Advel Application Note – AAN2024.1

Buffer-Modules to increase Hold-Up time

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1. Introduction

The "voltage dips" is a short, temporary drop in the voltage magnitude below a specific threshold in the distribution or customer's power supply line (CEI EN 50160 Standard). These voltage dips, even if short-lived, can potentially create big problems in the industrial sector. In fact, these can cause the shutdown of a system (which sometimes for safety reasons may require manual intervention to resume operation), the restart of a computer, the actual failure of equipment, and in general the discontinuity of a production cycle, resulting in production delays with possible penalties caused by contractual breaches, ...
Voltage dips, by definition, last between 10msec and one minute.
Interruptions lasting more than a minute generate more damage than voltage dips, however the latter are much more frequent, as well as unpredictable and largely random.

An **UPS** (Uninterruptible Power Supply) serves to protect the devices connected to it not only from voltage dips, but from actual blackouts. This is thanks to the energy accumulated within special batteries, which can provide autonomy of up to several hours. The problem with UPSs is... the cost, as well as the size and maintenance required by the batteries. The use of industrial UPSs is therefore limited to the protection of particularly critical activities; it cannot be used to protect all the equipment of an industrial system.
However, there are strategies to protect a system from voltage dips, without using UPSs.

2. Voltage dips

CEI EN50160 gives an approximate indication of the expected number of voltage dips, which in a year can vary from a few dozen to a thousand. This is because these are unpredictable and largely random events with annual frequency that varies considerably depending on the type of power system and the observation point (for example in areas with weak networks such as rural ones, voltage dips are more frequent than average).

Considering only "deep" voltage dips (in which there is a reduction in the effective value of the voltage below 60% of the nominal value) according to a UNIPEDE survey, in Europe we have the results summarized in Table 1

Amplitude of the dip	Duration (ms)			
	10 ÷ 100	100 ÷ 500	500 ÷ 1s	1s ÷ 60s
>40%	26	70	25	14

Table1 *– UNIPEDE survey (duration 3 years) on the characteristics of voltage dips in European medium voltage networks: the annual frequency is indicated with a 95% probability of not being exceeded.*

From this study it can be deduced, regarding deep voltage dips, that approximately 70% have a duration of less than 500msec, and approximately 90% have a duration of less than 1 second.

3. Hold-Up time

The "Hold-Up time" of a power supply defines how long the power supply can provide the nominal output voltage when the V_{in} fails, and therefore gives an indication of how long the power supply can withstand voltage dips of the network.

European regulations (**EN60950**, **IEC1000-4-11**) impose a Hold-Up time of at least 20ms for power supplies with single-phase 115-230Vac input, i.e. the time of one cycle of the sinusoidal mains voltage (1/50Hz = 20msec).

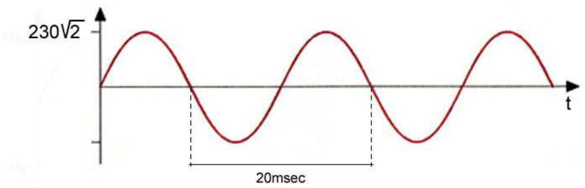

Figure1 *– The figure shows the sinusoidal trend of the mains voltage (230Vac) and the minimum Hold-Up time required by European regulations.*

If the voltage dip lasts beyond the Hold-Up time of the power supply, of course it turns off.
AC/DC power supplies found on the market typically provide a Hold-Up time equal to the minimum required by the mandatory regulations, i.e. 20msec.

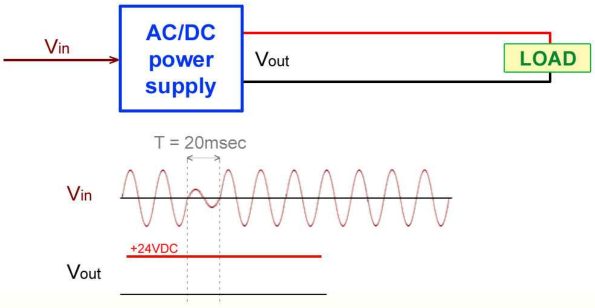

Figure2 – *All CE marked AC/DC power supplies must be able to withstand a voltage dip of 20msec*

Advel power supplies as standard provide an Hold-Up time typically up to 100msec at full load, protecting against 20% voltage dips, according to Table 1

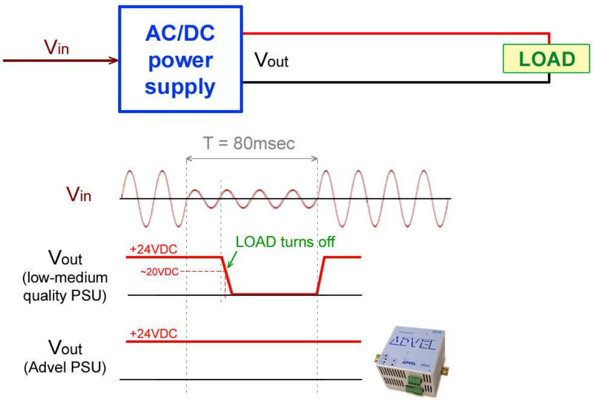

Figure3 – *The AC/DC power supplies produced by ADVEL can sustain voltage dips of up to 100msec as standard.*

However, if you intend to protect a user from most voltage dips, it is necessary to increase the Hold-Up time of the power supply up to 500msec or 1sec. This is possible using the so-called **Buffer Modules**.

4. Buffer-Modules

The Buffer Modules are installed on the DC output of the system whose voltage dip withstand time is to be increased.

The Buffer-Modules use electrolytic capacitors inside them as if they were batteries: these accumulate the energy needed to supply the DC voltage for a certain time, called "buffering time" (T_{buff}).

Furthermore, the Buffer-Modules can be placed in parallel, to achieve the desired buffering time for the system (see Figure 4).

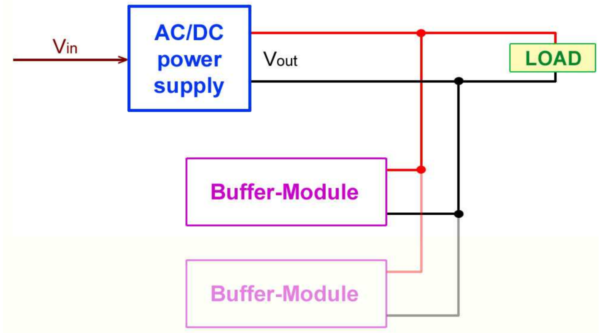

Figure4 – *The Buffer-Module must be wired directly to the DC output of the system, and more than one can be placed in parallel to further increase the buffering time*

Furthermore, the electrolytic capacitors inside the Buffer-Modules do not require maintenance and can work at an environment temperature much higher than that allowed for lead batteries (45÷50°C).

5. How Buffer-Modules work

To date, there are Buffer-Modules for 12VDC and 24VDC output on the market, with buffering times typically in the order of 250msec@500W (if used for lower powers they obviously provide proportionally higher buffering times, for example 500msec@250W).

Let's consider the example of an AC/DC system composed of:

- an AC/DC power supply with $T_{Hold\text{-}Up}$ = 20msec,
- a 500W 24VDC load,
- a Buffer-Module with T_{buff} = 250msec@500W.

For example, if a voltage dip of 180msec occurs at the input, it happens that:

for the first 20msec the power supply remains on ($T_{Hold\text{-}Up}$) and its output remains at 24V, after which it turns off; beyond 20msec it is the Buffer-Module that powers the load: the V_{out} of the Buffer-Module is a little lower than the nominal voltage, by a value ΔV = 1÷2V; once the voltage drop is concluded, the power supply turns on again and supplies the 24V voltage to the load (Figure 5).

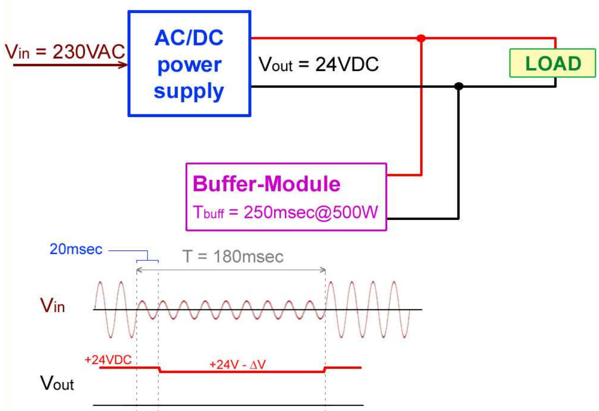

Figure5 – *If the voltage dip is greater than the $T_{Hold\text{-}Up}$ of the power supply, the Buffer-Module supplies voltage to the load*

6. How a Buffer-Module is made

Let's take a qualitative example. Consider a system composed of:

- an AC/DC power supply with $T_{Hold-Up}$ = 20msec,
- a 24VDC load of 1.2Ω (i.e. approximately 500W)
- a "capacitor-pack" on the output, 4x10000µF.

Let's see if this system is immune to a 180msec voltage dip.

In this example we chose to use n.4 10000µF_40V electrolytic capacitors, because these have dimensions consistent with those of a typical Buffer-Module.

It is known that capacitors have a discharge voltage that decreases exponentially with time constant RC. In our example RC = 1.2Ω x 40000µF = 48msec.

Suppose that the load switches off below 20V (typical value): it is not important in this qualitative example to calculate the precise value of the system buffering time, but by observing the discharge voltage of the capacitor-pack, it is immediately clear that this is not minimally adequate to overcome the voltage dip of 180msec: the discharge voltage of the capacitor-pack, especially in the first moments, drops very quickly and therefore reaches 20V in a much shorter time than the time constant, as shown in Figure 6.

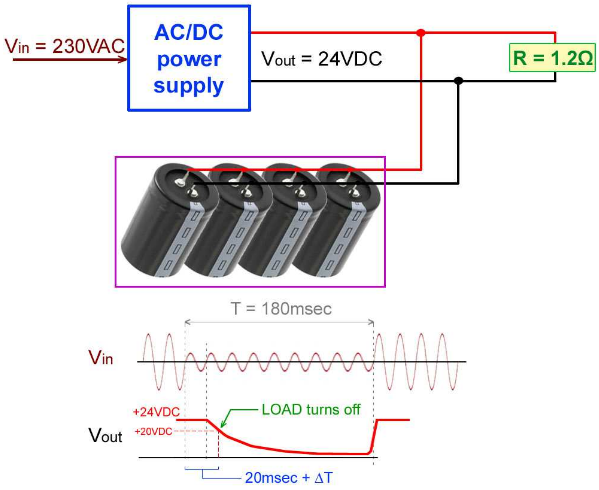

Figure6 *– A simple "capacitor-pack" is not a technically efficient solution for creating a Buffer-Module.*

It would be unthinkable to create such a system, as is easy to understand that such a system would require a very very large number of electrolytic capacitors to support this voltage dip.

So, contrary to what one might think, Buffer-Modules do not contain only electrolytic capacitors, but are much more complex objects.

Figure7a *– Open frame Buffer-Module from a well-known manufacturer*

Figure7b *– Buffer-Module, bottom view*

Figure7 shows a 24VDC Buffer-Module that is currently on the market, and which can deliver 480W for 300msec: you can clearly see that this contains n.4 3300µF_160V electrolytic capacitors.

Note that the four 3300µF_160V electrolytic capacitors have the same size as the four 10000µF_40V capacitors chosen in the initial example. However this Buffer-Module contains many other components, in fact it is a real <u>double-stage DC/DC converter</u>.

Figure8 shows the simplified internal diagram of the Buffer-Module, containing the two DC/DC converters:

the first of the two <u>boosts the voltage</u> to 150VDC, loading the internal electrolytic capacitors to this voltage, while the second provides a stabilized output voltage of approximately 24V and has a <u>wide-range input</u> from 10V to 150V.

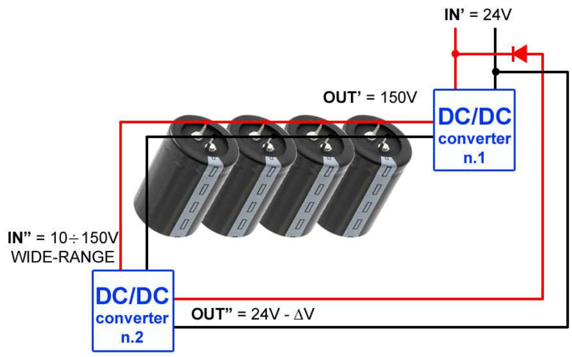

Figure8 *– Simplified internal diagram of a Buffer-Module.*

In practice, the two internal converters are small Flybacks: the first is very low power (about 3W) and only serves to charge the capacitor-pack (in about 30 seconds) and then keeps it charged, while the second can supply 480W but for only 300msec (and therefore does not require heatsinks or a large transformer).
The reason for this double conversion is that the energy accumulated in the capacitor-pack is used much more effectively, as the discharge time is almost completely used.
Figure9 shows the trend of the voltage of the capacitor-pack inside the Buffer-Module, called V_{cap}: when the external AC/DC power supply turns off, V_{out} starts to drop, but as soon as it reaches 22÷23VDC, converter no. 2 of the Buffer-Module keeps the V_{out} at this voltage value and begins to deliver current to the load, drawing power from the capacitor pack, which in turn begins to discharge. Converter no. 2 accepts a very wide voltage range as input, and therefore remains switched on as long as V_{cap} remains above approximately 10V.

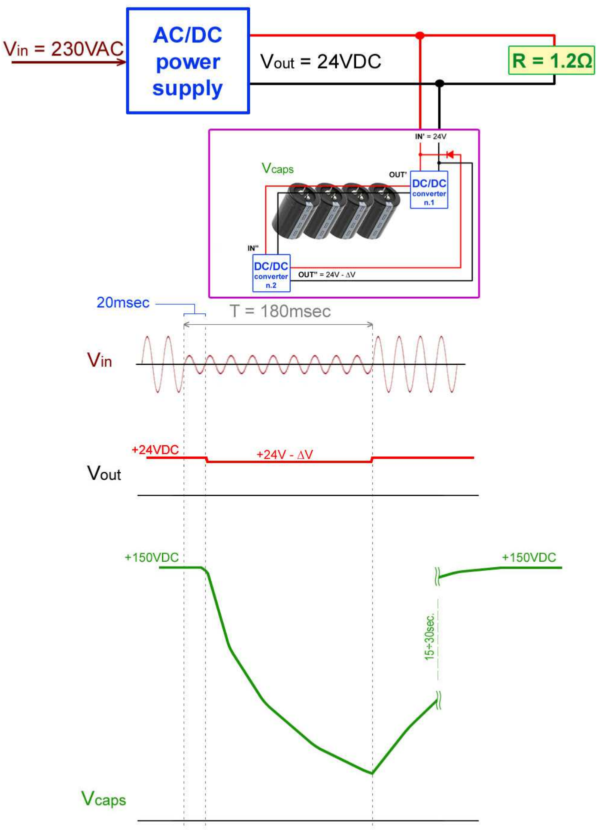

Figure9 –Voltage trend of the capacitor-pack inside the Buffer-Module.

The Tbuffering is indicated on the datasheet of the Buffer-Module, corresponding to the discharge time of the internal capacitor-pack, which obviously depends on the power absorbed by the load.
Once the voltage dip ends, the AC/DC power supply turns on again and give power to the load. At the same time, converter no. 1 of the Buffer-Module turns on and recharges the internal capacitor-pack in approximately 30 seconds: after this time the Buffer-Module is ready to support a new voltage dip.

7. Advel PSU with Hold-Up time = 800msec

Advel does not produce external Buffer-Modules, but produces the **SPS-DXH** series of power supplies, which have a much higher Hold-Up time than the standard SPS-DX series (100msec). For example, an **SPS251DXH** power supply:

- has a maximum continuous power of 250W,
- allows a boost of 500W for 5 seconds,
- has $T_{Hold-Up}$ = 800msec@250W.

Obviously the high Hold-Up time is obtained thanks to an internal capacitor-pack, which however is not positioned at the output, but is located in the input stage of the power supply (PFC), in parallel to the standard Hold-Up capacitors, as shown in Figure10.
Of course, given the high number of Hold-Up capacitors, these power supplies have an appropriately sized inrush current limiting system.

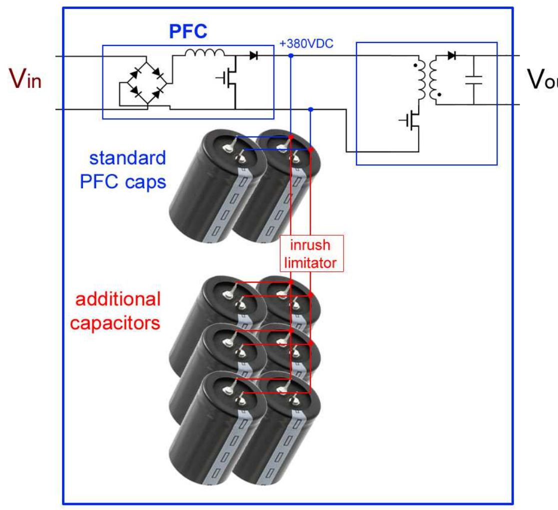

Figure10 *– Simplified internal diagram of an Advel* ***SPS-DXH*** *series power supply*

Advel's technical choice favors circuit simplicity, and therefore the reliability of the system, given that no further converters were added, which for obvious reasons would have inevitably lowered the MTBF of the system.

8. Single power supply with high $T_{Hold-Up}$ vs external Buffer-Modules

It may be useful to make an analytical comparison between two solutions:
AC/DC system with 250W load, one consisting of an AC/DC power supply + external Buffer-Module, and one consisting of a single AC/DC power supply from the Advel **SPS-DXH** series.

AC/DC 250W SYSTEM	n.1 power supply AC/DC 250W n.1 Buffer-Module	n.1 **ADVEL SPS251DXH**
$T_{Hold\text{-}Up}$ @250W	500÷600msec	800msec
$T_{Hold\text{-}Up}$ @500W	250÷300msec	400msec
$T_{ricarica}$	30 sec.	15 sec.
length		
V_{out} during the voltage dip	V_{nom} – (1÷2V)	V_{nom}
V_{out} = 12V	yes	yes
V_{out} = 24V	yes	yes
V_{out} = 48V	no	yes
V_{out} = 110V	no	yes
possibility of paralleling	yes (passive current sharing)	yes (**active** current sharing)

Table2 *– Comparison of the mechanical/electrical characteristics of two 250W AC/DC systems: one made with an external Buffer-Module, and one made with an Advel **SPS251DXH** power supply*

Both systems can deliver 250W maximum power, with a peak of 500W for a short period.
Some characteristics of the two systems are summarized in Table2. For the system with external Buffer-Module, a sort of average was made between the power supplies and Buffer-Modules currently on the market from 5 well-known international manufacturers.

The Advel system is larger, but can withstand much longer voltage dips and also has a shorter charging time for the internal capacitor-pack.
Furthermore, Advel can produce power supplies with 48VDC or 110VDC output, while to date there are no Buffer-Modules for these voltages on the market.
The output voltage V_{out} during the voltage dip remains unchanged with Advel power supplies, while it drops by 1÷2V on the system with external Buffer-Module.
To increase the total buffering time of the system, it is possible to place multiple Buffer-Modules in parallel. Advel **SPS-DXH** power supplies can also be placed in parallel, however with active current-sharing technology, which allows an equal distribution of the load current between the power supplies in parallel.

On the other hand, the external Buffer-Modules can be installed on an existing system, with AC/DC power supplies of any brand, and this makes them very versatile.

Regarding the reliability of the two systems, as already mentioned, it can be assumed that the one with the **Advel SPS-DXH** power supply has a higher MTBF than the one with the external Buffer-Module, given that the latter is made up of a high number of electronic components (in fact it is a double conversion converter).

Finally the cost must be considered, which however depends on many variables (quantity, particular discounts, ...) and is difficult to quantify. However, it is reasonable to believe that the two systems have an approximately equivalent cost.

9. Conclusions

Two systems for protecting against voltage dips on the AC line were compared: one with independent Buffer-Modules to be installed on the DC side, and one with Advel power supplies from the **SPS-DXH** series. The operation, advantages and particularities of both systems have been described.

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