EMC Specific Problems of Frequency Converters Used at Interlocking Device

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Abstract. *The paper deals with problems of electromagnetic compatibility (EMC) of frequency control drive of electromotive switch actuator of railway switch. The frequency converter with Pulse Width Modulation (PWM) and the output sinus filter are used for feeding of the asynchronous motor of the switch actuator. This drive is operated in an insulated system of feeding voltages. The drive is fed by a frequency converter with an unshielded cable with length up to 1.2 km. The EMC problems occurring at development and operating of the drive are analyzed in this paper. The used solution of these problems and experience with EMC of the given system from real operation are described in this paper as well.*

Keywords

EMC, PWM, interlocking device, control system, converter, sinus filter, switch actuator, railway switch.

1. Brief Description of the Application

A new electronic interlocking device developed by Automatizace železniční dopravy was used in the railway stations at the reconstruction of the second railway corridor. A control system and a drive of electromotive switch actuators are also parts of interlocking device.

The drive control of the electromotive switch actuator is made by the contact switching devices at the classical systems. The couple of special relays are used for drive switching-over of switch actuator. These relays have to comply with the enormous reliability requests due to their construction and used contact materials.

The delivered interlocking devices for the second railway corridor are contactless with high rate of microprocessor technology utilization. The requirements for contactless electronic switching were implemented at control of electromotive switch actuators, too. It was not possible to use the contactless electronic relays considering high safety and reliability requirements of devices, because breakdown can arise at these devices during fault, thereby unwanted switching-over of railway switch.

It was decided to use the frequency converters for feeding of motors of switch actuators in several stations from the reason of drive characteristics improving and the reason of possibilities verification and characteristics of safe contactless switching of switch actuators motors. During development of the new drive it was necessary to proceed from specific requirements of railway operation. Therefore the whole drive is solved from a viewpoint of the following areas of problems:

- The application of the existing switch actuator with asynchronous motors with short-circuit armature with star connection for voltage 380 V and nominal current 1.5 A.
- The enormous reliability requirements and drive safety requirements and also the specific forms of secure of these characteristics.
- The preclusion of converter damage at interlocking device faults.
- The solution of interface between the frequency converter and operating computer of station interlocking device.
- The resolution of EMC problems of drives under specific conditions of railway operation which are often different from standard solution [1], [2].

The frequency control drive is operated in isolated system 3x 400 V. The cubicle switchboard for control and feeding of 16 electromotive switch actuators form the base unit. The switchboard contains particularly frequency converters, filters, interfaced and control circuits of switch actuators and also overvoltage protections. The control circuits are galvanicly separated from a power part with electric strength 4 kV.

The motors of switch actuators are fed by unshielded cables from the switchboard. The length of a cable between a frequency converter and a motor depends on a localization of a railway switch in a railway station and it can reach up to 1.2 km.

The special secure control signals used for hardware unblocking of converters are necessary except the standard control signals for switching of the drive with the defined direction of rotation which are set by computers via converter interface cards. The existence of these signals is given by increased requirements for operation safety. At dimensioning of the converter, it came out from measuring results and a frequency converter for a motor with constant power 1.5 kW was used. The detailed information about the technical solution of the switch actuator drive is in [3], [4].

The drive system of switch actuators with frequency converters was being developed and activated in co-operation with university workplaces. These workplaces participated especially in hardware modifications of mass produced frequency converters focused on fulfillment of safety requirements, the solution of interface between frequency converters and computers of interlocking devices and the solution of EMC problems.

2. EMC Conception of Frequency Control Drive of Switch Actuator

The EMC of devices at network side is protected by network filter and reactors. The network filter is common for all converters in a switchboard and it is dimensioned for parallel operation of five drives because the simultaneous switching of a higher number of railway switches is not supposed at station operation. The EMC security at the converter output is significantly intensive and costly where length of unshielded cables to the motor is supposed up to 1.2 km [5]. The frequency converter works with switching frequency of PWM 10 kHz. Usage of three-phase sinus filters, which eliminate higher current and voltage harmonics, was only one way to interference elimination at the converter output [6]. The interference elimination at the converter output was measured and evaluated by ELFIS company according to the standard EN 50121-3-1. The measurements were done by using a selective microvoltmeter in 9 kHz to 30 MHz band. The reports were elaborated with results cited in [7], [8].

The magnitude of a parasitic signal in signal lines led parallel with the lines for feeding of a motor and the magnitude of a parasitic signal in the distance of 10 m from the power line were found out. The length of the line was 1 km from the motor to the converter. The level of parasitic signals did not exceed the values given by standards and the levels of parasitic signals were not measurable at numerous frequencies. The findings of measurement certified the usability of the designed type of sinus filter which is dimensioned for 2.2 kW motors. The filter is connected as gamma element. The filter reactors have ferrite cores and their inductivity in unsaturated state is 12 mH. The capacity of filter capacitors is 2 μF.

The effect of sinus filter is qualitatively visible from Fig. 1 and Fig. 2. The waveform of the output delta voltage of the converter is in Fig. 1 and voltage of output sinus filter is in Fig.2. The elimination of higher harmonics by filter is considerable.

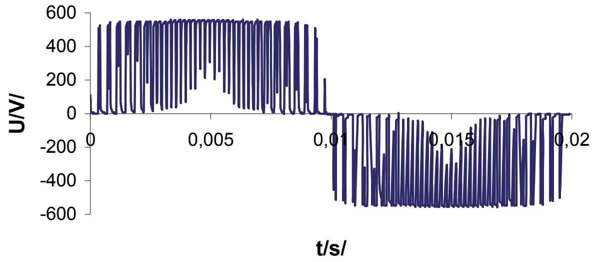

Fig. 1. The output of delta voltage of frequency converter.

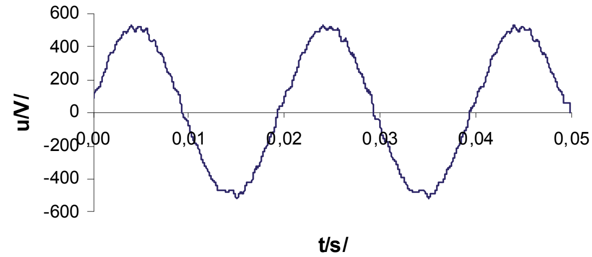

Fig. 2. The delta voltage of output of sinus filter.

3. EMC Specific Problems Solved after Putting into Operation of Interlocking Device

Usage of a sinus filter is essential in the given application however its usage did not avoid occurring of some parasitic effects due to a frequency converter with PWM. The parasitic capacities of power IGBT (Insulated Gate Bipolar Transistor) modules of converters are in the range from tens to units of nF. Relatively high parasitic currents with these capacities can arise because dv/dt at power elements run into values over 1000 V/μs [9].

The other parasitic capacities occur at the cable. The values of these capacities are in the range tens of nF/m. The parasitic capacities of the motor reach the values in the range of units of nF. Although the cable and motor are fed by voltage, which is behind the sinus filter, it turned out that this filter does not eliminate higher harmonics of current and voltages without remainder. The structure of a circuit with these parasitic capacities is in Fig. 3. The parasitic couplings, particularly capacitive couplings of the converter, cable and motor, emerged as problematic in operation. The certain potential came through the parasitic capacities of the motor on the case of switch actuator in rail yard. Thereafter the danger voltage to earth occurred on the case of the switch actuator because the magnitude of the voltages depended on insulation quality of switch actuator case from earth. At the worst cases the values of this voltage got over 100 V. These problems do not occur at the quality manufactured standard drives with frequency converters, because the converters work in an isolated system and all electrically passive parts are connected with earthed potential or possibly with protective earthed conductor. The problem was solved at last by connection of capacitor nodes in sinus filters and following earthing of these nodes. But this connection activated protection of isolative state because current of this protection was closed through discharge resistors of sinus filter capacitors. This problem was solved by centre disconnecting of discharge resistors from centre of sinus filter capacitors. The majority of switch actuators operated without any problems after these adjustments, defective shutdown of converter occurred at only a few drives sporadically and casually during switching-over of railway switches. In the case the converter reported the error of overload by current at starting. The pure theoretical solution was almost impossible in this case because the whole system is very sophisticated from viewpoint of PWM frequencies. This sophistication is given particularly by existence of many parasitic capacities in the system, the stochastic wave effects at feeding cable to motor and high dv/dt at frequency converter output. Moreover the specific configuration of drive is dependent on localization of switch actuator in station rail yard and trace of feeding cables.

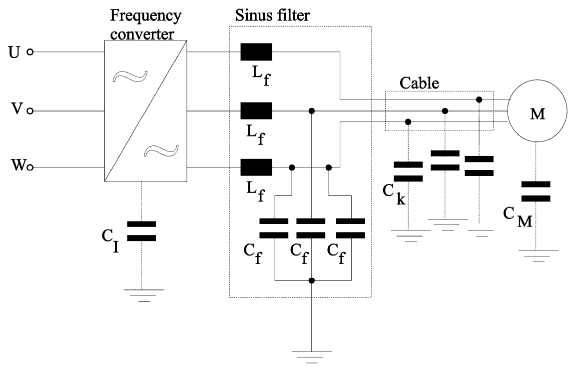

Fig. 3. Circuit structure of switch actuator drive.

The series of measurements was realized on the drive of the switch actuator in the station. During these measurements a relatively high value of current of higher harmonics generated by the converter PWM was found out. It is not possible to discover the exact trace of a parasitic current from our measurements. It is very probable that higher harmonics of voltage at the frequency converter output are sources of this parasitic current. Obviously this current is closed through parasitic capacities, converter leakages, a cable to the motor, the motor and the earthed center of the sinus filter. This current also increases total values of current at the converter output. During hard starting, current overflow can arise on which the output overcurrent protection of the converter reacts.

It was proved by measurements [10], that parasitic current of higher harmonic components closes through the earthed center of sinus filter capacitors, see Fig. 4. It gets peak values which are comparable with nominal values of motor current. If the earthing connection was disconnected the impedance of traces of parasitic current increases, the converter current decreases and there was no fault. In this case the dangerous contact voltage occurs on the frame of the switch actuator and also on the centre of sinus filter to earth. The converter PWM, as already noted, is source of this high-frequency voltage. This high-frequency source is relatively soft. This voltage is eliminated at the increasing of impedance of parasitic circuit by filter earthing, however, for the price of passing of insignificant equalizing currents which load the converter. The limitation of equalizing current arises also due to connection of filter centre to earth by impedance (resistance or inductivity) which was detected at the measurements. In this case this impedance with parasitic impedances behaves as an attenuator and a part of voltage of high-frequency source is reappeared on the frame of the switch actuator to earth. The limitation of equalizing current by insertion of impedance to earthing of the filter centre is unsuitable.

The comparison of measured results at two various railway switches is interesting. From this comparison it is obvious the equalizing current of filter centre at farther railway switch is lower. And so the magnitude of equalizing current is influenced by earthed impedance. This fact corresponds with reality that fault rate is influenced by climatic conditions.

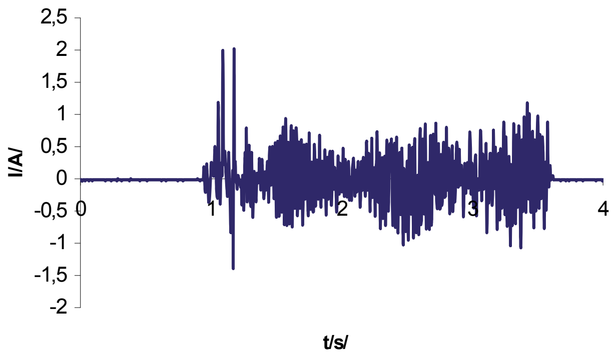

Fig. 4. Waveform of current in earthing of centre of capacities of sinus filter during switching-over of railway switch.

The deceleration of speed ramp of converter and reduction of initial voltage at starting improved the situation significantly, even if these measures resulted in reduction of motor current and partial extension of switching-over time. Sometimes, the faults of drive even so happened again and that is why the requirement of autorepeat of starting was set after faults. The problem of dangerous contact voltage was also found at the converter site in switchboard. The electrically passive parts of switchboard are connected with protective earthed conductor of feeding network. The electrically passive parts of converter, particularly coolers, were insulated from these parts of switchboard and also dangerous contact voltage was measured. Therefore these parts were connected with protective earthed conductor. Afterwards, the high interruption of start signals of converters coming to their logical inputs began to appear. It was not possible to switch off converters by these signals. At used converter the referential earthed potential of electronic control card is connected by capacitor with electrically passive parts of converter. This connection has to secure protection of control card against interference at the feeding from earthed network. The effect of this connection was counterproductive in the case of insulated feeding system. The elimination of interruption of input signals was reached after disconnection of this connection i.e. after taking out the coupling capacities of converter.

4. The Problems with Changed Technical Structure of Converters

The drives were operated without any problems after mentioned modification. After about three years of operation three frequency converters were damaged at thunderstorm by effect of lightning over-voltage. Therefore spare converters of newer production date were used. The characteristics and control are identical at older and newer converter from the position of a common user. The inner structure of newer converters was changed. The circuit connection of control part was modified partly. The different elements (particularly different power module and IGBT exciters) and SMD technology were used. After installation of these newer converters to drive of switch actuator at the station the converter notifies error immediately after start command (over range of maximal start current). It does not come to start of drive at all - always at all drives and at repeated start command.

The different philosophy of solution of overcurrent protections at newer converters is the cause that this effect did not come at the older converters. The overcurrent protection at the older converters is based on monitoring of input signal of an inverter. Special IGBT exciters are used at the older converters which have integrated overcurrent protection in each phase of inverter. This protection is based on monitoring of voltage drop at switched on IGBT. The increase of this drop indicates increase of IGBT current. The faulty switching off of converter is initiated at the overrange of values approximately 5 V. The described overcurrent protection is very sensitive and reacts very fast (from fractions up to units of μs).

The increase of sensitivity and reaction speed of overvoltage protection leads to reaction of this protection by relatively high current peaks which come through earthed centre of sinus filter, see Fig. 4. Less sensitive and slower overvoltage protection reacted on these peaks only exceptionally at the older converters. These faults were stopped particularly by autorepeat of start, as it was mentioned above. This reality is certified by fact, the newer converter works without any problems and faults at disconnection of capacitors centre of sinus filter however damage contact voltage occurs on the electrical passive parts of drive, as it was mentioned above as well.

The interaction to the parameters of filtering of higher harmonics between converter and feeding cable to motor can be considered for the most practicable technical solution on the basis of above mentioned description of problem. The measurements and testing in test base of AŽD and railway station were focused on this method. The tests were focused on increasing of the inductive component of the used sinus filter. The voltages and currents between unearthed frame of switch actuator and earth i.e. protective earthed conductor in various cases of solution of filtering were measured simultaneously.

The additional reactors with values 3 mH, 5 mH, 12 mH, 18 mH and 22 mH were put between sinus filter and converter during measurements. At mentioned tests it was found out that the negative effects proved in higher range at usage of drive in railway station than usage of drive in test base. In the test base, where short cable between the filter and the motor was approximately 10 m it was enough to elimination of converter faults to add the reactors with total inductivity 5 mH to filter. In the railway station where the cable length was approximately 1 km it was necessary to add additional reactors with inductivity 22 mH. Therefore it was recommended to add the additional output reactors to drives or to design new sinus filters with increased inductivity. The waveform of current in earthed centre of sinus filter after adding of reactors 22 mH is in Fig. 5. The detailed information is in [11] and [12].

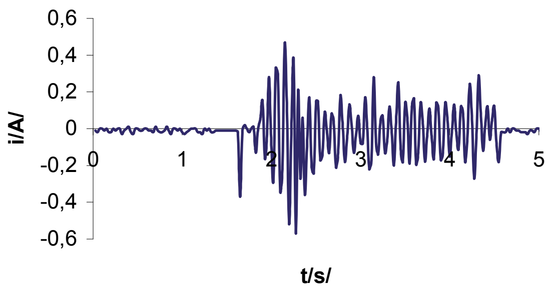

Fig. 5. The current in earthed centre of sinus filter after adding of reactors 22 mH.

5. Conclusions

Usage of frequency converters as element for safe contactless switching of motors of switch actuators of railway switch proves both from viewpoint of mechanical characteristics of drives and from viewpoint of protection of necessary functions under conditions of safe railway operation. Many problems with EMC of frequency converter with PWM operated in insulated systems with long feeding cable between converter and motor occurred in unexpected range. Considering very different conditions of using particular drives in real operation, it was not possible to use the theoretical processes to solution. Although many problems were solved satisfactorily, it is necessary to note that EMC of described application is not possible to regard as concluded. From this reason the described system was not used at the next process of building of the second corridor at the Czech Republic. At the present the contact electrical devices are used for switching of motors of switch actuators of railway switches, but the patented solution of safe contactless switch, which works without PWM, is made ready.

The computer simulations are significant tools at search of solution of problems in technical systems. It is valid at the solution of EMC problems as well. In the described case of this paper the simulation models were not built up from these reasons:

- The simulation models require exact knowledge of structure and parameters of a simulated system. In the case of frequency control switch actuator of railway switches the structure of the whole circuit depends on location of railway switch in yard, particular configuration of station yard and the connection of interlocking device switchboards in railway station. It was not possible to obtain the parameters of these very complicated structures from viewpoint of EMC neither from interlocking device contractor nor from Czech Railways.
- The parameters of electrical circuits of interlocking device are very variable and they largely depend on: state of railway bedding, insulation resistances, local conditions of solution of particular railway station, location of railway switch in yard, cable runs, weather conditions, season and immediate operating situation in railway station.
- The technical solution finding was proceeding in number of cases under real operating conditions. There was no time for problem solution at the level of computer models.
- The whole technical research project was supported financially by AŽD company with concrete budget where it was no space for research of problem at the level of computer models.

In general it can be stated on the basis of experience with the described application that usage of classical industrial frequency converters in isolated system, in addition with long feeding cable to motor, is from viewpoint of electromagnetic compatibility very problematic. It is suitable to give priority to the classical solutions under meeting usual criteria for structure at applications of frequency converters from viewpoint of EMC.

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