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GROUNDING OF CONTROL CABLE SHIELDS: DO WE HAVE A SOLUTION?

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Abstract: There are ongoing debates as to the number of grounding points for control cable shields. These debates arise in various specialized forums (in different languages) and on the pages of professional journals. Why? Perhaps, the reason is that the practical experience of equipment use goes beyond theoretical speculation. Sometimes the best results are obtained in the case of unilateral grounding of shields. However, there are situations when bilateral grounding of shields does a better job. This article discusses the reasons for these controversies and describes one of the new approaches to grounding of the shields.

Keywords: electricity transmission, cable shields, interference .

1. INTRODUCTION

Shielding is a common practice to increase noise resistance of equipment. Generally speaking, the electromagnetic shield is represented by a metal partition (barrier) between the source of electromagnetic emission and the protected area, see Fig. 1.

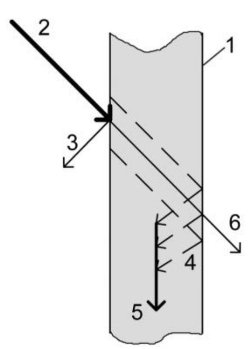

Fig. 1. Operation of a metal shield. 1 – metal partition (shield); 2 – electromagnetic wave energy impacting the shield; 3 – part of the energy reflected from the shield's surface; 4 – part of the energy reflected from the boundary layer created by the shield's wall and the outside environment; 5 – part of the energy converted into the current in the metal; 6 – the balance of energy penetrated through the shield into the protected area.

It is obvious from the figure that part 3 of energy 2 impacting the shield is reflected from the surface back into the spacing, while the other part 4 penetrates into metal and is reflected from the boundary layer created by the shield's wall and the outside environment. Another part of energy 5 is converted into an electric current inside the metal and the balance of energy 6 remaining after all these conversions finds its way into the protected area as a noise.

Grounding of control cable shields is considered to be an efficient practice to weaken these interferences. There are two major concepts of control cable shields grounding: on one side of a cable and on both sides of a cable, see Fig. 2.

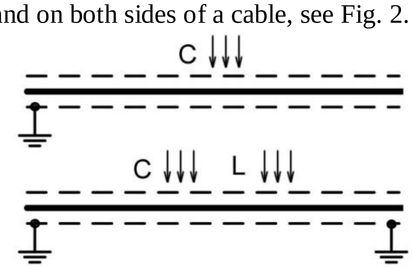

Fig. 2: Common grounding practices of control cable shields: on one side of a cable: protects against capacitive interferences (C); on both sides of a cable: protects from capacitive (C) and inductive (L) interferences

Obviously, both practices have different features and specifications regarding various types of interference. There are four major types of interference:

- Conductive
- Inductive
- Capacitive
- Electrostatic

Each of them is subdivided into two types:

- wire-earth interference –voltage is applied between each conductor and the earth. It is also known as asymmetrical, in-phase or common mode (CM) interference;

- wire-wire interference –voltage is applied between separate electric circuits or between the elements of the same electric circuit. It is also known as symmetrical, out of phase or differential mode (DM) interference.

Conductive interference spreads upon the direct electric contact between electric circuits. Thus, shielding of control cables is nonessential with this type of interference in these electric circuits.

Capacitive interference spreads via capacitance between the central cores of a cable and the earth; between the shield and the earth; between the shield and the central cores. Grounding of the cable's shield at one or two points will shunt the capacitance between the shield and the ground. On the other hand, it will also bring the "earth" closer to the central core, thus increasing the capacitance between this core and the earth. This expedites the capacitive interference to penetrate from the earth to the central cores. However, apart from interference spreading through the earth's circuits, there is noise coming from the adjacent cables, from high voltage wires, powerful high-voltage switching apparatus and other sources of electromagnetic interference. When this interference is in-phase, i.e. creates potential relative to the earth, the grounding of the cable's shield at one point will allow elimination of this interference completely. For example, there is a non-shielded cable in a common cable tray and occasionally significant pulse voltage occurs on its cores relative to the earth. Subsequently, single-point grounding of the adjacent control cable shield will ensure efficient protection of the control cable's central cores from pulse noise arising on the non-shielded cable. However, when the above mentioned pulse voltage arising in a non-shielded cable causes the pulse current flow (the most common situation) that generates the pulse magnetic field around it (differential inductive interference), obviously that single-point grounding of the adjacent control cable's shield will have no effect and the noise will be conducted in the central cores of the control cable. Grounding of the shield at both end-points establishes a closed circuit for the current conducted in the shield, and this weakens the inductive interference impact on the central cores of the control cable.

Static interference resulting from accumulation of a static charge on equipment parts, insulated from the earth with further discharging and breakdown of insulation to the earth, are not dangerous for cables as the charge flows freely to the earth through the existing insulation resistance and is not accumulated.

The examples discussed above show that single-point grounding of control cable shields protects the central cores from capacitive in-phase (relative to earth) interference only, while grounding at both ends will ensure protection of the central cores from any type of interference. Apparently, based on the above-mentioned thoughts, it is mostly recommended to use this type of grounding of control cable shields.

However, it is not all that simple! In reality, the grounding system is not so ideal. If the cable is long enough and the current flowing through the grounding system is significant, there will be a high difference of potentials between the shield's grounding points located far away from each other. According to [1], this difference of potentials in real grounding systems can reach 10+ kV upon the lightning strike. And this is not the most frightening situation that can happen. Upon the impact of a spatially distributed electric field of High Altitude Electromagnetic Pulse of nuclear explosion (HEMP), with the field gradient up to 50 kV/m near the soil surface on the grounding system (acting as a huge antenna), the difference of potentials can reach as high as tens of kilovolts at the coupling points of the long cables' shields. When this voltage is applied directly (i.e. through a direct contact) to the shield, it will result in high amplitude current flowing through it, and this can induce significant current in the cable's cores directly connected to electronic elements of equipment.

So, which type of control cable shield grounding is more preferable?

The majority of official documents, such as standards, guidelines, instructions of both civil and military application [2-8], suggest straightforwardly that the grounding of shields should be executed on both sides of a cable. Even though these documents are well known to specialists that operate electronic equipment of power systems (particularly, digital protection relays - DPR) all over the world, there is an ongoing debate as to the number of grounding points for control cable shields. These debates arise in various specialized forums (in different languages) and on the pages of professional journals. Why? Perhaps the reason is that the practical experience of equipment use is much broader than just theoretical speculation. Sometimes, unilateral grounding of shields gives the best results. However, there are situations when bilateral grounding of shields does a better job. What's the matter?

Personal communication with the top world specialists in this area, the authors of fundamental studies [9-11], could not have adequately clarified the situation. So, I tried alone to analyze the situation and find the answer to the question first mentioned above. As a result of thorough analysis of dozens of publications on this topic, including fundamental writings, where the issue of cable shields' grounding is discussed thoroughly and comprehensively (for example, in [11] a separate 119-page chapter 7 is devoted to this topic), I came to a discouraging conclusion that there is no (and cannot be any) single, comprehensive answer to the question first mentioned above. Moreover, it is not even possible to articulate any accurate general recommendation regarding selection of any specific shields grounding practice that will be clear and suitable for practical application by the power systems' staff.
This situation occurred due to the fact that available guidelines, recommendations, articles and even standards,

which suggest a certain type of control cables' shield grounding, justify the choice based on a very limited number of various factors that really impact the interference-resistance of electronic equipment by considering only one of them and neglecting the others. This is why we have an ongoing debate among energy industry workers regarding their preferences in terms of specific ways of shields' grounding and the reference to personal experience, which often contradicts the experience of other participants in the discussion. Which factors are we talking about?

1. Sensitivity of various types of electronic equipment to interference of different types, frequency, duration and amplitude is not the same. Thus, one interference may cause faults in the equipment's operation, while the other (even more powerful), which has another pulse frequency or duration will not result in fault conditions of the same equipment. This also means that the same interference coming to inputs of various electronic devices via different cores of a multicore cable can cause fault conditions in some devices, but have no effect in others.
2. Pulse current flowing through the shield of one cable may impact the current flowing in the central core of the same cable, and shields of adjacent cables running parallel in a common cable tray. Alternatively, current flowing in the central cores of non-shielded cables may affect the current in the shields of shielded cables, if both types are running in the same cable tray.
3. Different types of cable trays: metal or metallized plastic, open or closed – all of them differ in their ability to weaken electromagnetic interference.
4. Some parameters of the shield, such as inductive resistance to current flowing through the shield, as well as capacitive resistance between the central cores and the shield, between the central cores and the earth, and the shield and the earth, are significantly dependent on the frequency of interference or duration and the increasing of the leading edge of the pulse interference.
5. Different types of shields: single-, two-, three-, four-layer (fig. 3), made of foil only, made of braid only, combined (braid + foil); twisted pair cable only, twisted pair cable with different kinds of shields – all of them differ in their shielding ability at different frequencies, see Fig. 4.

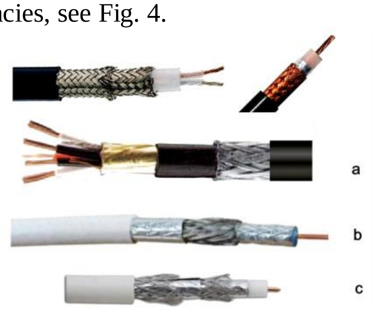

Fig. 3. Cables with double (a), triple (b) and four-layer (c) combined (braid + foil) shielding capability.

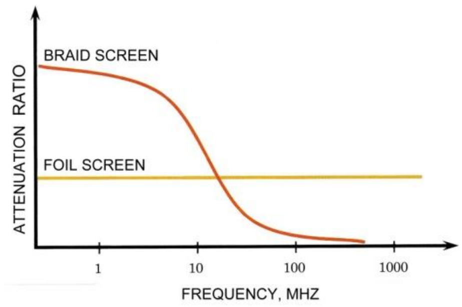

Fig. 4. Shielding coefficient as a function of frequency for shields made of braid and foil.

6. There is also a relation between the shield thickness and the frequency of an interference, as depending on the frequency, the electromagnetic wave can penetrate into the shield at different depths (a so called skin effect), which is comparable with the shield's thickness (0.1 – 0.2 mm), see Table 1.

Table 1. The depth of electromagnetic wave penetration into copper

Frequency, MHz	Depth of penetration, mm
0.001	2.09
0.01	0.66
0.1	0.21
1.0	0.066
10	0.02
100	0.0066
1000	0.0021

7. The shielding ability of the shield is also a function of the braid filling degree of a cable protected by this shield. There are shields with 60-90% of filling degree. In other words, the same interference can affect the equipment differently depending on the type of cable used.
8. The length of a shielded cable affects the absorbing ability of the shield upon the impact of electromagnetic field. What is especially important is the ratio of the wavelength to the cable length. In other words, interference of different frequencies (i.e. electromagnetic waves of different length) can affect the same cable differently; and alternatively, the same interference can affect the cables of alternative lengths differently.
9. The status, type and parameters of a grounding system can have a significant effect on the efficiency of grounded cable shields. The example above discussed the connection of the long cable shield to a real (rather than theoretical) grounding system at both ends.

10. In general, the proximity of a cable and even some of its parts to noise sources, as well as its direction in relation to these sources, plays a significant role.

Considering this limited list of factors influencing the efficiency of control cable shields, one can draw a conclusion that there is lack of data to reach an informed decision regarding selection of a certain type of the shield's grounding. The lack of a single factor, such as parameters of pulse interference that affects the cable, makes it impossible to make a straightforward decision. In addition, it becomes obvious that even the general estimated model (supposing it would be possible to build it) will be useless in practice due to the lack of input data for specific conditions. Thus, I think a conclusion about a specific practice of control cable shield grounding could be drawn based on the experience of operation of the specific types of equipment under the specific conditions.

Let us address another aspect of this topic, i.e. the issue of what should be considered a "dangerous" interference for electronic equipment of power systems. For example, is a single pulse with duration of several milliseconds (lightning) or several nanoseconds (HEMP) dangerous for such a common type of power system's electronic equipment as a digital protection relay (DPR), with a typical response time of 20-40 milliseconds? It is unlikely that it will be dangerous, as this interference will not have enough time to significantly affect a long-duration process of data processing and actuation of a necessary DPR's function. However, what happens if this "interference" has amplitude of dozens of kilovolts? Now we are not talking about a soft failure in the data processing software, it is rather an irreversible damage of internal electronic components. As mentioned above, these two are the most powerful, but short-duration types of interference penetrate into the control cable by means of direct contact (from the grounding system to the shield, provided it is grounded at both ends), and then they go from the shield to internal cores inductively. This means that the short pulse interference itself, lasting as long as the lightning charges or HEMP, is not dangerous for electronic equipment (at least for DPR), if its amplitude remains low.

Based on this discussion, the article offers an unusual method of control cable shield grounding. This method presupposes shield grounding at both ends, but one of them should be connected across a high-frequency choke (see Fig. 5), which features specific inductive resistance.

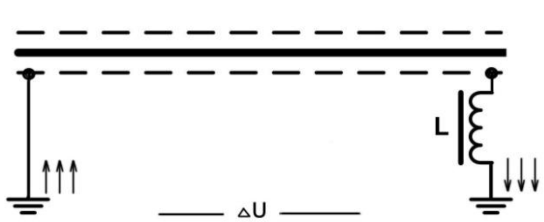

Fig. 5. The offered way of control cable shields grounding:

On the one hand, this suggestion contradicts to all the canons stating that even insignificant increase of the shield grounding circuit's inductive resistance reduces the shielding efficiency at high frequencies. However, nobody questions this: indeed, a choke included into the grounding circuit reduces the shielding efficiency from inductive noise (that is not very dangerous) at high frequencies (i.e. in case of very short pulses). While on the other hand, the most dangerous high power interference penetrating the shield from the grounding system by means of direct contact will be significantly suppressed.

Fig. 6. Conventional high-frequency chokes

Fig. 7. Ferrite rings in plastic holders with a locker

Regardless of their simplicity and the low price, these ferrite rings (filters in their essence) are very efficient in weakening the high-frequency current, see Fig. 8.

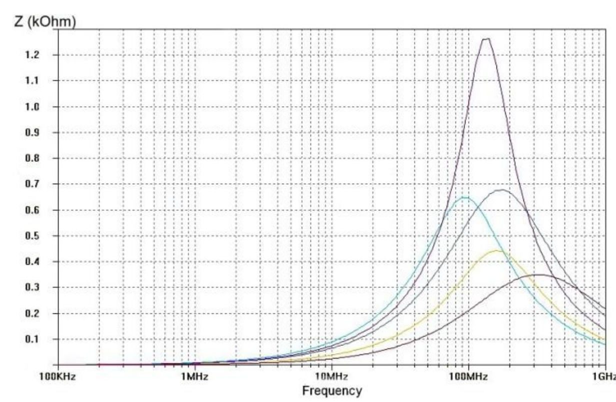

Fig. 8. Full resistance (Z) of a ferrite filter as a function of frequency of some ferrite types (typical)

For this type of grounding, both ordinary devices (see Fig. 6) are attached to the cable's break connecting the shield to the grounding system, and the modular ferrite rings in a plastic holder with a locker (see Fig. 7) that are put on a wire and do not require its breaking an function as a high-frequency choke. However, when using ferrite rings, some specific features of ferrite rings described in [12] need to be considered. In order to obtain the required frequency response, several ferrite rings of different types can be attached to one wire.

As for protection from low power interference, this method of control cable shield grounding goes in between the two basic approaches. Thus, in some specific cases it can be more efficient compared to conventional methods of grounding, while in some cases its efficiency is lower. However, under any circumstances the protecting high-frequency choke will prevent penetration of the most powerful and dangerous interference (lightning or HEMP) from the grounding system to the cable.

In case of continuous low-frequency noise (usually this is a rather powerful 50 Hz interference) in the shield, which leads to its excessive heating, an alternative method of limiting the low-frequency current in the shield by installing a capacitor in its grounding conductor (see Fig. 9) can be used in addition to the choke offered above.

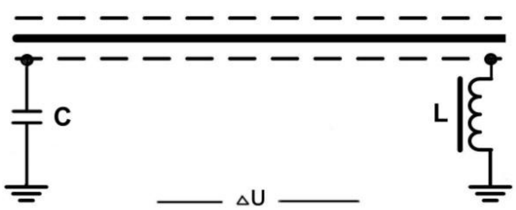

Fig. 9. Compound control cable shield grounding by means of capacitance and inductance that constitute a band-pass filter

This compound band-pass filter, that consists of capacitance and inductance connected in series, will efficiently suppress both low-frequency inductive noise and very short-duration powerful pulse interference of a conductive type coming from the grounding system to the shield.

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