Active Elimination of Supply Current Harmonics in a Subway Motor-Compressor Drive

Maxim Yakovenko, Alecksey Anuchin, Dmitry Shpak, Vadim Ostrirov
Department of Electric Drives
Moscow Power Engineering Institute
Moscow, Russia
anuchin@alecksey.ru

Mikhael Podlesny, Konstantin Milskiy
R&D Company "Cycle+"
Moscow, Russia

***Abstract*—This paper considers the problem of interference of the current, consumed by motor compressor of the subway train, with the frequencies used by collision prevention system. With the incremental modification of the power converter, which feds the induction motor of the compressor, the sizes of the input filters were reduced in order to increase reliability and price. This results in significant increase of the current consumption at the frequencies of 275 and 325 Hz used by collision prevention system of Russian subways. Possible solutions to the problem were considered and a strategy for active elimination of these harmonics was proposed. It uses constant power controller for the compressor drive that decreases 25 Hz harmonic produced by the load torque; thus, 300 Hz ripple from the rectifier at the traction station do not interfere with power ripple caused by mechanical of compressor. Therefore, subharmonics of 275 and 375 Hz were decreased and do not affect operation of the collision prevention system. The proposed control strategy is presented, it was implemented, and experimental results are provided.**

Keywords—Interference; Variable speed drives; Compressors; Railway communication; Railway safety

I. Introduction

During last decades the power electronic converters become more compact and cheap due to recent achievements in semiconductor industry, passive element manufacturing and control strategies [1]. The SiC switches are widely used in automotive applications as well as film capacitors which are more compact and reliable for the same AC current rating. But with the decrease of the converter weight and dimensions the problems of EMI and other interferences with the power source and power-line communication used increases.

The problem considered in this paper occurred due to overlap of several factors in the Moscow subway. From the very beginning the Moscow subway uses track circuits [2]. It uses frequencies multiple of 25 Hz (275, 325 Hz and some other) to transmit information about the distance between the trains. Simultaneously, the railways are used as a negative DC link busbar connected to the traction power supply station. The power supply station contains a regulated transformer and a rectifier; therefore, 300 Hz component is present in the supply DC voltage and current.

The research was performed with the support of the Russian Ministry of Education and Science grant (Project № 8.8313.2017/BCh).

For many years the pneumatic system of the subway trains was filled by the compressors with the DC motor drives [3, 4]. The pneumatic system is used for the train braking and door opening. Approximately 10 years ago Knorr-Bremse Company started to supply modern piston compressors with induction motors to the Moscow subway. The major advantages of AC induction drives are much longer time between maintenance of the drive and significantly greater reliability in comparison with the DC machine drive due to the absence of brushed contacts. A special inverter was designed which supplied induction motor compressor [5].

The motor-compressor and inverter operated together without impact to the collision prevention system until a new inverter was designed in order to reduce its price and increase reliability by replacing some components including replacement of the input electrolytic capacitors with the film ones (see Fig. 1). This decreased time constant of the input filter to a very small value increasing cutoff frequency to 1 kHz or higher.

The last factor is that the piston compressors of Knorr-Bremse Company installed at the coaches produce 25 Hz torque ripple when operating at the rated speed with 50 Hz power supply. This ripple results in DC link current ripple, which is modulated by 300 Hz ripple from rectifier, and results in the huge 275 and 325 Hz components of the consumed current in the supply rail. That components affects the operation of the collision prevention system and should be reduced.

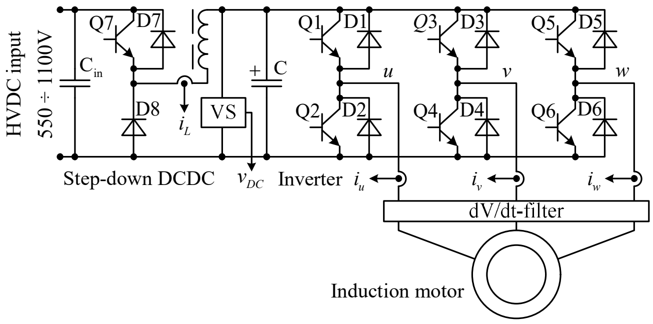


Fig. 1. Power converter of the compressor induction motor drive.

II. ELIMINATION OF THE INPUT CURRENT HARMONICS

In general, there two options that can be implemented by means of control system. First one is elimination of 300 Hz component from the input DC current; second, elimination of 25 Hz in the input current caused by compressor torque pulsation.

A. *Elimination of 300 Hz Component*

Due to small ratio between PWM and fundamental ripple frequencies (10000 Hz and 300 Hz) first option requires implementation of repetitive control system. Though it is possible to exclude 300 Hz AC component from the supply current, there will be a pulsation in the choke current of the buck-converter together with input voltage pulsation. That current ripple loads electrolytic capacitor of the inverter DC link and reduces its time to failure. The next generation of the compressor drive will have film capacitor in SiC buck-converter; therefore, the time constant of this filter will be reduced. For 220 uF capacitor and 8 kW compressor the current ripple of 15% from the DC current consumed is 2.2 A, which results in 33 V ripple in the output voltage. Further decrease of the film capacitor value is not possible, whereas desirable when SiC switch in the buck-converter is used. One more problem occurs at low input voltages, when buck-converter operates in the conducting mode. In this mode suppression of the 300 Hz AC component is not possible.

B. *Elimination of 25 Hz Component*

As it was shown, the problem of suppression of the rectification ripple is caused by permanent decrease of the passive elements in order to reduce system cost. For the elimination of any AC component an energy storage should be used. If electrical energy storages are reduced with the evolution of power electronic devices, the mechanical part with motor compressor remains the same for at least 10 years and there are no evidence that it will be changed significantly in the future. The use of mechanical inertia for different purposes, including energy saving [6], is well-know. In case of periodic load, it is desirable to decrease the reference tracking accuracy in order to decrease current ripple, which is responsible for torque and speed stability. The decrease in current pulsation reduces ohmic losses in the motor.

Considering the mentioned above, it was suggested to uses inertia to suppress the 25 Hz mechanical load pulsation. The proposed control strategy (see Fig. 2) takes three phase voltages, multiplies them by three phase currents and sums them in order to obtain the power provided to the motor. Then the alternating component should be evaluated. This can be done using high-pass filter. Of course, the alternating component should be filtered by itself with low-pass filter to avoid noises caused by measurement error. The time constant of the low-pass filter should not affect the mechanical load pulsation frequency but remove 300 Hz component. Both filters can be represented by a single band-pass filter. Finally, the reference to the drive should be corrected. The correction of the reference can be adjusted by changing k_{cor} coefficient.

III. SIMULATION RESULTS

The proposed control strategy was examined using model simulation. The compensation of the 25 Hz current consumption can be switched on and off in order to compare the behavior of the system in two different modes. In the first case the frequency is stable and both 300 and 25 Hz components are presented in the consumed current. In the second case the system adjusts the output frequency in order to eliminate the 25 Hz component. The consumed current of the DC rail without and with compensation is shown in Fig. 3a and 3b respectively. It can be clearly seen that the low-frequency ripple in the input current is significantly reduced when the correction is switched on. The spectrums of the consumed current for the same cases are represented in Fig. 4a and 4b. With the elimination of the 25 Hz component the 275 and 325 Hz subharmonics were removed.

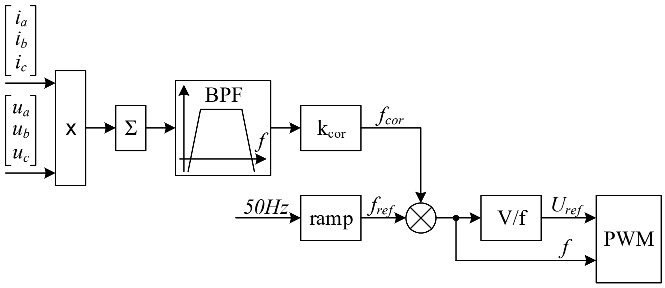
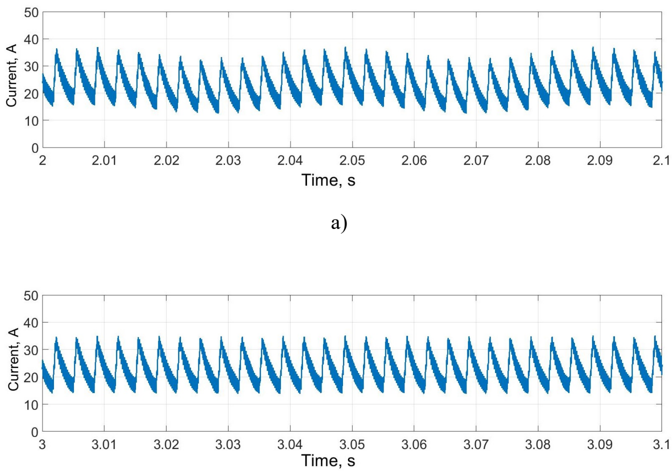
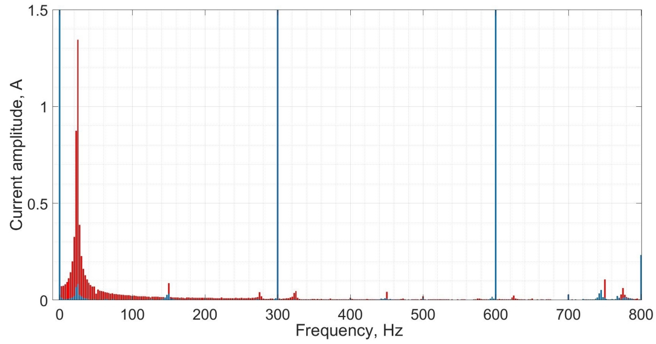


Fig. 2. Proposed strategy for load ripple compensation.

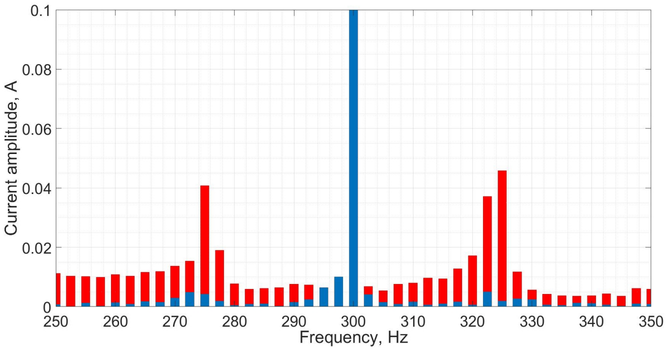


b)

Fig. 3. Simulation results (a) without correction, (b) with correction of the output frequency.



a)



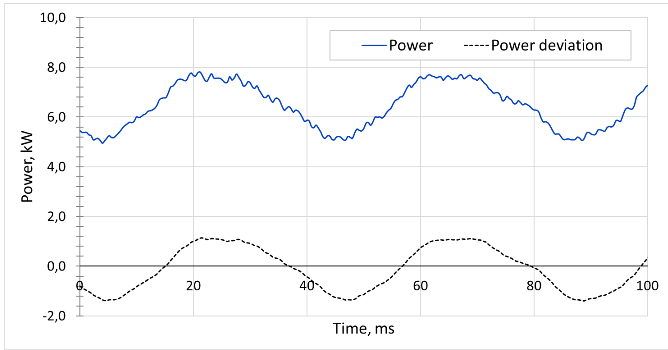
b)

Fig. 4. Spectrum of the consumed DC rail current (a) without correction in the frequency range form 0 to 800 Hz, (b) in the frequency range from 250 to 350 Hz: red – without correction, blue – with correction of the output frequency.

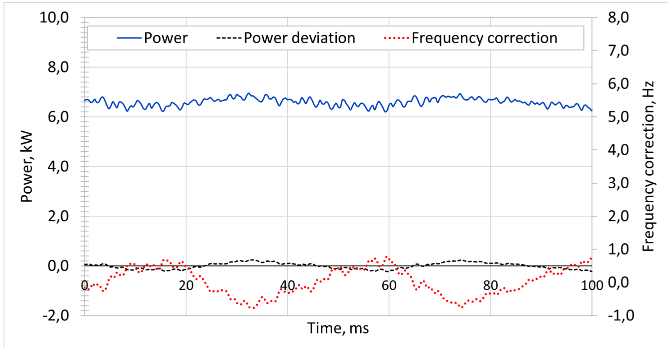
IV. Experimental Results

The experimental verification of the proposed strategy was performed at the subway coach with the real equipment. The oscillograms of the electrical parameters were obtained using digital oscilloscope embedded into microcontroller software. The deviation of the power delivered to the compressor motor was approximately ±1.5 kW with the average power of 6.5 kW. Its alternating component was distinguished and filtered from the 300 Hz rectification ripple (see Fig. 5a). When the proposed strategy was switched on, this component was used to correct the output frequency, which started to deviate by ±0.6 Hz. This affected to the alternating component of the consumed power, which was decreased to ±0.2 kW only (see Fig. 5b).

The spectrum of the consumed current was measured using a special device utilized by subway commissioning service which recorded the consumed current. The Fourier transform with the sliding window was performed to obtain the values of the selected harmonics during standard compressor operation cycle. The diagrams of the 275 and 325 Hz components without correction are presented in Fig. 6a and 6b correspondingly. These components went out of permitted values during almost the whole operation cycle. With the switched-on elimination of the 25 Hz component both 275 and 325 Hz subharmonics were reduced, while still exceeding the permitted limits for a short period of time as shown in Fig. 7a and 7b. Considering the magnitude and duration of the noises these curves lay into standard of safety operation for collision prevention system.

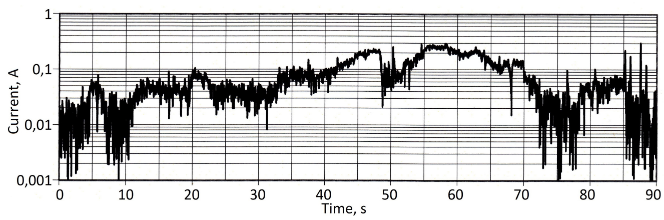


a)

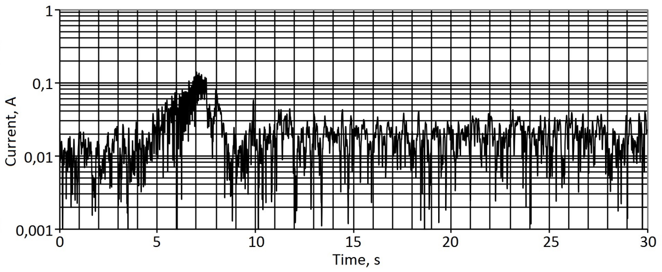


b)

Fig. 5. Experimental results (a) without correction, (b) with correction of the output frequency.

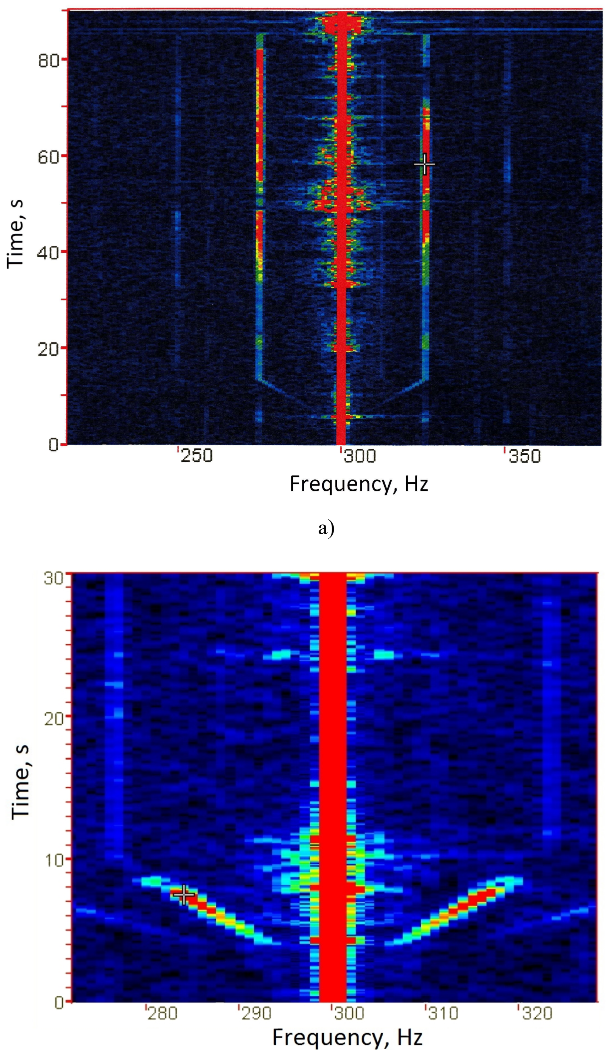


a)



b)

Fig. 6. Diagram of the interference current in the frequency range from 315 to 334 Hz during operation of the motor compressor drive (a) without correction, (b) for the proposed strategy.



a)

b)

Fig. 7. Spectrogram of the consumed DC rail current (a) without correction, (b) with correction of the output frequency, red above 0.1 Amp.

V. Conclusions

The proposed solution helped to eliminate components in the consumed current which are interfere with the collision prevention system communication used in the Russian subway. The solution utilizes the mechanical inertia of the motor compressor in order to stabilize the output power. That decreases the 25 Hz component ten times eliminating subharmonics of 275 and 325 Hz from the consumed current. The proposed solution was implemented in the embedded control system of the compressor drive and passed certification tests in the Moscow subway.

References

[1] C.F. Tong, A. Nawawi, S. Yin, K.J. Tseng, Y. Liu, and R. Simanjorang "Demonstration of 6kW/kg 50kW grid facing power converter for future aircraft", 2016 IEEE Region 10 Conference (TENCON), November 2016

[2] "THE INVENTION OF THE TRACK CIRCUIT", Signal Section, American Railway Association, 1922

[3] Electrical and Automatic Air Brake Equipment Instructions, Interborough Rapid Transit Company, Office of General Superintendent, New York City, June, 1904

[4] F. Shaoxuan, Z. Baoquan, Y. Ohtomo, T. Asada, H. Kimijima and K. Fujii, "Electrical Components and Air-conditioning Units for Lowenvironmental-impact Trains for Subway Systems in China", Hitachi, pp. 33-40, 2008

[5] A. Anuchin, V. Ostrirov, Y. Prudnikova, M. Yakovenko, F. Briz, and M. Podlesny, "Thermal stabilization of power devices for compressor drive with start/stop operation mode", 2016 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), 13-14 Oct. 2016

[6] D.M. Tobnaghi, M. Alirezaloo, M. Gheydi, F.A. Baroogh, and P. Farhadi, "Induction motor drive design based on efficiency optimization and drive loss minimization", 2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 23-25 March 2017