DC-INDUSTRIE
ENERGIEWENDE TRIFFT INDUSTRIE 4.0

Research Project DC-INDUSTRIE:

# DC Networks in Industrial Production

Direct Current

Power Supply

Energy Storage

Automation

Industry

Smart Grid

Energy Transition

DC-Supply

Industrial Production

## About research project DC-INDUSTRIE

The project „DC-INDUSTRIE – Intelligent open DC network in industry for highly efficient system solutions with electric drives" has a total volume of around EUR 10 million. It is sponsored by the Federal Ministry for Economic Affairs and Energy [Bundesministerium für Wirtschaft und Energie (BMWi)] and has a term of three years.

A total of 21 industrial companies, four research institutes and the ZVEI are jointly working on the project to implement the energy transition in industrial production and to therefore bring more energy efficiency and energy flexibility into industrial production.

The 15 association partners – Siemens, Bauer Gear Motor, Baumüller, Bosch Rexroth, Daimler, Danfoss, Eaton, KHS, Lenze, LTI Motion, Weidmüller, Fraunhofer IISB, Fraunhofer IPA, the University of East Westphalia-Lippe, the University of Stuttgart - are working together with 11 associated partners - ABB Stotz-Kontakt, E-T-A Elektronische Apparate [Electronic Equipment], Harting, Homag Group, Jean Müller GmbH Elektrotechnische Fabrik [Electrotechnical Factory], Leoni Special Cables, Phoenix Contact, SEW-PowerSystems, U.I. Lapp, Yaskawa - and the ZVEI in the interdisciplinary DC-INDUSTRIE research project for more energy efficiency and energy flexibility in industrial production.

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ZVEI:
Die Elektroindustrie

**Research project DC-INDUSTRIE:**
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# DC Networks Support the Energy Transition, Energy Efficiency and Industrie 4.0

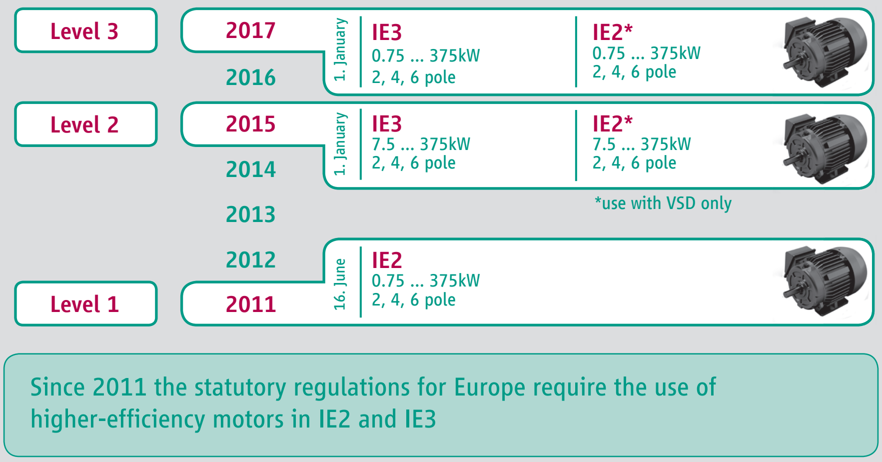
The third industrial revolution started in the 1970s. The focus here was on further automation through electronics and IT. Programmable Logic Controllers (PLCs) were increasingly used to control industrial equipment and processes in conjunction with variable speed drive (VSD), with the aim of further increasing productivity and energy efficiency.

Variable speed drive allowed continuous speed control of electric motors to optimize the production process and save electrical energy. Today, approximately 35 percent of all newly sold three-phase asynchronous motors are controlled with variable speed drive.

In the industrial sector, electric motors account for about 70 percent of electricity consumption and are thus the most significant load of electrical energy. Reducing the energy requirements of these drive systems by increasing their efficiency contributes to an equivalent reduction in $CO_2$ emissions. For this reason, the European Parliament established requirements for the environmentally responsible design of energy-using products for the first time with EU Directive 2005/32/EC and the follow-on Directive 2009/125/EC. These requirements were implemented for electric motors in Regulation (EC) 640/2009.

As an additional requirement for the European market, since 1 January 2017 all motors with rated power from 0.75 to 375kW must conform to energy efficiency class IE3, or alternatively IE2 for use in variable speed drive operation (see Figure 1). The international standard IEC 60034-30-1 defines efficiency classes from IE1 to IE4 for line-operated electric motors. These efficiency classes are specified for three-phase asynchronous motors operating at nominal speed and nominal torque. However, experience has shown that an energy efficiency regulation of a component can only sustainably reduce energy in certain operating modes. In the future, an ecological approach will be indispensable in order to reconcile both system costs and energy efficiency. This is a prerequisite for securing sustainable competitiveness and long-term jobs.

Figure 1: Statutory regulations for electric motors



For this reason, we would like to explore a new approach with the DC-INDUSTRIE project by means of direct current networks in order to support both the energy transition and energy efficiency, as well as Industrie 4.0

We aim to achieve this with a modified network infrastructure – based on direct current networks. The project „DC-INDUSTRIE – Intelligent open DC network in industry for highly efficient system solutions with electric drives" has a total volume of around Euro 10 million. It is sponsored by the Federal Ministry for Economic Affairs and Energy [Bundesministerium für Wirtschaft und Energie (BMWi)] and has a term of three years.

In order to illustrate the importance of this project, the limitations of today's alternating current power supply structures in the industrial environment will be reviewed first below.

## Recovery of Braking Energy is only possible to a Limited Extent

Our current electricity generation structure is based on power plants that feed into the utility grid. The distribution to the electrical load is carried out through the operation of transmission lines, interconnected networks and load distributors. Energy production and distribution is hierarchically structured. The flow of energy goes in one direction: from the producer to the electrical load.

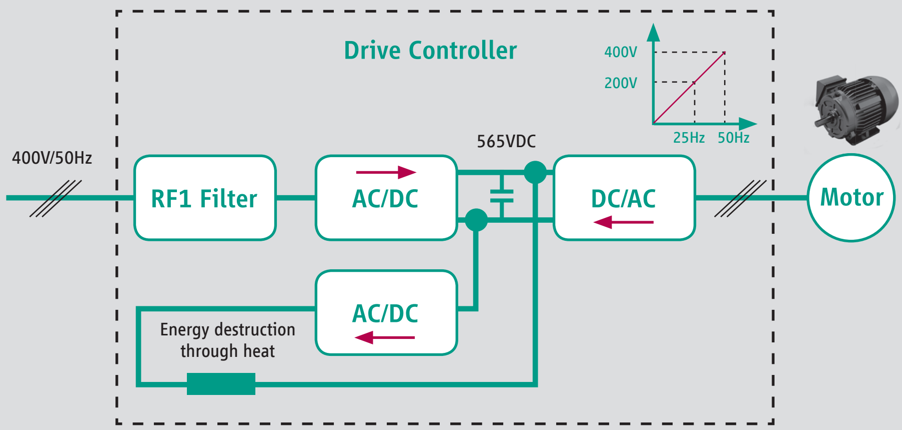
Due to the increasing use of decentralized power generation, e.g. solar energy and wind power, this structure has changed. Until now, power plant capacity has been adapted specifically to the energy demand. In particular, renewable energy generators contribute to the fact that the available electrical power generation can vary considerably. This leads to the fact that the necessary base-load generation needs to be very high to guarantee the security of supply. This means that there are production capacities that cannot be used efficiently because the producers and electrical load are very difficult to bring into conjunction with each other with today's structures. Therefore, smart grids will be required in the future, which stabilize themselves, thus enabling an optimization between available electrical energy and current needs.

Motors that require only continuous speed can be connected directly to the alternating power supply structure. Electric motors with an upstream variable speed drive can change the speed of the drives electronically. The advantage of using a variable speed drive is the continuous adaptation of the motor speed to the actual need, which can very often also lead to energy savings. A variable speed drive is supplied with the alternating voltage. This is first converted into direct current through a rectifier (B6 rectifier - see Figure 2). The direct current is converted into alternating current with variable frequency and voltage through a downstream inverter in order to electronically change the speed of a three-phase motor. However, if the three-phase motor is operating in the braking mode, e.g. in a crane that is in lowering mode, the energy flow changes. But this energy cannot be fed back into the grid by the variable speed drive because the input rectifier only allows the energy to flow in one direction. Therefore, the energy that is fed back must be dissipated via the direct current voltage circuit of the variable speed drive . For this purpose, a brake chopper is connected to the intermediate circuit. This monitors the intermediate circuit voltage with regard to the voltage level. If the intermediate circuit voltage exceeds a set threshold value, the brake chopper switches the braking resistor between the positive and the negative pole of the intermediate circuit. This is usually an additional external braking resistor that converts the braking energy into „heat“. A solution that is used today for drives with a power of less than 30kW. In the case of larger feedback capacities, an additional inverter is used to return the braking energy to the supply grid.

## Harmonics limit the use of variable speed drive

Today, variable speed drive are increasingly used for speed control. However, with increasing use, problems with mains effects arise that cause harmonics and distort the voltage. The reason behind this is input rectifiers that convert the alternating voltage into direct current voltage, thereby causing harmonics in the mains (Figure 3). In order to limit the voltage distortion within permissible values, there are therefore passive and active filters – also available for retrofitting. However, if the number of devices with input rectifiers on the mains increases, such as variable speed drive, LED lamps, PCs and power units, the problem with mains effects also increases, which very often necessitates the use of additional grid filters. There is no standard solution for harmonics, since each grid and its electrical load are very different. Ultimately, the operator is responsible for the voltage quality of its production facilities. The challenge is to comply with the voltage quality in accordance with EN 50160 at the grid supply to the customer facility. If variable speed drive or other devices with power electronics are increasingly installed, grid effects increase and influence the public grid also.

Figure 2: Current structure variable speed drives in brake condition

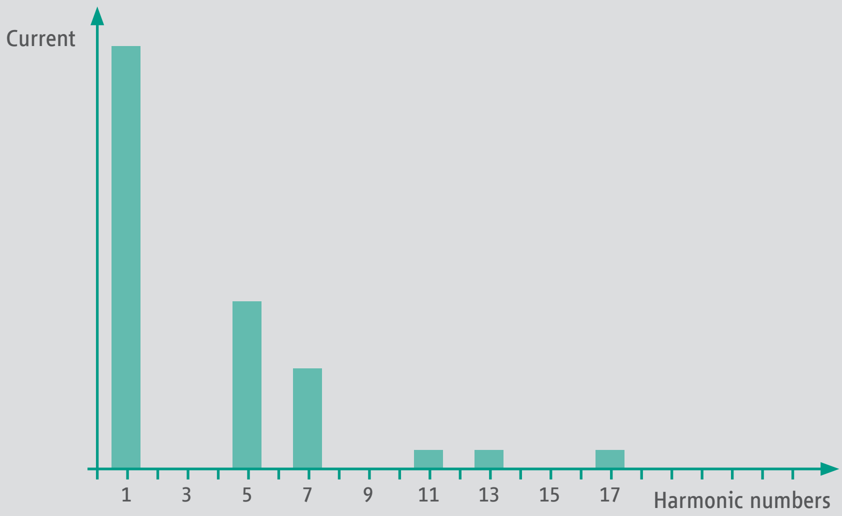



- Motors in generator mode, such as with hoist drives, can be operated with an additional braking resistor.
- The dissipated power loss in the lowering mode is burned up in the braking resistor.

## Current laws and standards do not take into account the actual operation of an electric motor

In order to determine the efficiency for a component to classify an electric motor, for example, a defined operating point has been determined. For the energy efficiency classes valid today, the operating point for the nominal speed and nominal torque was determined. So an operating point that very often differs from the actual load conditions.

Fig. 3: Harmonic analysis (example)




In order to reach a higher energy efficiency class, very often a higher use of materials is required, which leads to an increase in production costs. The higher use of materials can also increase the effective inertia of the load of an electric motor, which in the case of drives with high start/stop cycles can even lead to an increase in energy. Therefore, energy optimization always requires exact knowledge of the application, since this is the only way to optimize energy efficiency and total costs (investment and operating costs).

## Integration of the variable speed drive into the motor

Due to the high costs for RFI (radio-frequency interference) filters and voltage rectification, quite a few additional measures are required for a variable speed drive. These take up space and result in higher costs. A separate voltage conversion from alternating current to direct current is necessary for each inverter, which also causes additional losses. This is why it has been very difficult so far to design a variable speed drive compactly enough to integrate the electronics into the motor. Therefore, so far, most variable speed drive have been installed in the control cabinet and connected to the three-phase motor with a shielded power cable. Due to the high switching frequencies of >4KHz, additional capacitive cable losses occur, which are not negligible, especially in the case of long motor cables. However, the shielding results in higher cable and installation costs. If the variable speed drive could be more easily integrated into the motor, this problem could be improved by a short connection between the motor and the variable speed drive.

## Short power line interruptions can lead to production downtime

Production plants are increasingly being automated with electronically controlled motion sequences and the use of robots. Very often, these are electronically synchronized movement sequences, which must be safely controlled in every operating condition. Short-term power outages can interrupt the supply to the drives, which can lead to production downtimes and defective production. Therefore, stable power supply grids are a basic prerequisite for these production facilities. Unfortunately, practice shows that the problem of grid stabilization represents an increasing challenge, particularly as a result of changes in power generation structures.

The challenges presented show that a further increase in the use of inverters for the flexible control of electric motors is desirable and very often even necessary. This is the only way to improve both production processes and energy efficiency. However, mains effects and equipment costs limit the increase. Since the braking energy is not fed back into the grid in many cases, there are considerable energy efficiency potentials that must be used in the future. However, as long as application-optimized energy efficiency improvement does not take place, today's European and international legislation often leads to higher costs for energy efficiency motors.

In order to achieve significant progress in energy efficiency and system cost optimization, new approaches are needed. Automation and digitalization require a stable power supply. However, the increase in decentralized grid feeds with varying feed-in performances has exacerbated this issue. In order to enable energy efficiency, energy transition and Industry 4.0, new grid structures are required. This is why the German Electrical and Electronic Manufacturer's Association [Zentralverband Elektrotechnik und Electronikindustie (ZVEI)] initiated the DC-INDUSTRIE research project.

The introduction of a central direct current network (DC network) is intended to create the prerequisite for a significant increase in energy efficiency, taking into account optimized system costs. This will create a grid infrastructure that further increases the economic use of variable speed drive. Smart grids should be able to be stabilized and optimized much more easily, which should further increase the availability of flexible production. Now drives with integrated electronics (e.g. variable speed drive) are also possible and provide a lot of information from all drives that are operated on the DC network. This allows energy data to be linked to the process data. By integrating all active participants, information about the energy status is also made available via the grid management. This enables energy and cost-optimized operational management. Here, services in the cloud can provide support, since information from various participants are combined with production data and future energy requirements. Grid management can intervene and optimize by taking into account all relevant information. In addition, there is the possibility of carrying out analyses in reference to energy and the associated creation of preventive measures to prevent possible production loss. For example, the timely loading of storage capacity for buffering critical load conditions. Below, we will review the potential for improvement within the framework of the DC-INDUSTRIE research project and the goals we intend to achieve.

# Direct Current Networks for Production

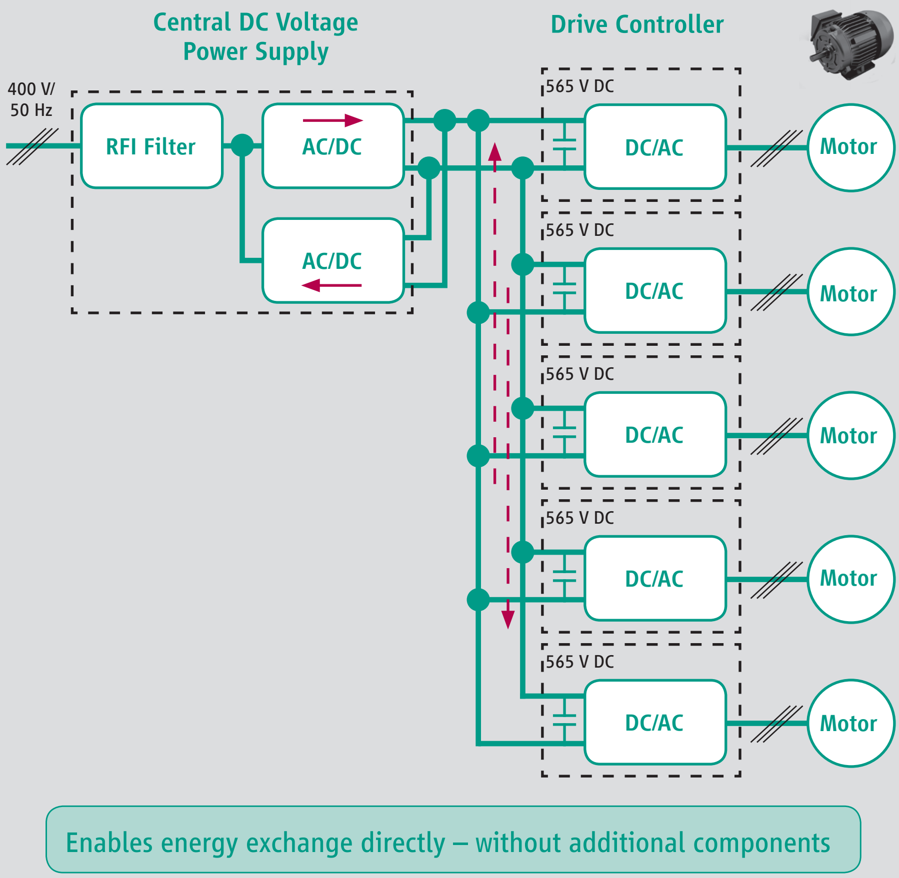
## Reduction of conversion losses

The new network structure is based on an alternating current supply, which provides the direct current power supply for production plants via a central rectifier. Active grid filters are integrated into the central rectifier to ensure the voltage quality requirements. Variable speed drive usually have an integrated rectifier with a grid filter that always necessitates a loss-dependent conversion of the electrical energy between alternating and direct current. The direct supply of the variable speed drive with direct current means that all decentralized energy conversion is no longer needed. Since central energy conversion (from AC to DC) is significantly more efficient, conversion losses are significantly reduced (Figure 4).

## Increased efficiency through direct energy consumption via DC bus connection

Through the direct supply of all electric motors via a variable speed drive with direct current power supply, all installed motors are connected via a common direct current voltage grid. This means that direct energy compensation of all driving and braking drives can take place. The central direct current voltage supply only feeds the differential energy and must also only convert this from alternating current to direct current (Figure 4). Additional components, such as brake resistors that heat energy, for example, are no longer needed. This means fewer components need to be installed and space can be

Figure 4: Grid structure for a drive controller with direct current power supply

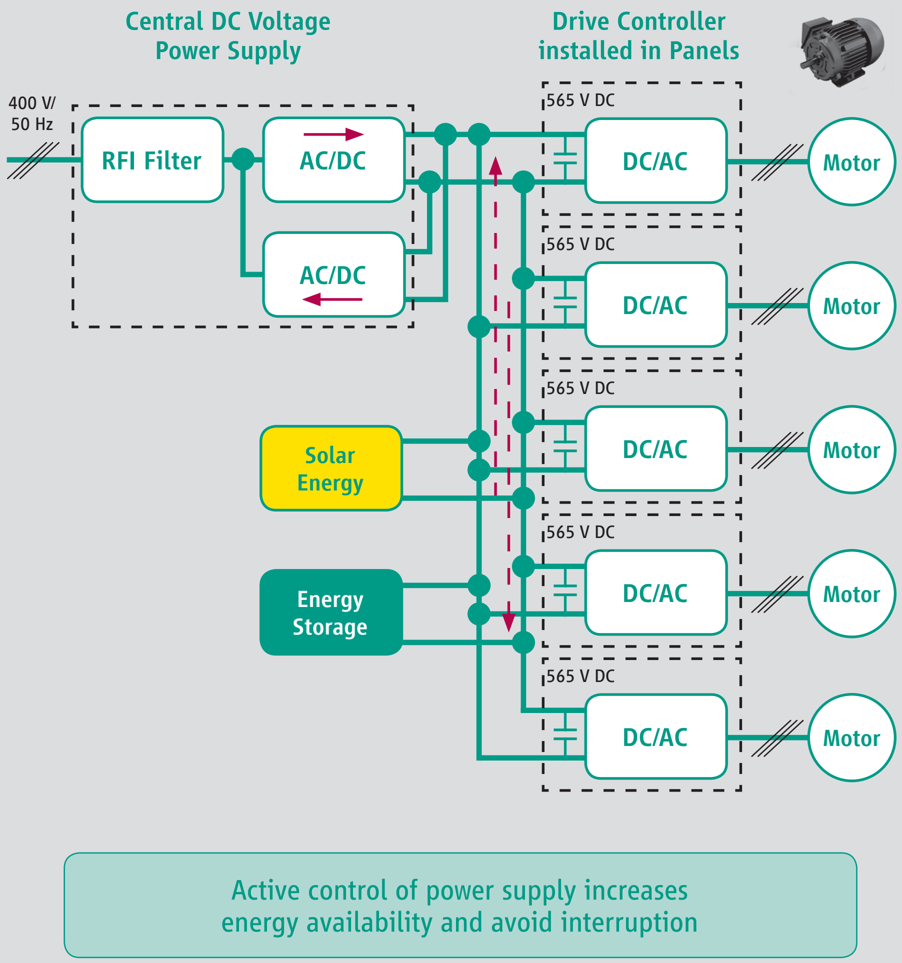


saved. A direct current voltage network essentially only causes ohmic transmission losses. Compared to an alternating voltage network, the capacitive and inductive line losses are eliminated.

## Smart grid – stable and robust power supply

A central direct current network can be buffered much more easily by means of energy storage in order to avoid power supply interruptions (Figure 5). This allows the factory power supply to be stabilized and voltage fluctuations can be more easily compensated for. In addition, in critical situations, electrical load can be used as generators to support the grid. These may be drives with large flywheels, e.g. fans, which are not required in the production process for a brief time. Furthermore, the central direct current voltage network offers the possibility of integrating photovoltaics directly at the direct current voltage level. In this case also, conversion from DC to AC is not required to be done by an inverter. This grid infrastructure offers the possibility of optimizing the purchase of energy in order to purchase the electricity as inexpensively as possible and to stabilize the grid.

Fig. 5: Power supply structure supports stabilizsation of energy availability



## Production flexibility supports Industry 4.0

Through the elimination of the input rectifier and the grid filter with variable speed drive, these can be designed more cost-effectively and more compactly. This simplifies integration into the motor, which can significantly increase the degree of acceptance. Variable speed motors allow for a reduction in variants and energy savings. They provide status signals from all DC-fed drivers, which are of great importance for flexible and safe production control. Grid management makes it possible to optimize operational management in terms of energy costs. The accessible information enables preventive production control measures to significantly increase the availability of production. This is a prerequisite for the successful implementation of Industrie 4.0.

## Simplification of electrical installation

As line losses drop and inverters become more compact, high power electronics can be mounted closer to the motor or even integrated into it. This eliminates the costs for expensive shielded motor cables. In particular, the high capacitive losses of the motor cables, between the inverter and the motor, are no longer relevant in these structures, in contrast to today's plant designs with long motor cables.

The DC-INDUSTRIE research project will explore the possibilities described above, with the aim of facilitating the introduction of a DC network after the project ends in 2019. The ZVEI, together with its members, is supporting this project because it supports both the energy transition in Germany and Industrie 4.0 This will therefore be an important building block for securing our global leadership position in automation.

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