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LONGITUDINAL INDUCTION VOLTAGE MEASUREMENT ON COMMUNICATION CABLES RUNNING PARALLEL TO OVERHEAD LINES OR POWER CABLES

Dean SHARAFI, Western Power, (Australia), dean.sharafi@westernpower.com.au
Dipl.-Ing. Ulrich KLAPPER, OMICRON electronics, (Austria), ulrich.klapper@omicron.at

ABSTRACT

Overhead lines and power cables carrying electrical currents induce voltages in other parallel lines and cables. The induced voltage, otherwise known as Low Frequency Induction (LFI) can result into malfunction and damage of the connected instrument and can endanger lives of people coming into contact with these conductors.

Eliminating the effect of induced voltages is practically not possible in most occasions, because the communication cables normally run in the same easement and corridors used by electrified power cables and overhead lines. Engineers must ensure the power system is designed in such a way that induced voltages on adjacent conductors are kept within the acceptable limits, safe for humans and connected equipment. The design can only be proven by commissioning tests once the power and communication systems are ready to be put in service.

This paper intends to briefly explain methods by which the longitudinal induced voltage can be measured and introduce a new method for this measurement.

KEYWORDS

Signal cables; longitudinal induction; Variable frequency

INTRODUCTION

Electro-magnetic field is created in the surrounding of a conductor as a result of current passing through the conductor. This field induces a voltage on adjacent conductors depending on the distance (separation) from the source of the field and other specific conductor's conditions such as angle with the electrified line, screening and bonding.
Power System Engineers are confronted with the task of designing a system, which induces voltages on adjacent conductors only within allowable limits. These limits are set by standards and achieved through collaboration of power and telecommunication industries.

Effect of electrical overhead conductors and power cable installations into telecommunication cables need to be measured by commissioning tests before energisation to ensure that these voltages are within the safe limits and then periodical tests need to be carried out to prove that the induced voltages are maintained safe for human beings and connected equipment. The magnetic field of buried power cables is less than that of overhead lines because the phases are closer together, however the signal cables are potentially also closer to the power cable so the problem is more or less the same.

SAFE VOLTAGE LIMITS

According to International Telecommunication Union's guidelines, there are two categories for induced voltages to be considered:

- Normal conditions
- Fault conditions

Under system normal operation, cables to which members of public may come in contact with, can have induced voltage of up to 60 Vrms with reference to earth. Cables that are not accessible by the public are allowed to have up to 150 Vrms under normal operating conditions provided that only technicians can access them.

An electrical fault due to insulation breakdown or other reasons can cause a rapid rise in the current flowing through a conductor. This excessive current creates a powerful changing magnetic field, which in turn generates a greater induced voltage on adjacent conductors. Under these conditions, the induced voltage of up to 430V is regarded as the allowable limit.

The above voltage values have been allowed to exceed provided that the probability of the higher induced voltages are low and protection fault clearing time is very quick. If the above two conditions are met, then the allowable induced voltage can go up to 1000 Vrms if the protection operates within 350 msec to 500 msec. In cases where the fault clearing time is less than 350 msec, the limit is allowed to rise up to 1500 Vrms. These allowable voltage limits are summarised in Table 1.

Line Category	Description	LFI V-Limit
A	High Reliability line with protective equipment that would clear an earth fault within 0.35 secs	1500 V_{rms}
B	High Reliability line with protective equipment that would clear an earth fault in, from 0.35 secs to 0.5 secs	1000 V_{rms}
C	Line not classed as a High Reliability as protective equipment would not clear an earth fault within 0.5 secs	430 V_{rms}
All	Normal operating conditions where the cable can be accessed by technicians	150 V_{rms}
All	Normal operating conditions where the cable can be accessed by the public	60 V_{rms}

Table 1 : Power Line Categories and LFI Voltage Limits

CALCULATION OF THE INDUCED VOLTAGES

When designing the power system, engineers take into account the currents, which may flow into conductors due to normal operating conditions and more importantly due to fault conditions. Checks must be made to ensure that under the above two conditions, the induced voltage on adjacent cables remain within the safe boundaries. Faults may include earth, which cause the earth currents to rise rapidly. Earth faults will cause current flow in earth-wires and these currents generate induce voltages on other conductors. Therefore following information is needed during the design stage:

- Phase conductor and cable shield data (information how the shield is grounded on both ends)
- Fault currents at the substation's,
- Mutual impedances between the phase conductors and communication cables, and
- Mutual impedances between cable shields and communication cables

This information is then analysed to create the calculated induced voltage value.

The current in the shield is calculated as the shield produces an induced voltage that opposes that created by the phase wire. The shield current however can decrease further from the fault if the cable has ground contact along its length.

The resultant induced voltage is the difference between the voltage induced by the faulted phase conductor and the shield.

The value of induced voltage is calculated using the following formula:

$$V = C.L.i.K \qquad [1]$$

where:
V induced longitudinal voltage [V]
C mutual impedance per unit length [ohm/km]
L length of exposure (between power and communication cable) [km]
i fault current [A]
K shielding factor {K=1 for no shielding}

The mutual impedance, C of two parallel circuits having earth returns is given by

$$C = 2\pi f \left| \log_e \left(1 + \frac{6 \times 10^5 \rho}{d^2 f}\right) \right| \times 10^{-4} \text{ [ohm/km]} \qquad [2]$$

where:
d geometric separation between earth return circuits in metres
ρ earth resistivity in ohm-metre
f system frequency in Hz

If the shield is not grounded on both ends the shield current is zero and the shielding factor K is 1.

MITIGATION MEASURES

Mitigation measures include increasing the number of shielding pairs in the communication cables, installing latent shielding for the communication cables via gas-filled protectors, installing an additional shielding conductor parallel to the power lines/cables, installing fibre optic interface along the communication cable, or reducing the fault level of the lines.

PROVING DESIGN BY COMMISSIONING TESTS AND TEST CHALLENGES

When the power system is ready to be put in service, the design must be proven by commissioning tests.

Commissioning tests involve simulating an earth fault by injection in the overhead line and measuring the induced voltages on cables in question. Measurement will be carried out on the communication cable with reference to earth. Since it is not practical to inject high currents with primary injection test units or generators, normally the injected current will be scaled to maximum fault current assuming system linearity. The major hurdle comes into place when trying to inject at or close to system frequency (50 Hz in Australia), due to existence of background noise caused by adjacent energised lines, "Standing Voltages". These standing voltages are sometimes as big as test voltages in magnitude and may render the test activities ineffective. Therefore attempts will be made to inject higher currents and varying the frequency as much away from system frequency as possible.

Testing personnel experience extreme difficulty in adjusting generators to operate in a range, which they are not primarily designed for, and 48 Hz to 52 Hz are the best they can get for the purpose of this test. Multiple measuring instruments are needed, which may include:

- -Phase Angle Meters
- -Double Beam Oscilloscopes
- -Selective Voltmeters
- -Chart Recorders
- -Spike Transient Voltmeters

Low impedance of the line or high voltage power cable through which the injection is taking place creates another difficulty and it is sometimes required to impose additional impedance on the circuit such as step-up or isolation transformers. Heavy equipment creates other logistic difficulties and requires a great amount of manpower and time for performing the tests.

NEW CONCEPT FOR PERFORMING COMMISSIONING TESTS

The new concept has been made possible by CPC100 and CP CU1 developed by Omicron. The device is capable of injecting frequencies ranging from 15 Hz to 400 Hz, providing an excellent noise suppression technique. The injected current can be tapped according to the line parameters and existing induction from other energised lines. Current injection is made with various frequencies, and induced voltage is measured simultaneously with the same applied frequency. The results are then extrapolated to show the response of the system for 50Hz frequency.

The difficulty is that in some occasions the injection location is far away from the location where induced voltages have to be measured.

7. SOLUTION

Western Power Corporation designed and carried out a test set-up to overcome this problem by utilising two CPC100 units and Global Positioning System synchronising devices to initiate the test two sets located at different locations at the same time. Test set-up is illustrated in Figure 1.

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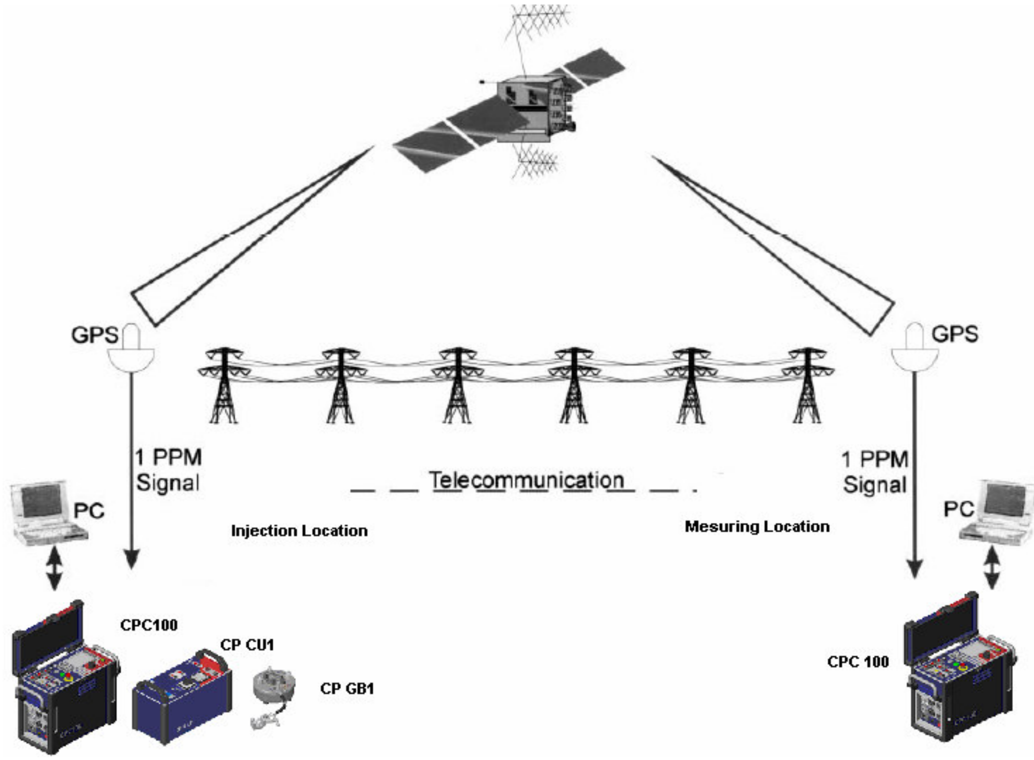

Figure 1: Test set-up. CP CU1 is an isolation and step-up transformer. It provides isolation between the operator and primary equipment with built-in current and voltage transformers to step-up the current and reduce voltage for measurement by CPC 100. CP GB1 works as a surge arrester and grounding equipment and connects the to the line under test.

The test procedure is as follows:

A CPC100 and a CP CU1 is connected at injection location, and another CPC100 measures the induced voltages at measuring point. These two devices are synchronised by CM GPS synchronising clocks so that they are initiated simultaneously.

Test files are prepared in the office in two separate files for injection and measurement units. These files are then manually merged once the test is performed and loaded into a file loader, which analyses the figures and creates impedance values if needed.

Induced voltage for 50 Hz can be obtained by averaging the values measured from 30 Hz and 70 Hz injection. This voltage can then be interpolated to maximum available fault current and checked against allowable limits.

CASE STUDY

This case study foots on a measurement performed on an overhead line, however the principle works similar for power cable installations. On Friday July 15 2005, Western Power Corporation performed the measurement of longitudinal voltage induction for the new Thornlie Railway Line Extension on behalf of Public Transport Authority of Western Australia

The new Thornlie extension to the existing 25 kV electrified lines runs closely parallel to the existing freight line. The freight line is dual gauge and generally about 11m from the single track electrified line. The main signalling and communication cable route is typically 25m radially distant from the electrified track centre line although, over approximately 100m, the average separation is around 18m. (Figures 2 and 3)

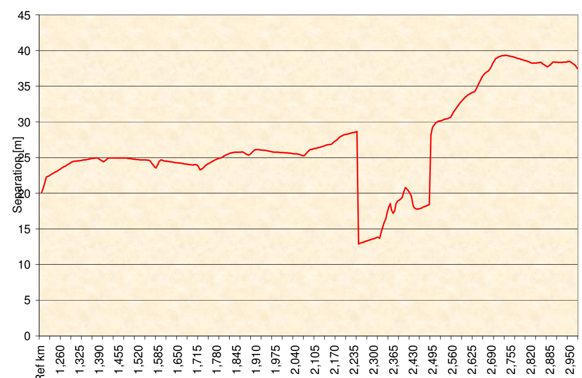

Figure 2: Separation of Communication and Signalling equipment from electrified line

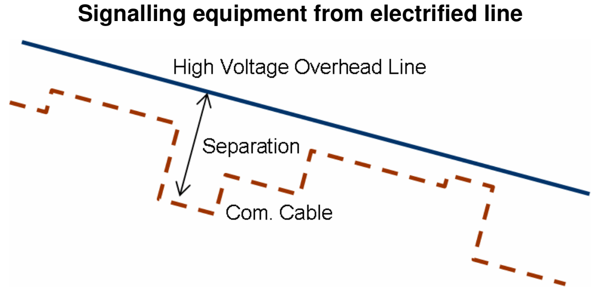

Figure 3: Separation of Communication and Signalling equipment from electrified line

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The electrified line has the capability of inducing voltages into existing signalling and communications cables. A report into induction determined that the induction over the parallel extent of the cable should be between 7.8V – 8.6V under normal train operation, depending upon soil resistivity, and 166V – 204V under traction fault conditions. In each case the predicted voltage was well under the values of 60V for communications circuits and 110V for signalling circuits adopted for normal operation and 430V, for each type of circuit, for fault conditions. This had to be proven by commissioning tests.

Test circuits for measurement consisted of a signalling core 3 km long and a communications pair 6 km long in cables in the same cable route paralleling the Thornlie line for its entire extent.

Injection tests were carried out from 30Hz to 90Hz to effectively filter out interference from 50Hz sources. The CPC100 was able to inject 50A into the line and measurements were performed by another CPC100 as the measuring unit. Figure 4 shows the result of one of measurements for 50A, which was then extrapolated to a normal maximum train load of 104A. Test configuration is illustrated in Figure 5.

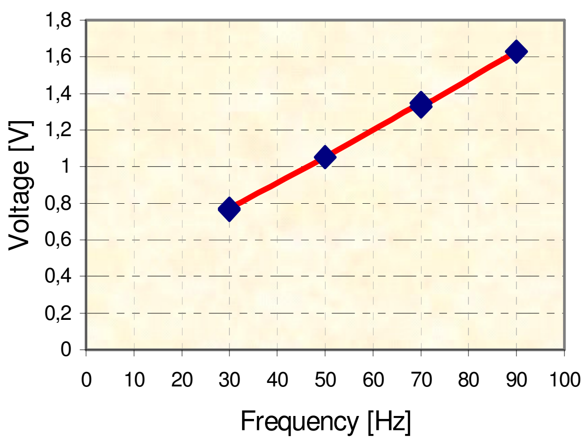

Figure 4: Result of measured induced voltages from mult-frequency injection. The value for 50 Hz is obtained by averaging the values for 30 Hz and 70 Hz.

In addition to measurement of longitudinal induced voltages on existing spare signalling and communications cable cores, an additional test was performed to measure the rail voltage rise, and thus estimate this under fault conditions, for a fault from catenary to rail in the mid point of the long 650m track circuit within a tunnel. The voltage rise was only accessible with respect to the concrete of the tunnel walls and floor and this was accessed via the fire main.

With a sweep frequency nominal injection current of 50A the voltage rise for two measurements were 1.02 and 1.05V extrapolated to a calculated fault level of 4000A, which was 83V.

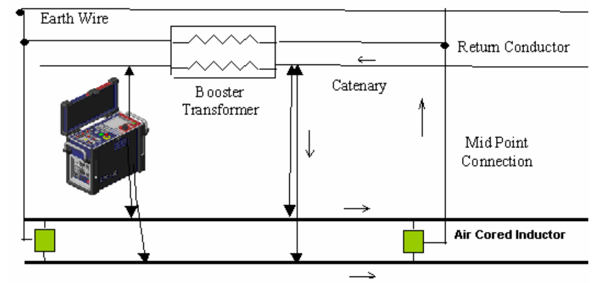

Figure 5: Injection test configuration

CONCLUSION

The new test method overcomes difficulty of conventional testing in eliminating the need for heavy equipment such as generators and transformers, and provides a more accurate and meaningful results by filtering out 50Hz noise. It is also a superb answer to the problem of testing in a large area, which integrates a number of testing techniques to achieve the frequency selective measurements of low frequency induction voltage.

REFERENCES

[1] CJC 6-1997 (SAA HB102-1997), Coordination of Power and Telecommunications – Low Frequency Induction (LFI): Application Guide to the LFI Code, Telecom Australia and ESAA, 1997.

[2] Klewe, H.R.J, Interference between Power Systems and Telecommunications Lines, Edward Arnold Ltd, London, 1958.

[3] Westinghouse Electric Corporations, USA, Electrical Transmission and Distribution Handbook, 1950.

[4] Thornlie Extension: Injection test report on testing of induction levels in WestNet Rail signalling & communications cables, Andrew Blackeley Smith, July 2005