Research on the Correlation of Control Malfunction with Induced Voltage of Control Signal Line According to Voltage Change of a Power Line

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Abstract – This induced voltage measurement test and electromagnetic field simulation are related to the possibility of control signal malfunction by power line. Through an experiment, this research analyzed whether the voltage causing control malfunction according to the on/off status of power permitted to power line was induced to control signal line. Also, the research calculated the voltage induced to control signal line and examined the phenomenon by conducting an electro-magnetic field-specific simulation through the finite element method for the cable model used in the experiment.

Keywords: Control signal line, Induced voltage, Control malfunction, Overall + individual shield ground

1. Introduction

As the voltage induced in power line can cause control signal malfunctions when there exist both the power line and control signal line for propelling the system, this paper states that preparation against such problems is needed. [1, 2]

To measure whether the voltage causing control signal malfunction is induced by a nearby power line, a test was performed by preparing an integrated cable sample, which was then modeled to analyze the phenomenon through an electromagnetic field characteristics simulation. The cable used in the experiment was '0.6/1kV TFR-CVVS, 8P× 1.5mm^2 cable (hereinafter integrated cable)' from LS Wire, and the voltage induced to the control signal line based on the on/off status of power line was measured.

2. Body

2.1 Measurement of control signal line induced voltage

The test circuit was connected as in Fig. 1, and the cable

was arranged as in Fig. 2. Then the control signal line was connected to the terminal block inside the terminal box to minimize the contact elements among stranded cables. In
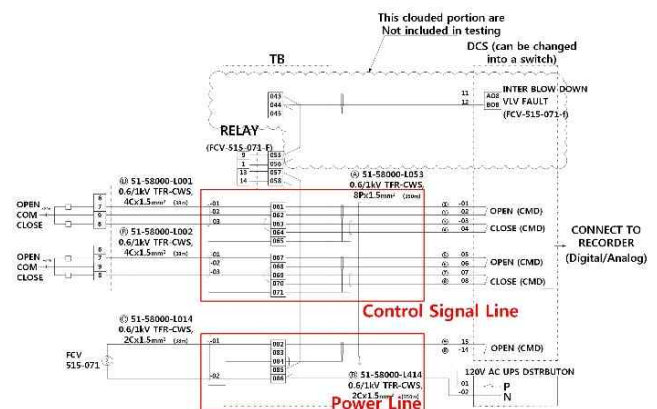

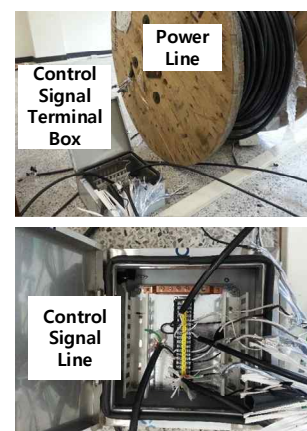**Fig. 1.** Test circuit diagram

Fig. 2. Test measurement cable and terminal box

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accordance with the integrated cable ground status, the voltage induced to the control signal line was expected to be difficult. Thus the ground state was divided into overall shield ground (experiment 1) and overall + individual shield ground (experiment 2) to conduct the test. [3, 4]

2.2 Analysis and review of test result

The integrated cable consists of a total of 8 pairs and 5 pairs among them were used. 1 pair was the power line and 4 pairs were used as control signal lines to send signals.

This test permitted 120 Vac (60Hz) phase voltage, a driving voltage, on the power line through UPS by minimizing the noise of power supply terminal and measured the changes of voltage on the 4 pairs of signal lines adjacent to the power line. Lecroy's Wave Runner 610Zi model was used as a measurement tool for sampling, and CP0303 current probe and HVD3102 voltage differential probe were used for measurement.

The switch for power line on/off was switched at an interval of about 1.5 seconds. The graph measured with an oscilloscope was in the order of voltage, electric current and partial enlargement of voltage at on/off of the control signal line. When the overall shield ground was used, the measured induced voltage was as in Fig. 3. The maximum
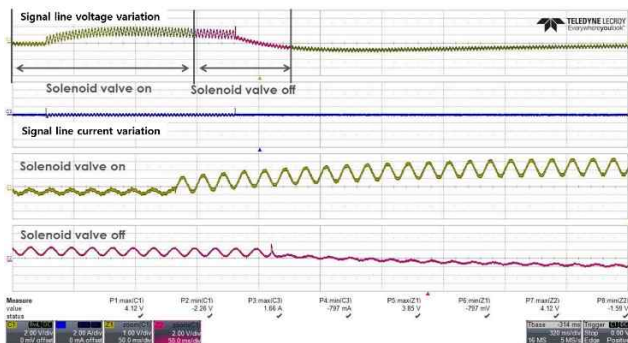

Fig. 3. The induced voltage of signal line measured with an oscilloscope during power on/off at an overall shield ground state
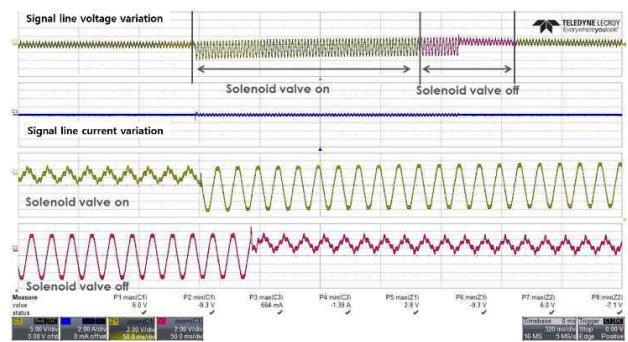

Fig. 4. The induced voltage of signal line measured with an oscilloscope during power on/off at an overall + individual shield ground state

voltage measured in this test was 4.8V at power on and 5.9 at power off, and the voltage was measured over 100 times for deviation analysis.

The test result after dividing the ground state into overall shield ground and overall + individual shield ground was as in Fig. 4. The voltage induced by using overall + individual shield ground was measured to be a maximum of 13.5V at power on and a maximum of 15.1 at power off. As seen on the result, 1.6V higher voltage at power off was induced to the control signal line, and its deviation analysis result was represented on Fig. 5 and 6.

A summary of test result was shown on Table 1. If the control signal line and power line were in the same integrated cable, the variation of magnetic flux according to the voltage change of power line abandoned certain voltage on the control signal line. Such phenomenon has the same principle as the 1:1 transformer of 1/2 turn as seen on Fig. 7 below. V_1 is power line voltage and its
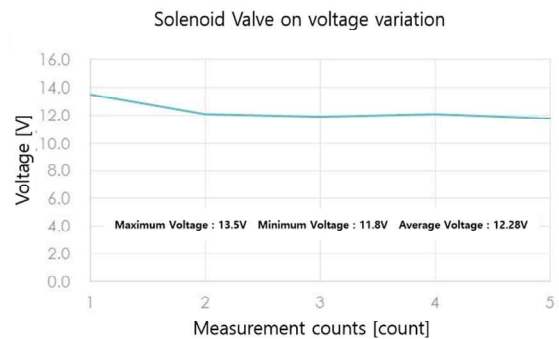

Fig. 5. Deviation analysis on the induced voltage of signal line measured by oscilloscope at power on during overall + individual shield ground state power
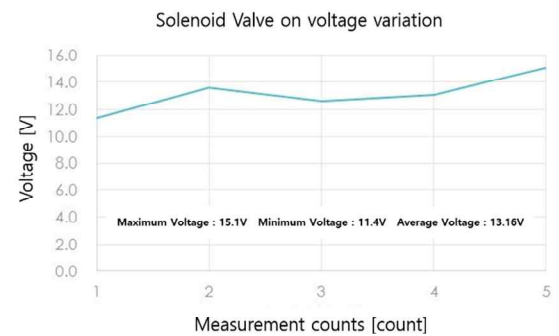

Fig. 6. Deviation analysis on the induced voltage of signal line measured by oscilloscope at power off during overall + individual shield ground state power

Table 1. Test result of voltage induced by integrated cable

Distribution		Voltage Variation		
Ground Situation	Switch Situation	Max	Min	Avg
Overall shield	Switch on	4.8V	2.3V	3.6V
	Switch off	5.9V	1.7V	3.8V
Overall + individual shield	Switch on	13.5V	11.8V	12.28V
	Switch off	15.1V	11.4V	13.16V
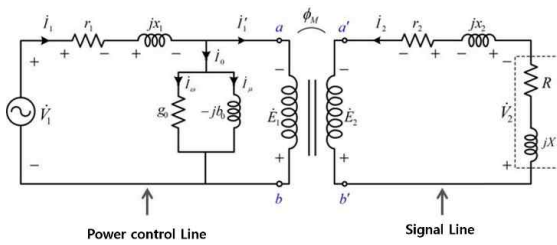
Fig. 7. Equivalent circuit of 1:1 transformer [7]

Table 2. Materials constituting TFR-CVVS Cable [8]

Items	Construction	Material or type
*1	Conductor	Circular stranded soft wire
2	insulator	Vinyl (PVC)
3	interposition	Proper interposition
4	Binders	Proper tape
5	Ground wire	Tinned Soft copper wire
6	Shielding	Al/mylar tape
7	Sheath	Fire retardant vinyl (FR-PVC)

Fig. 8. Cross-sectional Diagram of TFR-CVVS Cable

Fig. 9. 2D cable modelling: (a) 2D model; (b) Mesh (Finite Elements Method)
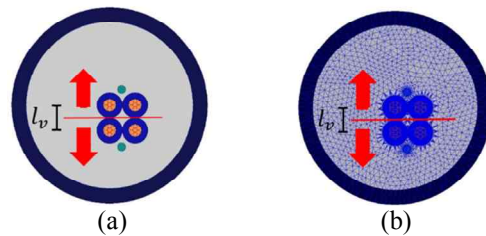
alternating current is 120Vac, and r_1 has a very value as the resistance of power line. V_2 is load voltage and R,X is load impedance. E_1,E_2 is primary, secondary induced voltage. I_1 is power line current, I_o is exciting current, Iω is Iron loss current and Iμ is magnetizing current. I'_1 is primary load current. Leakage reactance x_1, which represents leakage, is determined by the separation distance between power line and signal line, and if there is no leakage (100% magnetic coupling) 120V can be abandoned to the control signal line. However, as the insulator inside the cable has the relative permeability of 1, a huge leakage flux is expected to occur and a low voltage is abandoned to the control signal line as shown on the actual test. [5, 6]

If there is an enough separation distance, the leakage reactance can be very big (0% magnetic coupling) and voltage may not be abandoned to the control signal line. However, according to the cross-sectional diagram of the cable, there is no separation distance and the leakage reactance is considered for control signal line, so certain voltage is abandoned. Especially, the voltage induction phenomenon is influenced very much by an inrush current when electric power is put into power line. The magnetic flux can double depending on input phase even if there is no remanent flux, and it can be greater if there is remanent flux. Furthermore, since the cable does not consist of a ferromagnetic material, the magnetic flux can be increased by twice, raising the induced voltage of signal line. Such phenomena can be explained as the voltage measured on control signal line changes when the power is on and off, and the result of this test is a comprehensive result of these phenomena.

2.3 Characteristics of electromagnetic field and composition of simulation modeling and circuit

The cable used in the simulation was modeled in the actual size to raise the reliability of simulation result by referring to the specifications of '0.6/1kV TFR-CVVS, 8P×1.5mm^2 cable (hereinafter integrated cable) of LS electric wire. Figs. 8 and 9 are respectively the cross section and model of TFR-CVVS cable referred to for modeling and Table 2 shows the materials of cable composition. Also, the simulation must copy and reflect the environment and dynamic characteristics of test environment as much as possible. By assuming the power voltage used in the induced voltage measurement experiment as the induced
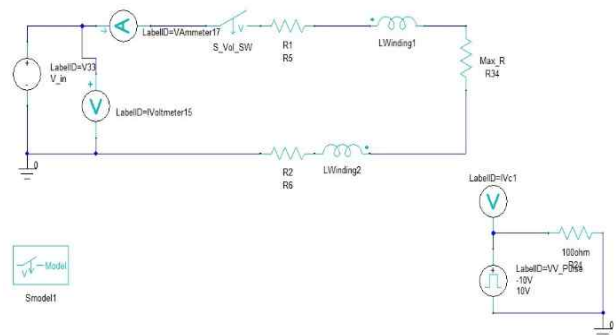

Fig. 10. Simulation circuit diagram

voltage of control signal line, this simulation constructed the simulation circuit as in Fig. 10 to artificially permit surge voltage to the power line at switch on/off to copy this in the simulation.

To estimate the voltage induced to the control signal line near the power line, the distance between the control signal line and power line of the cable modeling in Fig. 9 was determined as a variable (lv). Then, a simulation was conducted for the induced voltage generated by each cable separate from the power line to be similar to the experiment. This compared the size of induced voltage according to the separation distance in the same surge voltage. Since the integrated cable consists of a non-magnetic material, an insulator, as in Table 2, the simulation method of separating the control signal line
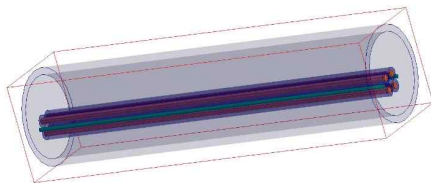
Fig. 11. 3D cable model

from the integrated cable can be seen as reasonable.

The surveyed cable resistance consisted of a control signal line that had 7 wires of cables in pairs at average of 4.25Ω, the resistance of cable for the measurement of induced voltage was approximated at about 8.5Ω to be applied on the simulation. Also, the model used in the simulation was created in 2D as in Fig. 9 instead of 3D as in Fig. 11. This simulation method could be used because electromagnetic characteristics in a structure consisting of a cylindrical shape like a cable had a longitudinal axis and the same characteristics. Thus, the result of 2D simulation using the concept of infinite could be multiplied by the component of longitudinal axis to draw a result value. This has a very high reliability because it is the same as the electromagnetic simulation method of cylindrical motor. Furthermore, the higher the number of elements is, the higher the accuracy of simulation becomes when the finite element method is applied, so the reliability of simulation was obtained by increasing the mesh of 2D model.

2.4 Analysis and review of simulation result

As seen on Fig. 12, the analysis of induced voltage size while changing the surge voltage showed that the induced voltage of control signal line was proportional to the voltage size of surge. The surge voltage could exceed the rating of measuring equipment during the experiment, so the surge electric current value was assumed as the standard. The analysis also demonstrated through the simulation that if a pulse voltage to copy 800V was permitted, about 17.2V of induced voltage was abandoned to the control signal line. On the legend of the graph, the unit representing the size of surge voltage is V.

The result value of this simulation was quite higher than the experiment value. However, the fact that a higher induced voltage of the control signal line could be generated in the simulation compared to the physical situation of actual cable indicates that the induced voltage was simulated in the worst stress condition. Moreover, since the size of magnetic flux linkage among cables varied depending on the separation distance between the power line and control signal line, the change of induced voltage was simulated by having the separation distance as a variable. The simulation also confirmed that the induced voltage of control signal line changed even when the distance between cables was changed based on a certain surge voltage. As mentioned previously, the magnetic flux due to the surge voltage permitted to the power line
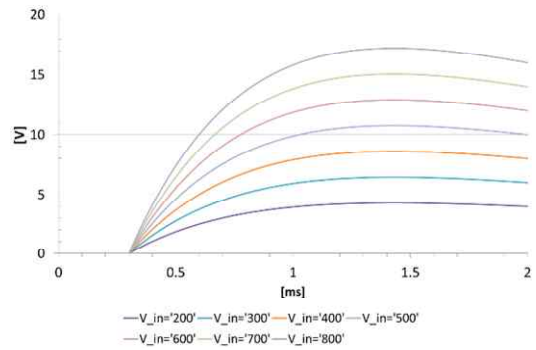

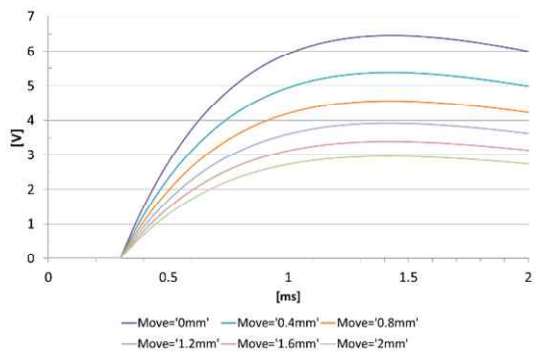**Fig. 12.** Change of induced voltage by surge voltage size

Fig. 13. Change of induced voltage according to the separation distance of power line and control signal line

influenced the magnetic flux that was linked to the control signal line, the amount of magnetic flux linkage decreased as the separation distance increased and the induced voltage also decreased due to the increase of leakage flux. Fig. 13 shows the result of induced voltage simulation that changed the separation distance from 0mm to 2mm based on 400V of surge voltage. As seen on the result, the closer the distance was, the higher the induced voltage was generated.

3. Conclusion

Based on the above simulation result, induced voltage was likely to occur among neighboring cables due to the voltage change of a nearby cable and voltage permitted by surge. Also, the simulation result confirmed that the size of voltage induced by a separation distance among cables and the size of surge voltage. This result demonstrated that the cables used as major signal lines in control must secure a power line and enough separation distance to generate a huge magnetic field nearby.

Acknowledgements

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