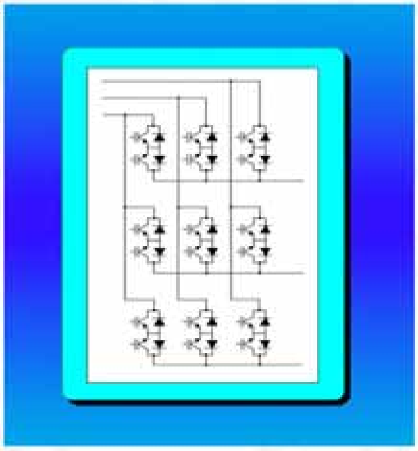


Energy Regeneration

INDUCTIVE COMPONENTS AG

V05/08

HighTech aus Deutschland

Introduction

Often motor-driven dynamic systems with either large, rotating masses or used for moving heavy weight loads, build up high levels of kinetic or potential energy so that when they are required to decelerate or stop then this presents a problem. The motor is required to run in reverse and operates as a generator of electrical energy which has to be diverted or dissipated. One simple method of doing this is to feed the surplus electrical energy into braking resistors which converts it into heat energy. Examples of systems that store kinetic energy are centrifuges, press-brakes, wind turbines, large fans and trains, whilst examples of potential energy sources are lifts, escalators and cranes.

Now that electrical energy is becoming a more precious commodity it is essential that as much of this as possible is recycled by feeding it back onto the supply network – a process known as regeneration. However, braking resistors may still be required as a back-up method when the supply network is not able to receive the regenerated power, such as in the case of power failures, incompatible voltage levels, or for safety critical situations.

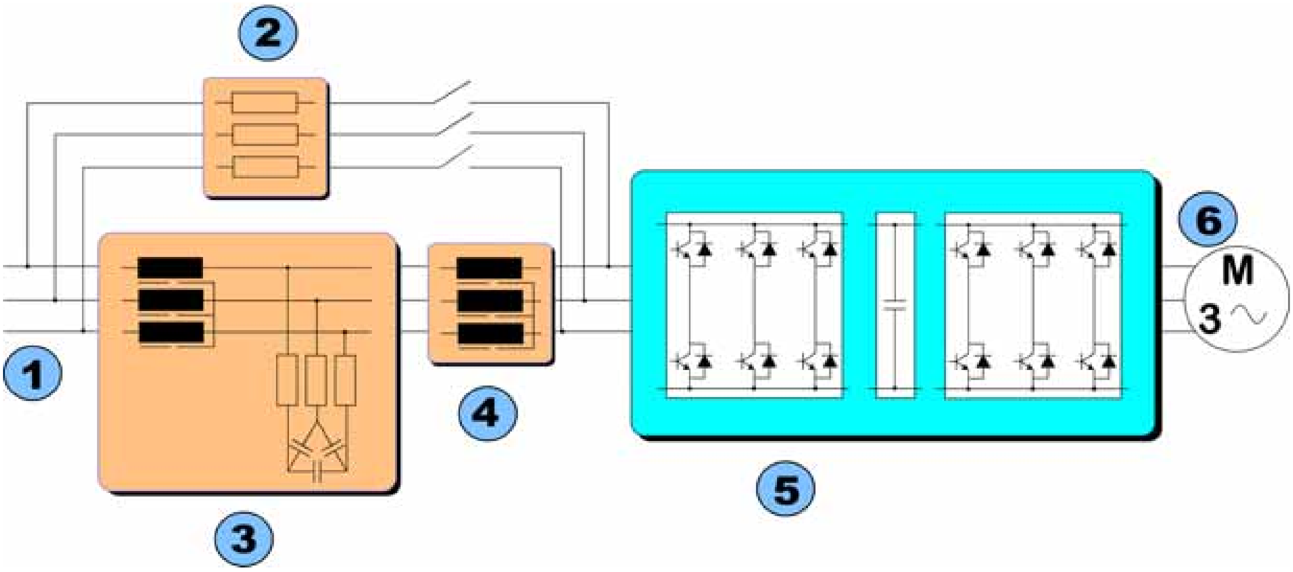
With the increasing use of controlled converters connected to the front end of frequency inverters (forced commutated bridge using GTOs or IGBTs controlled with PWM switching) it is becoming much easier to feed surplus power back onto the mains network because the electronic power control system can control the current flow in both directions, using the power semiconductors to control when the current is switched on and off, on both the load and mains network sides, unlike an uncontrolled rectifier bridge (naturally commutated) which relies on the current to pass through a zero-point to switch off its thyristors. There are other advantages in using such a system, e.g. the switching pattern of the controlled converter can be used to smooth the current during the charging and discharging of the capacitors in the DC link circuit and can also help with the reduction of mains conducted harmonic currents on the supply network side of the system.

With the introduction of new regulations such as the European EuP Directive 2005/32/EC (Eco design of Energy-using Products) the onus is with designers and manufacturers of electrical equipment to ensure that their products are energy efficient. Some governments also offer incentives such as grants to installers of “green” equipment. Therefore, it is only a question of time before regeneration of energy becomes commonplace in both domestic and industrial environments.

Picture of REO regenerative sub-system

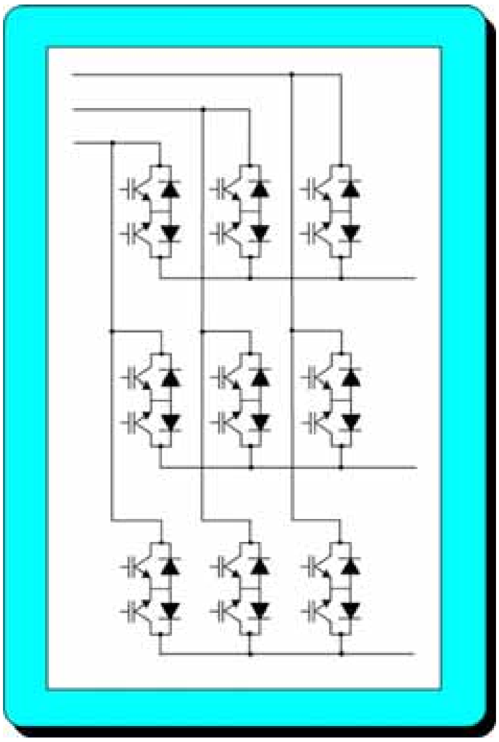
A typical regenerative power grid connection system

In the following example of a regenerative converter there are four major components that are connected between the power grid and the converter, which is also connected to the load; in this case an induction motor. A back-to-back frequency inverter has been selected for regenerating electrical power back onto the grid.



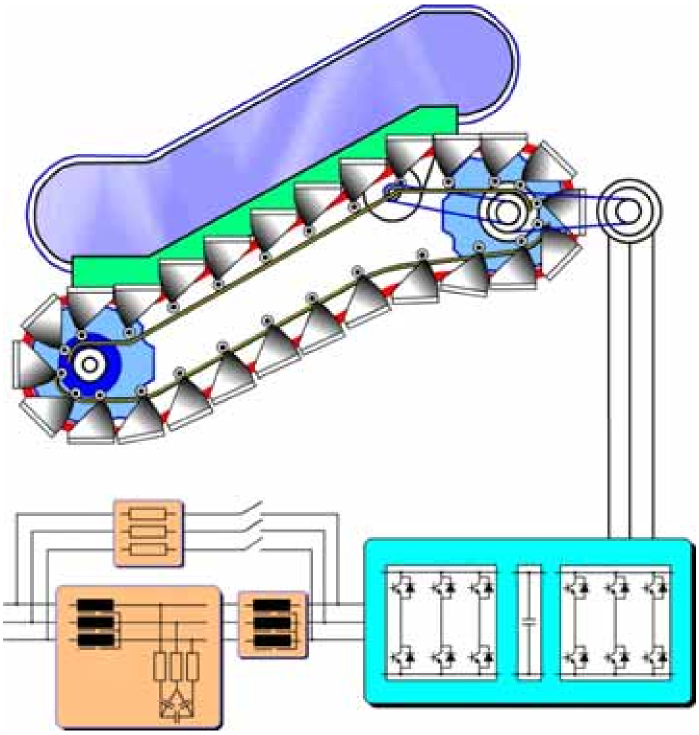
1) Connection to the public supply network via a standard EMC filter for removing conducted interference.
2) Load resistors that are switched in circuit when the frequency inverter is first started to reduce the current inrush and protect the DC link capacitors as they charge up.
3) Filter for removing harmonic frequencies on the current sine-wave when power is being regenerated from the load to the mains network.
4) A separate booster-reactor which increases the DC link voltage, thus allowing current to flow back onto the mains network.

The matrix converter



Unlike back-to-back inverters, matrix converters do not require a DC link with large capacitors because they convert three-phase AC directly into three-phase variable AC. However they do require 18 fully-controlled power switching devices and eighteen fast diodes, whereas back-to-back inverters only require 12 of each component. Hence matrix converters are much more expensive to produce but provide a better regenerative power capability. There is also a problem with the voltage transfer ratio which is limited to 86% of the input voltage which means that standard motors cannot be used on a standard supply. The big advantage of matrix converters is that they have inherent bi-directional power flow with four-quadrant voltage-current characteristics on both sides and input and output currents are sinusoidal.
Matrix converters require an input filter to circulate switching frequency harmonics and some current commutation methods use an auxiliary resonant circuit to achieve safe commutation.

Regenerating electrical energy from an escalator



Lifts and escalators are two good examples of where electrical energy can be converted from potential energy. When passengers are being transported from a high to a low level the drive motor acts like a generator and the surplus energy can be converted into heat by using dynamic braking resistors or it can be fed back onto the public supply network, which is obviously more desirable if the additional cost of a more sophisticated drive system can be justified for the application.

Design considerations

- When using a regenerative system special care has to be taken to ensure that the quality of the regenerated power is of sufficient quality to be accepted onto the grid and that the grid is fully protected from short-circuits and disturbances.
- The value of the capacitors for removing harmonics must be carefully calculated to ensure that together with the distribution transformer they do not create a resonant circuit.
- The frequency drive topology and hardware can influence the choice of filter components and each of the following have to be carefully considered:
  - The kind of modulation and modulation factor of the drive
  - Regeneration switching frequency
  - Impedances of the drive and the supply
  - Cable length
  - Special drive features (circuits to increase DC link voltage)
- It is also important to remember that the mains network may not always be free to accept regenerated electrical energy due to unscheduled power cuts or other unforeseen problems. Therefore a braking resistor will almost certainly be required for stand-by dynamic braking or for emergency situations.

REO INDUCTIVE COMPONENTS AG can help with the design and selection of components that are the best solution for your application, using engineering expertise, wide experience in all industries and specialised manufacturing skills.

Regenerative systems in trains

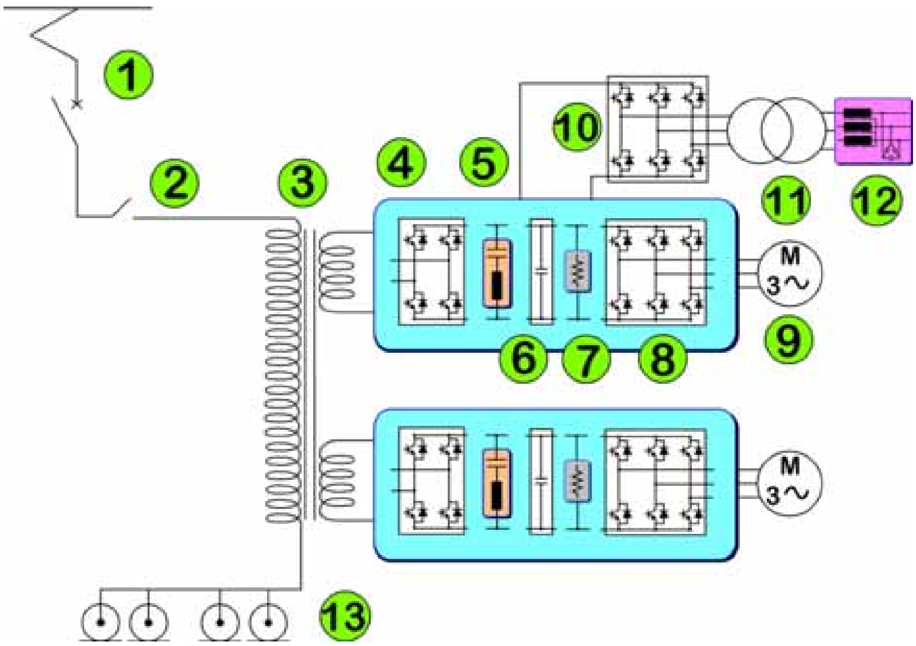
Trains during normal operation are required to stop quite frequently and sometimes quickly. The kinetic energy can be dissipated into friction brakes assisted by dynamic braking resistors to reduce wear and tear on mechanical components. With DC electrified railways, it is not possible to return power to the National Grid but if other trains are motoring on the same section (which is detected by measuring the supply voltage to make sure that it doesn't increase as the train regenerates power) then the power can be transferred. When another train isn't on the same section then braking resistors have to be used to dissipate the surplus energy.

On AC electrified railways regeneration is somewhat more complex but becoming increasingly achievable with the use of a controlled silicon rectifier. However, because the AC overhead power lines are fed from different phases of the National Grid and the wire is fed in distinct sections with an isolating section of wire known as a neutral section at regular intervals along a route which are non-receptive to regeneration. Along these sections a dynamic braking resistor is required for when the train is required to slow down.

In all systems it is useful to use regenerated power when normal power is not available from the overhead cable and particularly when the train has to be brought to a controlled stop with all emergency, lighting and communication circuits operational.

Diesel-electric locomotives are only able to use braking resistors.

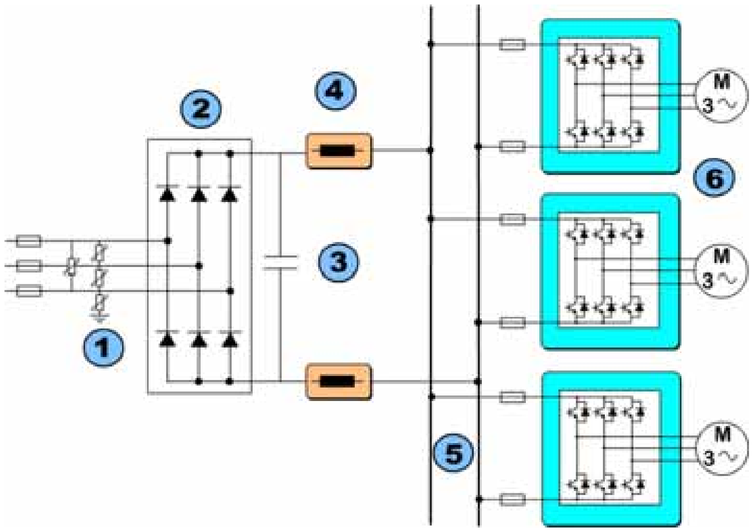
A typical AC Train System



1) 15kV 16.67Hz or 25kV 50Hz pantograph connection to overhead conductor
2) Short-circuit protection breaker
3) Step-down transformer
4) Four-quadrant chopper for converting AC to DC
5) Resonant LC filter to reduce 5th harmonic and smooth the DC for use by the frequency inverter
6) DC link storage capacitors for smoothing voltage
7) Braking resistor
8) Frequency inverter
9) Three-phase traction motor
10) Auxiliary frequency inverter
11) Auxiliary transformer
12) Filter for removing common and differential mode radio interference
13) Supply return through contact between the bogies and rail

The DC Bus System

Another way of regenerating electrical energy can be used with multiple frequency drive systems. By connecting the DC links of several drives together this allows regenerated/braking energy from one drive to be used by another motoring drive. This improves the efficiency of the system, since not all of the regenerated energy is wasted in heat generated from braking resistors and less power is drawn from the supply network. This can be particularly advantageous if one of the motors in the system is being used to provide tension in a line. Many DC bus systems are used in high-performance servo-drive applications where substantial amounts of energy are used in accelerating and braking drives.

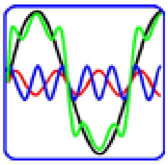


1) The varistor network on the input phases provides protection against line-line and line-earth voltage surges.
2) The use of a bulk input converter is preferred if the installation requires drives of different ratings to be connected together.
3) A high-voltage polypropylene capacitor should be fitted across the terminals of the rectifier module because this helps to reduce reverse recovery voltage spikes and can also provide a path for RFI currents in applications where long cable runs are required.
4) The DC link chokes of standard drives tend not to be in circuit if the drive is supplied with DC and hence it is necessary to have an external choke which is rated for all of the drives connected to the DC link. Splitting the inductance equally between the positive and negative DC link can provide some impedance to limit fault currents if an earth fault occurs in either the positive or negative DC link. The DC link inductance should be selected to keep the DC link time reasonably constant.
5) The DC bus is connected to all inverters.
6) Inrush current limiting is not required if the individual drives have their soft-start circuits (inrush resistors and relay/contacts) in circuit until the DC link voltage is at its correct level.
7) It may still be necessary to have a resistor for fail safe braking requirements.

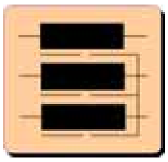
An example of REO Powerpack – 32A water-cooled filter/choke/braking resistor platform, with mounting space for power semiconductors

A selection of components available from REO INDUCTIVE COMPONENTS AG

Harmonic Filters

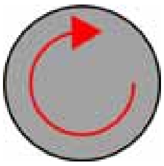


Harmonics are generated by the high speed switching of the power semiconductors in the frequency inverter and the charging and discharging of storage capacitors in the DC link. Harmonic distortion can be removed by connecting a choke before and after the power converters.



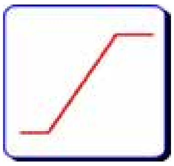
REO line reactors are designed to block all harmonics and to allow the fundamental frequency to pass through and this is achieved because inductive impedance increases as frequency does.

Braking Resistors

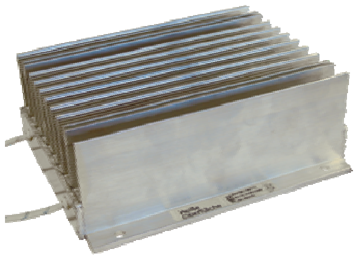


Whilst a dynamic system is rotating it is storing kinetic energy and when it accelerates too fast or is required to stop this can be achieved by the use of braking resistors. Braking resistors can be connected to the DC Link of a frequency inverter to convert the surplus electrical energy into heat energy. Most frequency converters have switch contacts built in to them which will connect the braking resistor when the DC voltage level exceeds a certain limit and will disconnect when the DC voltage falls to a safe level again.

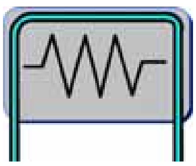
Soft-start Resistors



When an inductive component is switched onto the grid it draws a high magnetising current which can cause voltage sags, surges or flicker on the grid. It also causes mechanical shock to the drive system. To reduce the effect of this current inrush, resistors can be connected in series with the mains connection and after a short delay the resistors can be by-passed with a switch.



Water-cooled Resistors



When a water-cooled generator or frequency inverter is used to reduce the power to size and weight ratio of the wind turbine, then the circuit can be designed to incorporate water-cooled resistors also. The resistors produced by REO INDUCTIVE COMPONENTS AG have many unique features and one of these is a specially designed aluminium heat-sink housing that incorporates direct, water-cooling channels within the outer aluminium extrusion. The resistor winding is surrounded with quartz filling which provides shock resistance; short-circuit protection and a fast temperature transfer time.

REO World-wide Contacts

REO ELEKTRONIK AG	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG **Setzermann Medical Division**	Schuldholzinger Weg 7 D-84347 Pfarrkirchen	Tel. +49 (0)8561-9886-0 Fax +49 (0)8561-9886-40 www.reo.de setzermann@reo.de
REO INDUCTIVE COMPONENTS AG **IBK Drives Division**	Holzhausener Strasse 52 D-16866 Kyritz	Tel. +49 (0)33971-485-0 Fax +49 (0)33971-485-90 www.reo.de ibk@reo.de
REO INDUCTIVE COMPONENTS AG **Test and Power Quality Division**	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG **Train Technologies Nieke Division** **Centre of Competence**	Erasmusstrasse 14 D-10553 Berlin	Tel. +49 (0)30-3670236-0 Fax +49 (0)30-3670236-44 www.reo.de mail@nieke.com
REO ELEKTRONIK AG	Im Halbiacker 5a CH-8352 Räterschen	Tel. +41 (0)52-363-2820 Fax +41 (0)52-363-1241 www.reo.ch info@reo.ch
REO (UK) Ltd.	Units 2-4 Callow Hill Road Craven Arms Shropshire SY7 8NT	Tel. +44 (0)1588-673-411 Fax +44 (0)1588-672-718 www.reo.co.uk main@reo.co.uk
REO Engineering Services S.A.	Parc d'activités HERACLES Chaussée de Charleroi 91 bat 5 B-6060 Gilly (Charleroi)	Tel. +32 (0)71-287-716 Fax +32 (0)71-287-746 www.reo.de reoes@skynet.be
REO VARIAC S.A.R.L.	ZAC Du Clos aux Pois 1 6/8 rue de la Closerie-LISSES F-91048 Evry Cédex	Tel. +33 (0)1-6911-1898 Fax +33 (0)1-6911-0918 www.reo.fr reovariac@reo.fr
REO ITALIA S.r.l.	Via Treponti, 29 I-25086 Rezzato (BS)	Tel. +39 030-279-3883 Fax +39 030-249-0600 www.reoitalia.it info@reoitalia.it
REO CROMA Sp.zo.o.	ul. Pozaryskiego 28, bud 20 PL-04-703 Warszawa	Tel. +48 (0)22-812-3066 Fax +48 (0)22-815-690 www.croma.com.pl croma@croma.com.pl
REO-USA, Inc.	3250 North Post Road, Suite #132 USA-Indianapolis, IN 46226	Tel. +1 (0)317-8991-395 Fax +1 (0)317-8991-396 www.reo-usa.com main@reo-usa.com
REO-ESPAÑA 2002 S.A.	C/Manuel Ventura i Campeny 21B local 9 E-08339 Vilassar de Dalt (Barcelona)	Tel. +34 (0)937-509-994 Fax +34 (0)937-509-995 www.reospain.com info@reospain.com
REO Shanghai Inductive Components Co., Ltd.	No. 536 ShangFeng Road, Pudong, 201201 Shanghai, China	Tel. +86 (0)21-5858-0689 Fax +86 (0)21-5858-0289 www.reo.cn info@reo.cn
REO INDUCTIVE COMPONENTS AG **Moscow Representative Office**	Vienna House ul. Petrovka 27 107031 Moskau	Tel. +7 (0)495-956-55-57 Fax +7 (0)495-956-82-63 www.reo.de main@reo.de
NEEL REO SYSTEMS PVT.LTD.	406 Saphire Arcade 42, M.G. Road Ghatkopar (E), Mumbai 400 077	Tel. +91 (0)22-251643-26 Fax +91 (0)22-251643-17 www.neelreo.in info@neel.in