EMC of Frequency Controlled Electric Drives

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Abstract. *The paper deals with solution possibilities of EMC for voltage inverters, which uses PWM (Pulse Width Modulation). The paper offers solution of interference suppression which is raised by operation of frequency controlled drives. Possible interferences caused by inverters and their solutions are described at the first part of paper and real solution examples at the end of paper.*

Keywords

EMC, inverter, converter, sinus filter.

1. Introduction

A usage of frequency controlled drives with AC motors (like asynchronous or synchronous) increases in last few years. Power range of the drives is up to few MW. Power inverters use switching devices like IGBT (Insulated Gate Bipolar Transistor) or GTO Thyristors (Gate Turn-Off). Switching frequency range is from hundreds of Hz up to tens of kHz. High switching frequency causes high range of voltage and current rise. Due to this the problem with EMC of the drive rises. The paper tries to summarize main rules of EMC solutions of the drives. Various examples have been published [1], [2], [3] and [4]. The paper gives other practical examples. Real solutions from practice of the authors are given in this paper.

Analytical methods of solution are ineffective for EMC of drives even in laboratory conditions. They are completely ineffective in industrial plants. To reach satisfactorily EMC of drives, necessary rules should be observed during design, installation and operation of the drives. However the observing of the rules does not always ensure right behavior of the drive from EMC point of view. In case of EMC problem elimination, it is necessary to use empirical methods.

2. Frequency Converter and Its Typical EMC Problems

A drive with asynchronous motor fed by frequency converter is very often used. For servo drives, synchronous motors with permanent magnets fed by converters are typical. Power parts of frequency converter are the same for both groups of drives. Topology of a converter can be seen in Fig. 1. A frequency converter typically consists of the following parts:

- a diode rectifier is used on input of the converter (three phase or one phase for low power converters),
- a rectified voltage is smoothed by a DC bus capacitor,
- a braking chopper with a braking resistor is connected to the DC bus in case of braking,
- a voltage inverter on output consists of IGBT (most often),
- a voltage inverter uses pulse width modulation (PWM) with carrier frequency ranging from 1 kHz to 20 kHz.

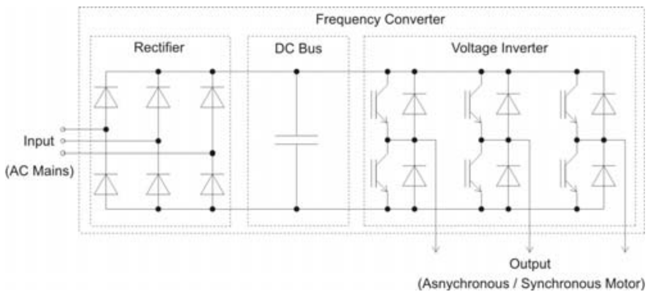

Fig. 1. Topology of frequency converter.

Typical interferences caused by converter:

- interference in mains – frequency converter loads the net by higher harmonics of current, operation of converter causes PF (Power Factor $PF=P/(UI)$) lower than 1, spectrum of current can speedily change shape,
- interference in output of converter – caused by high *du/dt* and *di/dt*, it adversely affects a motor (higher voltage stress to insulation, higher temperature stress, higher noise, torque ripples),
- high-frequency interference in range from 150 kHz to 30 MHz in input and output – it might cause negative influence to ripple control signal, radio and TV signal, security systems etc.,
- radiated emissions up to 1 GHz.

Elimination of interference

- input filters,
- output filters,
- space layout of a drive respecting EMC.

Frequency converter with typical anti-interference equipments is shown in Fig. 2.

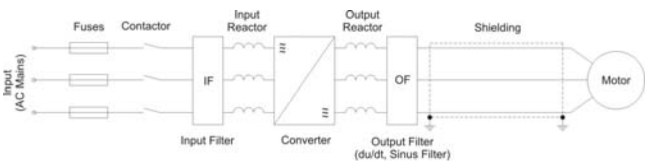

Fig. 2. Frequency converter with typical anti-interference equipment.

3. Standards

Czech standards for EMC of electronic equipment valid for frequency converters:

- (ČSN) EN 61800-3 – Adjustable speed electrical power drive systems. Part 3: EMC requirements and specific test methods.
- (ČSN) EN 61000-6-1 – Immunity for residential, commercial and light-industrial environments.
- (ČSN) EN 61000-6-2 – Immunity for industrial environments.
- (ČSN) EN 61000-6-3 – Emission standard for residential, commercial and light-industrial environments.
- (ČSN) EN 61000-6-4 – Emission standard for industrial environments.

4. Anti-Interference Equipment – Input Filters

Three or one phase rectifiers are usually used in input of the frequency converter. The rectifier is loaded by DC bus capacitor. Due to this, input current consists of high short pulses. The pulses are caused by charging of the capacitor in DC bus during voltage maximum. In case of three phase rectifier there are two pulses per half period of supply voltage. Whole energy, which is consumed by convertor, has to be transferred during these pulses. In case of one phase rectifier, input current consists of one pulse per half period of voltage. Input current of three phase rectifier is shown in Fig. 3.

Wide harmonic spectrum of the input current is obvious from Fig. 3. To avoid emission of wide spectrum, it is necessary to split the problem in high frequency band and low frequency band.

To suppress the high frequency interference, an input filter is used. This filter should be always used in case of frequency converter input. This filter is often integrated in a converter. The filter avoids interference in high frequency band from 150 kHz to 30 MHz. A π-networks or L-networks with LC devices are used as the input filter.

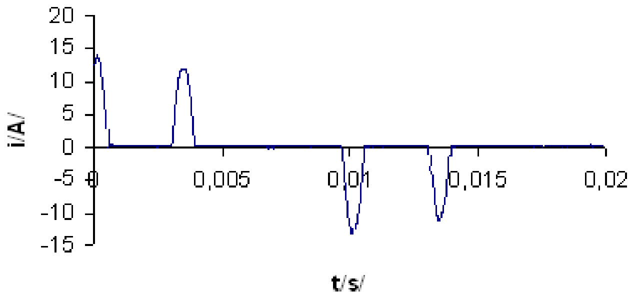

Fig. 3. Input converter current for 4 kW load.

If an input filter is used, the charging current may shut down a residual current breaker (if it is used). A four-wire input filter should be chosen in this case. The separation of PE and N conductors is also necessary. The usage of a delayed residual current breaker is another way how to avoid the shut down of the breaker.

The filter also consumes reactive power. In case of parallel operation of two or more converters, one filter can be used. It is obvious the filter has to be dimensioned to the total current.

5. Anti-Interference Equipment – Input Reactor

To limit input current spectrum, an input reactor may be used. The reactor also extends conducting time of rectifier diodes. Thanks to extended conducting time, the loading of the diodes gets lower. The reactor is necessary in case of high short-circuit power of the mains (at least 10 times converter power). The reactors are not necessary for converters with nominal power up to 5 kW or for mains with low short-circuit power. Some producers use integrated reactors in converters. In some cases, the reactor is connected between the rectifier and the smoothing capacitor.

When an extern reactor and input filter is used, the order of placing is without influence on correct function. In case of parallel operation of converters, the converters have to have their reactor.

Reactor parameters are dependent on nominal current of converter. Recommended inductances of reactor get lower with increasing current. Example:

Recommended inductance	Nominal current
10 mH	5 A
1 mH	20 A
0.4 mH	80 A

Low inductances do not limit input pulse current enough. However, too high inductances cause voltage drops and also have negative influences on current protection of converter.

6. Anti-Interference Equipment – Pulse Rectifier

Pulse rectifiers are effective solutions of low frequency interferences. Input current is less for dominant harmonic like 3^{rd}, 5^{th}, 7^{th} or more. Pulse rectifier can also adjust PF of input current near by 1. Topology of rectifier is similar to voltage inverter. The rectifier uses also pulse-width modulation. However the control of the rectifier is different. The main criterion of the control is constant voltage on DC bus capacitor. Secondary criterions are sinusoidal input current and PF near by 1. A possibility of braking energy recuperation to the mains is another advantage.

Frequency converter with pulse rectifiers are produced mostly for high power, usually over 10 kW. Disadvantage of the frequency converters with pulse rectifiers is higher price than converters with standard diode rectifier. Converters with pulse rectifier are used for drives with often dynamic braking. Thanks to recuperation possibility, usage of this converter can save energy.

7. Output Interference – Voltage and Current Peaks

IGBT switching time is between 0.1 μs and 1 μs. Due to this, rate of voltage rise is up to 5000 V/μs. Some producers purposely extend the switching time of IGBT by its driver. However this leads to higher switching losses. In case of this high rate of voltage rise, the cable parasitic parameters like resistivity, capacity, inductance and leakage resistance have indispensable influence (cable between converter and motor). Equivalent circuit of cable length element can be seen in Fig. 4.

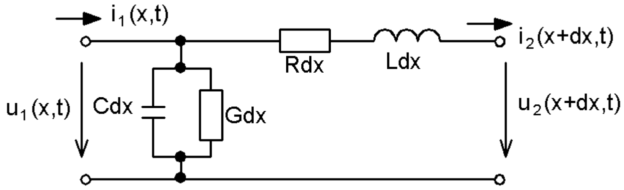

Fig. 4. Cable length element.

For example, parameters of cable CYSY 4 × 1.5 mm^2 are given at 1.5 MHz: R = 0.047 Ω/m, C = 0.12 nF/m, L = 0.343 μH/m, G = 33.3 μS/m. The parameters are frequency variable.

A converter output voltage consists of voltage pulses with a high rate of rise. Each voltage pulse causes voltage waves in cable. Voltage wave partially passes through and partially is reflected at point of wave impedance change. The point is typically at the beginning and the ending of the cable. If the end of cable is open, voltage wave is reflected with the same polarity. If the end is shorted, the wave is reflected with the negative polarity. Converters behave as voltage sources with low impedances. However motor impedance is very high instead of wave impedance of cable. Therefore the motor behaves as open end of cable. If the cable were lossless, the voltage at the point would be given as sum of all reflected waves. The situation can be seen in Fig. 5.

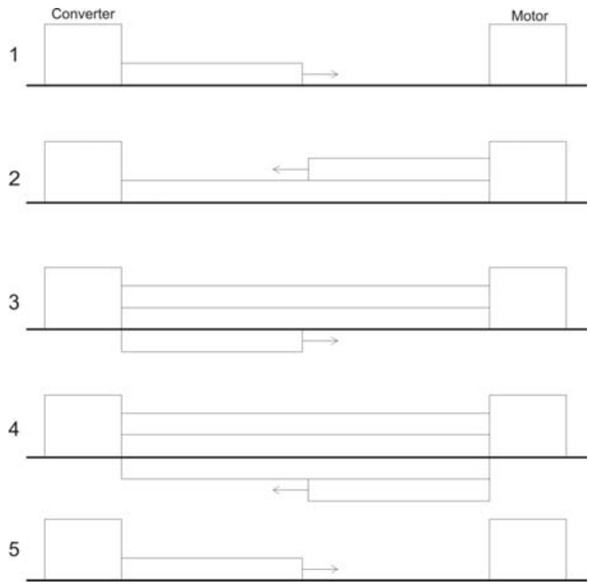

Fig. 5. Reflection of voltage waves between converter and motor.

Due to reflection, actual voltage on terminals of converter or motor can rise up to two times of DC bus voltage. The amplitude of overvoltage peaks depends on cable parameters and rate of voltage rise. Winding insulation of the motor is stressed by the peaks. Influence of the cable parameters commonly gets higher with cable length. However there are some exceptions, e.g. if voltage wave speed is half like speed of light and rate of voltage rise is 5000 V/μs, the worst case rises at 15 m of cable length.

Beyond the overvoltage peaks, current peaks can rise during operation of the converter. The current peaks are caused by charging of parasitic capacity of cable, e.g. current peak amplitude can be more than 10 A high for 150 m of cable length even for opened cable end. Peak width can reach a few μs. Due to this, a current protection of converter can be triggered.

8. Another Interferences on the Output of Converter

Converters fed motors are usually noisier then mains fed motors. The noise is intensive for PWM frequency up to 8 kHz. The noise can be suppressed by higher PWM frequency over 10 kHz. However problems with higher electromagnetic interference and higher switching losses rise. This leads to output current limitation.

Also output torque of converter fed motor is more rippled due to higher current ripple. The current ripple is caused by higher amount of current harmonic components. Torque ripple depends on motor design, PWM frequency and PWM algorithm.

Higher losses are another significant effects caused by converter feeding. Converter output voltage contains high amount of voltage harmonic components. This causes also higher amount of current harmonic components. An asynchronous motor works with slip close to 1 from harmonic component point of view. It means that the components produce short circuit losses of asynchronous motor.

9. Anti-Interference Equipment on the Output of Converter

Usage of anti-interference equipment depends mostly on cable length. Up to 30 m of cable length, the anti-interference equipment is not usually used. For longer cables, the anti-interference equipment is necessary. However for shorter lengths the usage of the equipment should be considered with respect of application local conditions.

There are a few ways to eliminate the negative influence of converter output. The first of them is usage of output reactors. The reactors limit the rate of output voltage rise *du/dt* and also limit current and overvoltage peaks on motor terminals. Output reactor inductance is usually chosen as one third of input reactor inductance.

Another way is a usage of a du/dt filter. The du/dt filter takes similar effect like output reactor. In fact, the filter is also based on reactors. Producers of converters usually offer the du/dt filters as accessory to converters. The du/dt filters keep the rate of voltage rise less than 500 V/μs, e.g. overvoltage peaks on motor terminals are less than 1000 V in case of 400 V AC mains. The du/dt filter is used.

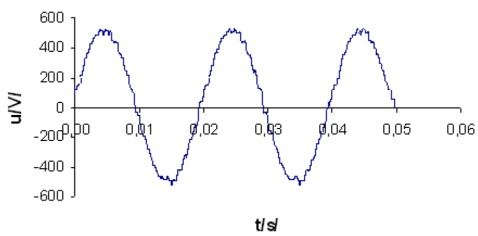

Fig. 6. Sinus filter output voltage.

The most effective solution is usage of a sinus filter. Filter output voltage is approximately sinusoidal (see Fig. 5). Output current is also sinusoidal. The filter eliminates negative converter influence on motor and eliminates electromagnetic interference too. The sinusoidal filter consists of LC devices usually connected to "gamma" element, e.g. for motor power of a few kW, the filter consists of reactor with non-saturated inductance of tens of mH and capacitors with capacity of a few μF. Reactors use ferrite cores. During operation, a voltage drop rises on filter terminals. The voltage drop can be even 10 % of converter output voltage. Although the sinusoidal filter is very effective anti-interference equipment, its usage is not frequent due its higher price. The price can be up to one third of converter price.

10. Common Rules for Installation of Frequency Controlled Drives from EMC Point of View

A correct shielding installation is necessary to reduce electromagnetic interference.

The usage of shielded cables is necessary for control signals. The shielding has to be grounded on one side or both sides of cable. It depends on local condition to decide between one and both sides grounding.

A cable between converter and motor has to always have shielding. The shielding has to be grounded on both sides. Note the shield cable has higher capacity than common cable. It leads to higher current peaks on converter output.

Shielded cable should be used also for mains of converter in case of longer distance between input filter and converter. The maximum distance for non-shielded cable is approximately 30 cm!

Metal pipes should not be used as shielding due to their higher impedance. Correct shielding is made from copper braiding.

In case of cabinet installed converters, conductive connection between cabinet and converter case is necessary in maximum surface. Insulated installation boards or installation columns should be avoided.

The shielding of cables should be conductive connected in maximum surface to reach minimum contact impedance.

Space division of power and control equipment is necessary. Conductive board installation between power and control equipment is advisable. Also power and signal cables have to be space separated. Galvanic separation between power and control part of drive has to be observed.

11. Problem Solution Examples

11.1 Example – Importance of Galvanic Separation

A stand for testing automotive gear boxes is installed at CTU (Czech Technical University) in Prague. The stand is driven by 22 kW asynchronous motor. The motor is fed through shielded cable length 5 m. Sensor signals use 8 m length shielded cable connected to PC measuring board. One of the sensor signals is IRC signal (incremental speed sensor). The IRC signal was extremely interfered during converter operation. Due to interference, PC board counter recorded extremely high speed. Problem has been solved by galvanic separation of IRC signal. The separation has been made by optoelectronic device.

11.2 Example – Search Even Unusual Solution

A frequency controlled drive with 3 kW asynchronous motor was installed during reconstruction of river weir control technology. A sinus filter was used because cable length was 150 m. A non-shielded cable was used between filter and motor. It was standard solution of a drive. However during start up a converter current protection was triggered. The problem was solved after consultation with the producer of the used converter. The producer did not suppose sinus filter connected on the converter output. A sinus filter with lower capacity has been chosen. Although the drive worked satisfactorily, another problem with security camera system raised. The second problem has been fixed by reactors connected on the sinus filter output. This example shows that sometime it is necessary to use unusually solutions. A sinus filter is known as a very effective anti-interference device. In this case, the satisfactory solution has been reached by usage of two anti-interference devices.

11.3 Example – Problems with Residual Current Breaker

Usage of residual current breaker is standard today. However the usage of this breaker for frequency converters sometime brings problems. A frequency controlled drive with 30 kW asynchronous motor was used for a ski lift. The converter was connected through a residual current breaker. The breaker was triggered every converter switch on. Many steps were done without success. As a final solution, the residual circuit breaker has been removed.

12.Conclusion

EMC problems became very important for all branches of electrical engineering including electric drives. The paper tries to offer practical methods to reach satisfactory EMC of frequency controlled drives. Typical rules for solving EMC problems of these drives are given. Experiences of the authors are the resources of the paper.

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