Protective circuits for electronics on electrical systems

Part 1: Disturbances by the electrical power systems

Overview

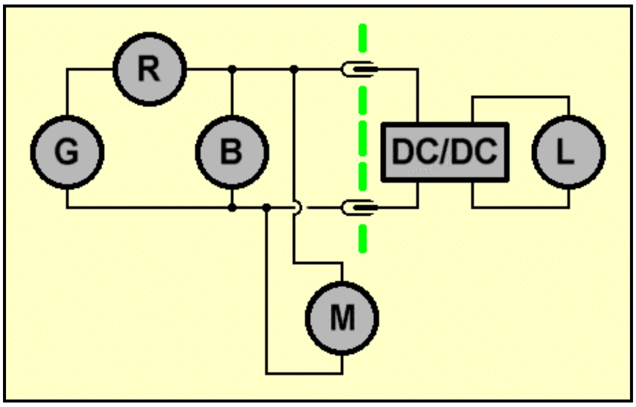
The operation of electronics (as actuation systems) on electrical power systems is endangered by disturbances. The following first part of the report describes disturbances which directly come from the electrical power system. These disturbances can affect the operation of the electronics. Based on our experiences with aviation actuation systems we present the cause for typical disturbances especially those occurring in experimental and research operation and proven countermeasures.

The operation of an actuation system utilises two different devices (in most cases): the control unit (to interface with the pilot and the actual motion of the actuator) and the power stage (to drive the actuators). The power consumption of the control unit is in the range of some watts while the power stage needs some 100 watts. The difference in the power consumption is the reason for different types of disturbances and countermeasures.

The results are also useful for other electronics operating on dc electrical systems. These are mobile applications without access to ac power outlets.

Typical set-up

An electrical power system basically consists of a power supply and several loads. The power supply itself consists of a generator G, a battery B and a regulator R in between. Typical loads are the control unit L (with an isolating dc-dc converter) and the motor M (with a non-isolating power stage). In this report we will focus mainly on devices as sketched on the right side of the green line.



Although everything operates on a nominally constant dc voltage it is typical that substantial deviations can occur with both higher and lower voltages, even with disruptions. Depending on the operation area there are different standards and requirements which cover the operation of equipment. Typical standards are RTCA DO-160 (for aviation) or MIL-STD-704 (for military vehicles).

Causes for disturbances

Different to the public ac power outlets the power systems on mobile platforms are generally just sufficient. The low dc voltage level (of typically 12V/14V or 24V/28V) generates much higher currents for the same electrical wattage compared to ac power outlets (with 110 V or 230 V). High power loads can cause a drop in the voltage level. The power system is usually designed to tolerate this. But all other loads are also affected.

The most powerful loads are in most cases electrical motors (e.g. electrical powered hydraulic pumps for the landing gear operation or the engine starter). When these motors are activated the electrical system can drop significantly (especially under unfavourable circumstances as low temperature or aged battery). On the hand: when these motors are stopped the voltage can bounce severely in the other direction as the voltage regulator has a certain time delay until establishing a steady voltage.

Typical disturbances

Power systems with battery backup can cause disturbances which affect equipment. For safe operation the impact of these disturbances must be reduced. Typical disturbances are::

- voltage drops or disruptions
- slowly rising voltages at power-on
- over-voltages

Other stresses or dangerous conditions (by electrostatic discharge, wrong polarity, wrong voltage) are not handled in this report.

Threat by voltage drops

The strategy against voltage drops depends on the necessary amount of energy: small loads can use a capacitor, while heavy loads need a second redundant power supply.

Additional measures to reduce the power consumption as the switch-off of specific heavy loads makes only sense in an emergency situation, together with a appropriate strategy to consume the remaining energy.

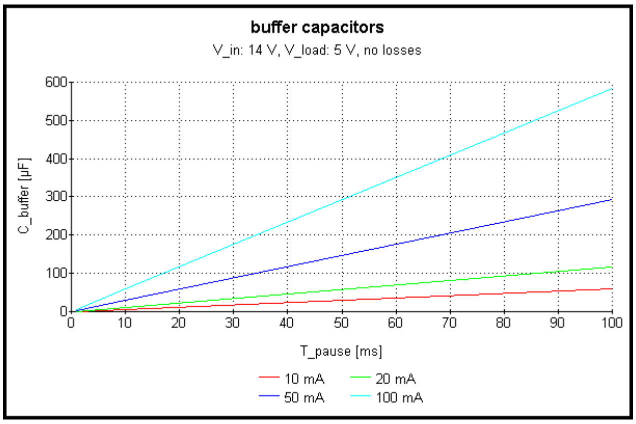
Buffer capacitors

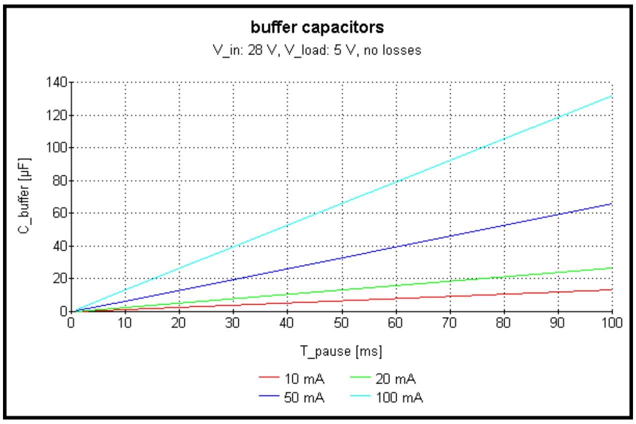
A often useful strategy against voltage drops are buffer capacitors.

With simplifying assumptions (e.g. no dissipation) we can calculate the necessary capacitor size depending on the duration of the power disruption and the load current. The diagrams are for a load voltage of 5 V and a power system voltage of 14 V or 28 V.

The diagrams clearly show that even with small currents and short disruptions the volume of the necessary capacitors can exceed the size of the device to supply.

So we need the best compromise between the buffer requirements (hold-up time and current) and the available space to achieve the necessary reliability.





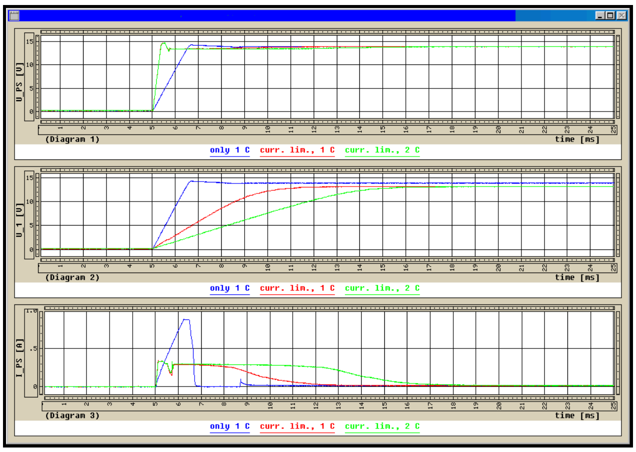
Low power loads (e.g. sensors)
To buffer low power loads (e.g. sensors) capacitors often suffice. The use of electrolytic capacitors widespread as this type allows for reasonable capacity. For high-reliability applications many electrolytic capacitors are less suitable, and the alternatives need more space.

On the other hand the more appropriate technologies for high-reliability applications (as ceramic, tantal, film) also have some features to be familiar with as some types tend to catastrophic behaviour (shorts, fire). Again: the countermeasures need even more space.

High power loads (e.g. motors)
The reliable operation of high power loads (e.g. motors) demands in most applications (or protection scenarios) the presence of a redundant power supply, consisting of back-up batteries and/or a second power generator.

Contrary to capacitors this is a maintenance intensive solution, further complicated by supervisory and switch-over electronics.

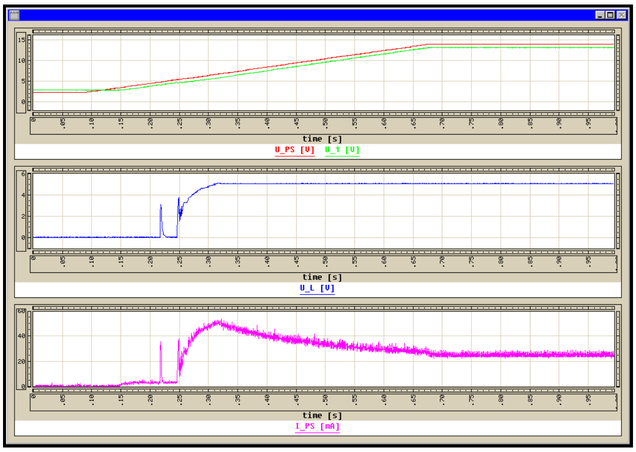
Side effects of buffer capacitors
The use of buffer capacitors has side effects. There is especially the current peak immediately after switching on the device. The current charges up the capacitor to the operational voltage. The inrush current is by orders of magnitude higher than the normal operational current. And when several devices are switched on together the current can trip the protective fuse. This behaviour is also very sensitive to the ambient temperature.



A useful countermeasure is an active inrush current limitation, as the picture of experimental measurements shows. In the case “only 1 C (blue)” a buffer capacitor is directly connected to the power system and is charged directly, creating a huge inrush current. In the case “current limiter with 1 C (red) the same capacitor is charged with a limited current. This procedure takes more time. In the case with another buffer capacitor "current limiter with 2 C" the peak current remains the same.

Threat by slow switch-on

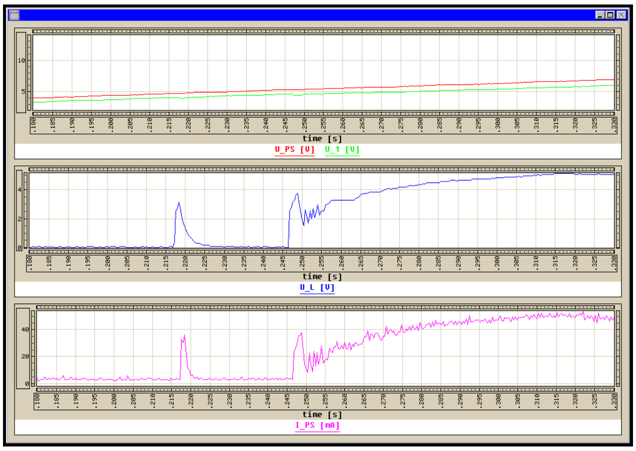
Another side effect of buffer capacitors is the finite ramp-up time of the supply voltage fed to the protected device. Some ICs or sub-components require a specific power procedure. At least the voltage rise has to be fast. More complex devices have several supply voltages and require a very tight power sequencing scheme.



Many cases can be solved by a supervising circuit which senses and waits until a sufficient high charging level is reached and then switches on the sensitive device. The supervising circuit is called "undervoltage lock-out (UVLO).

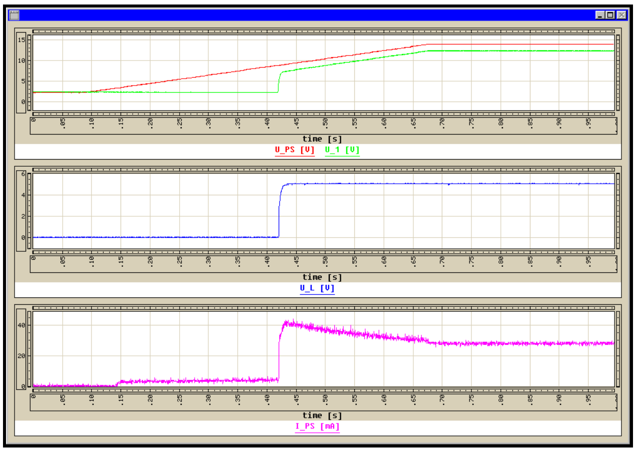
The pictures with measurements highlight the problem.

In the first picture the voltage of the power system ramps up slowly, but not unusually. The dc-dc converter connected to the power system starts for a short time (visible as the load voltage [blue] starts), but then collapses. When the power system voltage reaches a higher level the dc-dc converter starts again and stays active.



The second picture zooms the two starting procedures of the dc-dc converter. It shows that the converter starts for some milli-seconds during which the devices it supplies can come to an unsafe state.

The third picture shows the behaviour with an undervoltage lock-out circuit. The voltage is not fed through to so following load until a save level for operation is detected. The load voltage of 5 V is stable from the beginning.



The data sheet of the commercial standard dc-dc converter does not mention the sensible behaviour with slowly rising voltages. In fact, this "hick-up" behaviour was the reason for a time consuming debugging investigation. It shows that laboratory tests are essential, as the countermeasures are.

Example: Operating a motor

As stated before the reliable operation of a motor (e.g. as part of a control actuation system) with pure electrolytic capacitors is not recommended. Instead it requires a second power system (generator and/or batteries) and a switch-over device.

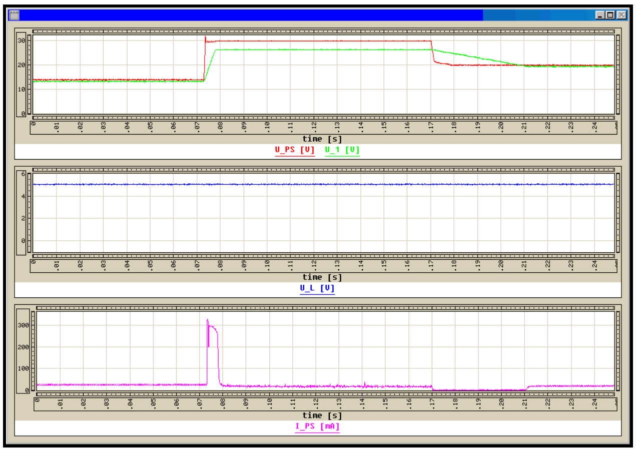
But the power stage of the motor also requires some capacitors, with the same potential problems at power-on. So these capacitors also have to be charged in a controlled procedure.

The operation of the power stage requires a certain size of capacitors. So the uncontrolled inrush current again is several times (or even magnitudes) bigger than the operational current. Without inrush current limiter it is probable that stresses happen, even over-stresses and catastrophic failures.

Threat by over-voltages

It is quite usual with generator-battery power systems that over-voltages occur which can reach many times the nominal voltage levels. Experience shows that without countermeasures these voltage levels can cause catastrophic failures. A safe operation requires a protective circuit to limit the over-voltage without disturbing the normal operation.

The picture shows the behaviour of the dc-dc converter with the on-board electrical system voltage (red) rising from 14 V to 30 V (according to RTCA DO-160 “Abnormal surge voltage”). The protective circuit limits the load voltage to 27 V (green), which is a safe level for the dc-dc input voltage, as opposed to the 30 V level. The dc-dc output voltage for the load (blue) remains stable at 5 V. At the beginning of the over-voltage event the input current (magenta) rises sharply, but remains within the safe operation area because of the current limiter circuit (again).



Even this rather small load requires an active protection circuit. The application of passive components (as Zener diodes or comparable components) fails because of the level of dissipated power and the duration of the disturbance.

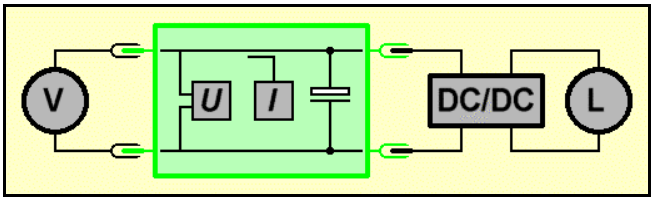
Usually we (the actuation system designer) can not influence the power output of the on-board power system, and this is the usual situation. So we must store the excess power (in capacitors, creating new resp. old problems) or we can dissipate the power by converting it to heat. The heat capacity limits the duty time, but also the repetition rate.

For the self-protection of the power stage the use and monitoring of temperature sensors is recommended, especially when frequent high-load conditions are to be expected. This is especially the case with experimental and research operations.

The verification should start in the laboratory as described in the examples.

Technical realisation

It is ideal to put all protective circuits into the electronic devices themselves. If not possible we can position a protective device between the on-board power system and the electronic device. Especially with standard devices (COTS: commercially “off-the-shelf”) there is often no specific or not sufficient protection included, as the previous measurements showed.



The protective device can be retro-fitted and supervise the on-board power system, both voltage and current. The protective device can also include the back-up capacitor. So the most important disturbances from the power system can be kept away from the load devices. But also other failures as shorts in the load can be detected and isolated, especially in experimental or research operations. To signal the overload condition LEDs are useful so the user gets a clear feedback.

It is possible to design the protective circuits with highly compact specialised integrated circuits. Practical experience shows that the availability over several years is not always guaranteed, especially not with continual research programs where damages may occur. So it makes sense to avoid a too special choice, though this will take more space.

Discrete components (as opposed to integrated circuits) are also better in customising the protective circuits to the required task, enabling a better adaptation to both the on-board power system conditions (the types of disturbances) and the specifics of the device to protect (e.g. operating current). This adaptation is also useful to reduce the extreme thermal stresses which occur while protecting the device.

Example: flight control system

It is instructive to show the combination of protective measures and the core actuation electronics to form a reliable component. Not only the development effort is remarkable, the necessary space is also important.

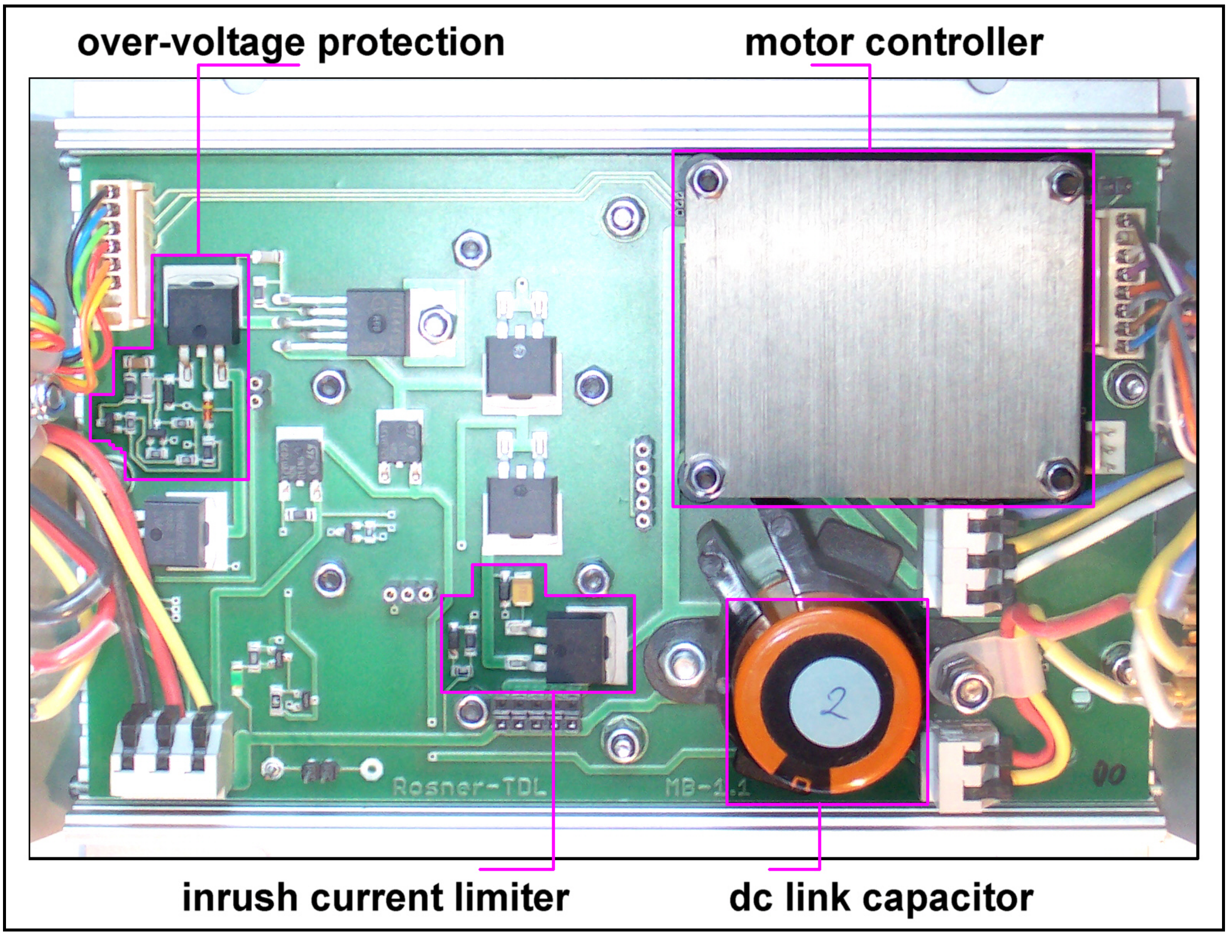
It is recommended to add the protective circuits (or sub-circuits) rapidly to gain a true picture of the space necessary to achieve the necessary level of protection.

The example makes clear that the design of the protective measures has a strong influence on the development effort and the space budget. So it is wise to tackle both from the very beginning.

Especially the space is in the aviation industry a precious good and it is vital to use it carefully, always keeping in mind the necessary reliability.

The photograph shows the central electronic board from the actuation electronic unit for an actuator (with BLDC motor with resolver commutation), acting in a flight control system (research program together with Stemme AG, Strausberg). In the photograph four areas are highlighted:

1. the core of the actuation system electronics: the motor controller,
2. the DC link capacitor, which is a protective component, too,
3. the over-voltage protection: active device against disturbances from the power supply system,
4. the inrush current limiter, which is mandatory because of the size of the DC link capacitor.



Some of the remaining components are also protective measures, but not part of this report.

Norbert Rosner
Actuation Systems

phone: +49 (0) 58 27 / 97 09 81
fax: +49 (0) 58 27 / 97 09 82

Neue Strasse 3
D-29 345 Unterluess
Germany

E-Mail: rosner@rosner-tdl.de
Internet: www.ROSNER-TDL.de