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Solutions of reducing an influence of converter-fed AC-drives on vicinity

***Abstract**. The paper discusses the negative impact of power converters on mains and vicinity. Higher harmonics of current and voltage, energy losses, electromagnetic radiation, and high level of noise are considered as examples. The preventive measures are discussed. The effectiveness of the low-pass filter applied between inverter and motor was investigated and results are presented.*

Streszczenie.** W artykule zaprezentowano przykłady negatywnego oddziaływania układów przekształtnikowych na sieć i otoczenie, do których można zaliczyć wyższe harmoniczne prądu i napięcia, straty energii, promieniowanie elektromagnetyczne oraz wysoki poziom hałasu. Opisano środki zaradcze. Przedstawiono wyniki badań skuteczności filtru dolnoprzepustowego zastosowanego między przekształtnikiem i silnikiem. (**Sposoby minimalizacji oddziaływania przekształtnikowych napędów prądu przemiennego na otoczenie)

Keywords: ac drives, power converters, electric power quality, environmental protection.
Słowa kluczowe: napędy prądu przemiennego, układy przekształtnikowe, jakość energii elektrycznej, ochrona środowiska.

Minimization of drives' influence on electric power system

Nowadays, the ac-motor is the fundamental final control unit of industrial drives due to the fast progress in power electronics. Since many years there is a possibility to set up ac-drives with technical parameters (static, dynamic and energetic) competitive with converter-fed dc-drives, whereas the well-known advantages (higher reliability, high rotational speeds, lower dimensions and moments of inertia) of ac-motors are kept. The fundamental disadvantages such as hunting and falling out of step of synchronous motors and stalling of squirrel-cage motors have been eliminated by the appropriate control. The range of application of ac-machines covers first of all high powers and rotational speeds, where dc-motors are not produced. Moreover, the application of ac-motors is necessary if special working conditions e.g. inflammable, caustic or dust ambiance are required [1].

The intermediate frequency converter, which feeds three-phase winding of motor, includes voltage source inverter (VSI). The electronic switches are applied for setting up the bridge of inverter. They are made of semiconductor power devices (transistors, thyristors and diodes) and they have similar properties to the electric switches containing pairs of contacts [2].

The power electronic converters applied in industrial drives, therein intermediate frequency converters, work in pulse way and introduce distortion to the power system. The higher harmonics in the power voltage appear as a consequence of the distortion what results in a number of disadvantageous effects. These are additional losses in: motors, transformers and cables conducting distorted currents. Additionally, electric devices with magnetic circuits (motors, transformers) fed with distorted voltage have higher losses in core than devices fed with sinusoidal voltage at rated frequency. The electric circuits fed with the distorted voltage or current are exposed to additional overvoltage pulses and heating an insulation. These phenomena are known as the reasons of motors' and transformers' damages.

In order to minimize the abovementioned consequences the following methods may be considered [3]:
- the application of the line choking-coils on the converter's input; the choking-coils decrease harmonic contents and current steepness as well as they smooth out waveforms;
- for high rated powers of ac-motors (over 250 kW) the input circuits of frequency converters (of low and medium voltage) are expanded; they together with supply transformer create multi-pulse circuits individually for each converter; the more pulses in the multi-pulse system within the input circuit occur – the less distortion of the supply current appears; the supply current can have total harmonic distortion coefficient even tens percents if a conventional 6-pulse input circuit is used;
- very good but unfortunately expensive solution is the application of active filters (Fig. 1); less expensive passive filters may be applied instead; however, application of passive filters has to be preceded by thorough analysis and gives the best results when load parameters of distortion sources are constant.

Minimization of noise and losses in electric motors

The commutation of the electronic switches in converter-fed drives at non-zero voltage and non-zero current causes disadvantageous phenomena, such as:
- losses of power and limitation of switching frequency as a consequence of losses,
- electromagnetic radiation as a result of switching high currents what causes the radio-noise,
- high level of the noise produced by motors fed with deformed currents and voltages.

The disadvantageous phenomena caused by the commutation of the electronic switches could be avoided if the resonance converters containing the switches interrupted at zero voltage or zero current will be applied. In order to minimize losses in motor and noise emitted by motor fed with distorted currents and voltages, an application of passive filters between inverter and motor may be considered. The structure of the test stand including this kind of filter is presented in Figure 2. The points where currents were measured by digital oscilloscope with memory are also shown.

The test stand consisted of: the prototypical specially designed induction motor of 7,5 kW fed from the frequency converter, the passive filter, the current probe and digital oscilloscope [4], [5]. The intermediate frequency converter consisted of: three-phase bridge 6D, the voltage source inverter and the dc-circuit between rectifier and inverter. The dc-circuit contained battery of capacitors. The voltage source inverter was set up as a bridge containing six transistors IGBT plus one transistor to brake the motor. The frequency converter included control panel based on direct torque control (DTC) method [6], [7].

The laboratory investigations into specially designed induction motor fed from the frequency converter were made with the application of the following equipments:
- the transistor-based frequency converter with rated parameters: power – 7.5 kW, input voltage, current and frequency – $3 \times (380 \div 460)$V, 25.5 A, 50Hz, respectively, output voltage and frequency – $3 \times (0 \div 400)$ V, $0 \div 120$ Hz, respectively, switching frequency – 3.3 kHz,
- the induction motor with rated parameters: 7.5 kW, 3×380 V, 50 Hz, 15.4 A, $\cos\varphi = 0.85$,
- three choking-coils with the magnetic core: 500 V, 50 Hz, 50 A, 5 mH,
- the battery of capacitors setting up as delta-connection: 3×500V, 8μF.

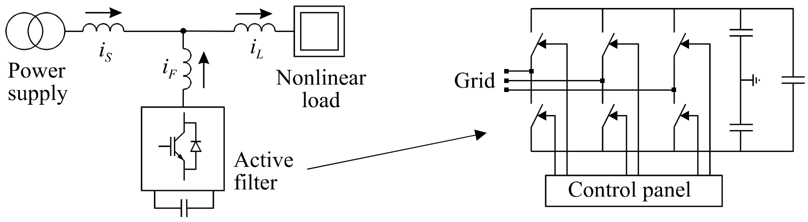


Fig. 1. The conception of application and simplified structure of the parallel active filter

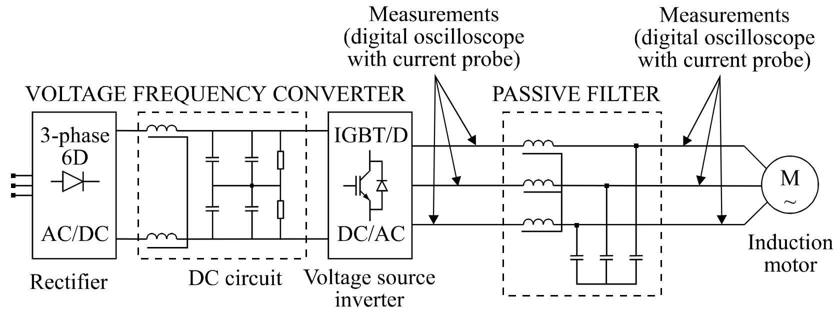


Fig. 2. The structure of the test stand

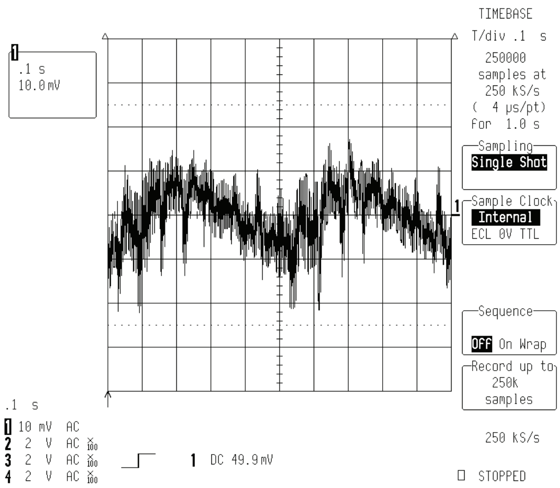


Fig. 3a. The current pattern versus time at frequency of 2 Hz; the current and time scales are 1 A/div and 100 ms/div (filter input)

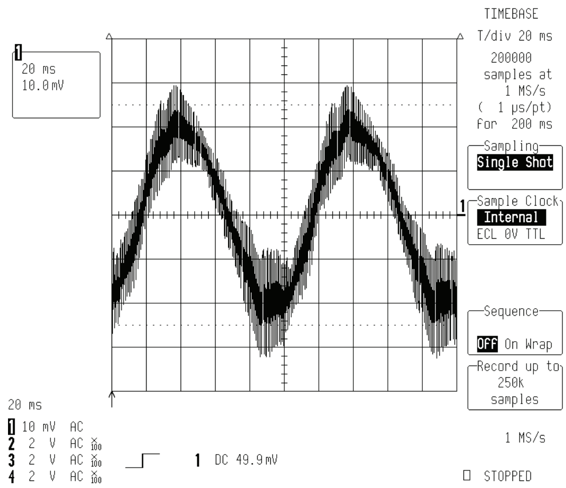


Fig. 4a. The current pattern versus time at frequency of 10 Hz; the current and time scales are 2 A/div and 20 ms/div (filter input)

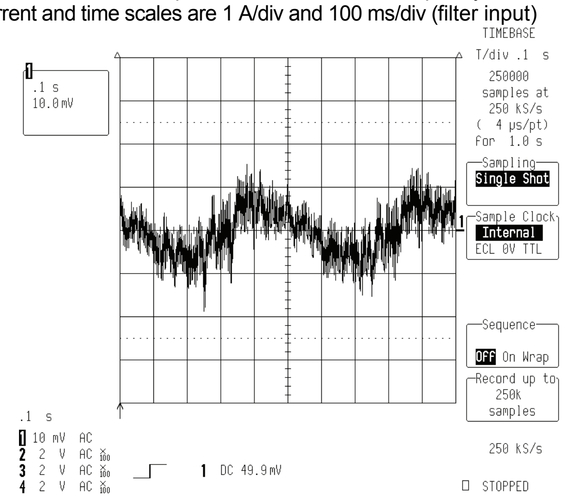


Fig. 3b. The current pattern versus time at frequency of 2 Hz; the current and time scales are 1 A/div and 100 ms/div (filter output)

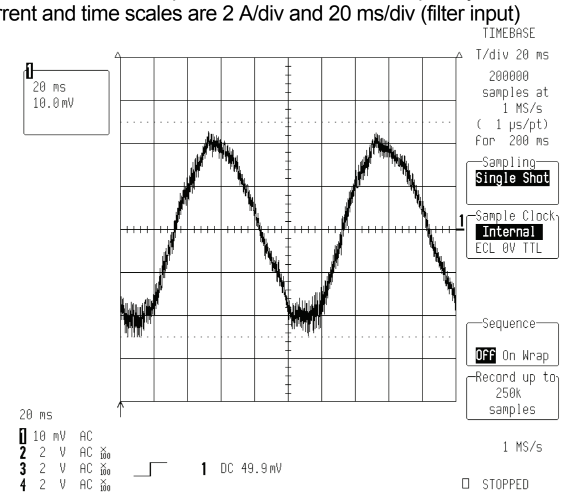


Fig. 4b. The current pattern versus time at frequency of 10 Hz; the current and time scales are 2 A/div and 20 ms/div (filter output)

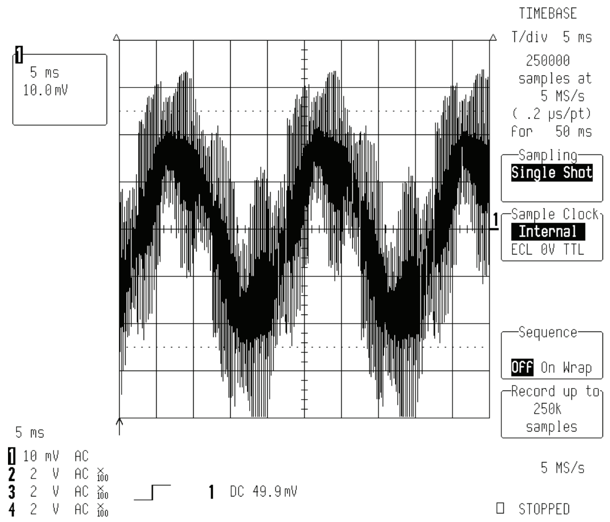


Fig. 5a. The current pattern versus time at frequency of 50 Hz; the current and time scales are 2 A/div and 5 ms/div (filter input)

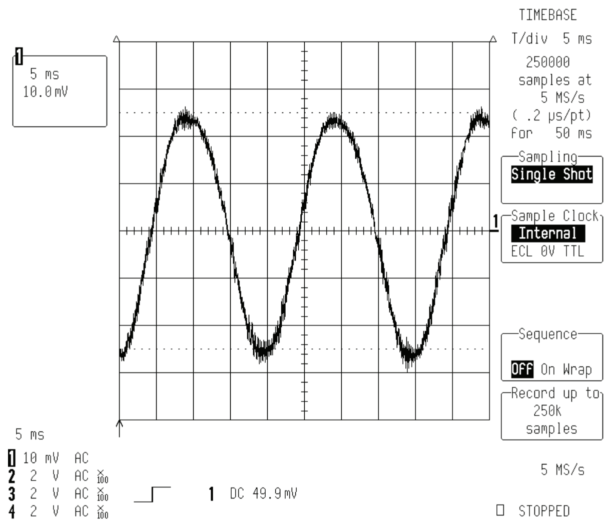
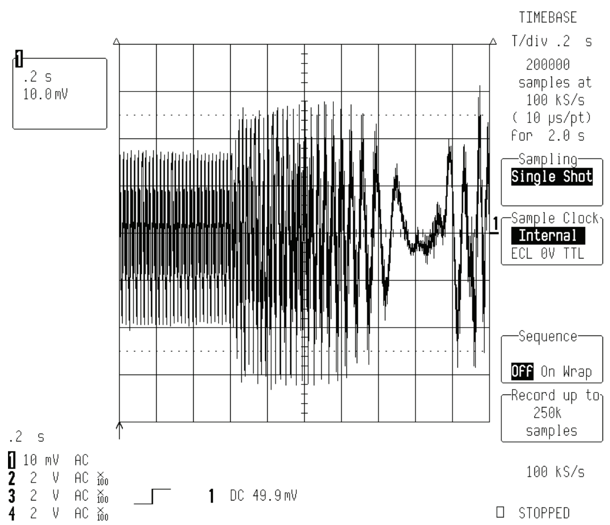
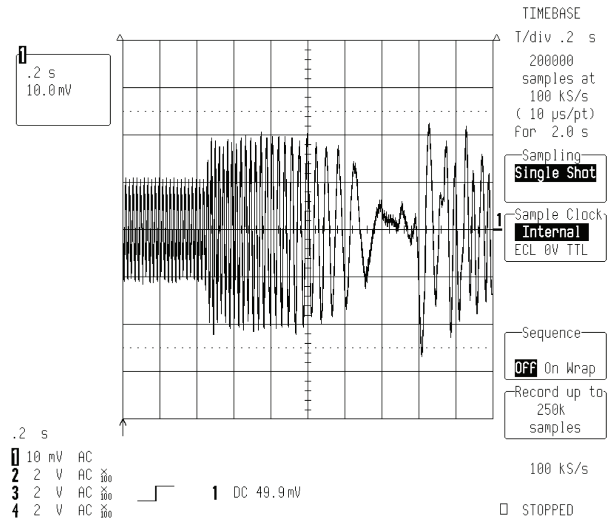


Fig. 5b. The current pattern versus time at frequency of 50 Hz; the current and time scales are 2 A/div and 5 ms/div (filter output)



a) filter input



b) filter output

Fig. 6. The current patterns versus time of reversed motor from 50 Hz to -50Hz; the current and time scales are 5 A/div and 200 ms/div

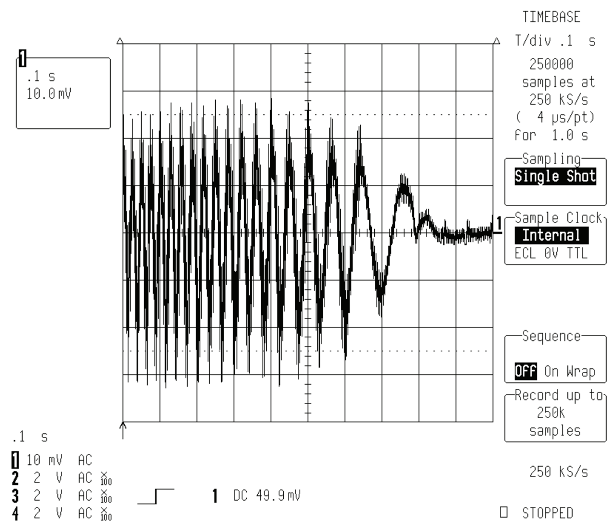


Fig. 7a. The current pattern versus time of braked motor from 50 Hz to 0 Hz; the current and time scales are 5 A/div and 100 ms/div (filter input)

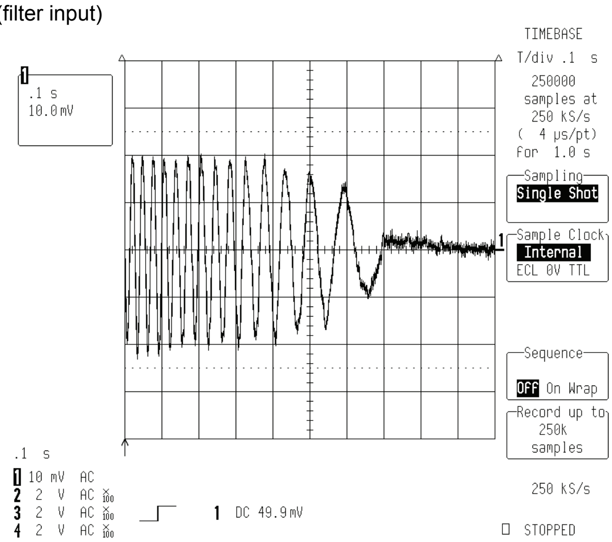
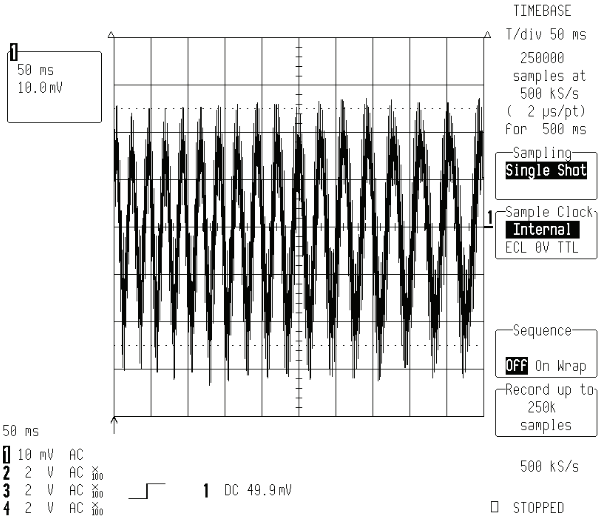
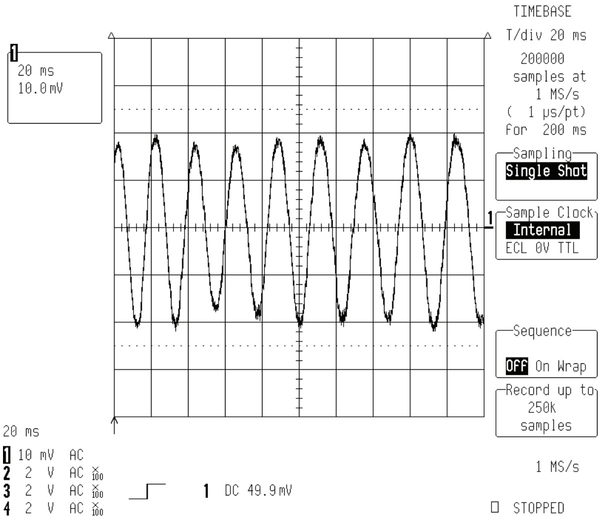


Fig. 7b. The current pattern versus time of braked motor from 50 Hz to 0 Hz; the current and time scales are 5 A/div and 100 ms/div (filter input)



a) filter input



b) filter output

Fig. 8. The current patterns versus time of the motor under rated load at 50 Hz; the current scale is 5 A/div whereas the time scales are 50 ms/div and 20 ms/div, respectively

Results of experimental investigations

The drive including an inductive-capacitive filter with parameters 5 mH / 8 µF was investigated.

The measured currents were registered by digital oscillo-scope and current probe with amplifier. The patterns of the phase-current of the motor and the current in the single filter branch versus time were measured for supply frequency 2, 5, 10, 30, 40 and 50 Hz, respectively. Selected results of experimental investigations into the specially designed induction motor fed from the frequency converter are presented in Figures 3 to 8.

Recap

The application of the energy-saving semiconductor devices allows to save the electric energy but it introduces distortion into the power grid. As a consequence of the distortion higher harmonics in power voltage appear what results in a number of negative effects. In order to minimize the abovementioned consequences the active filter applied between the grid and the converter may be considered. In order to minimize losses in motor and noise emitted by motor fed with distorted current and voltage, an application of passive filters between inverter and motor may be considered.

Selected results of experimental investigations into the induction motor fed from the intermediate frequency converter are presented in the paper. As a consequence of application of the low-pass filter between converter and motor the significant reduction of the distortion level can be observed in the patterns of the phase current. It results in minimization of disadvantageous phenomena described in the paper.

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