1) \times 0,4/1.000000$

$$\text{For } n=1 \rightarrow \lambda_{(1+1)UPS+BYP} = (1+1) \times \lambda_{PBUS} = (1+1) \times 0,4/1.000000 = 0,8/1.000.000$$

$$\text{MTBF}_{UPS+BYP} = 1 / \lambda_{(1+1)UPS+BYP} = 1.250.000 \text{ h}$$

$$\text{For } n=2 \rightarrow \lambda_{(2+1)UPS+BYP} = (2+1) \times \lambda_{PBUS} = (2+1) \times 0,4/1.000000 = 1,2/1.000.000$$

$$\text{MTBF}_{UPS+BYP} = 1 / \lambda_{(2+1)UPS+BYP} = 833.333 \text{ h}$$

$$\text{For } n=3 \rightarrow \lambda_{(3+1)UPS+BYP} = (3+1) \times \lambda_{PBUS} = (3+1) \times 0,4/1.000000 = 1,6/1.000.000$$

$$\text{MTBF}_{UPS+BYP} = 1 / \lambda_{(3+1)UPS+BYP} = 625.000 \text{ h}$$

Availability:

$$A_{[(n+1)UPS+BYP]} = \frac{MTBF_{[(n+1)UPS+BYP]}}{MTBF_{[(n+1)UPS+BYP]} + MTTR_{[(n+1)UPS+BYP]}}$$

For n=1 $A(1+1) = 1.250.000 / (1.250.000 + 12) = 0,9999904$ (5 nines)

For n=2 $A(2+1) = 833.333 / (833.333 + 18) = 0,9999978$ (5 nines)

For n=3 $A(3+1) = 625.000 / (625.000 + 24) = 0,9999616$ (4 nines)

Calculation of MTBF for a parallel redundant UPS system (n+m)(MTBF(n+m)UPS+BYP)Failure rate:

$$\begin{aligned} \lambda_{[(n+m)UPS+BYP]} &= (\lambda_{[UPS1]} // \lambda_{[UPS2]} \dots // \lambda_{[UPS(n+1)]} \\ &\quad // \lambda_{[UPS(n+2)]} \dots // \lambda_{[UPS(n+m)]}) + \\ &\quad + (n+m) \times \lambda_{[PBUS]} + \\ &\quad + (\lambda_{[BYP1]} // \lambda_{[BYP2]} \dots // \lambda_{[BYP(n+1)]} \\ &\quad // \lambda_{[BYP(n+2)]} \dots // \lambda_{[BYP(n+m)]}) \\ &\approx (n+1) \lambda_{PBUS} \end{aligned}$$

Reliability:

$$MTBF(n+m)[UPS+BYP] = 1 / \lambda(n+m)[UPS+BYP]$$

Availability:

$$A_{[(n+m)UPS+BYP]} = \frac{MTBF_{[(n+m)UPS+BYP]}}{MTBF_{[(n+m)UPS+BYP]} + MTTR_{[(n+1)UPS+BYP]}}$$

The reliability of a parallel redundant UPS (n + m) largely depends on the failure rate of the parallel bus, which is a single point of failure. Parallel redundant UPS chains, static bypass switches and their control electronics, and mains voltage are all redundant elements and therefore have less or even negligible impact on overall reliability.

The following constants are used in the calculations:

MTBFM = 50 hours, a figure that represents a “good quality” network

$\lambda_{PBUS} = 0.4$ per million hours

$$\lambda^{(n+m)}[UPS+BYP] = (\lambda_{UPS1}/\lambda_{UPS2} \dots / \lambda_{UPS(n+1)} // \lambda_{UPS(n+2)} \dots // \lambda_{UPS(n+m)}) + (n+m)\lambda_{PBUS} + (\lambda_{BYP1} // \lambda_{BYP2} \dots // \lambda_{BYP(n+1)} // \lambda_{BYP(n+2)} \dots // \lambda_{BYP(n+m)}) \sim (n+1)\lambda_{PBUS}$$

because the term $(\lambda_{UPS1}/\lambda_{UPS2} \dots // \lambda_{UPS(n+m)})$ supposing $n=2$ y $m=2 \rightarrow$

$$= (\lambda_{UPS1} \times \lambda_{UPS2} \times \lambda_{UPS3} \times \lambda_{UPS4}) \times (MTTR[UPS1] + MTTR[UPS2] + MTTR[UPS3] + MTTR[UPS4]) =$$

$$= (1/20.000) \times (1/20.000) \times (1/20.000) \times (1/20.000) \times (4 \times 6) = 0,00005 \times 0,00005 \times 0,00005 \times 0,00005 \times 24 = 1,5 \text{ exp } -16$$

For $n=4 \rightarrow 9,38 \text{ exp } -21$

For $n=5 \rightarrow 5,63 \text{ exp } -25$

Very low failure rate figures

And the term $\dots // \lambda_{BYP(n+m)}$ supposing $n=2$ y $m=2 \rightarrow$

$$= (\lambda_{BYP1} \times \lambda_{BYP2} \times \lambda_{BYP3} \times \lambda_{BYP4}) \times (MTTR[BYP1] + MTTR[BYP2] + MTTR[BYP3] + MTTR[BYP4]) =$$

$$= ((2/1.000.000) \times (2/1.000.000) \times (2/1.000.000) \times (2/1.000.000)) \times (4 \times 6) = 3,8 \text{ exp } -22$$

An even smaller figure.

The formula is therefore summarised as $\lambda^{(n+m)}[UPS+BYP] = (n+m) \times \lambda_{PBUS} = (n+m) \times 0,4/1.000000$

$$\text{For } n=2 \text{ y } m=2 \rightarrow \lambda^{(1+1)}[UPS+BYP] = (2+2) \times \lambda_{PBUS} = (2+2) \times 0,4/1.000000 = 1,6/1.000.000 = 1,6 \text{ exp } -5$$

$$MTBF[UPS+BYP] = 1 / \lambda^{(2+2)}[UPS+BYP] = 625.000 \text{ h}$$

$$\text{For } n=3 \text{ y } m=3 \rightarrow \lambda^{(3+3)}[UPS+BYP] = (3+3) \times \lambda_{PBUS} = (3+3) \times 0,4/1.000000 = 2,4/1.000.000$$

$$= 2,4 \text{ exp } -5$$

$$MTBF[UPS+BYP] = 1 / \lambda^{(3+1)}[UPS+BYP] = 416.666 \text{ h}$$

Availability:

According to the expression

$$\text{For } n=1 \text{ A}(2+2) = 1.250.000 / (1.250.000 + 12) = 0,999971 \text{ (4 nines)}$$

$$\text{For } n=2 \text{ A}(3+3) = 416.666 / (416.666 + 18) = 0,999956 \text{ (4 nines)}$$

In conclusion, it is evident that an $n+m$ configuration does not have to increase the availability of the UPS system with respect to the $n+1$ solution, mainly due to the criticality of the parallel connection.

Comparison of UPS configurations

In the case of a single UPS chain (rectifier, battery and inverter), the reliability of the UPS depends on the reliability of the rectifier, DC bus (batteries) and, specially the inverter.

By introducing a static bypass switch, which provides a backup power supply, reliability is increased by a factor of six if mains MTBF is 50 hours (good quality) and the mean time to repair of the UPS is six hours. This level of reliability is not, unfortunately, enough because it still substantially depends on the reliability of the mains and the quality of the after-sales service of the UPS supplier company (response time, travel time, repair time, etc.). Modern critical loads cannot trust the quality of the mains and longer repair times.

To overcome dependence on the mains, $n+1$ parallel redundant UPS configurations are recommended. The disadvantage of the traditional standalone UPS with an $n+1$ parallel redundant configuration is the relatively long repair time of the UPS (usually 6 to 12 hours).

With hot-swappable parallel redundant systems based on modular technology ($n + 1$), the critical load is completely separate from the mains. A faulty UPS module can be replaced without the need to transfer the operational UPS modules to bypass. Furthermore, replacement of the modules can occur in less than 0.5 hours, which drastically reduces repair time compared to traditional parallel systems.

The following example shows the impact on reliability and availability of the traditional UPS option in parallel redundant configuration (1 + 1) compared to a modular system in parallel redundant configuration (4 + 1).

Standalone vs modular UPS configuration ($n+1$)

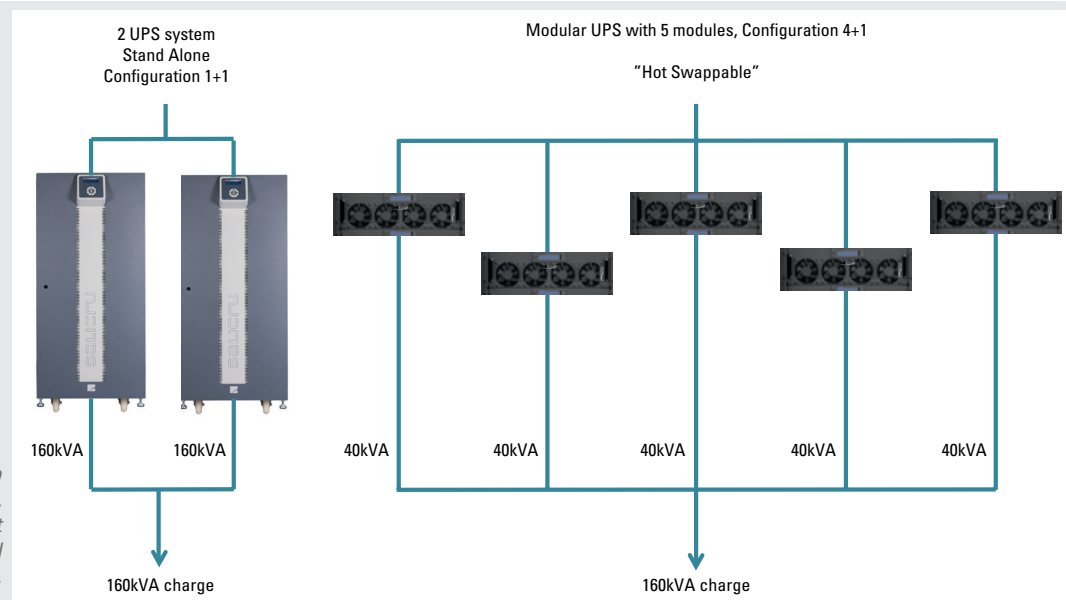


Figure 5: Block diagram of the two redundant UPS configurations, standalone parallel redundant system (1+1) and modular parallel redundant system (N+1).

Figure 5 shows a block diagram of two redundant UPS configurations. The system on the left shows a standalone parallel redundant system (1 + 1), while the system on the right shows a modular parallel redundant system ($n+1$) featuring hot-swappable modules.

Availability (A) is an important parameter in assessing the reliability of UPS configurations. A is defined as:

$$A = \frac{\text{MTBF}_{[\text{UPS}]}}{\text{MTBF}_{[\text{UPS}]} + \text{MTTR}_{[\text{UPS}]}}$$

The following table (Table 2), showing a comparison of reliability and availability data for both configurations, considers two cases:

1. Both UPS configurations have the same MTTR_[UPS] of six hours.
2. The traditional standalone UPS configurations have an MTTR_[UPS] of six hours, while the modular hot-swappable UPS configuration has an MTTR_[UPS] of 0.5 hours.

	Standalone redundant configuration (1+1)	Standalone or modular redundant configuration (4+1)
1) Standalone (1+1) vs (4 + 1)		
MTBF	Standalone 1,250,000 h	Standalone 500,000 h
MTTR	6 h	6 h
A	0.999952 (5 nines)	0.9999888 (4 nines)
2) Standalone (1+1) vs modular (4 + 1)		
MTBF	Standalone 1,250,000 h	Modular 500,000 h
MTTR	6 h	0.5 h
A	0.999952 (5 nines)	0.9999990 (6 nines)

Table 2. Comparison of the availability of the two configurations (1 + 1) and (4 + 1) in the two MTTR cases considered.

In case 1), the availability of the redundant configuration (1 + 1) is greater than that of the redundant configuration (4 + 1) if the MTTR is the same for both configurations. This is due to the fact that the MTBF of a redundant configuration (1 + 1) is greater than that of the redundant configuration (4 + 1).

In case 2), the availability of the redundant configuration (1 + 1) with a higher MTTR is less than that of the redundant configuration (4 + 1) because it has a much shorter MTTR.

Conclusions

In this article, different types of UPS have been analyzed and a number of concepts have been introduced to provide a quantitative assessment of the suitability of these types of UPS for critical applications. Concepts such as failure rate and MTBF (reliability) and MTTR have been described in terms of how they affect the most important final parameter for a critical application: A (availability).

A number of cases have also been considered showing the importance of MTTR for achieving high Availability. If a UPS fails in one of the above redundant configurations, there would be low Availability and the faulty device or module would have to be repaired or replaced as soon as possible in order to restore redundancy (high availability). With modular UPSs, shorter MTTR is achieved and, consequently, greater Availability, even if the number of modules in parallel is greater.

It has also been observed that, from the point of view of Reliability and Availability, the best option is a modular parallel redundant system (n+1). Surprisingly, according to the calculations carried out, configuration (n+m), where $m > 1$, does not improve configuration Reliability (n+1), since, in this study, the failure rate of the parallel bus is considered to be the most significant in the system.

There is, of course, still a long way to go in improving overall efficiency and both the electrical efficiency of each module and efficiency in managing the complete modular system, but there is no doubt, within the field of modular systems, about where the development of the UPSs of the future lies.

Therefore, and in answer to the question, Are they really more reliable?, it can be concluded that modular systems represent the last link in the evolutionary chain of the Uninterruptible Power Supply for critical applications as they improve the availability of energy, maintaining, or in many cases improving, the reliability of conventional systems.