Isolation of Faulty 24V Branches with Miniature Circuit Breakers (MCB's)

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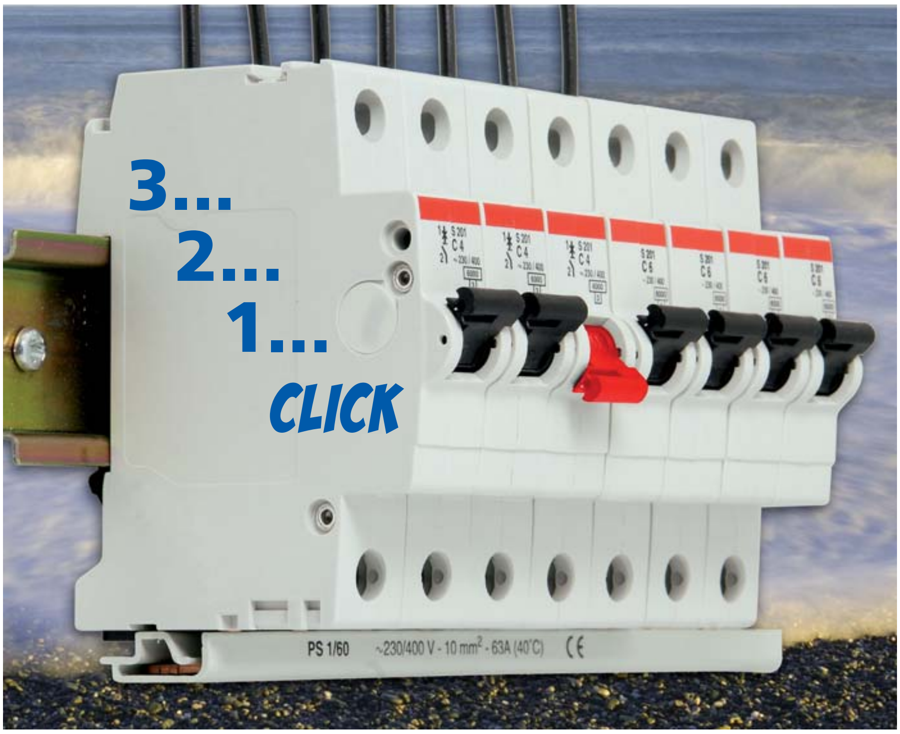
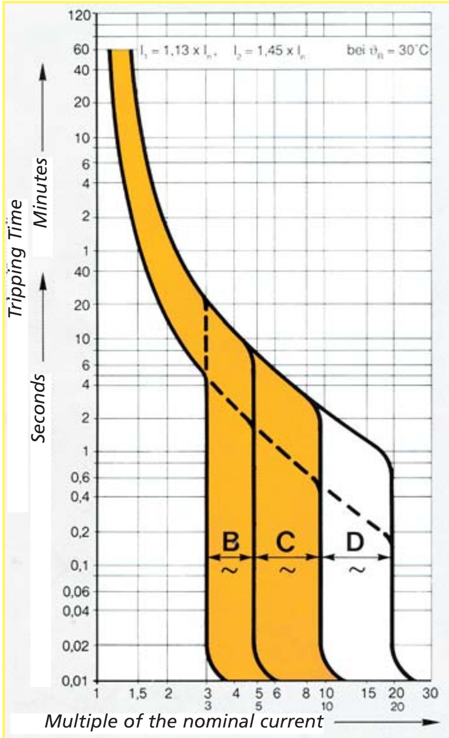
Standard miniature circuit breakers (MCB's) are without doubt, one of the most efficient and economical ways to open circuits on faulty branches.
MCB's are designed to protect wires and circuits. If the ampere value and the characteristics of the MCB are adapted to the wire size which is used, the wiring is considered as thermally safe regardless of whether the MCB opens or not.
In order to avoid an undesired tripping of the MCB by high load inrush current, MCB's allow a multiple of the nominal current for several milliseconds. However, this is in contradiction with the requirements of 24V DC circuits. A quick shutdown within 10ms is sometimes necessary corresponding roughly to the ride-through time of PLC's. This requires power supplies to deliver high current reserves and is also dependent on the impedance of the faulty branch to be sufficiently small in order for the current to actually flow.
This is not always simple, as is explained in this application note.



Modern machines and process equipment require more and more complex control systems combined with a continually increasing number of sensors and actuators which all have to be supplied with electrical energy. A voltage of 24V DC is used for the supply of these control and power circuits, normally generated from a central power supply and is distributed to the individual branches in a „parallel structure".
A common desire is for all the load branches to be individually protected and monitored so that smaller cross-sections of wires can not be overloaded and a quick fault diagnosistic and troubleshooting is possible. There should also be as few interconnections as possible with each other. If for example, a sensor cable becomes trapped in the door of a control cabinet, this branch should then be selectively isolated without shutting down the entire control system. Regulatory standards do not require such an isolation, but it is becoming increasingly common in custom specific requirements.

Quick release current from MCB's		
Characteristic	Electromagnetic tripping current (multiples of the nominal current)	
	with **AC**	with **DC**
A	2 to 3	2 to 4.5
B	3 to 5	3 to 7.5
C	5 to 10	5 to 15
D	10 to 20	10 to 30



Tripping Characteristic of MCB's
Source: ABB-Stotz-Kontakt Catalog SK4.

Circuit breakers

The simplest and most cost-effective method of protection is to use standard miniature circuit breakers (MCB's). These devices have an electromagnetic and thermal shutdown mechanism. The electromagnetic trigger value is described by using the characteristic of the MCB and there is a choice of four sensitivity categories (characteristic A to D). It is a fact that the known quick release currents only apply with AC current and can not be overlooked. In the case of DC current, the upper limit of the bandwidth of the characteristic must be adjusted by a factor of 1.5 according to the manufacturer's specifications. In practice, MCB's with B and C Characteristic are most commonly used. The A Characteristic is too quick and the D Characteristic is unnecessarily sluggish. It also does not matter if the MCB is loaded with nominal current before activation or if it was without current.
The thermal trigger mechanism is the same for all four categories. According to the characteristic curves of the MCB manufacturers, it can take between 20 seconds and 30 minutes with 1.5 times nominal current until the MCB opens the circuit.
These high currents which are required for a quick shutdown make particular demands on the power supplies with regards to the over-current capabilities. The electronic current limiting that is built into power supplies does not normally allow much more continuous current than nominal current.

Peak current capability of power supplies

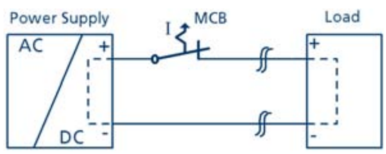
High dynamic peak currents and a continuous current flow during overload conditions have always been important features with PULS power supplies. This was further improved by the BonusPower® function in the latest generation of devices. An additional advantage of the PULS units are the large-sized output capacitors. These provide temporary additional high currents which help to activate MCB's. Although the output capacitors are partially discharged during this process, this should not cause any more interference in the event of a fault as they are only discharged for a few milliseconds. These measures often avoid oversizing of the power supplies which would otherwise be necessary.

Fault circuit impedance

The impedance of the faulty circuit is very important and is often critical. The best current reserve in the power supply unit does not help if Ohm's law does not permit current flow. Wire resistance has the greatest influence and is often underestimated. The influence of the wire resistance is best described in the following typical example:

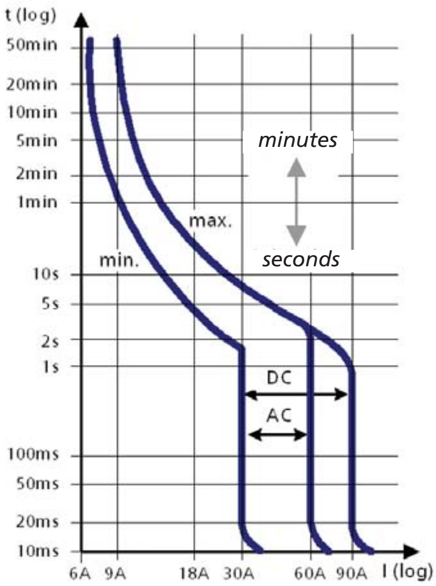
A display panel with a power consumption of 5.5 A is located 30m (total wire length of 60m) from the control cabinet. The panel builder uses a 10A power supply, a wire with a cross section of 1mm² and a 6A MCB with a C Characteristic to protect the wire and the display.
Calculation of the fault circuit impedance:

- Power supply unit (internal R)	= 30mΩ
- Connectors etc	= 20mΩ
- MCB's	= 20mΩ
- Short circuit (in the device)	= 45mΩ
- Line 50m 1mm2 (18 mΩ/m)	= 1080mΩ
Total	**=1195mΩ**



The resistance limits the current flow. Not more than the following current can flow in the event of a fault: I=U/R= 24V/1.195Ω = 20A

The 20A corresponds to 3.3 times the nominal current of the 6A MCB. The activation characteristics show that it can take between 4 and 20 seconds until the 6A MCB activates. This is provided that the power supply can deliver at least a current of 20A. A power supply that could deliver more current than the 20A (e.g. the 6 times nominal current) is of little use in this situation. As can be seen, it is virtually impossible to achieve a quick activation (within 10ms) with this length of cables. The only two possible ways to remedy this would be to use an electronic protection circuit (which are significantly faster and more precise) or to increase the wire cross-section. However, this involves significantly higher costs and expenditure.



Tripping Characteristic MCB, 6A C Characteristic

Case A:
Long wires length increases resistance and limits the current flow

Typically the resistance of the wire causes the most problems. In comparison to 230 VAC applications, where MCB's are most commonly used, the voltage of just 24V has significantly less "power" to "press" the current through the wire. If it is assumed that the power supply can deliver the required current, the maximum wire length depending on the wire cross-section can be determined via the resistance and the Ohm's law.

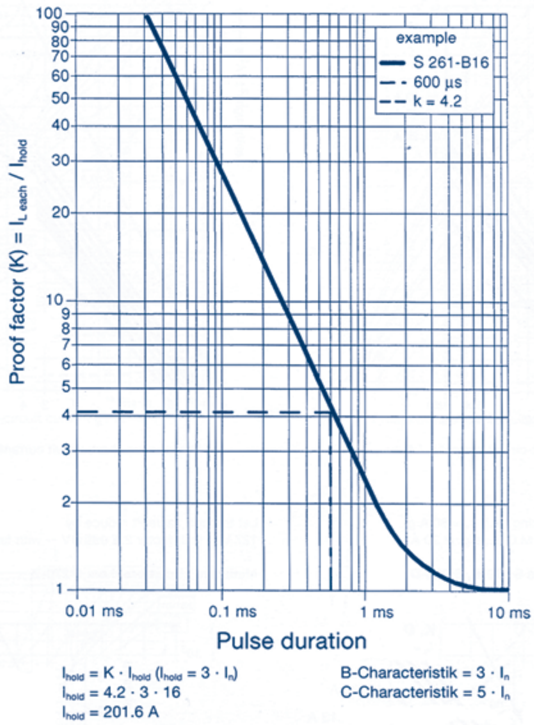
In the table below, 15 times the nominal current is adopted as the required current with the C Characteristic and 7.5 times with the B Characteristic MCB's. This represents a worst-case scenario. If this wire length is not exceeded and the required current is available, a quick shutdown can be ensured.

MCB	Required current	Maximum wire lengths *) 0.75mm²	1mm²	1.5mm²	2.5mm²	4mm²
C-2A	30A	33.0m	44.0m	66.0m	110m	176m
C-3A	45A	22.0m	29.3m	44.0m	73.3m	117m
C-4A	60A	16.5m	22.0m	33.0m	55.0m	88.0m
C-6A	90A	11.0m	14.7m	22.0m	36.7m	58.7m
C-8A	120A	8.3m	11.0m	16.5m	27.5m	44.0m
C-10A	150A	6.6m	8.8m	13.2m	22.0m	35.2m
C-13A	195A	5.1m	6.8m	10.2m	16.9m	27.1m
C-16A	240A	4.1m	5.5m	8.3m	13.8m	22.0m
B-6A	45A	22.0m	29.3m	44.0m	73.3m	117m
B-10A	75A	13.2m	17.6m	26.4m	44.0m	70.4m
B-13A	98A	10.2m	13.5m	20.3m	33.8m	54.2m
B-16A	120A	8.3m	11.0m	16.5m	27.5m	44.0m
B-20A	150A	6.6m	8.8m	13.2m	22.0m	35.2m

*) Do not forget that two wires are needed to supply a load. The distance (cable length) is usually only half the total wire length.

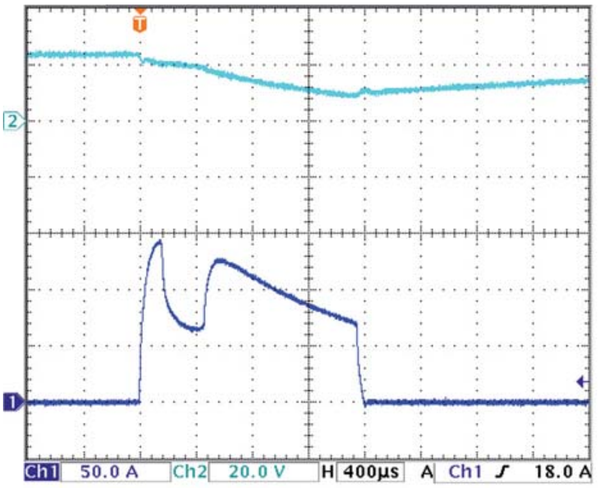
Case B:
Short and mid wire length with large output electrolytic capacitors in the power supply

If for example, the short circuit or fault occurs within the control cabinet, then the wire are typically short and the impedance of the faulty circuit is low.
Along with the tripping curves of MCB's (see diagram on page 2), there exists a pulse tripping curve which cover the time period shorter than 10ms. While higher currents are required, this situation can be handled by using the output capacitors in the power supply. The larger the capacitors, the higher the current and the quicker the shutdown occurs.
A series of test measurements show that MCB's opens between 600µs and 2ms when there is sufficient current. This delay appears to be accounted for by the mechanical sluggishness of the MCB's.



Source: ABB-Stotz-Kontakt Catalog SK4.

The following oscillogram shows this typical scenario.



These curves were established with a QS10.241 (10A) power supply and 4A C Characteristic MCB. The upper curve is the output voltage with 20V/DIV. The lower curve is the fault current with 50A/DIV. A short peak current of approximately 145A flows which is then interrupted by the MCB after 1.5ms. The slope of the voltage shows how the output capacitor is discharged. Approximately 3ms after the MCB has opened, the 24V voltage is then available again.
The output capacitor delivers the majority of the current and plays an important role in this situation. This additional current explains why MCB's often open in practice, even if the example of case A says that this should not be possible.

An over sized power supply which can deliver a higher current (even if it is just temporary) is often not needed.

In addition to theoretical considerations, PULS recommends that practical tests should be performed. The test results which can be found in the data sheets of each PULS power supplies are also a good point of reference. You should not be confused by the marketing hype from some manufacturers who have newly discovered this issue. With a little technical expertise, you can decide for yourself if the use of a MCB will provides the desired effect or if an electronic solution is required.