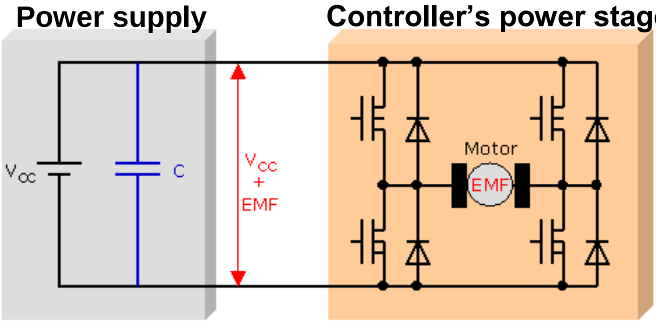
Energy recovery during motor operation

A motor might not just consume energy. It can also generate energy when it comes to the point that a load has to be decelerated. There is energy reversed from the motor (which is operating like a generator during deceleration) to the power stage of the motor controller. The motor controller reverse this energy mainly into the power supply (or battery) then. A limited amount of reversed energy can be buffered by internal capacitors of the motor controller and power supply. If there is a long phase or lot of energy recovery present (e.g. like in case of a crane or lift moving downwards with a load or in case of a high inertia like a centrifuge), the buffering might not be possible anymore and the supply voltages increases by this. It is possible that the power supply switches off (for some 100 milliseconds) again and again to protect itself or the the motor controller might report an “Overvoltage” error state and disables the power stage, i.e.there will be no controlled deceleration possible anymore.



The maximum occurring voltage depends to a high degree on the supply voltage V_{cc} and the speed n(0) at the beginning of the braking. Further influencing factors are the total mass inertia J_{tot} and the achieved deceleration rate a_{brake}.

- **n(0): Speed at start of deceleration**
  The speed at the beginning of the braking process defines how much energy must be dissipated. Limitations of covering reversed energy will be reached quite fast if the speed is quite high and the corresponding voltage level (= speed x speed constant) is in the range of the power supply’s voltage or the maximum voltage of the motor controller.

- **V_{cc}: Supply voltage**
  If the voltage by the power supply is already in the range of the maximum supply voltage of the motor controller, an “Overvoltage” error state can be triggered quite quickly in case of energy recovery and a rising supply voltage by this.

- **J_{tot}:Total mass inertia**
  On one hand, the total mass inertia is part of the kinetic energy which has to be braked: The higher the kinetic energy, the higher the supply voltage increases due to the energy recovery. On the other hand, a high mass inertia (like in case of a centrifuge) means that the deceleration cannot take place too rapidly: To a great extent the energy might can be dissipated in the motor winding or by the controller itself in case of a slow ramping down.

- **a_{brake}: Deceleration ramp**
  The deceleration ramp depends strongly on the maximum motor current of the power stage and on the mass inertia. The deceleration can be reduced by setting a current limitation or by setting the "maximum acceleration" parameter in case of motor controllers like maxon’s ESCON or EPOS. The energy recovery is split over a longer period of time then and can be better consumed by the controller as a permanent consumer, as motor losses, or by the power supply.

Energy recovery gets often a topic in case of highly dynamic applications demanding for high speeds, high supply voltages, and fast set value changes.

Especially in case of vertical applications (e.g. cranes, lifts) without sufficient friction or self-locking gears or in case of a high mass inertia (e.g. centrifuge) a remarkable amount of energy can be generated during a downwards movement or deceleration phase until standstill.

Typical applications or systems where energy recovery gets a topic:

- Crane or lift applications
  in case of moving the load downwards.
- Centrifuge
  because of the high inertia.
- Direct drives with a high inertia (= big rotative diameter) of the load
  e.g. disk-shaped or cylindric load
- Mechanical systems with a lowfriction and / or external force in one direction
  e.g. vertical axis, spring-loaded drives, hydraulic or compressed loads, …
- Systems with a compact or wall wart power supply
  e.g. power supplies which are typically in use for home or office applications.

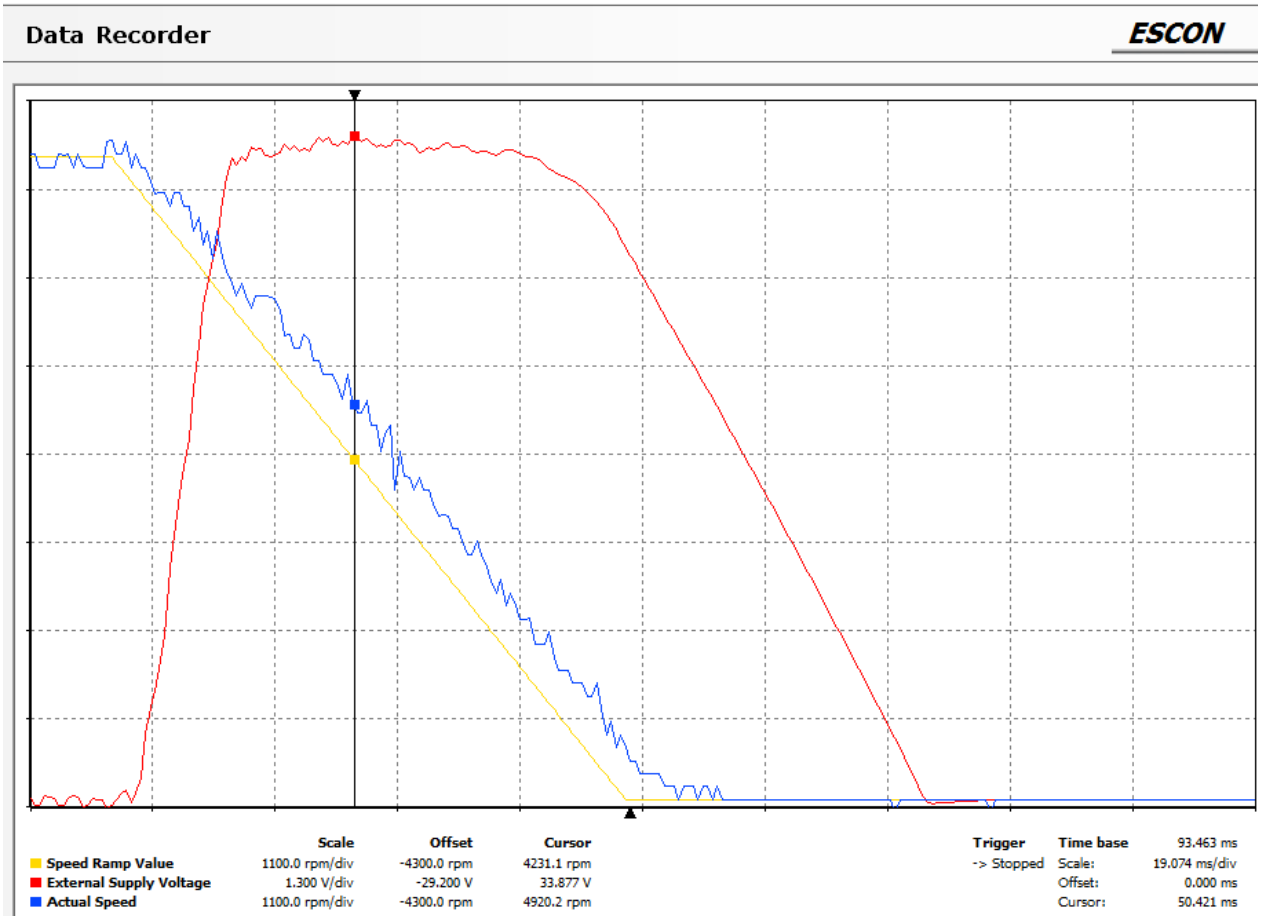
Typical signs of a too high energy recovery:

- Error states during control parameter tuning.
- Short supply voltage break downs of the power supply (in the range of some 100 milliseconds)
  which can just be detected by an oscilloscope.
- “Overvoltage” error messages of the motor controller
  esp. during deceleration phase or a vertical movement downwards.
- Instable control or error messages / problems
  during deceleration or a vertical movement downwards.

Evaluation of a voltage rise:

ESCON Studio's "Data Recording" tool can be in use to measure the supply voltage during the deceleration (or any other movement) phase of the controlled drive.

Screenshot of maxon's ESCON Studio "Data Recorder" tool:
(Diagram showing the supply voltage reaction in case of a sharp deceleration.)



Curve data:

- Yellow: Speed Ramp Value (configured for 100000 rpm/s deceleration)
- Blue: Actual speed (with some noise due to pulse-count measurement)
- Red: Supply voltage (Base line = 24V DC, Maximum value: 33.8 V)

Finding:
The supply voltage increases from 24V DC up to 34V DC during deceleration due to energy recovery.

Different measures to cope with energy recovery

There are different single or combined measures which can help to cope with a high amount of energy recovery, e.g. by buffering the energy or consuming it by other components.

One challenge is quite often that it is difficult or even impossible to estimate the amount of reversed energy and the system's reaction because there are lots of different influencing factors within the total energy chain (consisting of the power supply, motor controller, motor, load) and the resulting energy (depending on speed and inertia or external force). Finally there is always some testing required to prove that one single measure or a combination of different measures can limit the rise of the supply voltage below a critical limit and prevent an "Overvoltage" error state in case of a concrete application and motion profile.

1.) **Selection of the power supply**

The power supply within a motor control system is often underestimated although it is the initial link of the power chain which has to provide energy but also has to buffer energy in case of high dynamic motor applications.

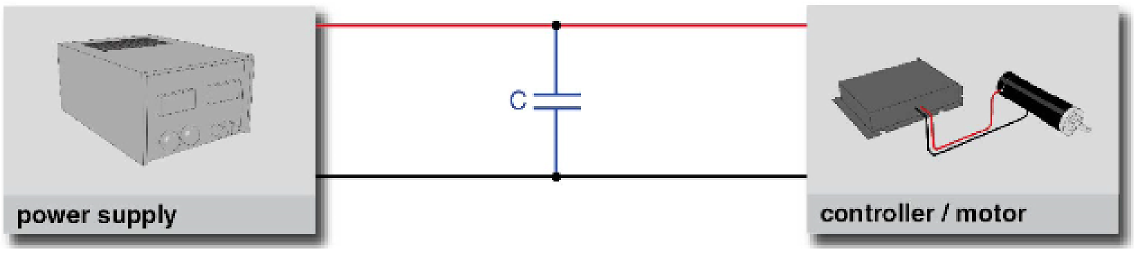
Power supplies in use by home or office applications (e.g. notebooks) seem to be an attractive choice concerning the compact size, high current output, and a low price. Actually such compact wall wart adapters or notebook power supplies supplies are not(!) suitable for motor control applications. Quite often these power supplies are the root cause of error messages like "Overvoltage", "Undervoltage", or problems during tuning or in case of a disappointing control during operation.

Compact-sized power supplies are often designed for products consuming energy (like notebooks) which do not reverse energy. These power supplies have just small internal capacitors which cannot take any reversed energy. The supply voltage increases even at a very limited amount of energy recovery. The power supply might switch off then or the motor controller reports error states or the control gets instable. The use of power supplies designed for industrial applications is generally recommended. Some of these are even optimized for motor applications. These power supplies have big internal capacitors to provide additional energy during acceleration and to buffer reversed energy during deceleration phase.

Conclusion:
A proper choice of an industrial power supply with sufficiently dimensioned buffering capacitors can already solve problems and error messages caused by reversed energy.

2.) **Additional capacitors**

An external capacitor in between the supply lines close to the controller can help to buffer the reversed energy and prevent a fast voltage increase. Typically there are capacitors of 47000 µF capacitors in use for that. It is important that the capacitor’s voltage rating can cope with the maximum supply voltage level plus some reserve (of at least 20-50%), e.g. use at least a 47000 µF / 70V capacitor in case of a 48V supply.



3.) **Mixing power consumers and "generators"**

Best case will be if a common power supply is in use for multiple devices, e.g. motors operating in deceleration phase while other devices (or motors) consuming the reversed energy.

There is no need to use different power supplies exclusively for single drives. This is even a drawback. A mixture of motors in different motion states (i.e. not all of these decelerate at the same time) supplied by one common powerful supply offers a good balance of "generators" (reversing energy) and "consumers". Finally this results in a high energy efficiency and there might be no need and no extra costs for additional energy recovery measures.

4.) **Configuration of deceleration profiles**

a) **Deceleration ramp**

If the slope of deceleration ramps can be reduced without any drawback concerning application requirements, this can reduce the supply voltage rise and solve “Overvoltage” problems without any additional measures in the best case.

b) **Multiple decelerating drives**

The biggest amount of energy is always returned at start of deceleration because it is still the state of full speed then. The energy is proportional to the inertia and speed^2.
If there are multiple drives in use within a system and all of these are starting deceleration exactly at the same time, this results in an accumulated high initial peak of returned energy. If it is possible to start the deceleration phase of each motor just a little bit time-shifted, the total amount of energy is averaged more constant over a longer period of time and the accumulated high energy peak at start is reduced.

5.) **Supply voltage**

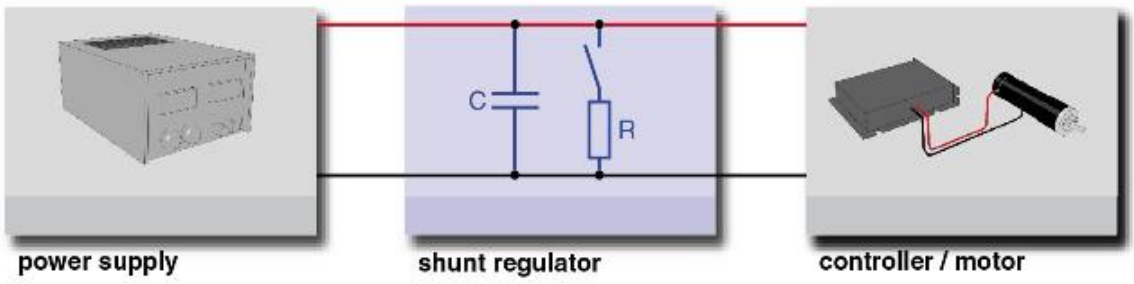
The difference in between the power supply voltage and the specified maximum supply voltage of the motor controller defines the margin before “Overvoltage limit” of the controller is reached. If an “Overvoltage” message is present due to energy recovery, it is recommend to aim for a difference of at least 10 Volt in between the supply voltage and the maximum specified voltage of the motor controller.

If possible, the supply voltage should be reduced by adjusting it more closely to the maximum required speed depending on application requirements. There is a general rule of thumb to estimate the minimum supply voltage:
Supply voltage = (Max. speed requirement / Speed constant of the motor) x 1.2

Another possibility will be to choose a motor controller offering a higher maximum supply voltage (e.g. 70V instead of 50V) and increasing the margin in between the power supply voltage (e.g 50V) and the “Overvoltage” error state.

6.) **Brake chopper / Shunt regulator**

If some or even all of the mentioned measures still cannot fully solve the problem due to the amount of reversed energy, one or more shunt regulators (or so-called brake choppers) have to be installed to consume the reversed energy, e.g. "maxon DSR 50/5" (#309687) or "maxon DSR 70/30" (#235811).



There can be one shunt regulator in use for multiple drives depending on the amount of reversed energy. The shunt regulator has to be placed in the supply voltage line in between the power supply and the controller.

maxon shunt regulator DSR 70/30 (#235811):

www.maxonmotor.com/maxon/view/product/accessory/chopper/235811

maxon motor

maxon motor control — **Shunt Regulator DSR 70/30**

Order Number 235811

Operating Instructions — **August 2005 Edition**

The Shunt Regulator DSR 70/30 is designed to limit the supply voltage of the amplifier. The adjustable threshold voltage allows a great voltage range to be covered.
The Shunt Regulator is an article from the supplementary product line of maxon motor control.

Putting it into operation is very easy; additional equipment is not required.

In normal operation the value of the supply voltage is appointed by the power supply.
4-quadrant amplifiers are able to feed back brake energy into the supply and therefore work like a generator. Thus a long braking process can cause the supply voltage to rise due to the fed back energy.
The task of the Shunt Regulator is to limit the voltage increase up to a permissible value and to transform the excess energy into heat.