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Experimental Study on Electrical Characteristics of Grounding Method for Shinkansen Lines

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***Abstract*— In Japan, the groundings of signalling and communication equipment are installed for various purposes. Therefore, many groundings are installed especially around the signalling and communication house where the equipment are arranged intensively. On the other hand, in Europe, there are many cases where groundings are commonly used by various purposes. In this paper, the authors performed experiments to compare the effect of the individual grounding method and the common grounding method, and examined whether or not the authors are able to connect each grounding of the signalling and communication equipment including power equipment such as high voltage distribution cubicle and substation apparatus used in the high speed railways in Japan.**

Keywords- grounding method, lightning surge, ground fault, signalling equipment, shinkansen

I. INTRODUCTION

In Japan, the groundings of signalling and communication equipment are installed for various purposes in order to prevent human being and equipment from high voltage due to the lightning and the ground fault, and to reduce the induced voltage from the power source system. Therefore, many groundings are installed around the signalling and communication house where the equipment are arranged intensively. However, there are many problems about the grounding such as the construction in the limited space and the requirement of the grounding of low resistance level. In contrast, the groundings such as those for buildings constructed in the narrow sites and the communication base stations are generally connected to each other. It is estimated that these connected groundings are superior from the viewpoint of construction and cost [1].

The purpose of this research is to investigate whether or not the authors are able to connect the respective groundings of the signalling and communication equipment including power equipment such as high voltage distribution cubicle and substation apparatus used in the high speed railways in Japan called the Shinkansen. The authors measured the characteristics of voltage and current in case of applying current simulating the lightning or the ground fault, in order to compare the effect of the individual grounding method and the common grounding method.

II. GROUNDING METHOD OF SHINKANSEN TRACKS

A grounding configuration of the wayside equipment and structures of the Shinkansen is shown in Fig. 1. The signalling house has many groundings independent of each other. As for the signalling cables between the signalling houses or between the signalling house and the field equipment, the cables with screening sheath are used, and both the terminals of sheath cables are connected to the ground to protect the induced current and voltage. Rails are not connected to the ground positively, however the rails are connected to the ground by leakage conductance. Additionally, the platform is connected to the rail by Rail Potential Control Devices (RPCD) in order to reduce the touch voltage [2]. On the other hand, in Europe, there are many cases where groundings are connected to each other by connected grounding lines in the ground.

The groundings of signalling equipment of the Shinkansen can be broadly divided into five categories as shown in TABLE I. The groundings at the respective places such as the signalling house, the insulation hut between the substation and

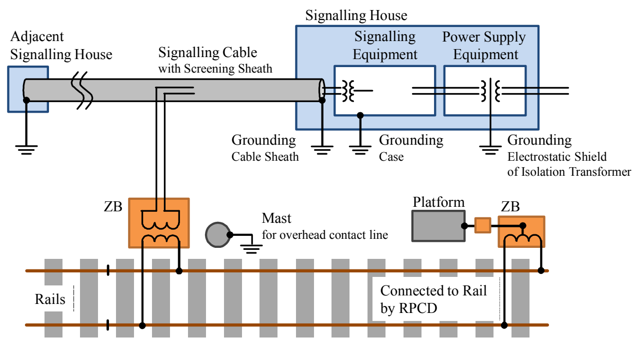

Figure 1 Grounding configuration of wayside equipment and constructions along Shinkansen tracks.

TABLE I GROUNDING TYPES OF SIGNALLING EQUIPMENT.

Symbol	Uses	Grounding resistance
E1	Equipment casing	Reinforce of house or < 10Ω
E2	Shielding cable	< 0.5Ω/km × Cable length
E3	Surge protection	< 10Ω
E	Preventive danger	< 100Ω
E	Insulating hut	< 50Ω

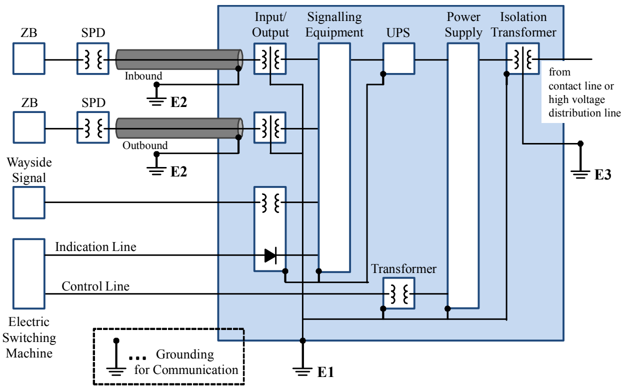

Figure 2 Schematic illustration of groundings in signalling house.

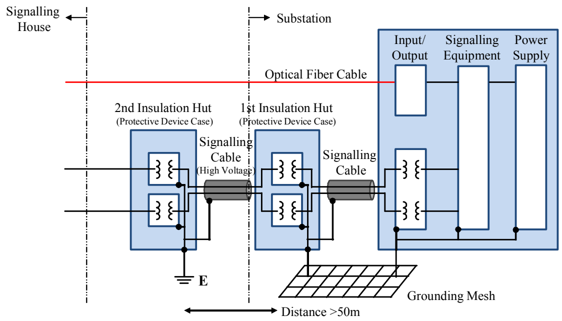

Figure 3 Schematic illustration of groundings in insulation hut and substation.

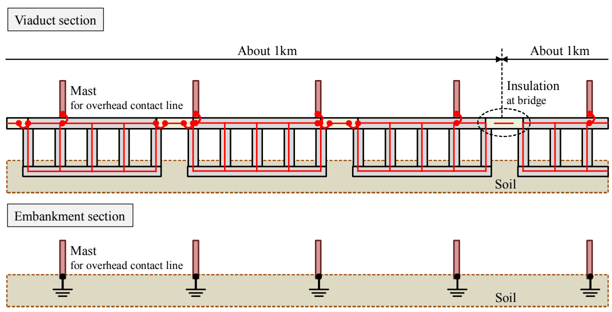

Figure 4 Schematic illustration of grounding systems on track structure.

the signalling house and the structure around the track are as follows.

A. Signalling House

The schematic illustration of groundings in the signalling house is shown in Fig. 2. The groundings of the signalling house are composed of three subsystems: equipment casing (E1), shielding cable (E2) and surge protection (E3). E1 uses the reinforcing bar of the viaduct structure as the grounding and the equipment casings installed in the signalling house are connected to each other. If the signalling house is not built in the viaduct section, E1 adopts independent grounding and the grounding resistance is less than 10Ω. E2 is the system to connect the cable steel and the sheath of the signalling cable to the ground in order to reduce the induced voltage and current. E2 adopts independent grounding in every direction of laid signalling cable. E3 is the system to connect the shield between the primary and the secondary coil of the isolation transformer to the ground with low resistance in order to prevent the equipment from the lightning surge. In the current Shinkansen, these groundings (E1 to E3) are established separately from each other, and are also independent of the groundings used for power supply and communication equipment. Thus, many groundings are installed around the signalling house. It is difficult to install different groundings in the limited space so as for them to be separated more than 5m from each other.

B. Insulation Hut

The schematic illustration of the groundings in the insulation hut and the substation is shown in Fig. 3. The grounding of the signaling equipment installed in the substation and the sectioning post is connected to the mesh grounding for them. If the potential of the substation rises due to the ground fault, this method is able to protect the signalling equipment by rising the potential of the signalling equipment to the same level as that of the substation. On the other hand, the groundings between the substation and the signalling house are isolated, and as the communication lines, optical fiber cable is used for isolation. The signalling cables between the substation and the signalling house need electrical connection. Thus, the second isolation hut is installed outside the substation site. This method protects the signalling equipment by dielectric strength of the isolation transformer in the hut and high voltage cable against the potential rise of the grounding mesh in the substation. As the standard rule, the isolation transformer in the hut and the sheath of the high voltage cable are connected to the ground less than 50Ω and should be installed separated more than 50m from the grounding mesh in the substation.

C. Wayside

Both the terminals of the sheath of signalling cable are connected to the ground. When the signalling cable is laid between the signalling houses, the signalling cable is connected to the ground at each of the respective signalling houses. In the embankment section, the equipment casing is connected to the ground with less than 100Ω in order to prevent human being and equipment from high voltage. Figure 4 shows the example of the groundings in the viaduct section and embankment section, indicating that the groundings are different depending on the track structures. In these sections, the grounding for signalling equipment is not installed, but the grounding for power supply such as the mast for overhead contact wire is installed. In the viaduct section, the large scale grounding is established by connecting the reinforcing bar of viaduct structure and the grounding wire of the mast as shown in Fig. 4.

III. FIELD TEST METHODOLOGY

A. Field Test Site

The purpose of this research is to investigate whether or not the authors are able to connect each grounding of the signalling and communication equipment in the Shinkansen. The authors measured the characteristics of voltage and current in case of

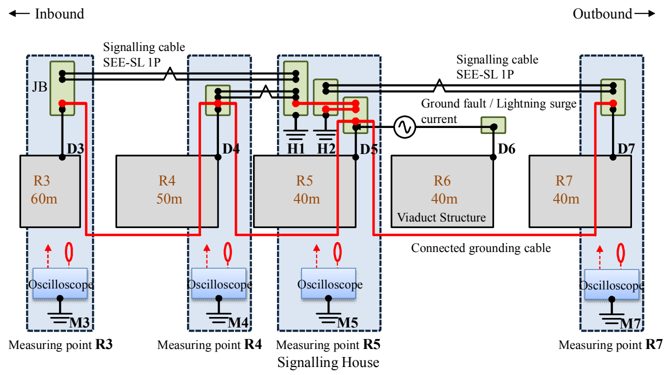

Figure 5 Outline of experimental setup.

Figure 6 Photo of test field site.

applying current simulating the lightning or the ground fault in order to compare the effect of the individual grounding method and the common grounding method.

The field test site should be such that many independent and low resistance groundings could be installed so as to simulate the groundings of signalling house and wayside equipment. In this regard, the groundings of the mast of overhead contact wire (D3 to D7) were used as the required testing groundings. This field test simulated the common groundings in the signalling house, including the groundings for the adjacent signalling houses and wayside equipment [3]. Figure 5 and Fig. 6 show the outline and the photo of the field test site. The signalling cables were temporarily laid on the ground surface at D5 to D3, D4 and D7 with the simulated signalling house at the center. Two groundings called H1 and H2 of which grounding resistances were less than 30Ω were installed around the simulated signalling house to be used for grounding of the cable sheath. Additionally, the connected grounding cable was temporarily laid on the ground surface between each grounding from D3 to D7 in order to simulate the connected groundings. Each signalling cable was laid between the Joint Boxes (JB) as short as possible, and the connected grounding cable was laid on one side of elevated track structure, on the opposite side of which the signalling cables are laid in order to prevent induced current and voltage from that cables.

The groundings for ensuring the reference potential called M3 to M7 of which the resistance were less than 100Ω were

TABLE II VALUE OF GROUNDING RESISTANCE.

Grounding name	Grounding resistance		Mutual relation (D5)
	Voltage drop method	Earth tester	
D3	2.01Ω	7.8Ω	—
D4	2.30Ω	8.4Ω	7%
D5	2.55Ω	7.8Ω	Ref.
D6	2.37Ω	4.9Ω	—
D7	2.64Ω	4.8Ω	—
H1	—	25Ω	51%
H2	—	27Ω	16%

TABLE III RESULT OF GROUND RESISTIVITY AT FIELD TEST SITE.

Depth	Ground resistivity	Classification*
0 – 0.28m	574.7Ωm	Middle
0.28 – 3.55m	718.4Ωm	Middle
3.55 – 9.13m	216.8Ωm	Middle
9.13 – 15.58m	91.3Ωm	Low
15.58 – 20.52m	307.2Ωm	Middle
20.52 – 30.36m	49.9Ωm	Low
30.36 – 39.12m	386.0Ωm	Middle
39.12 – 60.00m	30.9Ωm	Low

Classification Low: $\rho < 100\Omega$m
Middle: $100 \leqq \rho < 1000\Omega$m
High: $1000 \leqq \rho$

installed at respective measuring points. The steady grounding resistance values of the groundings used in this time were measured by the voltage drop method and the earth tester. Results of the measurement of each grounding resistance are shown in TABLE II. The true grounding resistances are values of the measurement by the voltage drop method, because the grounding of the mast is the large scale grounding. Relations between each grounding are also shown in TABLE II. When the reference is D5, the mutual relation to D4 was 7%, H1 was 51%, and H2 was 16% [4]. These values depend on the placement between groundings.

On the other hand, the ground resistivity was measured by Wenner's four-terminal method at the field test site. As a result, this field test site had a middle resistivity (575Ωm) layer at the position 0.28m in depth, similarly a middle resistivity (718Ωm) layer at the position 0.28m to 3.55m in depth, and a low resistivity layer at the position 9.13m to 15.58m in depth as shown in TABLE III.

B. *Measurement System*

The field test site had four measuring points as follows: the simulated signalling house (R5), the inbound measuring points (R3 and R4), and the outbound measuring point (R7). The testing current simulating the ground fault and the lightning surge was applied from D6 to D5. AC 60Hz, 20A as the current simulating the ground fault was generated by an engine generator and some transformer for the test of the ground fault, and 1.2/50μs, 100A as the current simulating lightning surge was generated by an impulse generator (MS-129, Sankosha) for the test of lightning surge. Measuring instruments such as oscilloscope were placed at the respective measuring points. The current and voltage at each measuring point were measured by the oscilloscope via CT (Model 411, Pearson) or high voltage probe (P5100A, Tektronix).

C. Conditon of Groundings

The field tests were arranged under the condition that the authors simulated the individual grounding method used for the current Shinkansen, the common grounding method in the signalling house and the connected grounding method. These conditions were simulated by changing the wiring in the JBs. In the signalling house, D5 was connected to the through cable from D3 to D7 (bus line) and was also connected to H1 and H2 with the equipotential bonding wire (branch line).

As shown in Fig. 5, the resistance of 1kΩ simulating signalling equipment load and the two electrode Gas Discharge Tube (GDT) were attached at both the terminals of the signalling cables. The sheath of signalling cable was connected to the ground at both the terminals. The simulated grounding methods are as follows. (1) Individual Grounding Method: The simulating the grounding method used for the current Shinkansen, the groundings in the signalling house (D5, H1 and H2) were made independent. (2) Common Grounding Method: The grounding method connected to the groundings in the signalling house (D5, H1 and H2). (3) Connected grounding Method: The grounding method connected to all the groundings (H1, H2 and D3 to D7, except for D6).

IV. FIELD TEST RESULTS

A. Waveform of Applied Current

The current AC60Hz, $20A_{rms}$ simulating the ground fault was applied, and the current 1.2/50μs, $100A_{p-p}$ simulating the lightning surge was applied. The front time of the actual applied current simulating the lightning surge as shown in Fig. 7 was longer than the intended waveform due to the influence of the cable between the impulse generator and the applied point of D5.

B. Case of Ground Fault

In the case of simulating the ground fault, the potential rise of each grounding and the shunt current are shown in Fig. 8 and Fig. 9. According to Fig. 8, the major difference between the individual grounding method and the common grounding one are the potential rise of D5, H1 and H2. In the common grounding method, these groundings have the equal potentials, and the potential rise of D5 is reduced compared with that in case of the individual grounding method. This is because these groundings share the applied current as the parallel circuit (D5, H1 and H2) in case of the common grounding method. On the other hand, in the connected grounding method, the connected groundings have almost the equal potential and the potential rise of D5 is reduced compared with that in case of the common grounding method. This is because all the groundings share the applied current as the parallel circuit (H1, H2 and D3 to D7 except for D6) in case of the connected grounding method.

As indicated in Fig. 9, the major current route to the adjacent signalling house is the cable sheath in case of the

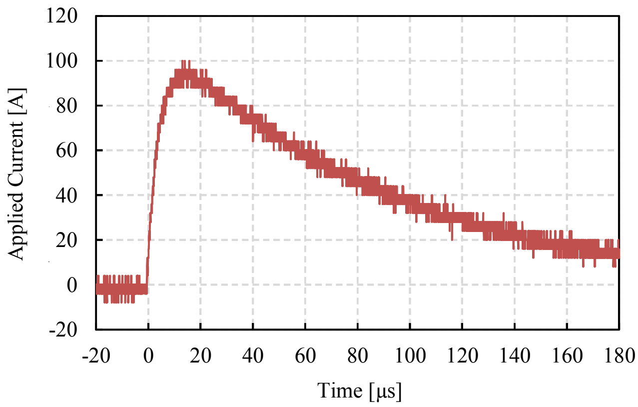

Figure 7 Waveform of applied current simulated lightning surge.

common grounding method, and the connected grounding cable in case of the connected grounding method in contrast. In case of the connected grounding method, the current was shared by the connected grounding cable, and the ratio of the sheared current by the connected grounding cable to that by the cable sheath is about 100. Here, the conductor resistance of IV 22 mm^2 used for the connected grounding cable is about 0.8 Ω/km and that of the cable sheath is about 200 Ω/km. Therefore, the ratio of the conductor resistance of the cable sheath to that of the connected grounding cable is about 100, and this value agrees with the experimental result. On the other hand, the current of the connected grounding cable in case of the connected ground method is about three or four times as large as that of the cable sheath in case of the common grounding method. It is estimated that this result is not only due to the difference in the conductor resistance, but also due to the difference in the composed circuit as a whole including the grounding resistance and the ground resistivity.

C. Case of Lightning Surge

The potential rise of each grounding and the shunt current in case of simulating the lightning surge are shown in Fig. 10 and Fig. 11. According to Fig. 10 and Fig.11, the results in case of simulating lightning surge are similar to that in case of simulating the ground fault. As for the potential rise of the connected groundings between D5, H1 and H2, the potential rise in case of simulating the ground fault is the same among the respective groundings, however, the potential rise in case of lightning surge is not the same among the respective groundings, and the potential rises of H1 and H2 are a little smaller than that of D5. This is because the results depend on the kind and length of the cable connecting each grounding. The resistance of the connecting grounding cable is almost ignored in case of the ground fault. In contrast, the component of the cable inductance is dominant due to transmission to the adjacent groundings at the transient state in case of the lightning surge. Focusing on the shunt current in the whole test site, the potential rise in case of lightning surge are a little different among the connected groundings, because the current flowing into the distant groundings in case of the lightning surge is smaller than that in case of the ground fault. Therefore, these results show that the relationship among the respective groundings such as D5, H1 and H2 in case of the lightning

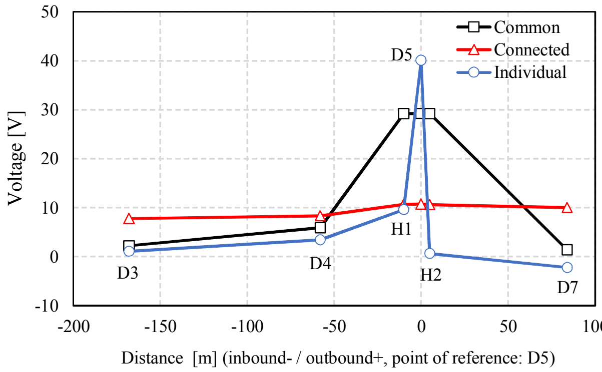

Figure 8 Voltage of groundings at each measuring point (ground fault).

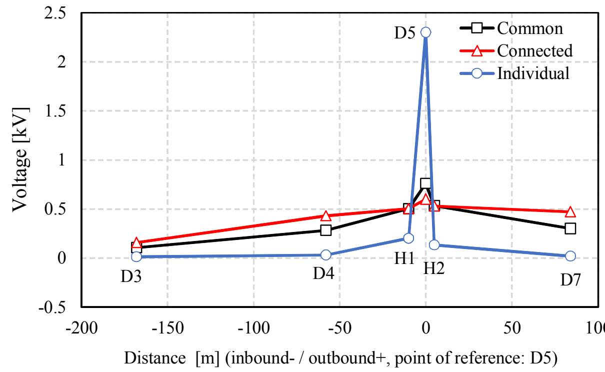

Figure 10 Voltage of groundings at each measuring point (lightning surge).

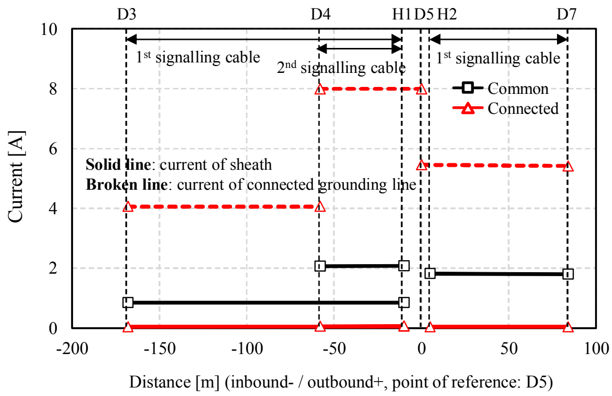

Figure 9 Shunt current at each measuring point (ground fault).

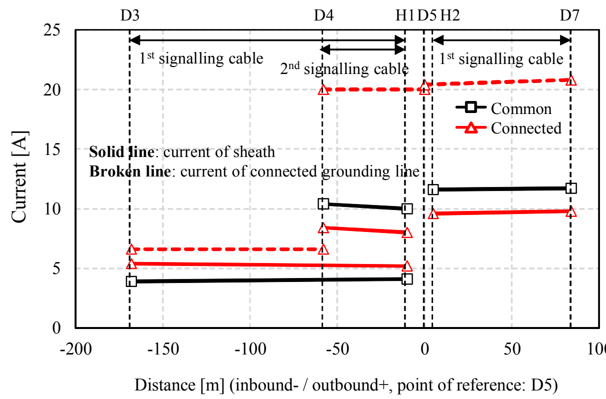

Figure 11 Shunt current at each measuring point (lightning surge).

surge is smaller than that in case of the ground fault due to the high frequency. Additionally, as a result, the shunt current is hard to spread to the distant in case of the lightning surge because the impedance of the connected grounding cable and the cable sheath in high frequency are larger than that in commercial frequency such as that of the ground fault current. It is estimated that the potential distribution is similar to this result when establishing a fault point besides D5.

V. Discussions

A. Comparison of Grounding Methods

From the results of this field test, the authors compared the common and connected grounding methods with the individual grounding method which was set as the standard.

1) Individual Grounding Method: The potential rise of the groundings unrelated to the grounding having the potential rise and that of the equipment in the signalling house were reduced, because the groundings were independent of each other. On the other hand, it is estimated that the equipment in the signalling house will be broken by difference in the potential among the respective equipment became the large difference of the potential is generated in the signalling house.

2) Common Grounding Method: The potential of the groundings unrelated to the grounding of which the potential rises up, and the potential of the equipment in the signalling house rise up due to the connection of the respective groundings in the signalling house. Further, the shunt current is transmitted in the cable sheath up to the adjacent signalling house, and the potential of the groundings in the adjacent signalling house rises. However, it is estimated that the equipment in the signalling house will not be broken by the difference in the potential between each equipment, because the difference in the potential rise between each equipment in case of the common grounding method is smaller than that in case of the individual grounding method.

3) Connected Grounding Method: The potential of the groundings unrelated to the grounding of which the potential rises up, and the potential of the equipment in the signalling house rise up due to connection of all the groundings. Further, the shunt current is transmitted through the connected grounding cable up to the adjacent signalling house, and the shunt current in case of the connected grounding method is larger than that in case of the common grounding method. Thus, it is estimated that the equipment in the signalling house will not be broken by difference in the potential between each equipment and between each signalling house due to reduction of the difference in the potential among all the groundings.

B. Investigations of Connecting Each Grounding

In investigating whether or not the authors are able to connect the each grounding, it is important to make clear the effect of the connected each grounding on the equipment in comparison with that of the individual grounding method. The authors considered the following items as an effect investigation based on the field test results in the individual, common and connected grounding methods. (1) Estimated potential rise in the fault (ground fault and lightning surge) in the connected groundings, (2) Frequency of occurrence of potential rise in the connected groundings, (3) Generation of line voltage by the current flowing into the cable sheath, (4) Value of the current flowing into the cable sheath, and (5) Electric corrosion by the near DC electric railway.

It is considered that it is able to determine whether or not the authors are able to connect each grounding by the following cases of the connected type investigating these items of the effect. (1) Case of connection between the groundings used for the signalling equipment (E1 to E3), (2) Case of connection between the groundings used for the telecommunication equipment (the grounding estimated to have no direct lightning strike (case of telecommunication No. 1), or that estimated to have the direct lightning strike (case of telecommunication No. 2)), and (3) Case of connection with the groundings used for the power equipment (the grounding used for the high voltage distribution cubicle (case of power No. 1), or the grounding used for the substation (case of power No. 2)).

Examples of investigation results are shown in Fig. 12. Figure 12 indicates that the groundings of the signalling equipment (E1 to E3) can be connected to the groundings which is estimated to have no direct lightning, and in case of ground fault, overvoltage does not exceed protective performance of the signalling equipment against overvoltage. In case where there is a DC electric railway in the neighborhood, it is difficult to lay the connected grounding cable because there is some possibility of the electric corrosion. In the future, the above investigation cases need to be discussed in more detail.

VI. Conclusions

In this paper, the authors measured the characteristics of voltage and current in case of applying the current simulating the lightning or the ground fault in order to compare the effect of the individual grounding method and the common grounding method, and investigated whether or not the authors are able to connect the respective groundings of the Japanese Shinkansen's signalling, communication and power equipment.

As a result, it has been shown that the potential of the groundings unrelated to the grounding of which the potential rises and the potential of the equipment in the signalling house rise up due to connection of the respective groundings in the signalling house. On the other hand, it is estimated that the equipment in the signalling house will not be broken by difference of the potential between each equipment, because the difference in the potential rise between each equipment in case of the common grounding method is smaller than that in case of the individual grounding method. Further, in case of the connected grounding method, the equipment in the signalling house will not be broken by difference in the

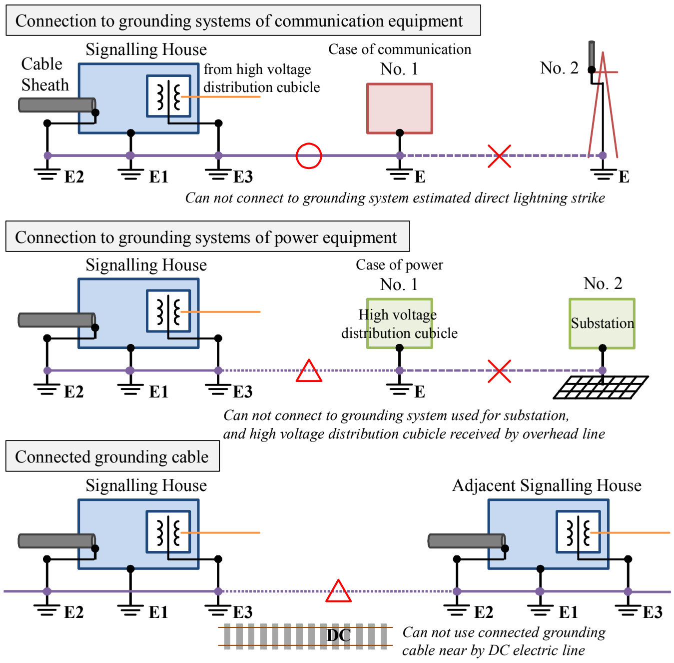

Figure 12 Examples of investigation results.

potential between each equipment and between each signalling house due to reduction of the difference between all the groundings. In investigating whether or not the authors can connect each grounding, it is important to make clear the effect of connecting each grounding in comparison with that in case of the individual grounding method. The authors considered five items for the effect investigation based of the field test results in the individual, common and connected grounding methods. In the future, the authors will investigate the effect corresponding to the grounding method and the target equipment for connection in order to determine whether or not the authors can connect each grounding.

Acknowledgment

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