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Comparative analyses of different variants of standard ground for automatic control systems of technical processes of oil and gas production

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Abstract. The paper analyses efficiency (interference resistance) of standard TT, TN, IT networks in control links of automatic control systems (ACS) of technical processes (TP) of oil and gas production. Electromagnetic compatibility (EMC) is a standard term used to describe the interference in grounding circuits. Improved EMC of ACS TP can significantly reduce risks and costs of malfunction of equipment that could have serious consequences. It has been proved that an IT network is the best type of grounds for protection of ACS TP in real life conditions. It allows reducing the interference down to the level that is stated in standards of oil and gas companies.

1. Introduction

Validity of signals in ACS TP depends on electronics that provides electric supply and data communication. Electromagnetic interference can make equipment that has electrical circuits give false or inaccurate signals, thus, certain risks occur: risks associated with decisions about control of TP or the quality of automatic control, consequently, it may lead to financial costs.

Even expensive and reliable controllers, input-output modules and sensors may be inoperable if EMC and principle of grounding were not taken into account during installation of automatic systems [1]. Incorrect grounding can cause: unpredictable failures, enlarged measurement error, malfunction of sensitive elements, reduced speed of the communication system caused by errors in digital data channels, instability of the controlled parameters, errors in the collected data [2].

The interference in cables, sensors, operational units, controllers and metal cases of the equipment is usually an interference in the grounding conductors. It is caused by excitation of the electromagnetic field around them that leads to excitation of the interference in the conductors of measurement channels of AS.

2. Interference effect

There are various sources of interference: atmospheric electromagnetic radiation, equipment, power supply network 220 V 50 Hz, static electricity, changeover network load, galvanic couple, thermoelectric effect, an electrolytic process, moves of a conductor in the magnetic field, etc.

State certification in all countries outlaws equipment that is a source of abnormally high interference. However, an interference level cannot be attenuated to zero. Besides, projects contain a lot of sources of interference due to improper grounding or non-certified equipment.

Production of oil and gas implies extraction, separation, transportation of hydrocarbon products in adverse climatic conditions. It is hard to reduce the interference in ACS of oil and gas production, as sources of interference and receivers are distanced, interference is often random, unstable and undetected excitation.

It is hard to measure interference during approval tests of ACS TP and during exploitation. It is almost impossible to carry out accurate theoretical analyses at the design stage, as technical literature proposes a method of mathematical notation that describes interference and the dynamics of interference by complex nonlinear differential equations with differential coefficients and discrete variable parameters. Thus, experience and intuition are important for assembling of grounding circuits [3].

Almost all measures of protection of ACS TP against electromagnetic interference (EMI) are based on grounding systems. All electrical and electronic technologies used in production are encountered in the grounding system and, consequently, they shall be solved where they occur. Communication lines connecting parts of ACS TP of oil and gas production can be hundreds meters long, and sometimes a low quality of ground or an improper connection can cause high interference.

Grounding, as a method of EMC of components of automation and control systems, significantly reduces risks and costs that are caused by interference and/or malfunction of the equipment, reduces direct costs associated with replacement of the equipment and reduces indirect costs associated with failures and breakdowns. The above stated affirms necessity of comprehensive analyses of grounding in ACS TP of oil and gas production.

The aim of this paper is to carry out comparative study of standard ground networks that reduce electromagnetic interference in ACS TP of oil and gas production, which exist in measuring and control channels and processing units.

The impact of industrial, network and atmospheric electromagnetic interference is less associated with the form of ground electrodes than with the systematic communication via grounding circuits that exist between ACS of TP. Special recommendations and requirements of safe grounding of the equipment are taken into account while choosing a proper type of grounding for the equipment used in oil and gas production. These standards determine protective capability of a ground network and dictate in what way grounding should assure EMC of electrical components. EMC is an ability of a devise, used in ACS of TP, or an equipment unit, or a system to function correctly in the electromagnetic environment and not to produce inadmissible interference.

EMC of automation and control systems can be evaluated via analysis of electrical circuits connecting the grounding electrodes and electrical components in the printed circuits. Henceforth, these requirements determine circuit characteristics of a ground network of each components of an ACS of TP in general.

Theoretically, a system should have zero resistance to reduce interference. But it is a perfect situation, which is unachievable in real conditions, in particular, due to characteristics of counters of propagation of insulation current in the standard ground networks.

3. Grounding system

Electrical potential of current conducting conductors of ACS of TP in relation to a conducting ground plane is given in such Russian and international standards as XY-Z [4]. “X” stands for coupling with solidly-grounded neutral and has: “T”- the very coupling with the ground, “I” – insularity or coupling with high impedance. The second symbol “Y” stands for the coupling between the electrical device and ground: “T” - the very coupling with the ground , “N” – connection to the neutral, which is connected to the ground. The third symbol “Z” stands for connection of neutral to the protective ground (“P” earth “E”), to the conductor, which connects open metal parts of electricity generating equipment of a consumer: “S” – neutral and protective ground is divided; “C” – neutral and protective ground is connected with mutual conductor – PEN. Thus, we get abbreviations that are used for various systems of power distribution: TT, IT, TN-S, TN-C-S. Ground network TN is the most widespread for protection against short circuits [5].

The TN-S ground network is a TN ground network, but its zero protective and zero working conductors are separated along the whole structure. TN-S has a significant advantage – it provides proper security for workers. Such grounding protects human, equipment and building from voltage, and that is important for oil and gas objects.

The TN-C ground network is a TN ground network, but its zero protective and zero working conductors are combined in one conductor along the whole structure; zero protective and zero working cables are marked as PEN. However, it is an outdated circuit and now it is replaced by TN-S.

The TN-C-S ground network is a TN ground network, but functions of its zero protective and zero working conductors are combined in some part of one conductor. Nowadays TN-C-S ground network is used to renovate equipment in oil and gas industry, but it is a transitional step from the TN-C ground network to the TN-S ground network (therefore, its name has letters C and S).

This system has an advantage: it has simple lightning-discharge protection that eliminates high voltage between PE and N, and it also has protection against short circuit of a phase on the body of the device via regular automatic circuit breakers. It also has disadvantages: it is poorly protected destruction of the PEN cable on the way from a transformer substation to the connected equipment. In such a case, there is phase-to-ground voltage in wire PE on the consumer's side, and it cannot be automatically turned off, as PE cannot be turned off. Industrial buildings in the city have an equipotential bonding system that protects them (all metal binding is charged and there is no risk of current injury when you touch two different devices), and ACS of TP of oil and gas production in open spaces have no protection against the above mentioned, thus, it is unsafe to use it. Nevertheless, electrical installation rules recommend this network if certain measures preventing from destruction of PEN (mechanical protection) by means of iterated grounding are taken. This task can be solved via grounding on the overhead pole line with the interval determined in the regulatory documents (not more than 200 meters for regions that have less than 40 thunderous hours a year, not more than 100 meters for regions that have more than 40 thunderous hours a year). If it is impossible to fulfill these conditions, electrical installation rules recommend the TT network [6].

The TT ground network is a system with solidly grounded neutral of power source; open conductive parts of an electricity generating equipment are grounded via a grounding device electrically dependent from solidly grounded neutral of the power source.

The network has an advantage: it is resistant to destruction of a neutral on the way from a substation to the consumer. This destruction does not change grounding capability. It also has some disadvantages: it requires more complicated lightning protection, as there can be a high pulse between N and PE, and it does not let an ordinary automatic circuit breaker to trace a short circuit of a phase on the body of the device (and then on PE). The reason is rather big resistance of 30-40 Ω of local grounding. According to the above mentioned, electrical installation rules recommend the TT network as supplementary for open-air systems, where we have a risk to touch a device and a ground at the same time (or grounded metal elements).

In the case of the standard types grounding system (TN and TT), it is good practice to provide the protection of equipment from a short circuit and the protection of workers from the life-threatening currents. At the very core, it is a physical connection of electrical automation circuits to a common potential, which in ACS projects is called a “grounding device”. Theoretically, according to the recommendations of standards, all grounded points should be connected to the ground potential without resistances or inductances. However, this is impossible in practice. As consequence, breaking this rule can unpredictably result in malfunctions of automation systems, increased measurement errors, slowdown of sensitive components, slowdown of the communication system due to the errors in channels of the digital exchange, the instability of control parameters, and the occurrence of errors in the data collection. The IT grounding system, better known in Russia as a grounding system with an isolated neutral, designed and suitable for protection of the people, electrical equipment and power lines from short-circuit between phases while working with high currents [7].

In the IT grounding system (Figure 1), a neutral conductor of power supply is isolated from ground, grounded by devices with a lot of resistance, and exposed conductive parts are grounded severally. Insulation current applied to the metal casing or ground is low and does not influence the working conditions of the attached electrical equipment in this system. In other words, the IT grounding system excludes the immediate shutdown in the event of ground fault and occurrence of bow at the unexpected contact between the conducting part and prevents occurrence of very large step voltage, even for a short period of time.

Therefore, this type of grounding system is most common power supply activities in gas, oil, chemical industry, where there is a danger of ignition of combustible materials from electrical fixtures, that is why, this system is recommend for field devices PCS of Oil and Gas Engineering.

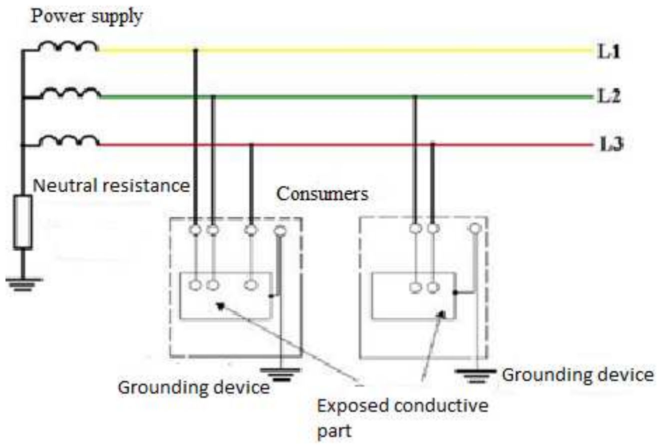

Figure 1. An IT grounding system.

4. Grounding circuit and current loop

Contour protective grounding in ACS is a prime factor that determines an interference immunity of automation and control systems. This contour can be realized as a form of single point grounding and a form of multi-point grounding.

The only grounding point is characterized by a connection to the ground from which it is connected to all devices PCS (topology "tree" or "star"). Theoretically, all the points that have to be grounded are connected to the ground potential without resistances or inductances. Although it is impossible in practice, this configuration is used for grounding the enclosure of equipment in industry and for high-frequency electronic systems, which are installed in small areas, such as supervisory process control facilities.

A multi-point grounding scheme occurs in ACS because there are different requirements for grounding field devices and automation, analogue and digital circuits ACS (Figure 2).

Multi-point grounding with equalizing of overall potential is more preferable in comparison with single point grounding. In the historical practice, it was realized for protection from high-frequency interference in computer systems via the grounding in the form of the SRG-grid. This type of grounding is used for communications environments with a high level of radiated electromagnetic interference, particularly. SRG- technology was recommended, for example, for computer transceiver stations due to high sensitivity to interference type RS-232 data channels. However, nowadays necessity in SRG is reducing due to occurrence of new technologies, ensuring a higher level of protection against high-frequency interference (shielded coaxial cable, twisted pair or fiber optics) [8]. Parasitic occurrence of interference in the transmission of signals in industrial automation systems can be divided into the following groups: the impact through the conductive connection; inducing through mutual inductance; interferences by capacitive coupling; high-frequency electromagnetic interference; nonequipotential "land".

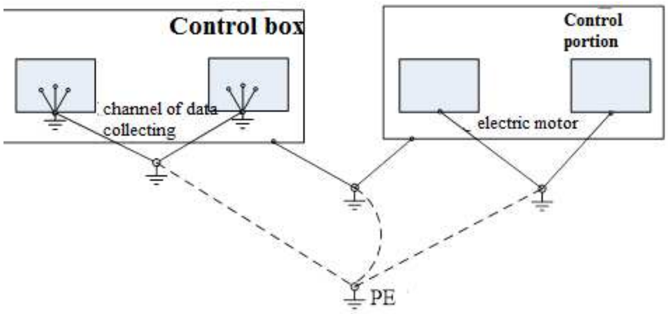

Figure 2. Common ground in APCS.

Supply main 220/380 V, 50 Hz and power supply units are the sources of the next interference: background with a frequency of 50 Hz; voltage surges from lightning; short damped oscillations when switching inductive loads; high frequency noise superimposed on the sine wave of 50 Hz; very-low-frequency noise occurring as the instability of the value of the mains voltage (RMS) in time; a long-time distortion sine wave and harmonics at saturation of the transformer core. These interferences are superimposed on the control signals of execution units APCS, the analog and digital channels of data collection and protection circuits [9].

The penetration route network interference is shown in Figure 3. There is a power or an isolation transformer included in the single-phase 220 V, 50 Hz. The network is represented by an equivalent voltage source and an equivalent source of interference. The neutral conductor of power supply is grounded on the main board process ACS. The output of power supply is grounded too for electrical safety. When using the TN or TT grounding system, the current path interference takes place, as shown in Figure 3, including the resistance of the grounding conductor. As a result, there is a potential interference in the grounding point, which is the source of the interference's load power supply in the measuring channel. When using the IT grounding system, ground currents are isolated in individual circuits and there is no problem with their mutual influence.

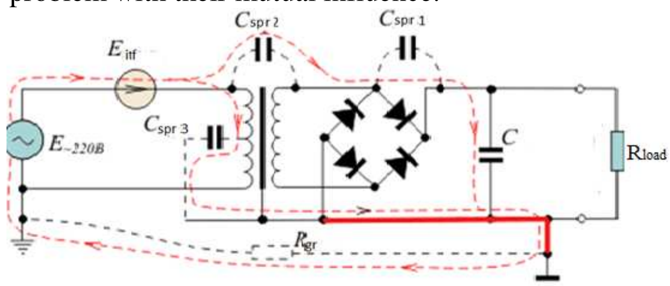

Figure 3. The penetration path of interference.

The main components of the current loop of analog channel measurement include direct-current power supply, transducer and the precision impedance input device of the PLC. In the current loop of the analog signal the interference circuit is formed, which will be closed-loop through the protective ground and through the power supply DC ground. As a result, there is the secondary current path interference, which creates the potential interference in the precision parts of the measurement channel [10].

The value of ground resistance via the individual electrode can be determined as the ratio between the obtained electrode potential and current, which is inserted into the ground through this electrode and is not critical for electromagnetic capability. Although low resistance should be the main aim for the grounding, for the safety of equipment and people, and for the protection against lightning, it is not necessary to ensure the proper performance of electromagnetic capability of electronic systems.

In fact, for construction of the current-type system of transmission data in PCS the main task is to prevent the occurrence of current loops in the ground circuit. Therefore, to reduce the current level of ground loops, it is recommended to use a large resistance in the reception signal measurement circuit. Electrically separating of the source signal from the ground's analog input signal amplifier, it can significantly reduce the effect of the current in the ground circuit.

Finally, when considering the principal components of digital signal circuits (the source and the load), there are two forms of loop current: a differential useful signal mode, when current flows from the source to the load for one conductor and returns through the other, and a common mode, characterized by uncontrolled signal (noise). For the current of common-mode, the interference occurs in the same direction in both conductors to the third conductor, which is connected to ground. And this interference can be reduced by increasing the resistance of the ground circuit too.

When making a selection of the ground topology it is necessary to be guided by the following fact. The grounds connected components in the circuit of digital signals with a different impedances do not give the benefits in using noise compensation of differential signal receive channels (e.g., RS 485). In this case, the source or load is grounded at one end. That is why, the common-mode interference in the conductors will be compensated in the common mode. Many suppliers of measurement instrumentation for process automation are recommended this way.

5. Summary

This paper describes a comparative evaluation of electromagnetic interference in the automatic control system induced by the using of standard safety types of the grounds. Awareness and understanding of the grounding problem are necessary when the project works, the development of external wiring circuits ACS, in particular. The problem of interference resistance for industrial automation systems should be treated with a careful attention, because the wrong choice of the wiring diagram or cable configuration, grounding and shielding systems can significantly devaluate the dignity of APCS. According to the execution of the analysis, an IT system that reduces the electromagnetic interference level by reducing ground loop current is the most suitable for circuits ACS data collection and execution units.

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