White paper: Reliability of parallel redundant UPS

A parallel redundant UPS configuration with de-centralised static bypass switches provides the highest availability for mission critical applications

The primary objective in the implementation of a UPS system is to improve power reliability to the limits of technical capability, the ultimate aim being to totally eliminate the possibility of any power disturbance or downtime. When they first appeared in the 60s, static UPS systems comprised a rectifier, battery and inverter, and were used to stabilise the output power and to continue to support the load, without break, in the event of a supply failure. The reliability of this simple UPS chain depended predominantly on the inverter reliability. An inverter failure meant an immediate load crash.

In the early 70s the static bypass switch was introduced to enable an interruption-free load transfer to the standby mains in the event of an inverter failure or overload. The standby mains, although far less reliable than the UPS, serves as a reserve power supply in the event of an inverter failure, enabling continuation of the power supply to the load while the inverter is being repaired. This new architecture substantially improved the overall reliability, which no longer depended predominantly on the inverter reliability. The reliability of the new UPS with static bypass depended on the quality of the mains ($MTBF_{MAINS}$), the time-to-repair of the UPS ($MTTR_{UPS}$), and on the reliability of the static switch.

However, dependence upon computer-controlled real-time information systems has grown exponentially in recent years and the highest reliability UPS configurations have become an everyday requirement. Very critical loads cannot rely on a power supply configuration of a single UPS with static bypass system; the need for (n+1) redundant parallel UPS configurations is becoming standard. A comparison of the reliability for various UPS configurations is based on the reliability figures presented in MIL-HDBK-217 F (Not.2, 1995). The following calculations were implemented on the PowerWAVE Series UPS and have been confirmed by field statistics.

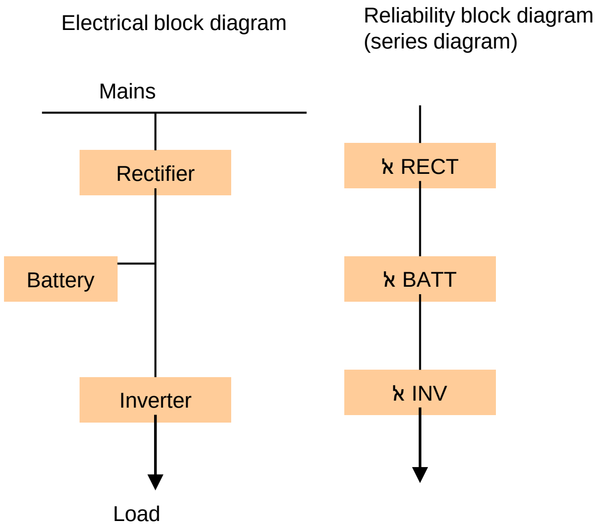

Figure 1 Single UPS without static bypass - electrical block diagram and reliability diagram

Single UPS without static bypass switch (SBS)

The reliability of a single UPS without bypass depends on the reliability of the rectifier, battery and inverter (see Figure 1). For example, in the event of an inverter fault, the load would crash.

Calculation of MTBF ($MRBF_{SU}$)

($MTBF_{SU}$ is the mean time between failures of single unit without static bypass
λUPS is the failure rate of single unit without static bypass switch
λRECT is the failure rate of the rectifier
λBATT is the failure rate of the battery
λINV is the failure rate of the inverter)

$MTBF_{UPS} = 1/\lambda UPS$

$\lambda UPS = \lambda RECT + \lambda BATT + \lambda INV$

Figures from statistical failure analysis show λRECT = 20 per million hours, λBATT = 10 per million hours, λINV = 20 per million hours. If these figures are applied in the equation, $MTBF_{UPS}$ for a UPS system without static bypass switch will be 20 000 hours.

Single UPS with static bypass switch

The reliability of a single UPS can be increased significantly by introducing a redundant mains power source and linking it to the main UPS supply source by means of a static bypass transfer switch (Figure 2). For example, in the event of an inverter fault the load will not crash, but will transferred to mains without interruption.

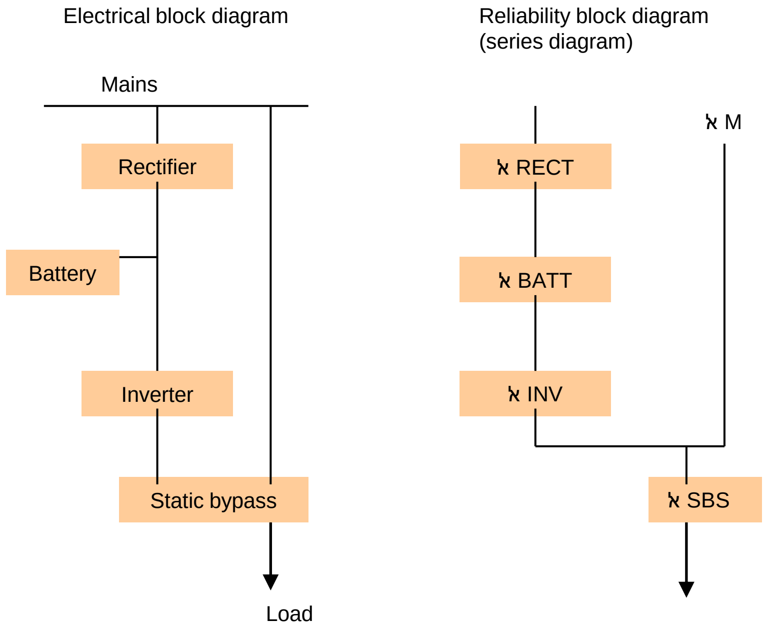

Figure 2 Single UPS with static bypass - electrical block diagram and reliability diagram

Calculation of MTBF ($MTBF_{SU}+_{SBS}$)

(For all subsequent calculations):
$MTBF_{UPS}+_{SBS}$ is the mean time between failures of single unit with static bypass switch
$MTBF_{M}$ is the mean time between failures of the mains
$\lambda_{UPS}+_{SBS}$ is the failure rate of a single unit with static bypass switch
λSBS is the failure rate of the static bypass switch with control circuit
λPBUS is the failure rate of parallel bus (only for parallel systems)
λM is the failure rate of the mains
µSU is the repair rate of the static bypass switch ($\mu SU = 1/MTTR_{UPS}$)
µM is the repair rate of mains ($\mu M = 1/MTTR_{M}$)
MTTRSBS is the mean time to repair of static bypass switch
$MTTR_{M}$ is the mean time to repair of the mains)

$MTBF_{UPS}+_{SBS} = 1/\lambda_{UPS}+_{SBS}$

$$\lambda UPS+SBS = \lambda UPS//\lambda M+\lambda SBS$$

$$\lambda UPS/\lambda M = \frac{\lambda UPS\ \lambda M\ (\lambda UPS + \lambda M + \mu UPS+\mu M)}{\lambda UPS\ \lambda M + \mu UPS\ \mu M + (\lambda UPS+\lambda M)\ (\mu UPS+\mu M)+\lambda^2 UPS+\lambda^2 M}$$

$$= \frac{\lambda UPS\ \lambda M\ (\mu UPS+\mu M)}{\mu UPS\ \mu M} = 6 \text{ per million hours}$$

Note that all calculations are performed using the following constants:
$MTBF_M$ = 50 hours, this figure represents a 'good quality' mains
$MTTR_{UPS}$ = 6 hours
$MTTR_M$ = 0.1 hours.
Furthermore, from statistical failure analysis, the figures for the failure rates of the static bypass switch for the power part and the control electronics part give λSBS = 2 per million hours.

Using these results:
$\lambda_{UPS}+_{SBS}$ = λUPS//λM + λSBS = 6 + 2 per million hours = 8 per million hours, or
MTBFUPS+SBS = 125 000 hours.
In the above formula it can be seen that the reliability of the UPS with static bypass switch ($MTBF_{UPS}+_{SBS}$) depends largely on three parameters: the reliability of the mains, the MTTR of the UPS and the reliability of the static bypass switch. This dependence is illustrated in Figure 3.

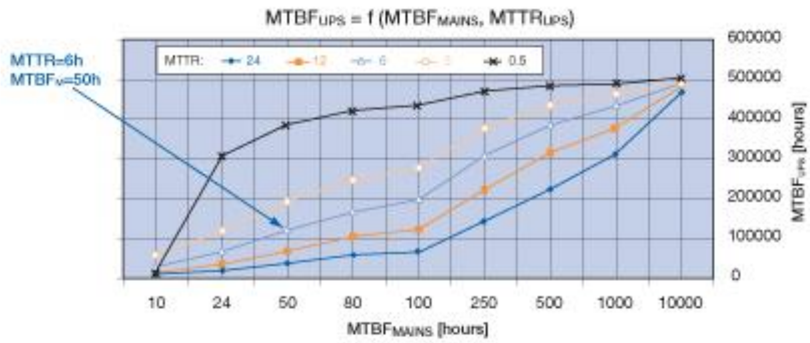

Figure 3 Graph showing the dependence of the $MTBF_{UPS}+_{SBS}$ on $MTBF_{MAINS}$ and $MTTR_{UPS}$

Parallel redundant UPS with static bypass switch

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

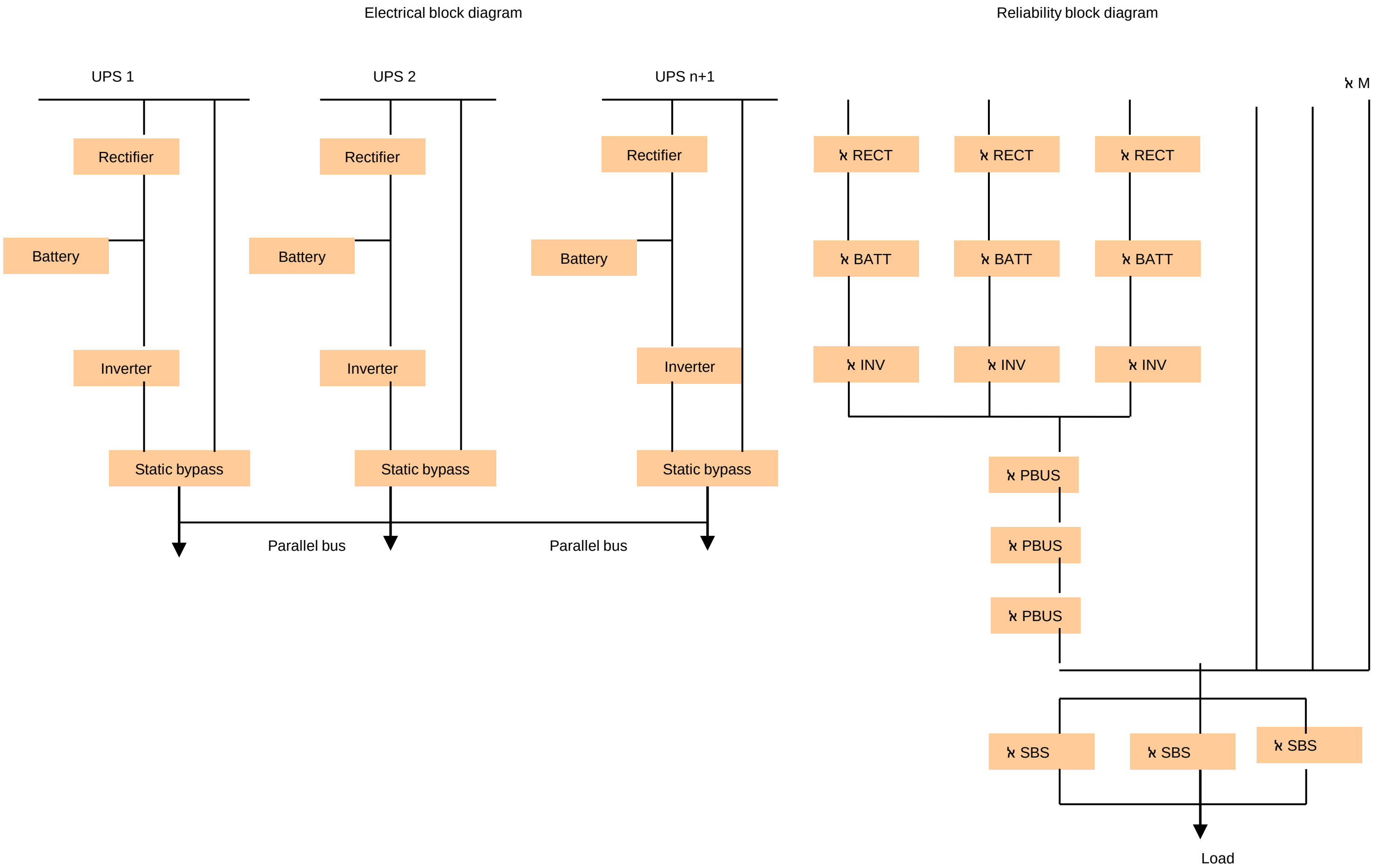

Figure 4 (n=1) parallel redundant UPS with static bypass – electrical and reliability block diagram

Calculation of MTBF for an (n+1) redundant parallel UPS system ($MTBF_{(n+1)UPS+SBS}$)

Failure rate, $\lambda_{(n+1)UPS+SBS}$ = (λUPS1//λUPS2……..//λUPS(n+1)) + (n+1)λPBUS + (λSBS1//λSBS2……..//λSBS(n+1)) ~ (n+1)λPBUS

Reliability, $MTBF_{(n+1)UPS+SBS} = 1/\lambda_{(n+1)UPS+SBS}$

Availability A(n+1)UPS+SBS = $\dfrac{MTBF_{(n+1)UPS+SBS}}{MTBF_{(n+1)UPS+SBS} + MTTR_{UPS}}$

The following constants are used in the calculations (Figure 5):

MTBFM = 50 hours, this figure represents a 'good quality' mains

λPBUS = 0.4 per million hours.

The reliability of an (n+1) parallel redundant system depends largely on the failure rate of the parallel bus, which is the only single point of failure. The UPS parallel redundant chains, the static bypass switches and their control electronics, as well as the mains power lines are all redundant and have therefore minor or even negligible impact on the overall reliability.

Redundant parallel configuration	Reliability (MTBF) hours	Failure rate (λ) per million hours
(1+1) redundant configuration	1 250 000	~ 0.8
(2+1) redundant configuration	830 000	~1.2
(3+1) redundant configuration	650 000	~1.6
(4+1) redundant configuration	500 000	~2.0
(5+1) redundant configuration	420 000	~2.4

Figure 5 MTBF and failure rate for (n+1) redundant configurations

The following constants are used in the calculations (Figure 5):

MTBFM = 50 hours, this figure represents a 'good quality' mains

λPBUS = 0.4 per million hours.

Comparison of UPS configurations

In the single UPS chain (rectifier, battery and inverter), the reliability of the UPS largely depends on the reliability of the inverter.

By introducing the static bypass switch, which provides a reserve mains power supply, the reliability will increase by a factor of six if the mains MTBF is 50 hours (good quality) and the MTTR of the UPS is six hours. This reliability level is unfortunately not sufficient, because it still depends substantially on the reliability of the raw mains and on the quality of the UPS aftersales organization (response time, travelling time, repair time, etcetera). Modern critical loads cannot rely on the mains quality and on longer repair times.

To overcome the dependance on the raw mains, n+1 redundant parallel UPS configurations are recommended. The disadvantage of traditional standalone n+1 redundant configuration is the relatively long repair time of the UPS (typically six to 12 hours). By implementing modular, hot-swappable, n+1 redundant parallel systems based on modular PowerWAVE technology, the critical load will be completely mains independent. A faulty UPS module may be replaced without the need to transfer the healthy UPS modules to raw mains. Furthermore the replacement of the modules takes at most 0.5 hours, which dramatically decreases the time-to-repair in comparison with traditional parallel systems.

The following example shows the impact on the reliability and availability of the choice of UPS configuration, comparing a traditional (1+1) redundant UPS configuration and a modular (4+1) redundant UPS configuration.

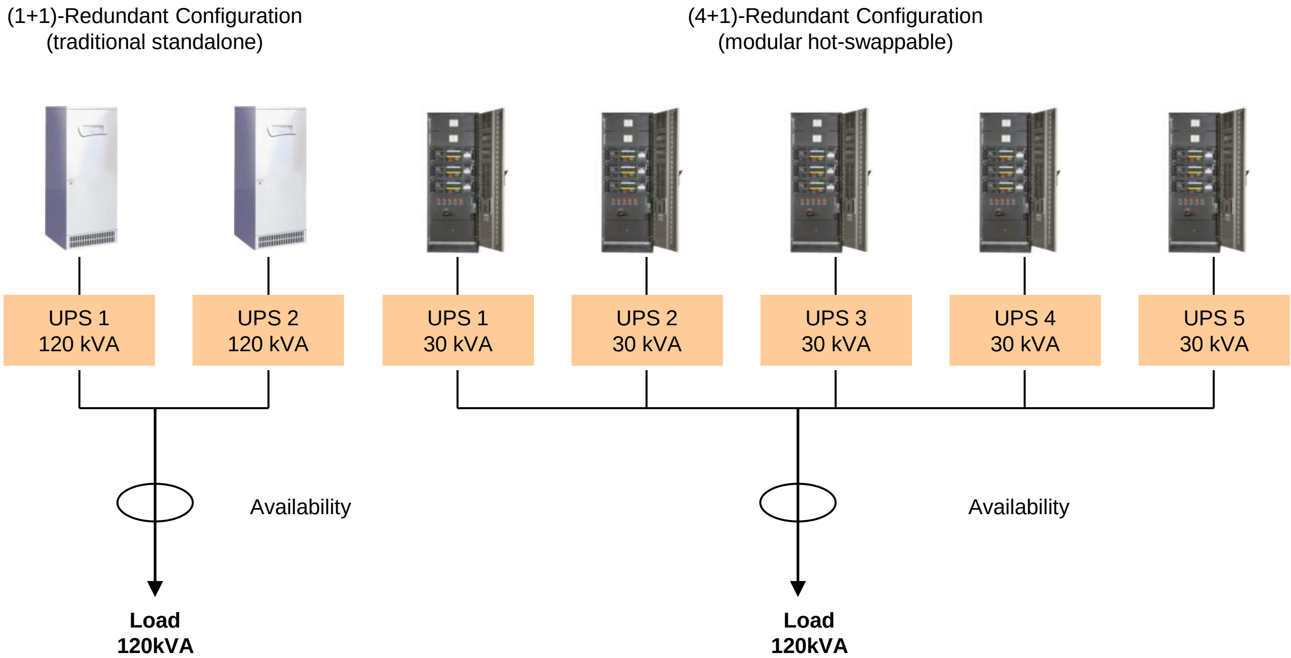

Figure 6 Block diagram of two redundant UPS configurations

Figure 6 shows a block diagram of two redundant UPS configurations. The system on the left represents a (1+1) redundant configuration with traditional standalone UPSs, whereas the system on the right side represents a (4+1) redundant configuration with modular hot-swappable UPSs.

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

$$A = \frac{MTBF_{UPS}}{MTBF_{UPS} + MTTR_{UPS}}$$

Figure 7 compares the availability of the configurations shown in Figure 6. Note that the MTBFUPS figures are taken from Figure 5. Two cases are considered:

Case 1: both UPS configurations have the same $MTTR_{UPS}$, six hours

Case 2: the traditional standalone UPS configurations has $MTTR_{UPS}$ of six hours, whereas the modular UPS configuration with hot-swappable modules has $MTTR_{UPS}$ of 0.5 hours.

	Redundant configuration (1+1)	Redundant configuration (4+1)
Case 1	stand-alone	stand-alone
MTBF	1 250 000 hours	500 000 hours
MTTR	6 hours	6 hours
Availability	0.**99999**52 (5 nines)	0.**9999**888 (4 nines)
Case 2	stand-alone	modular, hot swappable
MTBF	1 250 000 hours	500 000 hours
MTTR	6 hours	0.5 hours
Availability	0.**99999**52 (5 nines)	0.**999999**0 (6 nines)

Figure 7 Comparison of availabilities of 1+1 and 4+1 configurations

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

In Case 2, the availability of a (1+1) redundant configuration with longer MTTR is lower than the availability of a (4+1) redundant configuration with a shorter MTTR.

Conclusion

These cases show how important MTTR is for reaching high availabilities. If in one of the above redundant configurations one of the UPS is faulty, there will be no redundancy left (low-availability regime) and the faulty part/module must be repaired or replaced as quickly as possible in order to restore redundancy (high-availability regime). With PowerWAVE modular UPS, the shortest MTTRs are achieved and, consequently, the highest availabilities, even if a larger number of modules are paralleled.

Contact

Uninterruptible Power Supplies Ltd
Woodgate
Bartley Wood Business Park
Hook
Hampshire
RG27 9XA

Phone: 01256 386700
Email: sales@upspower.co.uk
Web: www.upspower.co.uk