PULS

Electronic fuses to protect 24V DC load circuits

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This "Application Note" describes the function, advantages and disadvantages of the various types of electronic fuses, and compares them to the new PISA protection module from PULS.

Unlike traditional miniature circuit breakers, electronic fuses monitor and limit the current with greater accuracy and cut-out faulty branches with much shorter delays. This means that a faulty branch can be safely opened even with long cable runs or small wire sizes.

However, choosing electronic fuses can also present some issues. Often they are too sensitive and tend to trip too fast. It is also important not to choose too small of a power supply so that the necessary current required for tripping of the fuse can be supplied in the event of a fault.

The design of a protection concept for 24V branches using the new PISA module is much less complicated and incorrect adjustments or sizing errors can be eliminated.

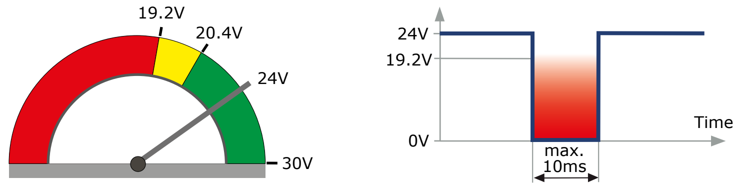
INFO:
The use of traditional miniature circuit breakers with 24V DC systems is covered in application note AN38 (Isolation of Faulty 24V Branches with Miniature Circuit Breakers) from PULS.

A requirement of the new Machinery Directive 2006/42/EC is the critical check of the effect of faults on the 24V DC power systems. No hazardous situations are permitted to occur during the tests. Machines must not start up accidentally, it must be possible to bring them to a standstill at any time and they must not cause any hazards, such as overheating or fires.

Faults in the 24V DC power supply can be caused by power failures or mains fluctuations. Buffer units or DC UPS's can help in these circumstances.

However, load-side faults which can cause a voltage brown-out on the 24V DC power supply are much more critical. For example, if a trapped power cable causes a short-circuit, virtually all the current from the power supply flows into this faulty branch. This branch must be quickly disconnected (cut-out) to avoid disabling the entire system at the same time. It doesn't necessarily have to a be a short circuit. Connecting a load with a large input capacity can also create an overload with a similar effect.

In practice there are typically three types of loads that need to interact in a machine; sensitive electronics, robust electromechanical components and safety-relevant circuits. Using a shared power supply unit for types of loads has been standard practice.
Especially sensitive are the electronic loads



Permissible voltage range for 24V DC systems according to EN/ IEC 61131-2 section 5.1.1.1

The range from 19.2 to 20.4V is only permissible as a superimposed AC-ripple voltage

Maximum permissible voltage interruptions for 24V DC systems according to EN/ IEC 61131-2 section 5.1.1.3

Figure 1:
Limit values conforming to EN/ IEC 61131-2

such as a PLC that even with the shortest interruptions of the supply voltage suffers a loss of function or an accidental re-start. The permissible limits for the ride-through time and the supply voltage range of control components are specified in EN 61131-2 and shown here in figure 1. Any deviation from this is critical.

Characteristics of switched-mode power supplies

A short-circuit represents a very low-ohmic load for the power supply and "absorbs" the majority of the current of a system with multiple branches. In these situations, modern, switched-mode power supplies normally used to generate the 24V DC supply voltage, changes from the voltage regulation mode to current limitation mode to protect itself. As a result, the power supply output voltage drops. If the current limitation value is below the tripping point of the fuse

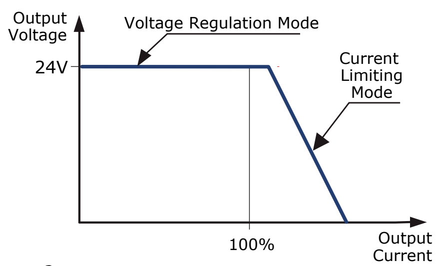


Figure 2:
In the event of overload, the switched power supplies change to current limitation mode

or circuit breaker, it will not be able to switch-off the electric circuit. Traditional miniature circuit breakers or melting fuses are imprecise or too slow in most cases. Electronic solutions are much better suited here.

Electronic fuses

Electronic fuses measure the current utilizing a shunt resistor and a semi-conductor as a switching element. The first electronic fuses have already been on the market for around 10 years. These devices did have exact current shut-off values, but not the desirable dynamic response of miniature circuit breakers. It was not uncommon that they would shut off even at inrush current surges due to operating conditions and therefore resulted in accidental machine standstills. Displays, motor control centers and other loads with large input capacitors could only be switched on when oversized ampere values were selected.
This flaw has been suppressed by some manufacturers in the latest generation of devices. They were designed to be resistant to dynamic power requirements and can thus easily connect capacitors of up to 20,000µF. A certain amount of resistance remains for anyone who had a problem in the past. Incorrect triggering can also cause damage in just the same way as failing to trigger in the event of a fault. A precise study of data sheets and practical tests are therefore urgently recommended.

Two basic differences with electronic fuses

Electronic fuses can be equipped either with or without active current limitation. The simpler type of models only contain current monitoring with subsequent output shut-down. This concept does permit a more cost-effective design for the electronic fuse, but puts a larger burden on the power supply as the current can flow virtually "unchecked" into the faulty branch. This results in less current for the remaining loads, which means that the faulty branch need to be cut-out very fast to avoid excessive long voltage brown-outs causing a subsequent chain reactions of failures.
Furthermore, it is not possible to turn-on

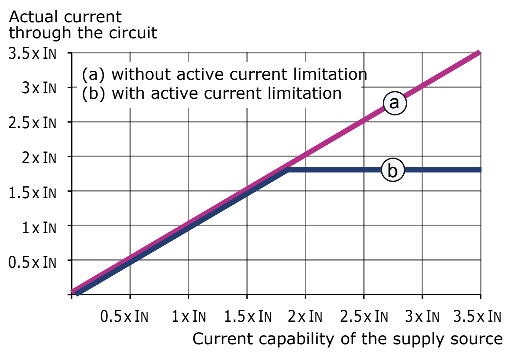


Figure 3:
Electronic fuses with and without active limitation

loads with large input capacitors. With this technology, it is advisable to connect the individual branch circuits with a time delay to the supply voltage. This spreads the inrush current surges of the individual branches and lowers the peak currents for the power supply.

The other option for electronic fuses are the more complex models, which include an active current limitation. Such devices limit the maximum current electronically to around 1.5 times the nominal value. This means there is then much less burden on the power supply. The time to cut-out faulty branches can be chosen much longer since the current is actively limited which makes this concept less sensitive to short peak loads and also allows large capacitive loads to be connected.

Tripping characteristic of different fuse elements in practice

The oscillograms given on the right side of this page show the different characteristics of the various techniques for

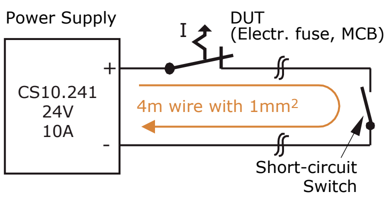


Figure 4: *Test setup*

protecting 24V DC circuits. The tripping characteristic of various 6A electronic fuses and one 6A miniature circuit breaker were tested in combination with a 10A power supply. The oszillograms show the response in the event of a short-circuit with a 4m wire and a cross section of 1mm2. All tests were conducted with a standardized test setup.

In tests 1-3, the 10A power supply had already reached its full current capabilities with 6A fuses, when using the PISA module. A 10A load could easily be supplied without any loss of the protective effect.

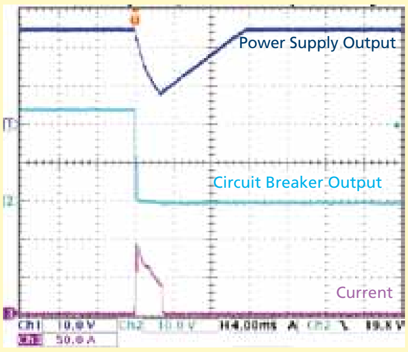


Figure 5: *6A MCB C-characteristics*

- **6A Miniature circuit breaker with C-characteristic**

The current increases to almost 100A and the miniature circuit breaker opens after approx. 3ms. The output voltage then slowly recovers again. This behavior is determined primarily by the cable length. If this length is longer, the wire resistance increases and limits the current. The tripping would then have a considerable delay, which would mean an extended brown-out or black-out of the supply voltage.

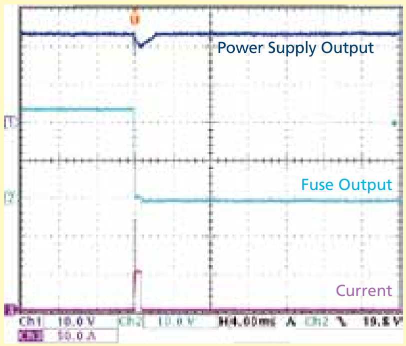


Figure 6: *6A Electronic fuse without active current limitation (Lütze LOCC-Box, set to slow blow)*

- **Electronic fuse without current limitation: LOCC box with 6A from the company Lütze**

This type of electronic fuse does not have any active current limitation. The current flows virtually unchecked into the short-circuit at over 50A. The tripping must be correspondingly fast to avoid brown-outs or black-outs of the supply voltage.

The fast response of this fuse has a tendency to initiate false tripping with inrush current surges from loads with moderate to large input capacitors during normal operating conditions.

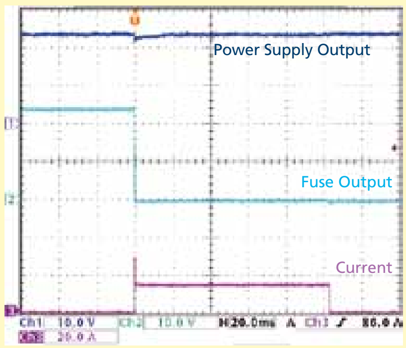


Figure 7: *6A Electronic fuse with active current limitation (E-T-A ESX10-T)*

- **Electronic fuse with active current limitation: ESX10-T with 6A from the company E-T-A**

In this case the output current is actively limited before the tripping. The 6A fuse is internally set to around 1.8 times the nominal value for dynamic load compatibility. In practice, 12A is measured, that the 10A power supply can also supply without voltage brown-out. Nominal value greater than 6A should not be used together with this 10A power supply. The dynamic current is available for 100ms. During this period, even large capacitors can be easily be charged.

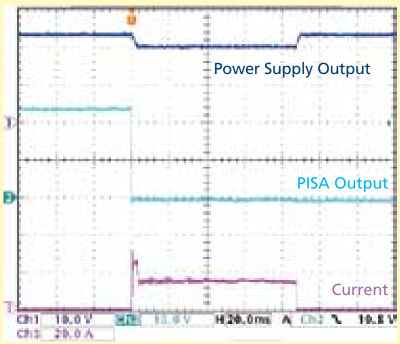


Figure 8: *PULS PISA module 6A output*

- **PISA module with 6A output channel from PULS**

The output current is limited dynamically to typ. 25A or to a smaller current value that ensure a minimum supply voltage of 21V. The first short peak with around 25A is the discharge of the output electrolytic capacitors in the power supply. 15A will then be flowing. This is the current level that can be drawn from the power supply without breaking a level below 21V. Thanks to this input voltage dependent current limitation, a 10A output channel of the PISA model could be used too, without loosing protection effect.

New

The new PISA module from PULS: Guarantees the PLC power supply and protects against cable overload.

The basic idea of the PISA module is to connect sensitive loads such as PLC's, controls or safety relevant circuits directly to the power supply. A safeguard is introduced to ensure that other loads connected to the same power supply do not overload the circuit and bring the output voltage of the power supply down. This results in sufficient supply voltage for the sensitive loads. Less critical loads that do not respond to short voltage interruptions or that could even be the cause for the faults on the 24V power supply are connected behind this safeguard circuit. This safeguard works like a valve. It permits only so much current that the input voltage (corresponding to the power supply output voltage) does not drop below 21V. This ensures an uninterrupted voltage supply for critical loads if these are connected to the same power supply as the PISA module. If necessary, the wires to these loads can be protected using standard miniature circuit breakers or lead fuses.

The safeguard in the PISA module actually works very simply. The standard current monitoring for electronic fuses was replaced with voltage-dependent active current control. The loads connected to this can then use the maximum possible remaining current provided by the power supply without danger. No reserve current is needed for triggering the tripping of a fuse. How this works in practice is shown in the oscillogram in figure 8.
Actually a logical step, but one which is being used for the first time here.

Another task of the PISA module is the distribution of the current from a powerful power supply to four current-monitored output channels. This permits cabling with smaller wire cross-sections. Each output channel has electronic power measurement. If a permissible channel current or the permissible total current for the module is exceeded, the module limits all output currents and shutdown all four outputs with a time delay. In addition to this first shutdown mechanism, there is a second current monitoring system and braking element (Mosfet) installed, which operates redundantly to the first shutdown mechanism and becomes active in case of a failure inside the PISA module.

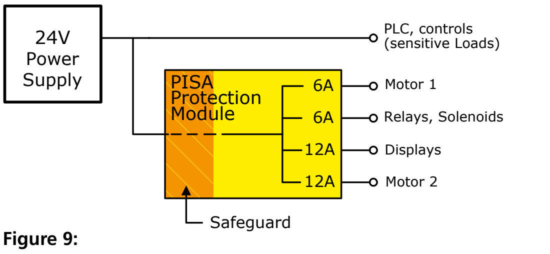


Figure 9:
Critical loads are connected directly to the power supply. Non-sensitive loads or "interrupters" are connected behind the safety shield of the PISA module

There are several different PISA modules with different output currents available (fixed ampere values from 4x1A to 4x10A as well as combined modules with 2x3A + 2x6A and 2x6A + 2x12A)

Protection of small wire sizes

For the coordination between wire sizes and load currents, the relevant regulations must be observed. In most cases, these are VDE 0891, VDE 0100-523 and IEC/EN 60204-1.
The following cross sections are suitable for typical applications:
- ≥0.14mm² for 1A output
- ≥0.25mm² for 2A output
- ≥0.34mm² for 3A output
- ≥0.5mm² for 4A output
- ≥0.75mm² for 6A output
- ≥1.0mm² for 10A output
- ≥1.5mm² for 12A output

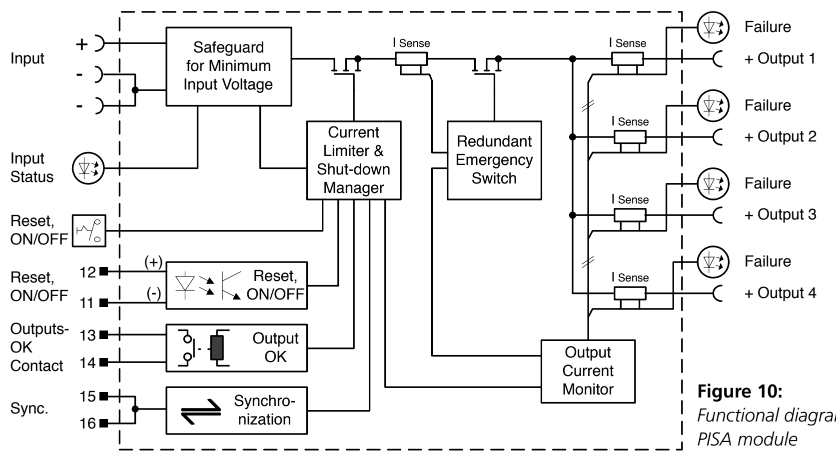


Figure 10:
Functional diagram PISA module

The PISA module sets a new standard for the costs

One argument against electronic fuses is often the considerably higher costs in comparison to the familiar traditional miniature circuit breakers. For this reason, in developing the PISA module it was an important objective to optimize the costs as far as possible.
One measure to achieve this is the 4-channel module design. This saves mechanics, electronics and cabling.
Another measure is the collective shut-down of all outputs in the event of a fault. The collective shut-down of all branches does require some thought as to whether or not this could be a problem. Although in most cases this fear is unfounded. For example, if a motor is jammed, it is no longer relevant whether or not another motor or solenoid is supplied. It is important that the control remains alive and that it can carry out the pre-programmed actions for this situation.

This collective shut-down also has some advantages. The dynamic characteristics are specified per module and not per output. If an output is only connected to a "harmless" load, the other outputs benefit from this. This dynamic flexibility reduces the risk of nuisance tripping.

The result of the cost optimization was very successful:
The costs for a PISA module are around half the costs of the standard market 4-channel electronic fuse modules or are only slightly greater than the total costs of four traditional miniature circuit breakers with an auxiliary contact. At these costs it is also not such a problem if one channel is not being used or needed.

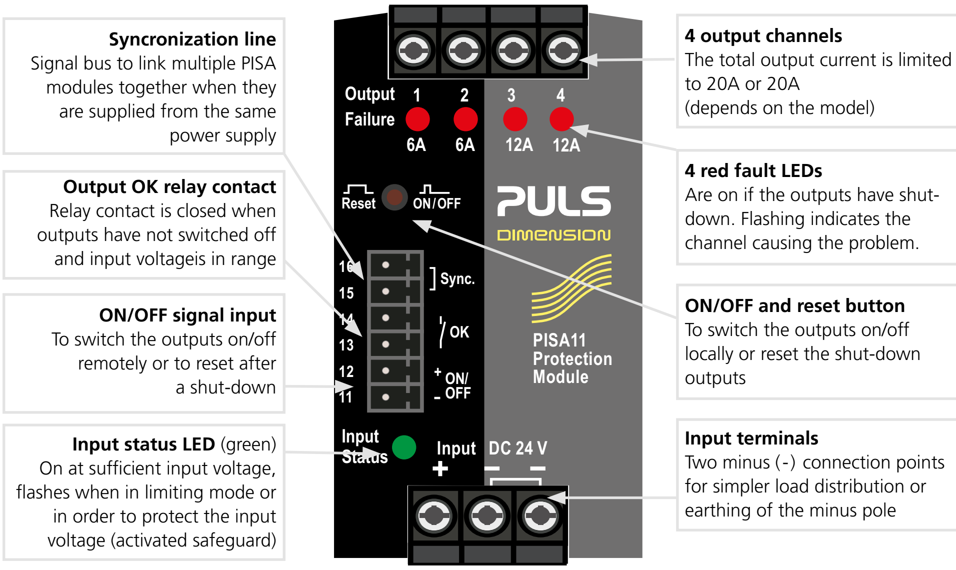


Figure 11: *Front elements on the PISA module*

At a glance: **Advantages of the PISA module**

- Cost-effective
- At least 21Vdc available for critical loads even in the event of a fault
- Protects small cable sizes against overload
- Connection of large capacitive loads possible
- Active current limitation of the output current
- Avoids nuisance tripping thanks to highly dynamic reserves
- Easy integration into systems and machinery, virtually no risk of incorrect sizing or incorrect planning
- Outputs remains switched off until the fault is acknowledged manually. No reset after cycling the input power.
- A faulty branch can be identified via a red LED.
- Targeted turn-on and shut-down of the outputs for easier commissioning and troubleshooting – either on the device itself, using buttons, or using a signal input
- Integrated relay contact for remote monitoring
- Low internal resistance, low power losses
- The current on the 24V DC power supply can be used at 100%.
- Extremely compact: four output channels require only 45mm width on the DIN rail

Correct sizing of power supply and fuse elements

Only a carefully designed power supply and fuse concept guarantees reliable protection.
With individually protected branch circuits as shown on the left side of figure 12, the inclination is to underestimate the total power requirement and to choose a too small power supply.
Electronic fuses are usually specified precisely in the tripping current, but normally need 1.5 to 1.8 times the nominal current for a fast tripping. This is an intended behavior to avoid nuisance tripping in case of short peak current demands (e.g. when a motor starts). The power supply must therefore be oversized for this "extra current" which is needed for a fast tripping in case of a fault in the system. Otherwise, the protective effect and selectivity will be questionable.

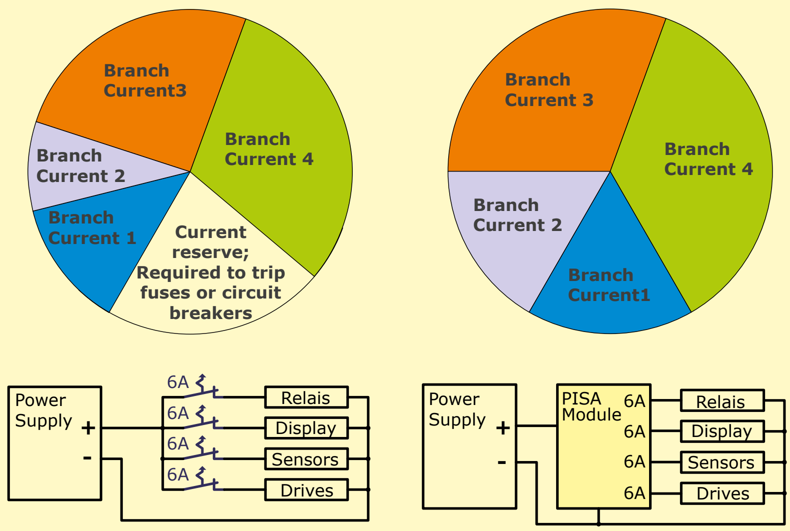
What does this mean in practise?
For example, if you have four branches two requiring 1A nominal current and two others at 3.5A each. Two electronic fuses with 2A and two with 6A would normally be chosen. In normal circumstances, 9A flows where a 10A power supply might be choosen.
If a 3.5A group then suffers a fault or a short-circuit, the 6A fuse requires 9A to trigger. This means that, together with the other three branches, the power supply must be able to supply 14.5A to shut-down the faulty branch.
The necessary current reserve is determined by the fuse with the greatest maximum ampere value and in this case is 5.5A. In practice, a 20A standard power supply would need to be used in this example, even though the nominal current is only 9A.

If a plant is modified, refurbished or extended during operation, there is a danger lurking here. At this time, it is very likely that nobody would think about the required "current reserve" any more, and the power supply is loaded up to the permitted nominal current. In the case of a branch failure, the power supply is then limiting the current before the fuse can cut-out the faulty branch.

The picture when using the new PISA module looks entirely different.
With the PISA module, no "current reserve" is required and a standard 10A power supply is sufficient. In a serious situation, the faulty 3.5A circuit would draw so much current, that the power supply will switch from voltage regulation mode into current limiting mode. The output voltage would drop, but the PISA module monitors this voltage and prevents the voltage dropping below 21V by limiting the output current. The limitation mode remains for a while before the PISA module shuts-down the outputs completely, if the fault does not correct itself during this period of time. The supply of sensitive electronic loads such as controls is then in place without interruption. This characteristic also means that incorrect sizing, as described in the previous example, is not possible.

Efficient safety concepts for 24V DC systems are not as trivial as initially suspected. A traditional approach with selective single channel fuses will work, but would be very expensive.
It is advisable to investigate the necessity for a selective shut-down of all individual branches.
In many cases, money can be saved with the new PISA module from PULS without having to taking into any risks.

Figure 12: *Choosing the right size of the power supply depending on the fuse concept*



Traditional approach:
The power supply performance cannot be used at 100% for the loads.
A "current reserve" is required to trip circuit breakers or fuses in the event of a fault.

PISA approach:
100% current for the loads.
Thanks to the supply voltage monitoring, no current reserve is needed for tripping of fuses or circuit breakers