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Electromagnetic compatibility of field controllers with intrinsically safe measurement circuits

The article features the EMC(electromagnetic compatibility) requirements concerning resistance of power protection devices with intrinsically safe circuits. The most important standards and recommendations were presented for the construction of electronic devices for industrial automation systems.

keywords: electromagnetic compatibility, intrinsic safety, power protection devices.

1. INTRODUCTION

Field controllers with intrinsically safe measurement circuits are important elements of fire-proof distribution boards used in underground mining. These controllers are integral parts of power protection devices, that is why they are bound by all standard regulations concerning such devices. Due to the size of its fire-proof enclosure, a field controller is placed near a contactor or a switch where there are high, often excessive, levels of electromagnetic disturbances [1]. Due to the existing connecting processes of high values of current, it is particularly difficult to comply with the requirements of electromagnetic compatibility in the scope of resistance. Another issue is to fulfil the requirements of intrinsic safety of intrinsically safe monitoring and control circuits which come out of the enclosure. These circuits run dozens or even hundreds of meters and are subject to electromagnetic disturbances which are generated during the connecting processes and are distributed along power cables. In order to fulfil their role, intrinsically safe measurement circuits must have suitable resistance to these disturbances. The circuits use microprocessors more and more frequently. After the measurement signals are processed, the microprocessors transmit them in a digital form to the non-intrinsically safe part. Disabling electromagnetic disturbances by using LC filters in these circuits is much limited due to the requirements of intrinsic safety.

The article features the issues related to electromagnetic compatibility in the realm of field controllers. It also presents sample solutions of intrinsically safe measurement circuits implemented in field controllers which allow to fulfil the requirements of electromagnetic compatibility. Finally, the results of laboratory tests are discussed.

2. SOURCES OF EMC DISTURBANCES FOR POWER PROTECTION DEVICES WORKING IN MINING CONDITIONS

Electromagnetic compatibility of electric or electronic devices requires that these devices should work properly in a certain electromagnetic environment [2]. This can be achieved by a proper level of resistance and reduced emission of disturbances which can interfere in the work of other devices. Disturbance emission levels and resistance to disturbances were determined in the standard PN-EN 60255-26:2014 [5]. Power protection devices are equipped with intrinsically safe and non-intrinsically safe inputs/outputs: measurement-, bi-stable- and power supply inputs as well as relay outputs and transmission circuits called ports. It is important to note a special role of the enclosure – usually made of metal, equipped with an earthing terminal called enclosure port. The disturbances are emitted both through the enclosure and the power supply port. The resistance to disturbances applies to all ports available in the device, including the enclosure and the earthing conductor.

Electric devices are sources of electromagnetic disturbances both during normal and disturbed operations. It is necessary to minimize the disturbances emitted by the sources in order not to exceed the level admissible for other devices. In mining conditions the disturbances resulting from natural phenomena, e.g. those related to storm-generated lightings, are scarce. Still, there are phenomena related to the following:

- connecting processes related to the connections of current circuits or reconnection of voltage on busbars,
- distribution of power-frequency earth-fault currents,
- conductive-, capacitive- and inductive couplings related to mutual interference of installations,
- propagation of waves in connection lines and cables,
- electromagnetic radiation through the enclosure and earthing conductor.

Electromagnetic disturbances infiltrate to power protection devices through many channels, e.g. through the following types of couplings:

- field couplings through the enclosure – non-frequency electric and magnetic fields,
- capacitive couplings between elements and conductors,
- inductive couplings,
- couplings related to conduction.

Table 1 features a list of standards concerning the resistance of power protection devices.

Table 1.

Standards concerning the resistance to disturbances of power protection devices

Type of disturbance	Enclosure	Earthing conductor	Auxiliary supply input	Communication links	Inputs and outputs (incl. measurement circuits)
Radiated, radio-frequency, electromagnetic field disturbances PN-EN 61000-4-3	X	X			
Electrostatic discharge disturbances PN-EN 61000-4-2	X				
Power frequency magnetic field disturbances PN-EN 61000-4-8	X				
Conducted disturbances induced by radio-frequency fields PN-EN 61000-4-6		X	X	X	X
Electrical fast transient/burst disturbances PN-EN 61000-4-4			X	X	X
Oscillatory wave 1MHz PN-EN 61000-4-12			X	X	X
Surge PN-EN 61000-4-5			X	X	X
Voltage dips, short interruptions and voltage variations on AC/DC PN-EN 61000-4-11 PN-EN 61000-4-29			X		
Power-frequency disturbances (concerning only bi-stable inputs) PN-EN 61000-4-16					X

3. ELECTROMAGNETIC COMPATIBILITY OF INTRINSICALLY SAFE CIRCUITS

Though, according to the ATEX directive, intrinsically safe circuits cannot generate explosion hazards, all electromagnetic compatibility tests should be conducted for these circuits in a similar way as for non-intrinsically safe ones. It is very difficult to achieve the required resistance to disturbances in this case because, due to intrinsic-safety reasons, the use of blocking capacitors or equivalent series inductance in the form of anti-disturbance ferrites put on cables is limited to merely a few microhenries. When microprocessor measurement circuits are applied, it is important to distribute the mass of the process circuit properly, to use fast diode shield voltage limiters and include series resistances which, together with included capacities, will make anti-disturbance RC filters. Figure 1 features a connection diagram of the PW2 field controller. On the left side of the figure there are intrinsically safe resistance measurement circuits (marked blue), intrinsically safe control circuits and relay outputs circuits. Both intrinsically safe and non-intrinsically safe circuits were exposed to disturbance signals of the same values. Table 2 presents the levels of hazards/exposures for particular inputs and outputs.

Table 2.

Levels of electromagnetic hazards for particular inputs and outputs of power protection devices with intrinsically safe and non-intrinsically safe circuits

Type of port	Type of hazard	Level of exposure
Intrinsically safe inputs and outputs	BURST SURGE Radio conducted disturbances 150 kHz – 80 MHz F damped disturbances 1MHz	4 kV 2 kV 10 V RMS 1 kV/2.5 kV to PE
Bi-stable and measurement inputs and non-intrinsically safe outputs	BURST SURGE Radio conducted disturbances 150 kHz – 80 MHz F damped disturbances 1MHz	4 kV 2 kV 10 V RMS 1 kV/2.5 kV to PE

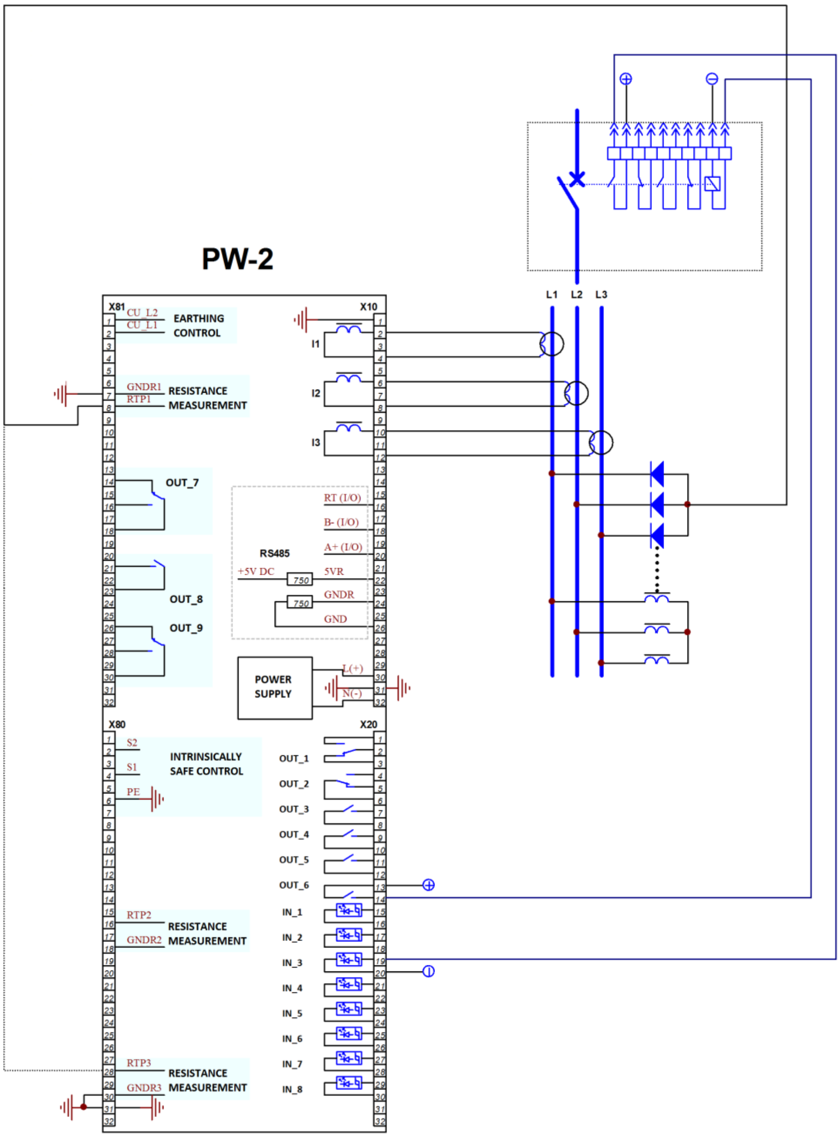

Fig. 1. Connection diagram of a sample PW2 field controller responsible for measurement and protection functions

4. ANALYSIS OF THE EXCITATION OF CURRENT-VOLTAGE TRANSDUCERS IN TRANSIENT STATES

Coreless current transducers, operating like Rogowski coils, are elements which can store energy from an electromagnetic field initiated by current flow. These transducers are used in the mining industry too. They can be described by an electric equivalent circuit which has a character of a series-resonant circuit with the resistance *R*, inductance *L* and capacity *C* [3,6,7]. The value of the capacity *C* is determined based on the response of the transducer to the uni-step of current in the primary circuit [4]. A typical value of the capacity *C* for a transducer made with the use of printed circuits technology is 100 pF.

In steady states, at amplitude-*A* harmonic current flowing in the primary circuit, the maximum output voltage of the transducer is equal to $A \cdot S$, where *S* is a conversion coefficient, typically equal to 1 mV/A for the frequency of 50 Hz. For currents occurring in mining installations the output voltage of the transducer does not exceed several dozen volts, while the energy collected in the capacity *C* is smaller than 1 μJ. The output voltage of the transducer in transient states has a completely different character. Here the spectrum of the current signal is very wide, which is caused by the differentiation process executed by the transducer on the measured current.

Transient states in mining power networks are caused by a number of factors, such as connecting processes, short circuits or surges which are propagated from the surface to the mine underground. Currents in transient states often have big amplitudes and fast current ramps or drops. Assuming certain waveforms of phase currents in transient states, it is possible to determine the output voltage of a transducer, either in an analytical or numerical way. Two cases were taken into consideration: circuit closing at zero voltage and circuit closing at maximum voltage. The latter case corresponds to a fault situation in the circuit too. The calculations were conducted for a coreless transducer made with the use of the PCB technology and developed within the project. Parameters of the electric equivalent circuit of this transducer are very similar to those of the electric equivalent circuit of coreless transducers offered on the market [4]. The u(t) voltage at the output of the transducer was determined from the inverse Laplace transform:

$$u(t) = Lap^{-1}\big(T(s) \cdot I(s)\big) \tag{1}$$

where $T(s)$ is the Laplace transform of the voltage-current transfer function of the transducer

$$T(s) = \frac{M \cdot s}{1 + s \cdot C(R + s \cdot L)} \tag{2}$$

while $I(s)$ is the Laplace transform of the current function in the primary circuit.

Circuit closing at zero voltage

The measured current has a form of a sinusoid ramping from zero (Fig. 2).

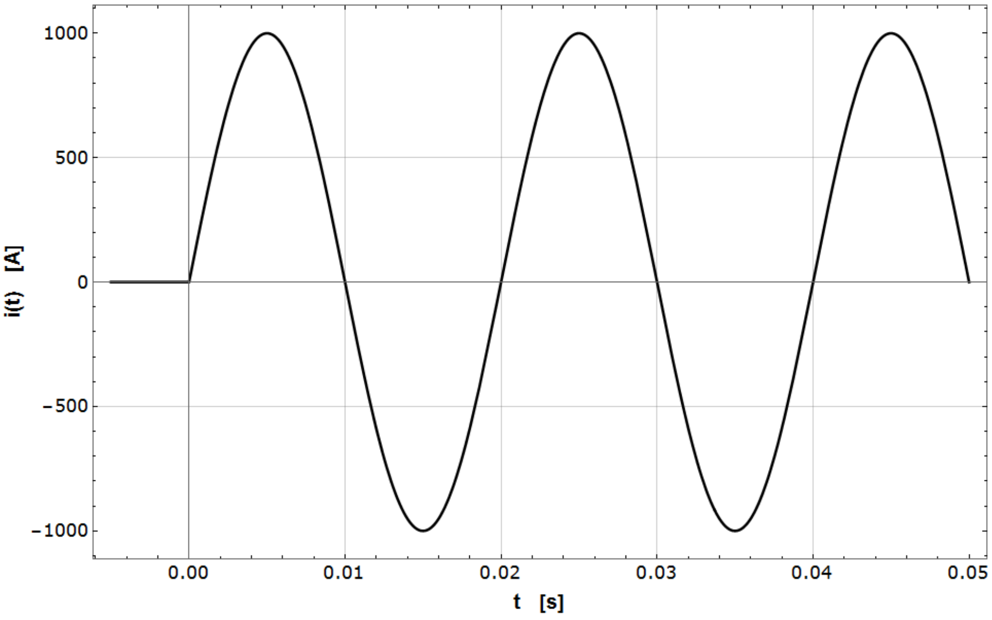

Fig. 2. Waveform of the measured current with circuit closing at zero voltage

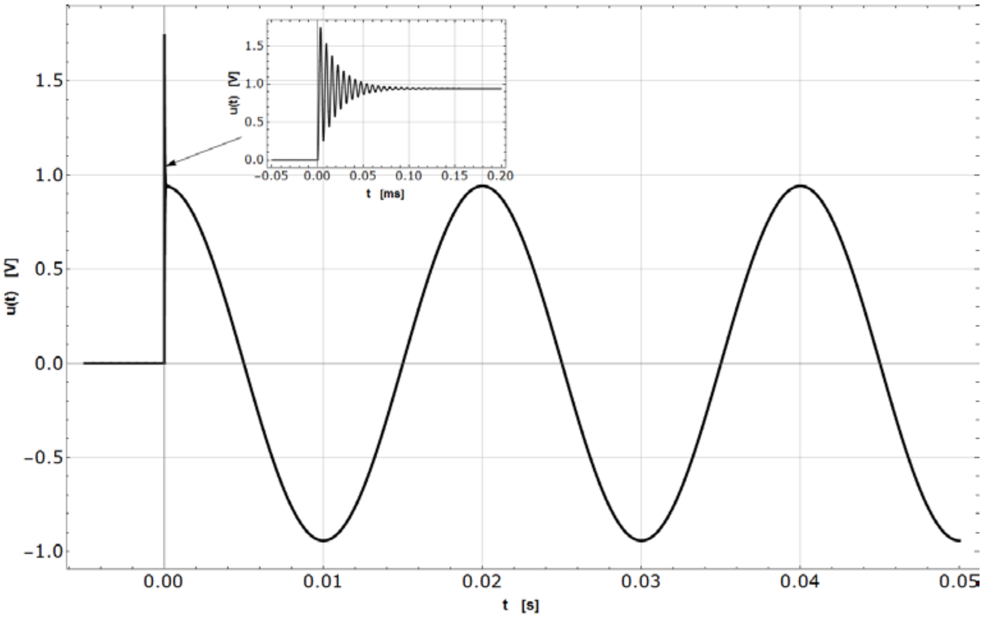

Fig. 3. Voltage at the output of the transducer with circuit closing at zero voltage

The output voltage of the current has a cosinusoidal waveform preceded by damped oscillations (Fig. 3). The maximum voltage at the output of the transducer is, at the initial moment, twice as high as the peak voltage in a steady state. Similarly to steady states, the energy accumulated in the capacity C does not exceed 1 μJ.

Circuit closing (short circuit) at maximum voltage

In this case the initial waveform of the measured current has a character of a uni-step with non-zero ramping time. However, the ramping time depends on the distance between the short circuit and the place of measurement as well as on the parameters of cable lines. Figure 4 presents the initial voltage at the output of the transducer when the current ramping time was equal to 1 μs while its amplitude – about 700 A.

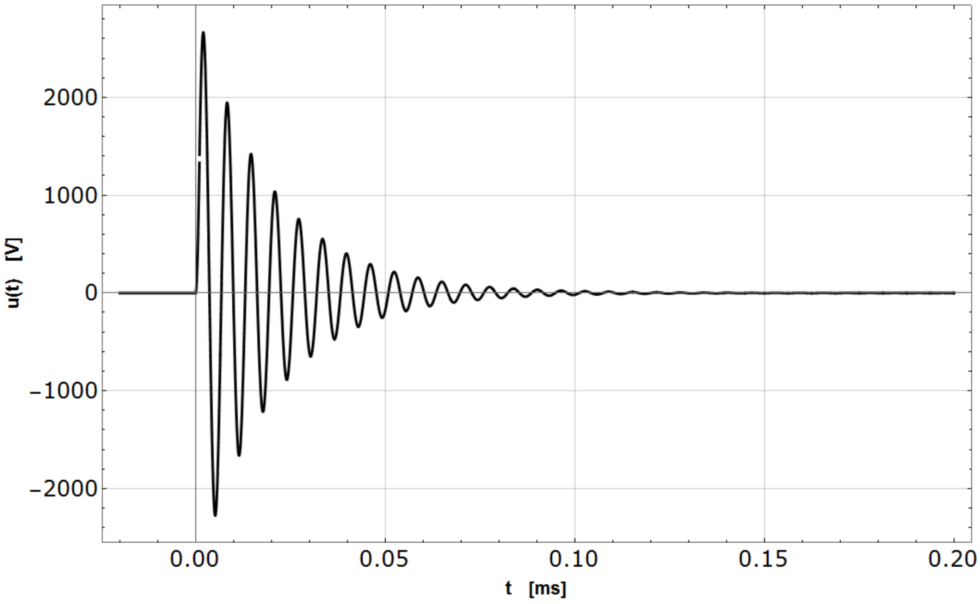

Fig. 4. Voltage at the output of the transducer when the ramping time of current step is equal to 1 μs

The voltage at the output of the transducer in the case of current step excitation has an oscillation-damped character. Yet the oscillation amplitude achieves the value of about 2,750 V for current step ramping times equal to 1 μs and the amplitude of 700 A. In real conditions the ramping time in the circuit is much longer while damped oscillations have a much lower amplitude.

5. CONCLUSIONS

The requirements of electromagnetic compatibility refer to both intrinsically safe and non-intrinsically safe circuits which co-operate with power protection devices. Therefore, to ensure long-term reliable operation of these devices, it is necessary to expose their intrinsically safe and non-intrinsically safe circuits to the same disturbance levels of electromagnetic fields while testing. As it was demonstrated by sample numerical analyses, there may be damped oscillations at the terminals of current transducers when power is being switched on in a power cable. It is more difficult to block disturbances in the intrinsically safe part because the requirements of intrinsic safety have to be followed. The volume of these disturbances has to be under control so that the levels admitted by valid standards should not be exceeded. The emission levels are closely related to the purity of electromagnetic working environments of other electronic devices. Therefore, in order to reduce the level of these disturbances emission from a device, and to raise its resistance to external disturbances, it is necessary to design and install the devices in compliance with the mentioned regulations. The enclosure of the device should be grounded with the shortest possible cable, preferably in the form of a braid for mass installation.

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The article was reviewed by two independent reviewers.