EMC filters

Application notes

Date: August 2022

1 Variable frequency drives

Motor drives consume a high proportion of the energy used throughout the industry. Variable frequency drives not only make it possible to save energy, but processes can also be controlled more efficiently. The generic term variable frequency drives includes all types of power electronics frequency control. In practice, the focus is on alternating current or three-phase systems, where DC link converters are used most frequently.

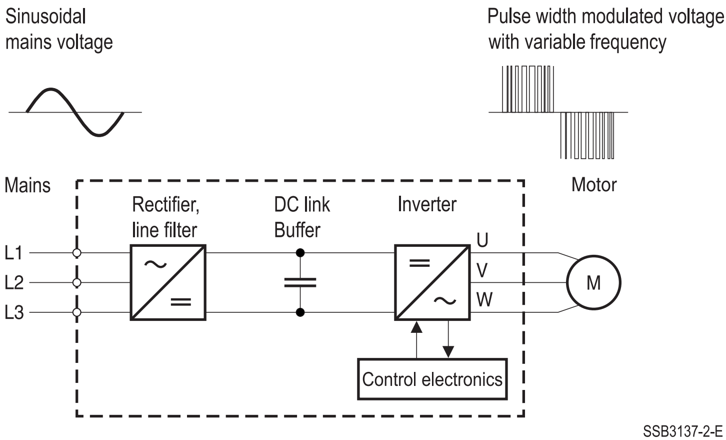


Figure 1 Principle of a frequency converter with an intermediate voltage circuit

DC link converters are implemented with a double forming process. On the line side level, the AC voltage is converted to a DC voltage. Instead of rectifier diodes, regulated semiconductors are also frequently used (AFE: Active Front End).

Depending on the circuit and control, the level of the DC link voltage or the line side harmonic component can be influenced, the energy from the DC link can be fed back into the supply network. This always makes sense if the mass powered by the motor needs to be decelerated. This converter is known as an AIC: Active Infeed Converter). The clocking on the input side must be decoupled with an appropriate filter concept, in order to maintain the limit values for the network quality in the supply network and avoid a hard switching on capacitive load inputs.

A standard circuit concept is an LCL filter with an AFE choke on the converter side and a so-called "Clean Power Filter" (LC circuit) on the line side. This filter arrangement is only used to decouple and smooth the filters and does not replace the fact that, depending on requirements, EMC filters are virtually always needed.

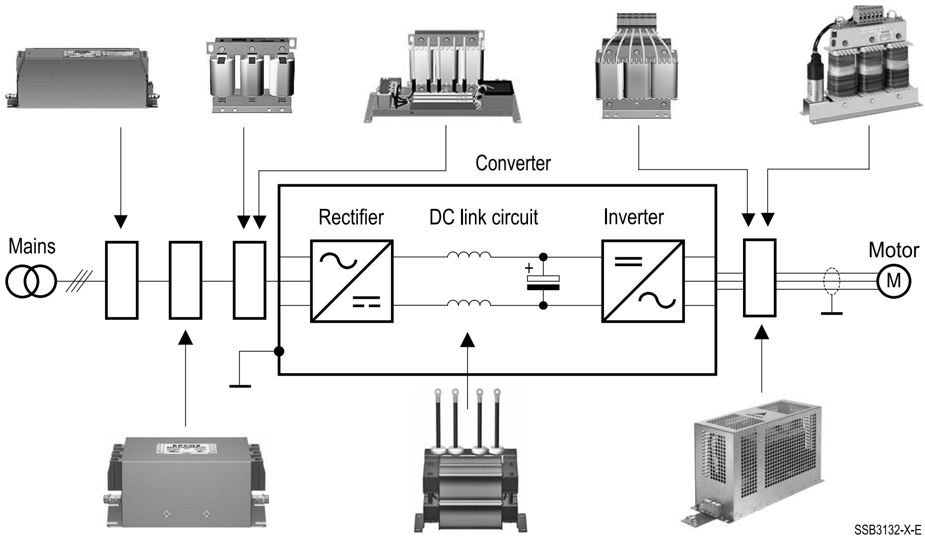
DC link capacitors, if necessary supplemented by a DC link choke, smooth the rectified AC voltage. On the output side, the converter converts the DC link voltage to a different voltage and frequency. Both the voltage and frequency may vary in theory.

To ensure electromagnetic compatibility (EMC) and maintain applicable regulations and standards, converters must have an integrated or external EMC filter on the line side. The motors used must be suitable for converter operation.

The use of output filters may also be required to reduce the slope steepness on the converter output and for motor protection, see also the "Output filters" in the document "Technical information" chapter.

An overview of all possible filter and choke solutions for converter applications is shown in Figure 2. Customer-specific solutions are also possible under certain conditions.

Active LeaXield™ filter	Power line choke	LCL filter	dv/dt choke	Sine-wave filter



Power filter (2-, 3- and 4-line filters)	Customer-specific DC link choke Upon request, application optimised	Sine-wave EMC filter SineFormer®

Figure 2 Filters and chokes for converter applications

Figure 3 shows an example of the mode of operation of an EMC filter in a converter application. Without using an EMC filter, the interference voltage of the motor (light grey) is clearly above the limit values defined in the standard. By using an EMC filter, the EMC performance can be considerably improved and the limit values maintained.

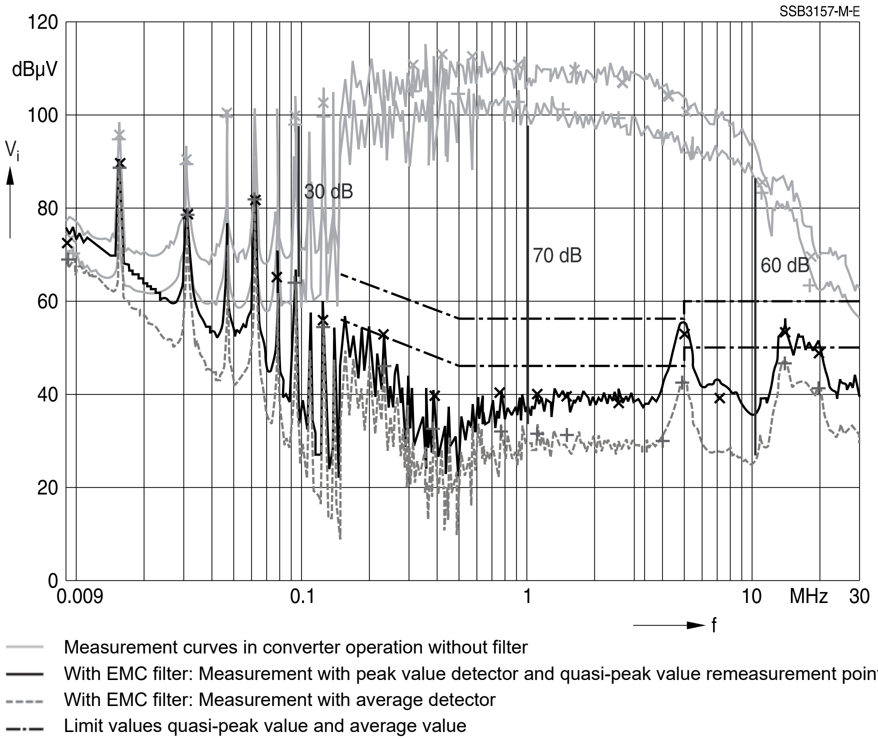


Figure 3 Interference voltage measurement with and without EMC filters

Finding the right EMC solution depends first and foremost on a systematic procedure accompanying the overall product development. If no internal measurement options are available or support is required during development, the TDK EMC laboratory in Regensburg offers such services.

The offer comprises EMC inspections and the preparation of recommendations in the laboratory or in the case of large test pieces also at the customer’s site, provision of loan samples through to final EMC tests based on the accreditation of the impartial EMC laboratory.

Since electromagnetic compatibility is not only affected by EMC filters but is also decisive when installing devices and systems, it may be beneficial if customers are present for the measurements in the EMC laboratory. In doing so, a mutual dialogue can take place and possible changes can be discussed and directly tested.

Detailed information on the TDK EMC laboratory can be found in section "EMC laboratory" on page 162.

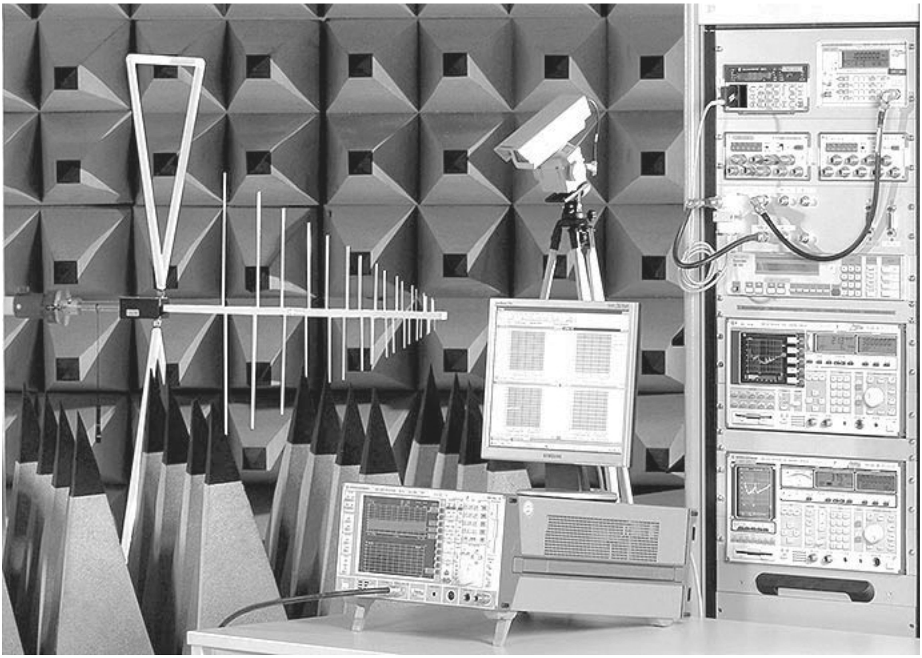


Figure 4 EMC laboratory Regensburg

2 Electromobility

The term electromobility defines the use of electrically powered vehicles. At the core of e-mobility are electrically powered railways, streetcars, buses, lorries, motorcycles and electric bikes in addition to cars. Electromobility is considered as the key technology when it comes to future-proofing the transport system. One basic feature of electromobility is that the drive of the vehicles is partially or fully electrically powered. Batteries and gas storage combined with fuel cells are the most commonly used energy storage systems. In Germany, the Electromobility Act (EmoG) not only encourages the use of battery electrical vehicles but also plug-in hybrid and fuel cell vehicles.

Figure 5 Electric car at a charging station

Owing to the limited battery capacity, a powerful and nationwide charging infrastructure is an urgent need for electric vehicles with battery storage.

In locations where the vehicle is regularly parked or parked for a longer period of time (home environment, workplace, hotels etc.), slow charging AC charging stations tend to be used. DC charging stations are used at all locations, where a high charging power is needed due to a short charging time.

When charging with alternating current, the on-board battery charger of the vehicle converts the alternating current to direct current. In contrast to this, the power conversion at DC charging stations takes place outside the vehicle, meaning that the charging current is fed directly into the high-voltage battery of the car. In both cases, the battery management system (BMS) handles the interface communication between the battery and the charging infrastructure, for instance, for controlling the current or charging duration.

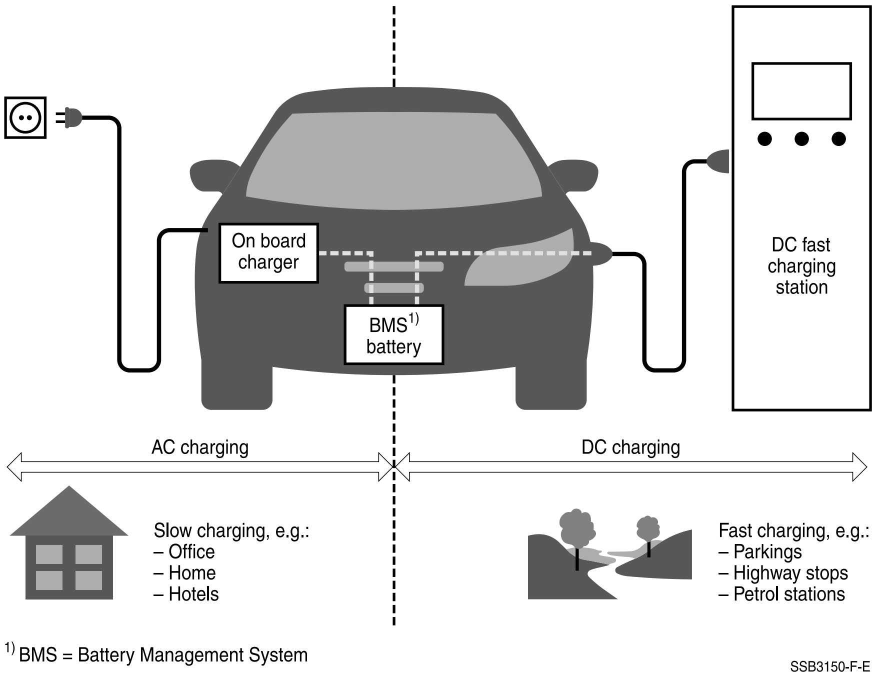


Figure 6 Charging options for electric vehicles

In addition to manufacturer-specific connectors, e.g. Tesla Supercharger, two charging interfaces have been defined as standard interfaces for developing public charging infrastructure, CCS (Combined Charging System, also known as Combo 2) and CHAdeMO (backronym: CHArge de MOve).

In European cars, the CCS plug connector is used as an interface, which generally enables AC or DC charging. As a second exclusive DC charging system, CHAdeMO is rather important and originates from Japanese automobile manufacturers.

In principle, both systems permit very high charging powers of far above 100 kW, which shortens the charging duration and therefore makes the process more convenient for the user and increases market acceptance. CCS 2.0 therefore permits charging powers up to 350 kW, while CHAdeMO 2.0 permits up to 400 kW.

Currently typical charging powers for 1-phase AC systems are 3.7 kW (230 V; 16 A), for 3-phase AC systems between 7 and 22 kW or a maximum of 43 kW (230/400 V; 63 A) and for DC systems at 80 to 150 kW (400 V; 400 A).

Figure 7 Charging options for electric vehicles and "vehicle connection to a Combo 2 fast charging station"

Figure 8 shows a schematic representation of the structure of a DC charging station. On the line side, the LeaXield™ active leakage current filter, EMC filter as well as power line chokes and LCL filter can be used.

The DC link to the AC/DC converter often feeds several DC/DC converters. TDK has buck boost chokes or resonance chokes in its product portfolio for DC/DC converters.

At the output of the DC/DC converter to the charging connection, in many cases a 2-line EMC filter is required in order to fulfil the interference voltage limit values on the DC connection defined in IEC 61851-21-2. Due to the diverse requirements listed below and the various implementations, EMC filters for DC charging stations do not tend to be standard products but rather customer-specific solutions.

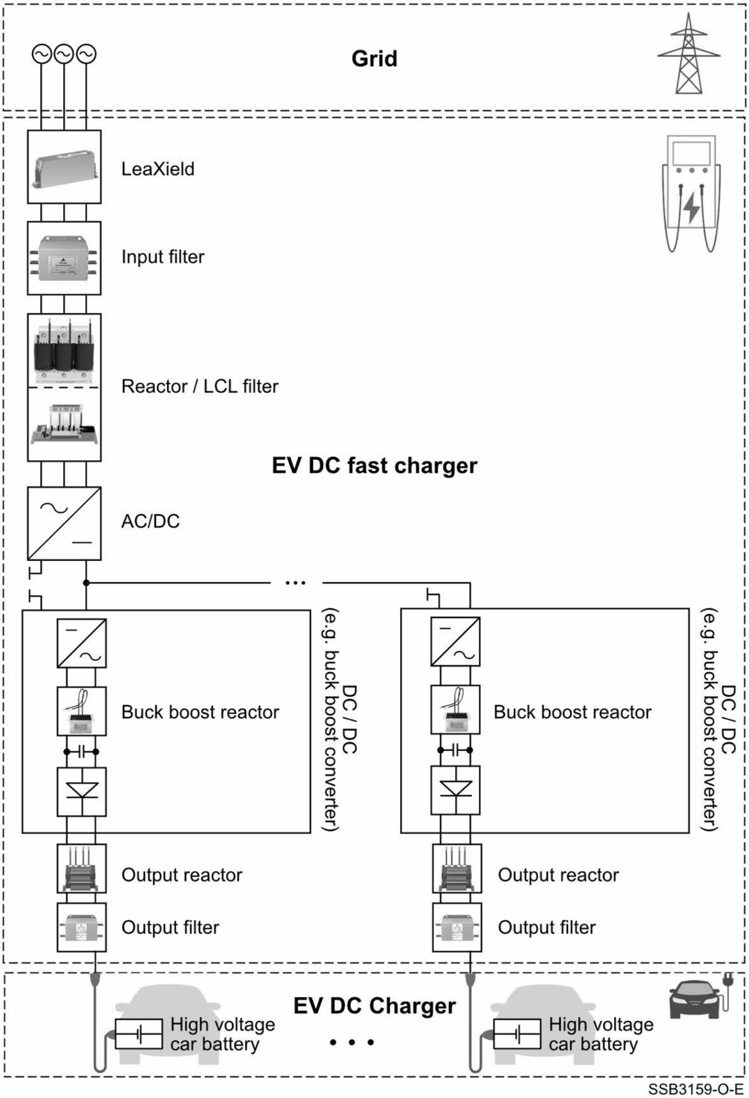


Figure 8 Structure of a DC charging station

As there were not any product standards in place for charging stations, the measurement and evaluation of the emission on the DC charging connection was frequently based on generic standards, such as IEC 61000-6-4 for equipment in industrial environments. In contrast to IEC 61000-6-3, IEC 61000-6-4 does not include any limits for high-frequency emissions at the DC connection, the measurements of the conducted emissions up to 30 Mhz have only been performed on the low voltage AC network connection.

The gap in standards has been closed with the publication of the IEC 61851-21-x series of standards regarding "EMC requirements for electric vehicle conductive charging systems". IEC 61851-21-2 describes "EMC requirements for off-board electric vehicle charging systems" and is therefore relevant for DC charging stations with high power. In addition to EMC limit values for the AC side, limit values for the DC side are also determined in this standard for the first time. As well as the charging outputs, communication lines are also included in the testing. Furthermore, the limit of the leakage capacitance must also be observed due to safety requirements (IEC 61851-22).

Our experts from the EMC laboratory in Regensburg (comp. "EMC laboratory" chapter) will be delighted to provide you with extensive support.

In the case of charging systems for the North American market, the UL 2202 standard "Electric Vehicle (EV) Charging System Equipment" is also to be observed.

Charging points or even charging stations are often designed as closed switch cabinets. This sometimes includes considerable climatic ambient influences for electric components. A temperature range of -30°C to +50°C at 5% to 95% relative humidity is to be assumed.

The conditions within the housing may vary from one manufacturer to the next. With this in mind, TDK recommends using filters for these applications which are fully covered by a high quality potting material. The potting provides additional protection against the ingress of moisture into the capacitors and increases the lifetime of the filter this way.

In addition to products for the charging infrastructure, TDK also offers filter solutions for the DC bus system for electrically powered vehicles. As shown in Figure 9, emissions are caused by the converter, which may interfere with other electrical components, such as the BMS, the on board electronics or communication systems.

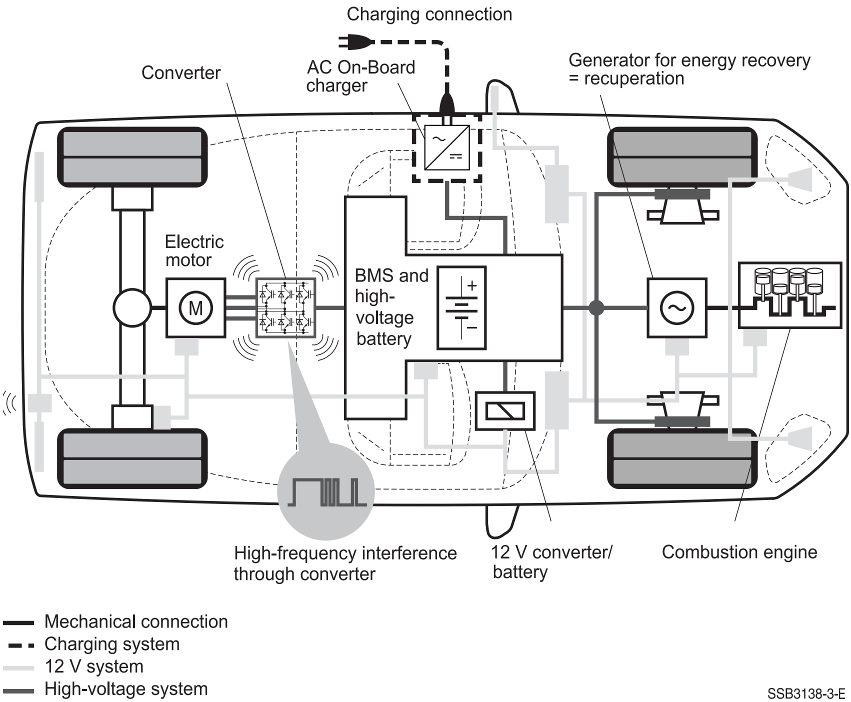


Figure 9 Generation of EMC emissions in an electric vehicle

The frequency converter used in the drive system represents a source of high-frequency interference, due to the fast switching edges, which can be distributed via the motor leads and high-voltage supply lines in the vehicle. The frequency converter is often located directly at the motor housing due to the integration density in the vehicle. In such cases, the motor leads are guided by the housing. Alternatively, shielded lines are used as motor cables.

In order to minimise coupling with other vehicle supplies, e.g. the low voltage on board supply or communication lines, the HV DC supply lines between the loads, e.g. the frequency converter and the HV battery have a shielded design.

The use of high-quality, shielded cables and connectors is a very expensive approach. Furthermore, the cables and plug connectors only have a finite shielding attenuation, which may worsen considerably throughout the service life due to corrosion. Should repair work be required, i.e. when replacing a cable, the shielding quality of the restored connection can only be inferred to a limited extent.

A cost-optimised and reliability solution is on the other hand offered by the use of EMC filters in the HV bus system.

These are usually implemented for smaller loads at the converter in a discrete manner, in contrast to external filters. Using EMC filters means complex shielding of the cables is no longer required, as shown in Figure 10.

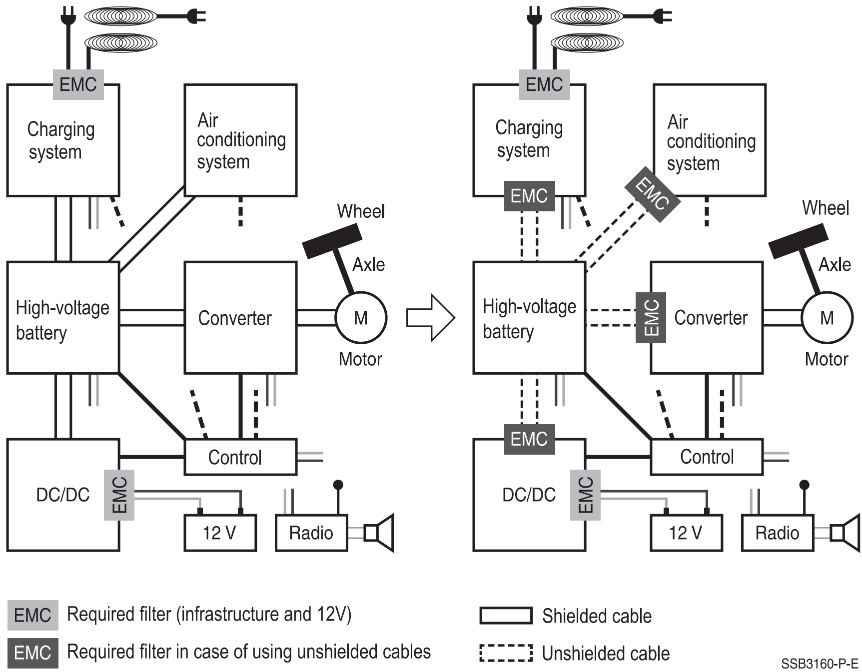


Figure 10 Left: Loads on the bus system when using shielded cables Right: Loads on the bus system when using EMC filters

Due to the highly specific requirements in automotive applications, EMC automotive filters tend to be customer-specific solutions. If you are interested, please contact your TDK sales partner.

3 EMC in wind turbines

Wind power plays a significant role in the generation of renewable energies. In contrast to solar power, wind power is also available at night. However as wind is not always available and not with sufficient speed, it does not tend to be regarded as a reliable energy source. In order to compensate for this, spare capacity is required from well balanced power plants or efficient storage in large plants.

Over the past few decades wind turbines have been continually further developed. In the meantime, the power of an individual wind power generator has even exceeded the 10 megawatt mark. As these energy quantities can hardly still be transported in the low voltage network due to the high currents and thus necessary large conductor cross-sections, a close connection to the medium voltage network is required.

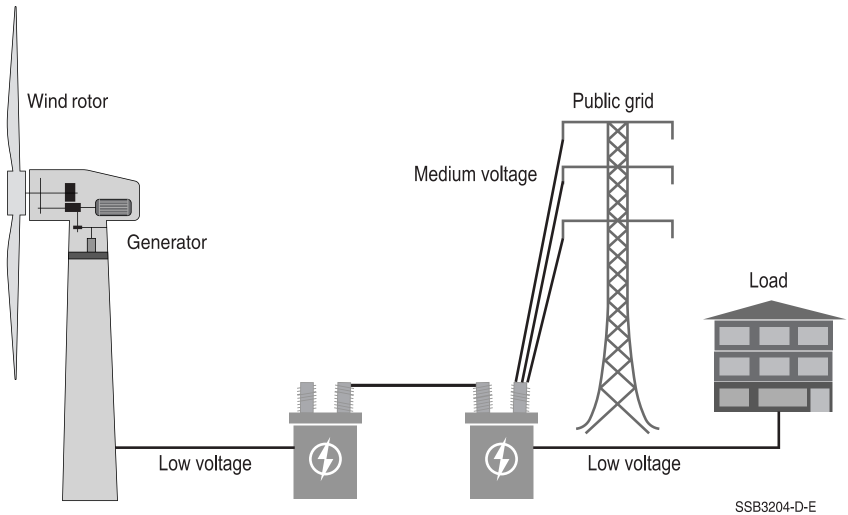


Figure 11 Wind power grid connection (Ministry for Economic Affairs and Energy of the State of Brandenburg)

By connecting the wind turbines to medium voltage transformers, the systems work in a network decoupled from the public energy supply network. It is not absolutely essential that conducted limit value levels are maintained within this network. There are however increasingly aspects, which call for major wind power providers to use EMC filters in the plants. In addition to the electrical isolation of the two transformer windings, parasitic coupling capacitances also act between the windings, whose effects are often underestimated.

Figure 12 shows a conducted interference voltage measurement, with the source of interference on the low voltage side of transformer 1. Transformers 1 and 2 are connected to the medium voltage level; the conducted interference is measured on the low voltage side of transformer 2. The illustration clearly shows the extent of the interference level and the limit values being exceeded. This indicates that a medium voltage transformer does not always adequately decouple EMC interference between the low and medium voltage network.

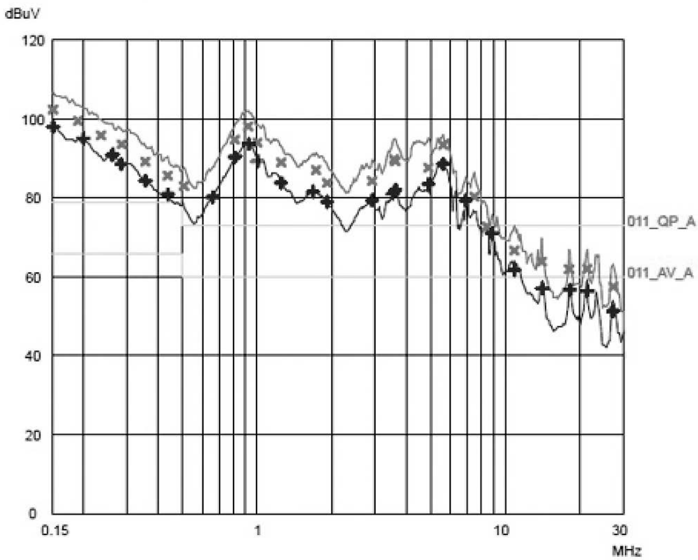


Figure 12 Interference voltage curve at low voltage feed point, supplied power approx. 450 kW. The limit value curves are clearly exceeded without filters.

The main reason for using EMC filters is generally the large number of long lines and cables in a wind park. In the case of existing conducted interferences, the long lines function in a similar way to antennas and lead to airborne interferences. The limit value specifications for electrical and magnetic fields around the area of the turbines are also to be observed, which may be exceeded by these interferences.

In addition to exceeding legal limit values, the interferences may also have effects on the functioning of the control and adjustment technology. Wind turbines are state-of-the-art systems equipped with a high level of control and adjustment technology, such as measuring devices for wind speed and direction, rotation sensors and control technology for pitch control.

If the limit value levels in the supply network are not maintained, extensive investigations will be needed, in order to verify the full functioning of the components under an increased interference level.

In addition to the reliability of the components, personal protection is also of importance here. Even when using measuring devices at the service sockets available in the plants, maintaining EMC standards is decisive when it comes to ensuring the exact function of the measuring devices, for example.

When selecting the filter, often only the AC voltage side of the low voltage network is viewed. Depending on the size of the plants, long interconnections are often available on the DC voltage side, which may lead to radiated interference. In order to minimise such interference, it is useful to also often use an EMC filter on the DC side.

For the reasons mentioned above, using EMC filters in wind turbines is an increasingly absolute necessity, whose costs are low when compared with the overall investment and offer a great benefit in terms of the safety and reliability of the plants.

TDK offers numerous components to improve the network quality for wind power generation. For example, chokes along with capacitors form series resonant circuits for undesired harmonics or suppress the clock frequency.

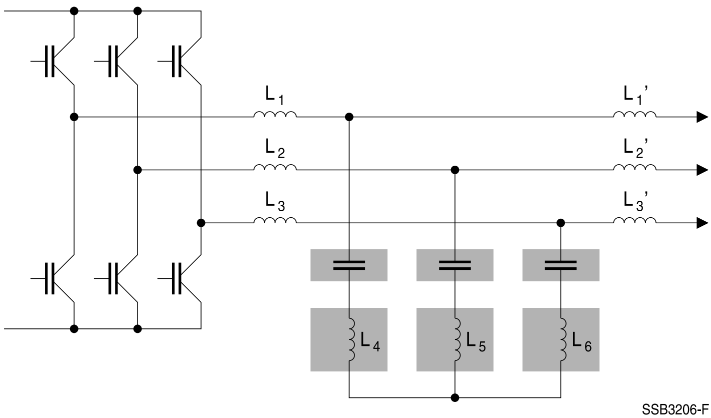


Figure 13 Output filtering of power converters: The combined chokes L4 to L6 along with capacitors form a series resonant circuit, which attenuates the clock frequencies.

4 Medical engineering

Medical progress is based considerably in the measuring and equipment technology used. The applied physical principles differ greatly here. In magnetic resonance tomography (MRT) a magnetic field is established around the body of the patient, which is up to 100,000 times stronger than the earth's magnetic field. In order to generate such high magnetic fields, corresponding power supplies with high power and therefore high currents are required.

In contrast to this, there might be medical measurements in the same building with very low signal levels, which are being influenced significantly by external interferences.

A well known example is the electrocardiogram (ECG). Here the electrical activity of the heart muscle fibres are measured with a voltage level of only around 0.1 … 0.3 V.

In order to represent the measurement signal with sufficient quality, numerous measures must be taken to minimise the interference.

This includes shielding and band-pass filters against electrical interference fields or twisted measuring lines against magnetic interference. It is important to protect the patient against leakage currents, especially as even the contact with low leakage currents would pose an additional risk to weakened patients. In order to keep leakage currents to a minimum, special filters are often used for medical applications without or with only very small Y capacitors.

Figure 14 shows an example of the structure of a filter without Y capacitors in contrast to a standard filter, based on the example of a 2-line filter (B84111F*).

Wiring diagram (standard version) **Wiring diagram (medical version)**

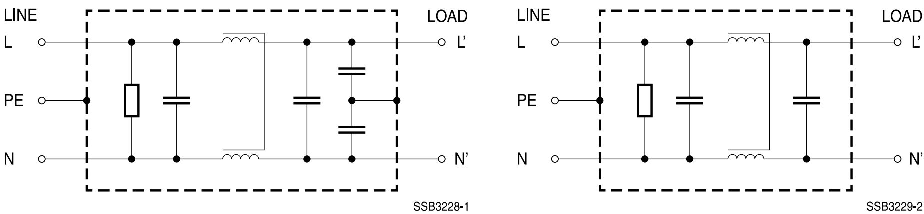


Figure 14 Comparison of a 2-line filter with or without Y capacitors based on the example of the B84111F* filter

Virtually all medical devices have a common feature - connection to the power supply network via plug connector. In the case of mobile devices, this tends to be an IEC power connector (C14 or C20). Conducted interference becomes an issue when the grid is connected.

Figure 15 SIFI filters and IEC inlet filters from TDK

When selecting the EMC filters in medical engineering, special attention needs to be paid to observing applicable standards and specifications. In order to protect patients, for example, in IEC 60601-1 the patient auxiliary current, patient leakage current and overall patient leakage current are defined and limited. Alongside the personal protection standards, the generally applicable EMC standards according to the "Technical information" chapter,"EMC standards" section are to be observed.

In addition to providing protection against EMC interference, the EMC filters fulfil a second task: The choke and capacitor components cause transient, i.e. very brief overvoltages from the power supply network to be weakened. High-value medical devices are therefore more effectively protected. Depending on the required level of protection, surge voltage protective components may also need to be used.