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Mapping The Underworld (MTU): Magnetic Field Technologies

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Mapping the Underworld

Introduction

Before commencing excavation or other work where power or other cables may be buried, it is important to determine the location of the cables to ensure that they are not damaged during the work.

The magnetic field produced by the current flowing in a power cable can be used to detect the presence of the cable and estimate its burial depth. Alternatively, cables that do not directly carry currents may also be detected by power currents, as neighbouring power cable, and even overhead power lines can induce currents at power frequencies and harmonics thereof in these cables.

The aim of this work package is to utilise a passive array of magnetic sensors together with advanced signal processing techniques to detect underground electricity cables and other metallic buried infrastructure, even when stacked or laid in close association, and finally to develop the technique so that it can be integrated in the multi-sensor device.

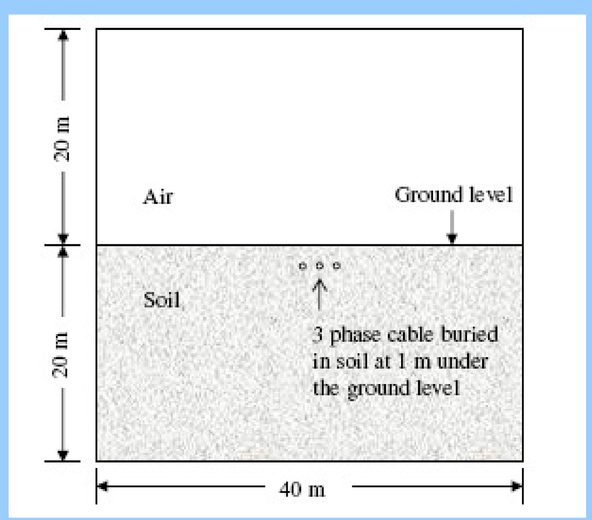
The work package consists of three interlinked activities: 1) finite element modelling of fields around cables and the development of suitable techniques for estimating their location; 2) small-scale laboratory experiments to compare the theoretical results with fields from cables and adjacent metal pipes; 3) large-scale field trials in a controlled environment.

Figure 1: Laying the underground cable for a new road.

Conducted work

1. Modelling of magnetic fields of a three-phase underground cable

The magnetic fields of the cable arrangement shown in Figure 2 has been modelled using the FEMLAB software (Electromagnetics Module). The main parameters of the model are listed on the right.



- 3-Phase 400kV XLPE Underground Cable, 2500mm^2 copper conductor
- The buried depth is 1 metre, the cable spacing is 0.5 m
- Perfectly balanced system
- The ac current through each cable is set at 400A (rms)
- Computation domain: 40 X 40 m

Figure 2: Modelling situation of the 400kV XLPE cable used in simulations

Figure 3 shows the magnetic flux density distribution at 1m above ground level at 60° intervals in the ac cycle. It may be noticed that as the current in the central cable passes through zero, the magnetic flux density is almost twice as large as at the other times for which the field was calculated. In addition, it can be seen that significant magnetic fields are largely restricted to a 10m range. This may help when attempting to locate the cables by allowing more distant sources to be neglected.

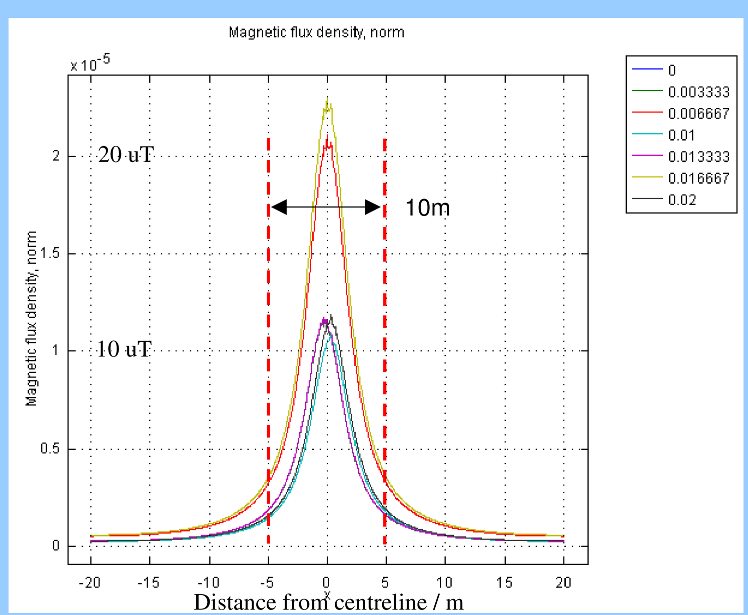


Figure 3: Magnetic flux density distribution at 1m above ground level during the ac cycle

In conclusion, modelling results are useful for magnetic field sensors choice and arrangement in the real test.

2. Experiment testing

a) Laboratory testing for a cable with a large loop using a single coil

A schematic diagram of the testing apparatus is shown in Figure 4. The apparatus consists of a current transformer (CT), a power cable, a coil, a low-pass filter & amplifier and a oscilloscope. Figure 5 shows a photograph of the whole experiment apparatus. In this experiment, A large loop of 3-core 11kV power cable is used as a detect object. The CT is used to induce an a.c current to flow through the power cable, thus generating magnetic fields around the cable. A search coil was designed and manufactured for these tests, more details about this coil can be found in 'Coil design and parameters'. The low-pass filter and amplifier is used to reduce the noise level by atenuating the high frequency signals and to improve the measurement sensitivity by providing a 100 times voltage gain. An Oscilloscope (Tek DPO 2024) was used to observe and record the measurement values.

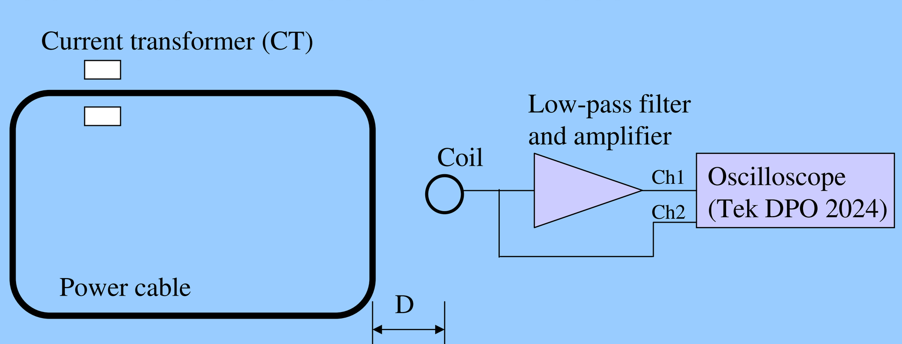


Figure 4: Schematic diagram of experimental setup for laboratory testing

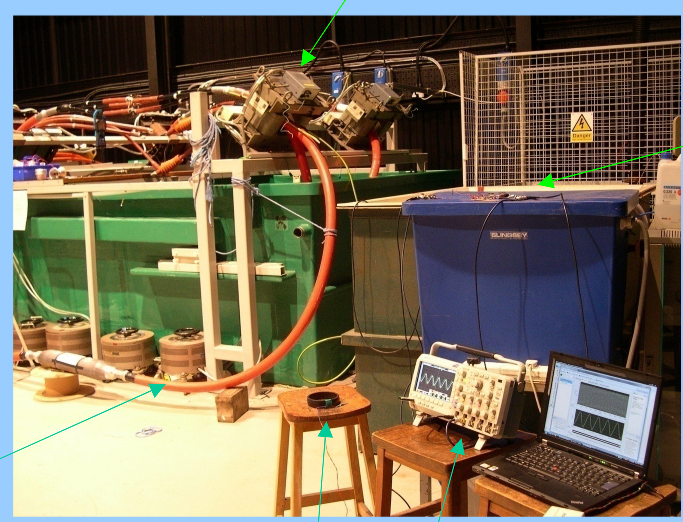
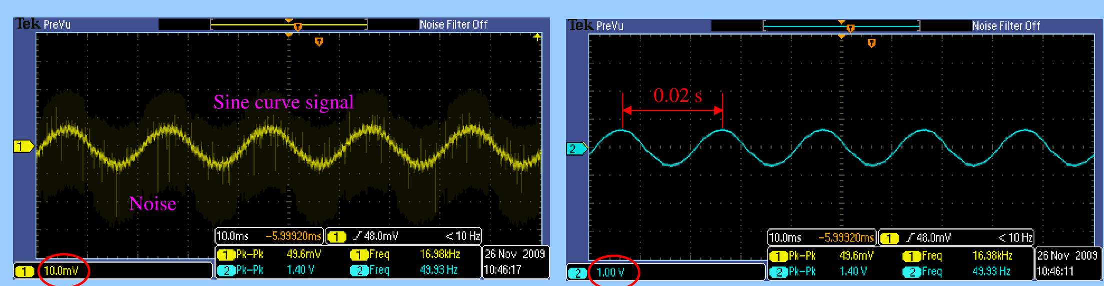


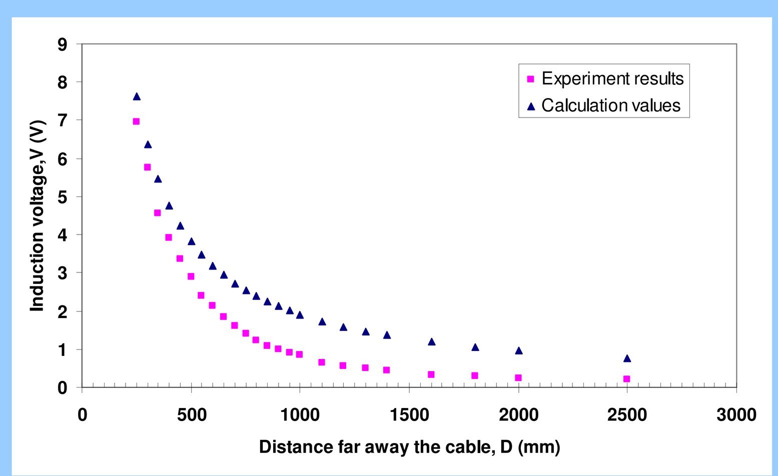
Figure 5: A photograph of the whole experimental apparatus

A typical test result is shown in Figure 6, it was obtained with the current in the power cable set to 6.84 A and the distance between the coil and the cable set to 750 mm. It can be seen that a very clean and easy to measure 50 Hz signal was obtained from the filter. The peak-peak voltage of this signal is 1.40 V, which means that the 50 Hz voltage induced in the coil is 14 mV.



Channel 1 (yellow): induced voltage signal direct from the coil

Channel 2 (Blue): output signal from filter and amplifier (100 times voltage)



The experimental results are lower than the calculated values for two reasons: 1. the cable is not straight, 2. there is a metal tank near to the coil. Both of these factors are likely to have a significant effect on the magnetic field.

Figure 7: Induced voltage as a function of the distance away from the cable

b) Testing for underground cables on a pavement

For these tests, the oscilloscope was replaced by a data acquisition card and a laptop to eliminate the need for mains power.

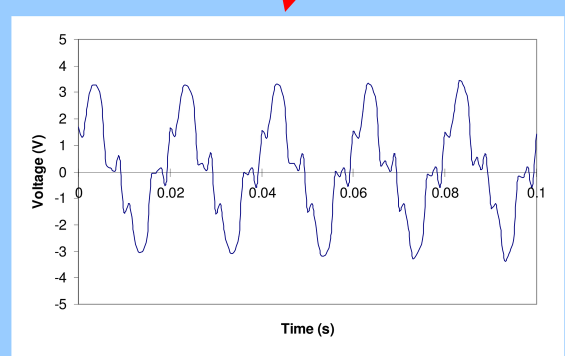


Figure 8: induced voltage of the coil as a function of time

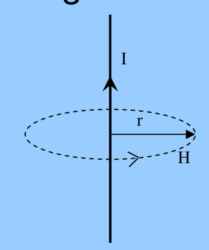
Test results show that a 50 Hz signal can be detected as shown in Figure 8, but its shape is obviously different from the very standard sine curve (shown in Figure 6) obtained in the laboratory testing. Probably, this is due to the existence of harmonic currents in the cable, but harmonics can also be caused by the presence of iron near to the cable.

Magnetic Field Technologies

Basic Theory - Electromagnetic Induction

- Electric current can generate magnetic fields (Oersted's experimental discovery). The magnetic field of a long straight current can be expressed by:

$$B=\mu_0 H=\mu_0 \frac{I}{2\pi r}$$



where B is magnetic flux density, H magnetic field strength, μ_0 permeability of vacuum, I current and r distance between the line and measurement point see the figure above.

- Any change in the magnetic field of a coil of wire will cause a induced voltage (electromotive force) in the coil. Its transfer function $V=f(B)$ results from Faraday's law of induction is given by

$$V=-n\cdot\frac{d\Phi}{dt}=-n\cdot A\cdot\frac{dB}{dt}=-\mu_0\cdot n\cdot A\cdot\frac{dH}{dt}$$

where Φ is the magnetic flux passing through a coil with an area A and a number of turns n.

For a steady state sinusoidal field of amplitude B and frequency f and a coil with n turns of mean radius a, the amplitude of the induced voltage is given by

$$V=2\pi f(n\pi a^2 B)$$

- By detecting the magnetic fields around a cable, we can locate cables or buried metal pipes.

Search Coils as Magnetic Field Sensors

- From the equations above it is clear that coils can be used to detect the presence, strength and direction of magnetic fields.
- However, use of such search coils requires either an oscillating magnetic field or movement of the coil through the magnetic field.
- Search coils are easily designed and manufactured to give an appropriate sensitivity for the range of fields to be measured.
- Search coils are produced with a variety of sizes and shapes, to suit the amplitude and frequency of the field to be measured and the required spatial resolution.

Coil Design and Parameters

Figure 9 shows a induction coil designed and manufactured for this experimental testing as a magnetic field sensor.

Coil Parameters:

- Turns number: 2000
- Width of the coil: around 20 mm
- Mean diameter of the coil: 100 mm
- Material: Copper Enamelled Wire of 0.2 mm in diameter (SWG36)
- Sensitivity: 4.93 mV/μT
- Former: Teflon

Figure 9: An induction coil designed for this experiment

Future work

- Build a complete measurement system consisting of a number of coils, a data acquisition system (USB port, 32 channels) and a laptop.
- Using the MATLAB software with programming to realize data logging and processing. Investigate algorithms for further processing of the data for data visualisation, graph display and data output into a centre service station.
- More experiments for different test situations such as single phase and three phase, one cable with large loop, one cable with return current, one trefoil formation cable with three phase current and three individual cables in flat formation with three phase current.
- Independent experimental tests to determine the number of turns and diameter of the search coil required to ensure adequate resolution and accuracy of the field measurements.
- Produce a support structure to hold an array of search coils (possible coil arrangement 5 horizontal upper coils + 5 horizontal lower coils + 5 vertical coils).
- Design or purchase a suitable trolley to carry all the measurement equipment (coils, a NI measurement modules, a laptop, batteries etc). This must have minimal impact on the field near the coils.

Contact Details

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Website

Mapping the Underworld has a new website which was launched at the end of 2009, including a News feed and Blog to furnish you with regular web-based updates. This can be found at **www.mappingtheunderworld.ac.uk**

Selected Publications:

Wang, P., Lewin, P., Goddard, K. and Swingler, S. Design and testing of an induction coil for measuring the magnetic fields of underground power cables In: *IEEE International Symposium on Electrical Insulation* 6-9 June, 2010, San Diego, USA. (submitted)

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