High Voltage Technologies Research Group

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Energy Harvesting in Substations for Autonomous Sensing

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Fig. 1 Measuring magnetic flux density using voltage logger.

Introduction

Condition monitoring is increasingly deployed in the supply of electrical power with the aim of improving the reliability of supply and extending asset life expectancy. To work towards these aims:

- Sensors must be low-cost and fully autonomous: "fit-and-forget"
- Sensors must be self-powered since:
  - Mains voltage is often unavailable in potential sensor locations
  - Changing batteries is expensive on high voltage equipment

Energy harvesting is a rapidly expanding area of research covering harvesting from a wide range of energy sources including vibration, solar, wind, thermal gradient and electromagnetic. Energy harvesting provides a path towards low-cost sensors that are simple to deploy. Electromagnetic energy harvesting, from both the electric and magnetic fields, is particularly suitable for the substation environment and has been the subject of this research.

Demonstrator: Harvesting from magnetic fields

Built to harvest sufficient energy to power the MICAz 2.4 GHz wireless sensor from the modest magnetic flux density, ***B***, present in the safe area of a substation.The harvester consists of a 0.5 m long, cast iron cored coil connected to voltage conditioning electronics including:

- Voltage doubler, providing ac/dc conversion and energy storage.
- "Start-up" circuitry, monitoring voltage accumulated on storage capacitance before applying power to the wireless sensor when adequate charge is available, and then ensures proper shut-down if ***B***-field should reduce.
- DC-DC converter to deliver regulated 3V supply to wireless sensor.

Laboratory testing was carried out in the magnetic field generated using a Maxwell coils as shown in Fig. 2.

Temperature data was transmitted a distance of 12 m in *B*-field of 18 μT$_{rms}$

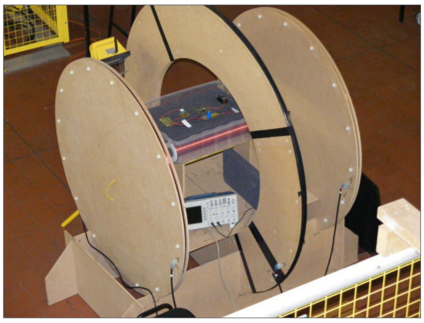

Fig. 2 Demonstrator, harvesting from the magnetic field, under test in the laboratory.

Demonstrator: Harvesting from electric fields

- An EH 301A module acts as the energy buffer. A separate voltmeter can be connected to measure the voltage on the buffer's capacitors.
- A temperature sensor module detects the temperature at locations of interest. The reading is displayed on an LCD panel meter once sufficient power has accumulated on the buffer.

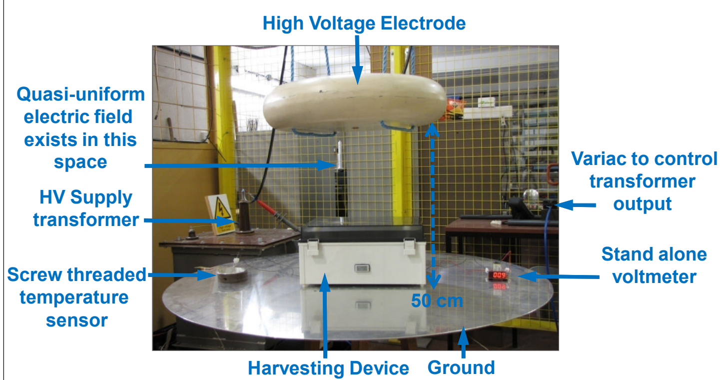

Fig. 3 Demonstrator harvesting from the electric field under test in the laboratory.

Electromagnetic surveys in substations

The magnetic and electric fields were surveyed in the safe area of two air-insulated, 400 kV National Grid substations:

- Substation 1 is outdoor at a node in the transmission network.
- Substation 2 is indoor adjacent to a nuclear power plant.

Measurements were taken at locations where wireless sensor nodes are likely to be installed.

Table 1. Results for the magnetic flux density, *B*

	Substation 1	Substation 2
50% data points lay in range:	1.7 – 3.9 μT$_{rms}$	13 – 59 μT$_{rms}$
Highest *B* near equipment of interest:	13 μT$_{rms}$	167 μT$_{rms}$
Variation in *B* over 2 hour period:	6 – 16.5 μT$_{rms}$	no variation

Table 2. Results for the electric field strength, E

	Substation 1	Substation 2
Strongest field strength observed:	>100 kV/m	97 kV/m
Weakest field strength observed:	11 kV/m	9 kV/m
Most observed field range:	10 – 30 kV/m	10 – 45 kV/m

Energy harvesting in the substation - trials

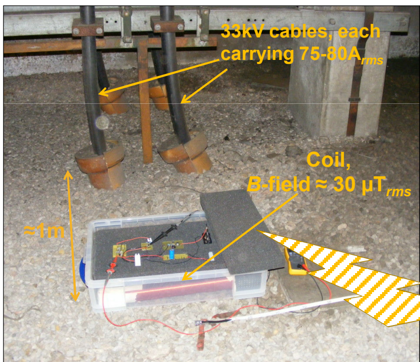

Fig. 4a Fully-powered wireless sensor harvesting from magnetic field.

Harvesting from the magnetic field

Demonstrators were tested in a 275/33 kV indoor substation. Fig. 4a shows a wireless temperature sensor, fully self-powered from the magnetic field. **Temperature data was successfully received 18 m away (Fig. 4b).**

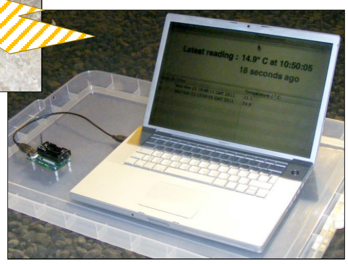

Fig. 4b Basestation displaying transmitted data, 18m from sensor.

Fig. 5 Demonstrator placed at chosen location in the substation.

Harvesting from the electric field

Fig. 5 shows the electric field harvesting unit. **Temperature reading on the display was observed and recorded photographically.**

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