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SENSOR NETWORK FOR POWER LINES MAGNETIC FIELD MONITORING

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Abstract: *Within projects of technological development of the Republic of Serbia in period 2011-2014, our research team proposed project of information network for daily control of magnetic field sources. Information network is designed on technology of wireless sensors, and possible implementation can be for magnetic field monitoring in power systems, such as transmission lines, substations or distribution transformers. In this paper some ideas of information network utilization for monitoring of magnetic field in vicinity of power lines are presented.*

Key Words: ***power lines, magnetic field, monitoring***

1. INTRODUCTION

Parts of the electric power system such as transmission/distribution lines or distribution transformers placed nearby residential area have been polluted working and leaving environment in the sense of the electromagnetic (EM) radiation. A number of studies of health effect of EM field of extremely low frequency (ELF), have led to increasing public concern about human body exposure to the EM radiation emitted by such sources [1]-[3]. These concerns will continue in calling for the continuous informing public about their exposure to the EM radiation.

The interest recently shown by municipal and provincial agency for non-ionizing radiation protection [4], has created significant developments in the field of EM field monitoring. Therefore, in this paper we present possible utilization of an information network [5]-[6], as support for continuous investigation and monitoring of the overall level of magnetic field in low frequency range applications. The proposed system is unique solution at national level, which is able to monitor all sources that emit EM field, as it is shown in Fig. 1.

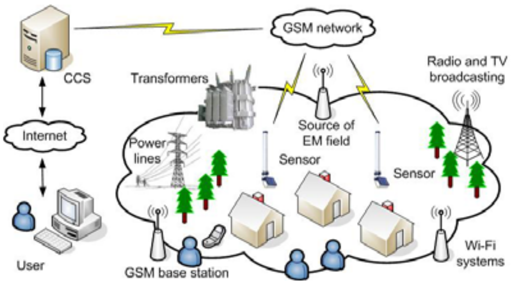

Fig. 1. *Basic diagram of information network.*

Proposed information network is based on broadband area monitor sensors [7]-[9], which on a daily basis provide automatic monitoring of EM field. Sensor results are daily collected in a centralized database [5]-[6], and compared with legally prescribed limits of exposure [10]. The information network is a significant support in efforts to take systematic care about public exposure to the ELF magnetic field, taking into account the public concern about the long-term exposure to such fields.

2. SENSOR CHARACTERISTIC

The broadband area monitor sensor can be used for monitoring of electric (E) and/or magnetic (B) fields. In this paper we consider monitoring of the low frequency magnetic field.

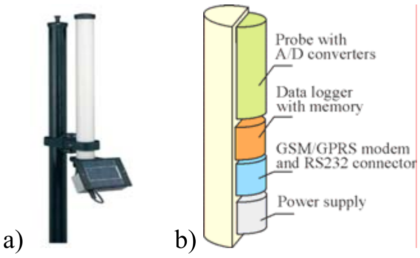

Fig. 2. *a) Sensor unit with solar panel, b) Sensor's hardware component.*

Sensor is a small size unit, 45 cm length, as shown in Fig. 2a, and consists of the: probe, post-processing data logger with internal memory, GSM modem and RS232 connector, as shown in Fig. 2b.

Sensor also has a solar panel for recharging internal battery which is highly important for autonomous work, as shown in Fig. 2a. With this autonomy sensor accomplishes measurement in arbitrary long time. In case of total darkness internal battery provides full operation of the sensor of more than 80 days

Sensor provides broadband measurements of the total magnetic field and it has internal circuits for estimating average (AVG or RMS) or maximum (MAX) value of total magnetic field.

The main part of the sensor for magnetic field measurement is a B-field probe. Frequency and measurement range depends on used probe and in case of magnetic field they are described in Table 1.

Table 1. *Magnetic (B- field) probe specification.*

Frequency range	10 Hz to 5 kHz
Measur. range and overload	50 nT to 200 µT 1 mT without damage
Measur. resolution	1 nT
Stored field values	AVG, RMS, MAX
Duration of measure.	24 hours per day
Flatness	40 Hz – 1 kHz ± 1 dB (typical 0.6)
Anisotropy	±0.3 dB @ 50 Hz, 3 µT
E-Field rejection	> 20 dB
Size and weight	83 mm length, 53 mm diameter, 110 g

Functionality of the sensor can be briefly described in three main stages, as depicted in Fig. 3.

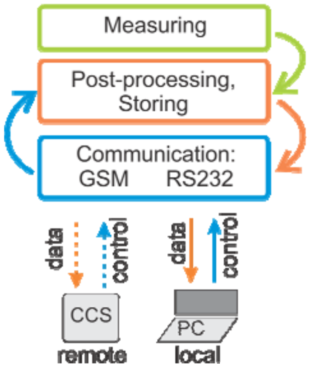

Fig. 3. *Functionality of the sensor.*

First, signal obtained from the field probe, after preprocessing in A/D convertor, continuously coming to the data logger. Second, data logger according to the setup performs post-processes and stores signal in an internal memory. Third stage is remote communication between sensor and CCS via GSM modem, used for upload and download of measuring data or configuration files. More details about communication can be found [11].

3. FIELD MONITORING

The B-field probe performs simultaneous three-axis measurements, as shown on Fig. 4, which allows obtaining the total magnetic field independently of the tri-axial orthogonal arrangement. Isotropic measurement avoids sensor manual rotation and therefore also the presence of technical personnel on the sites.

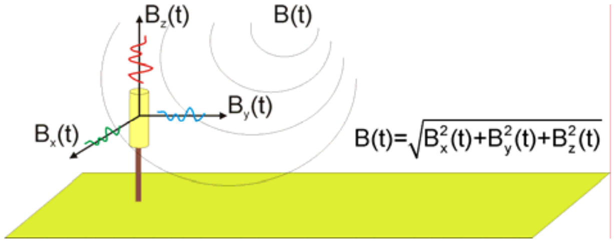

Fig. 4. *Isotropic response.*

The B-field probe with internal circuits continuously perform measuring and sampling every 3 second, providing 20 samples of measurement value per minute. These values are digitalized in an A/D convertor, inside the field probe, and send to the post-processing unit.

The data logger, according to the sensor's setup parameters, performs arithmetic (AVG) or quadratic (RMS) averaging over window of collected samples. Besides the averaging, sensor is capable to detect maximum (MAX) value, over the same window of samples.

The number of samples depends on averaging time interval which can be arbitrarily set, usually 6 min for public exposure to EM fields [11], [13]. Estimated values, AVG or RMS and MAX, present output values from the sensor.

An example of estimation of field level values at every 1 min with averaging period of 6 min, based on 120 collected samples in the previous 6 minutes, is shown in Fig. 5. Sensor simultaneously processes B_{AVG} or B_{RMS}, and B_{MAX}, and stores them in to the internal memory.

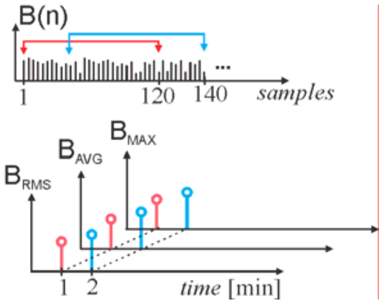

Fig. 5. *Example of processing of the measured values.*

4. POWER LINES APPLICATIONS

The sensor's small size, narrow shape and weather resistance enables easy indoor and outdoor installation. Mounting on poles, array of sensors can be deployed for power lines monitoring, as shown in Fig. 6.

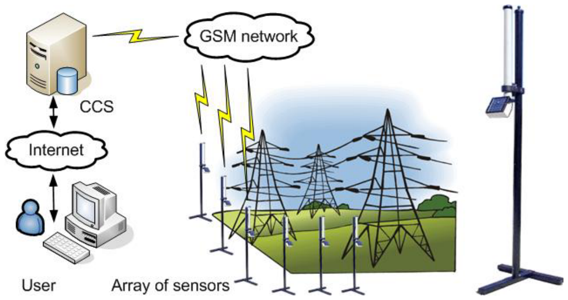

Fig. 6. *Group of sensors placed nearby power lines.*

Advantages of such monitoring system, consisting of the group of sensors that are spatially distributed around the EM fields sources, are:

- simultaneous measurement, and
- measurement in arbitrary long period.

Whit these abilities and some more described in [6], measurement system can perform several low frequency magnetic field applications regarding to exposure of human beings [14]-[16], matching measurement goals and methods proposed by standard IEC 61786:1998 [14].

Some of these goals are described in following sections.

A. Characterization of magnetic field levels

For this purpose one three-axis meters can be used to make spot measurements of the maximum and resultant magnetic fields, respectively. For more definitive measurements, a magnetic field meters with recording capability need to be used for times thought to be representative when producing the full range of field values. For example, in residences near power lines or distribution lines this might involve several 24h records, repeated during each season of the year [14].

Placing sensors nearby the power lines and setting up the long term measurement it is possible to monitor the magnetic field fluctuation during a day or month, as illustrated in Fig. 7 [6]. Sensor has ability to continuously measure average (RMS) and maximum (MAX) magnetic field values from 5 days (capturing every 30 sec) to 169 days (capturing every 15 min) [6], [9].

In a case of balanced three-phase system where magnetic field is linear function of electrical current, Sensor can track variation of electrical currents in the lines.

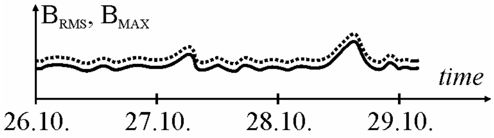

Fig. 7. *Example of the long term measurement.*

Under overhead power lines uniformity of magnetic field levels depends on displacement and phase arrangement of the conductors [15]. In case when magnetic field levels near the ground is considered to be uniform a single-point measurements, measurements at height of 1 m above ground, are sufficient. In case when magnetic field is considered to be the non-uniform, according to method [17] based on standards [14]-[15], a three point measurements are appropriate, as described in Fig. 8.

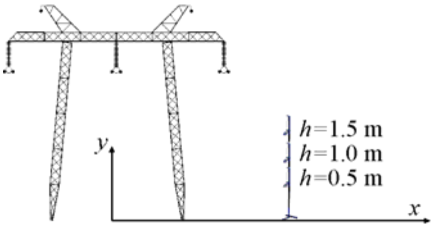

Fig. 8 *Measurement of magnetic field at three points.*

The system of three sensors placed at heights of 0.5 m, 1 m and 1.5 m, will apply a long term three points measurement, as shown in Fig. 9.

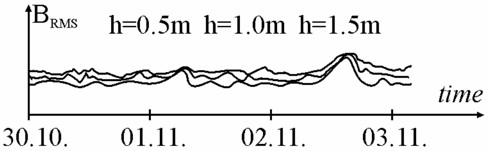

Fig. 9 *Example of long term three point measurement.*

An average exposure level is calculated as arithmetic mean of the three RMS values obtained from the three-point measurement [15].

$$B_{avg} = \left(B_{h=0.5m} + B_{h=1.0m} + B_{h=1.5m}\right)/3 . \tag{1}$$

The same system could be used to determine level of the non-uniformity of magnetic field, by moving the system along *x*-axis, shown in Fig. 8, and calculating maximum value of

$$\left(\left|B_h - B_{avg}\right|\right)/B_{avg} \times 100\ (\%) , \tag{2}$$

where B_h is magnetic field level at heights of 0,5 m, 1,0 m and 1,5 m above ground, and the B_{avg} is the arithmetic mean of the three levels [15].

Other situations such as public areas adjacent to underground cables, indoor substations, etc. are considered to be non-uniform and three point measurements shall be used as appropriate [15].

B. Characterization of spatial and temporal variations

The spatial distribution of magnetic fields away from the power lines is typically unknown. Because magnetic fields are produced by load currents and ground return currents that can vary significantly with time, the temporal variations of magnetic fields can easily exceed 100 %. Due to electric current temporal variations, measurement of magnetic field with the classic hand hold measurement system at different locations could not be determined at the same instant. Therefore, the data are indicative of possible variations. Simultaneous measurement with several spatially distributed sensors will detect these possible variations.

According to measurement procedures [17] with regard to exposure of human beings, described in [16] it is necessary to measure lateral and longitudinal magnetic field profile in vicinity of the power lines.

A) Measurements in lateral profile

As shown in Fig. 10, sensors can be distributed perpendicularly at equal distances to power line.

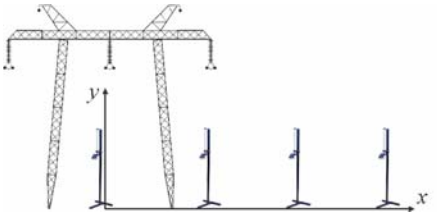

Fig. 10. *Measurement of magnetic field lateral profile.*

This placement enables to measure the lateral profile of magnetic field and to simultaneously track spatial and temporal variations of magnetic field.

B) Measurement in longitudinal profile

Placing a number of sensors underneath the power line aligned with one phase conductor, as shown in Fig. 11, it is possible to measure longitudinal profile of magnetic field and to simultaneously track spatial and temporal variations of magnetic field. Simultaneous measuring of magnetic field and electric currents could be used to find relation between the normalized magnetic field (B [T/A]) and conductors height. For example, this could be used to track conductor's sag during the season, which will be analyzed in some further research.

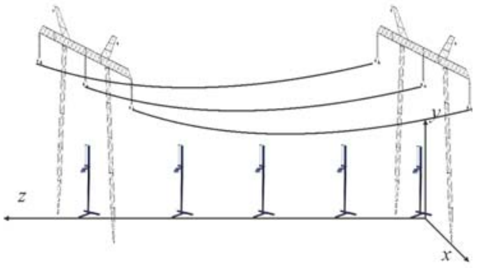

Fig. 11. *Measurement of magnetic field longitudinal profile.*

C. Characterization of TWA magnetic field

A number of epidemiological studies on occupational and childhood cancer, that have examined the possibility of health effects from exposure to power frequency magnetic fields, have considered estimated a time-weighted-average (TWA) magnetic field [14]. Sensor which continuously records the field values can be used to determine the TWA magnetic field. The TWA is calculated using expression [18]

$$TWA = \sum B_i t_i \big/ \sum t_i \,, \qquad (3)$$

where t_i is the period of time during which one sample is taken and B_i is the average magnetic field over time period t_i.

D. Characterization of magnetic field intermittency

There are reports indicating that intermittent exposure to power frequency magnetic fields may be more effective in evoking certain biological responses than exposure to steady-state fields [19]. However, it remains unclear how frequently the field values should be recorded or over which time intervals they should be averaged to capture this kind of irregularity. The sensor has ability to measure and record field values with arbitrary frequency of recording and time of averaging [7]-[9], accomplishing this goal.

E. Characterizing the incidence and duration of the field levels exceeding a candidate threshold value

Models that predict biological effects often assume existence of some threshold value below which there is no effect if public is exposed to magnetic field [14].

The sensor has ability to set up threshold level and send alarms with time and date when field values reach such threshold.

F. Characterization of magnetic field polarization

It should be noted that during measurements of elliptically or circularly polarized fields, the resultant magnetic field will be greater than the maximum magnetic field. [14]. With simultaneous measurement of resultant and maximum magnetic field it is possible to calculate field polarization parameter

$$m = \sqrt{2 B_{\mathrm{RMS}}^2 \big/ B_{\mathrm{MAX}}^2 - 1} \qquad (4)$$

which represents the semi minor vs. semi major axis ratio [16].

Because sensor measures only total magnetic field to calculate field polarization parameter it is necessary that a predominant frequency is power frequency of 50 Hz.

5. CONCLUSION

This paper suggests implementation of the wireless sensor technology for measuring and monitoring of magnetic field generated by the power lines. The benefits of measurement using single or several sensors are time and cost effectiveness avoiding technical personal on the site, accuracies and precision. It is possible to setup a number of sensors for simultaneous and long term measurement in order to meet the international and national public exposure regulation.

6. ACKNOWLEDGEMENT

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