



Western Power

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

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ABSTRACT

Overhead lines 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 corridor used by electrified overhead lines, and in many cases utilize the same towers. 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.

1. 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 into telecommunication cables need to be measured by commissioning tests before energisation to ensure that these voltage 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.

2. 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 60V rms with reference to earth. Cables that are not accessible by the public are allowed to have up to 150V rms 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 1000V rms if the protection operates within 350 msec to 500 msec. In cases where the fault clearing time is less than 350 msec, the allowable limit is allowed rise up to 1500 V rms. These allowable voltage limits are summarised in Table 1.

3. 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, earth-wire conductor and tower impedances,
- Tower dimensions and spanning distances,
- Fault currents at the substation's,
- Mutual impedances between the phase conductors and communication cables, and
- Mutual impedances between the earth-wire conductor and communication cables

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

The current in the earth-wire is calculated as the earth-wire produces an induced voltage that apposes that created by the phase wire. The earth-wire current however decreases further from the faulted tower as current is allowed to return to earth via the tower earths.

The resultant induced voltage is the difference between the voltage induced by the faulted phase conductor and the earth-wire.

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

$$V = CLiK$$

where: **V** = induced longitudinal voltage [V]

C = mutual impedance per unit length [ohm/km]

L = length of exposure (between o/h line 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

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

where **d** = geometric separation between earth return circuits in metres

ρ = earth resistivity in ohm-metre

f = system frequency in Hz

4. 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.

5. 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 instrument 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 create other logistic difficulties and require a great amount of manpower and time for performing the tests.

6. 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.

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 extrapolated to maximum available fault current and checked against allowable limits.

8. CASE STUDY

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)

The electrified line has the capability of inducing voltages into existing signalling and communications cables. A report¹ 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 3km long and a communications pair 6km 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

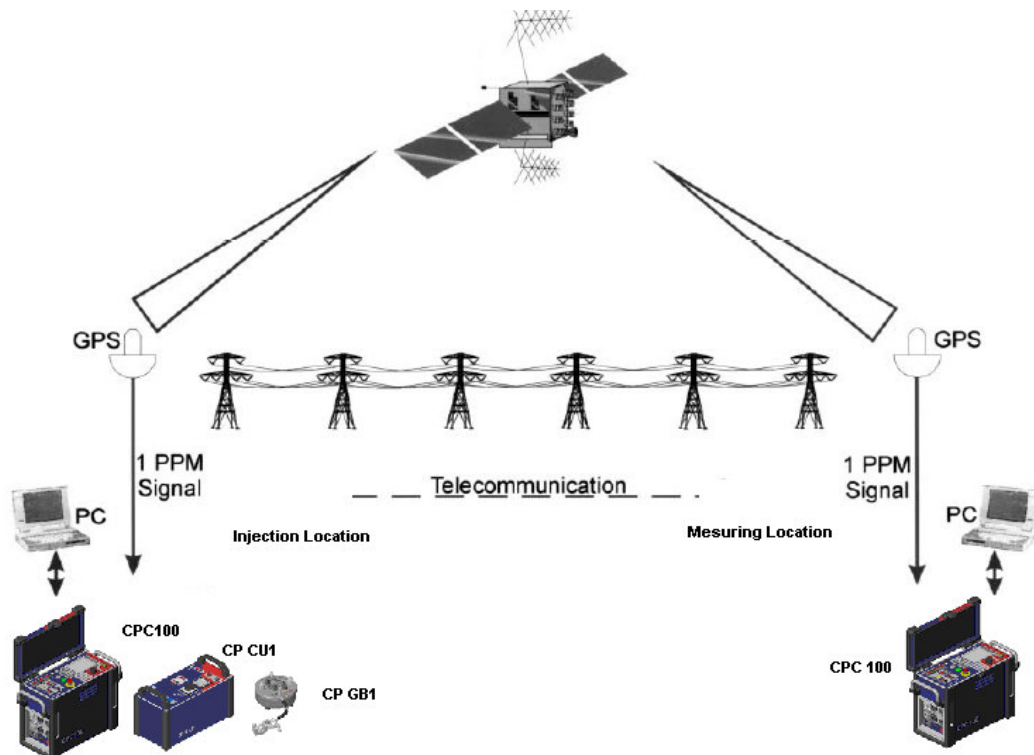
unit. Figure 4 shows the result of one of measurements for 50A, which was then extrapolated to a normal maximum train load of 104A. Test configuration is illustrated in Figure 5.

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.

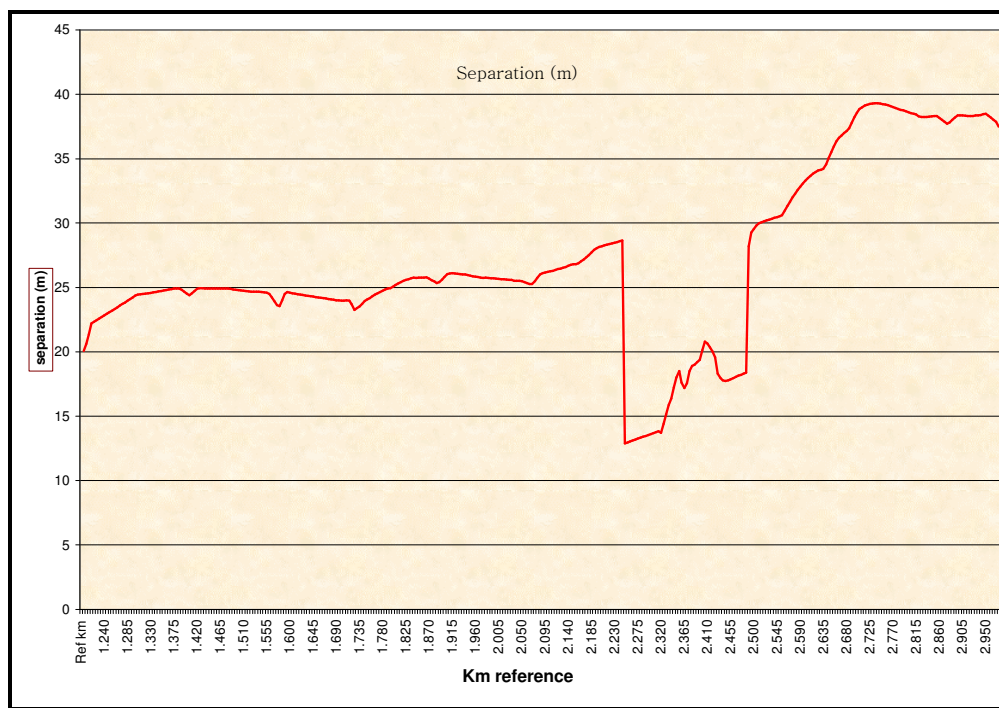
With a sweep frequency nominal injection current of 50A the voltage rise for two measurements were 1.02 and 1.05V extrapolated to a calculated fault level of 4000A, which was 83V.

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.

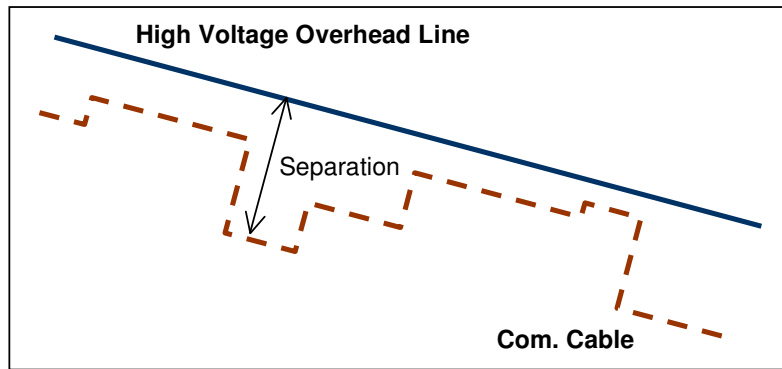
¹ "Beckenham - Thornlie 25kV Railway Extension: Calculations of Induction into Adjacent ARG Cable", Andrew Blakeley-Smith & Associates, 14-Jan-04



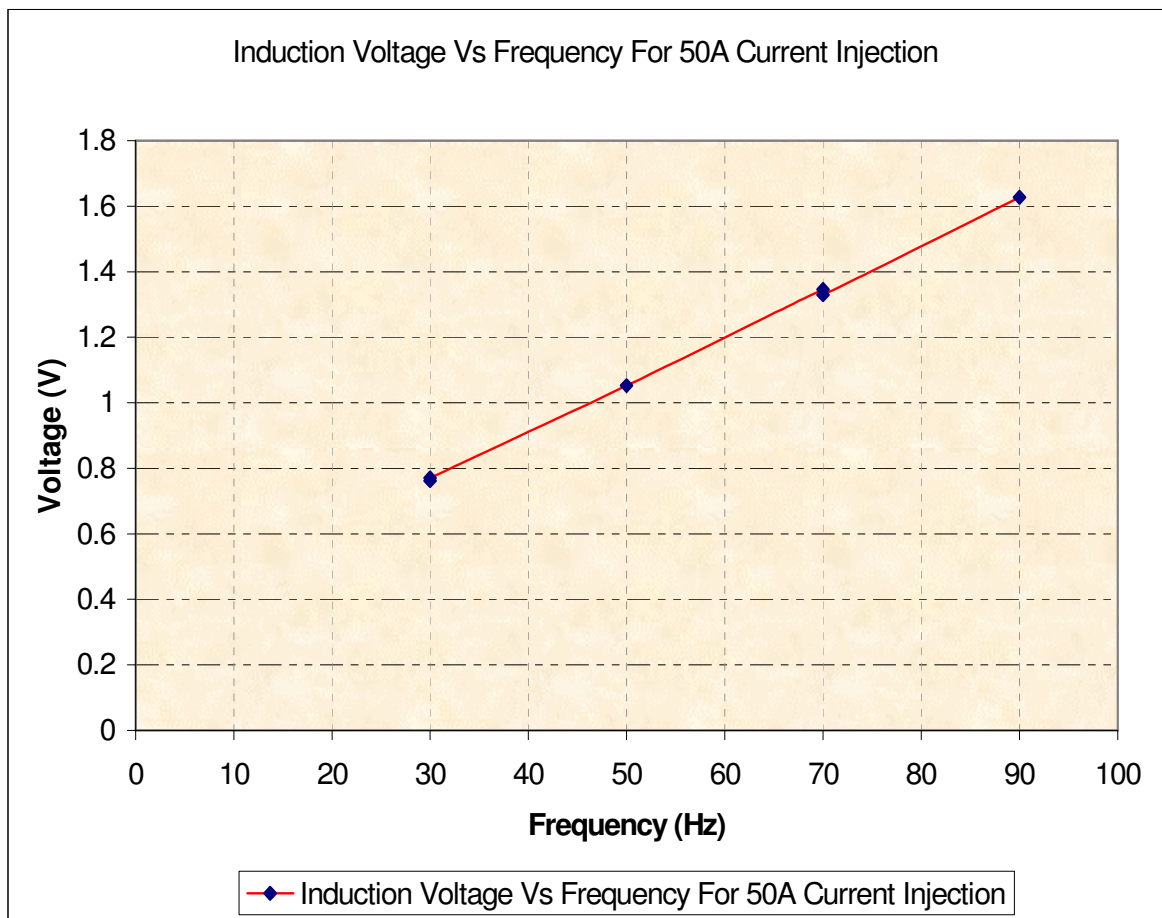
(Figure 1) Test set-up. CPC U1 is an isolation and step-up transformer. It provides isolation between the operator and primary equipment with build-in current and voltage transformers to step-up the current and reduce voltage for measurement by CPC 100. CP GB1 works as a surge arrester and grounding equipment and connects the to the line under test.



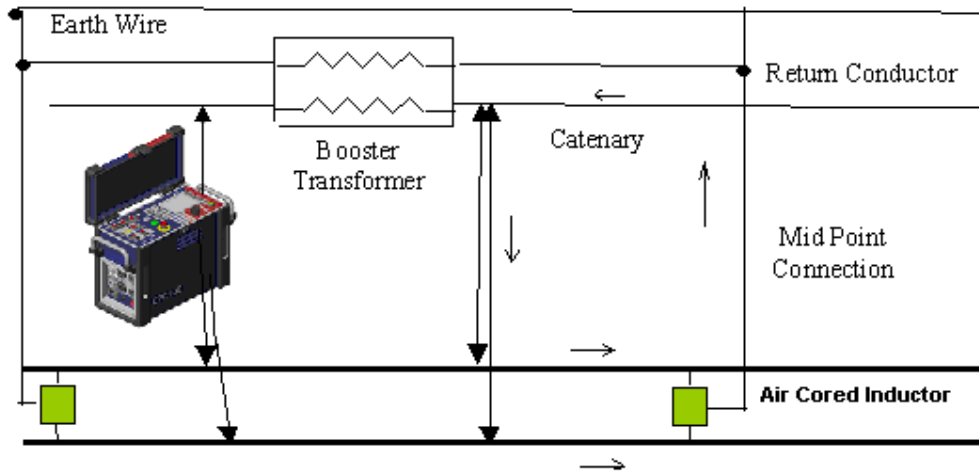
(Figure 2) Separation of Communication and Signalling equipment from electrified line (Thornlie Extension).



(Figure 3) Separation of Communication and Signalling equipment from electrified line. (Used for illustration purposes only)



(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.



(Figure 5) Injection test configuration

LINE CATEGORY	Description	LFI Voltage Limit
A	High Reliability line with protective equipment that would clear an earth fault within <i>0.35 secs</i>	1500 V_{rms}
B	High Reliability line with protective equipment that would clear an earth fault in, <i>from 0.35 secs to 0.5 secs</i>	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	110 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

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*