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Wireless Sensor Network for Distributed Measurement of Electrical Field

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Introduction

High voltage transmission lines (HVTL) are the most important energy supplier to cities and industrial areas. Diagnostic of HVTL is problematic due to the high expenses of measurement equipment that is connected directly to the wires. As an alternative, non-contact diagnostic the electrical field density measurement is one of the options for estimation of HVTL parameters [1]. To minimize the interference with the electrical field during the measurements, wireless communication is needed between the sensors that measure electric field strength and a computer where the data processing calculations are done [2]. The use of wired communication is unreasonable if ten or more sensors are used while wireless data transmission gives more freedom and easier deployment of the additional sensors if needed. The sensors have to be placed in a line perpendicular to the conductors in the area below and several meters on both sides of the transmission line. Different HVTL geometries may require different number of sensors. This paper discuses development of wireless sensor network (WSN), hardware and software for electrical field density measurements based on previous research where the system with one sensor was developed [1]. The objective of the measurements is not just determining the parameters of the line but also the field strength near the power lines, especially if place is inhabited.

Wireless sensor network design

Main disadvantage measuring electrical field density using one sensor node is inability to measure field strength in several points under line at the same time. The development of this wireless sensor network (WSN) was motivated by previous research where one moving sensor was used to measure the electric field density [1].

Wireless network for this application has several requirements. All sensors are deployed in an open area under the transmission line. Distances between the sensors vary depending on the geometrical configuration of the lines. The sensor measurements must be done simultaneously before the transmission to the computer (PC), therefore time synchronization is needed.

One conclusion from the previous research was that more than ten sensors are needed for more precise amplitude calculations [1]. The proposed solution is wireless sensor network consisting of one receiver module (master) connected to PC using UART interface and thirteen wireless electrical field sensors. The number of sensors can be increased to improve precision. Fig.1 shows architecture of the system with one sensor and receiver module.

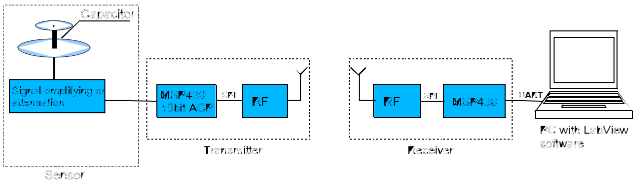
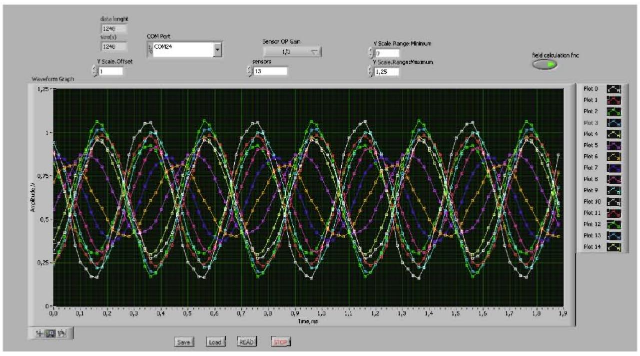


Fig. 1. Architecture of the system with one sensor

All sensors are placed in one line perpendicular to the electrical line conductors. Each sensor receives command to start sampling operation. The command is sent from a master device. Once the command is sent, the master goes into receive mode and waits for valid packages from the transmitters. The master device is controlled by PC using Lab View software. The graphical user interface for the control and monitoring is shown in Fig.2.

The proposed solution for the data communication is following. Each sensor has its own unique identification number by which the master device determines the sender. All sensors use the same frequency channel and share the same address.

Time synchronization in WSN is essential where data extraction from the environment must be performed simultaneously and sent to a master device at predefined time intervals. The synchronization operation is done each time the sensor receives the “start sampling” command.
Once the sampling operation is completed, the data is transmitted to the master using the time division approach.



data lenght: 1248
size(s): 1248
COM Port: COM24
Sensor OP Gain: 1/3
sensors: 13
Y Scale.Offset: 1
Y Scale.Range:Minimum: 0
Y Scale.Range:Maximum: 1,25

Fig. 2. Lab View graphical user interface

Hardware design and calibration

The wireless sensor module for electrical field measurements consists of three major blocks:

1. Electrical field sensor and analog signal amplifier;
2. Microcontroller;
3. Transceiver.

Important aspect developing such sensor modules is weight and dimensions of the module, because they are deployed on lightweight plastic tubes 1,90m above the ground surface. The sensor nodes are made as light as possible. Another requirement for the modules is to make modifications or reprogramming easy.

Each board is designed as a universal module, compatible with different development boards or platforms. The system can be used for other applications only by replacing the sensing device. For example, different sensors (magnetometer, accelerometer, temperature, humidity sensor) with analog or digital outputs can be connected as all pins from micro controller are accessible to the interface.

A parallel plate capacitor is used as a sensing device. Fig. 3 illustrates the electrical field sensor module. The top plate can be changed to provide different electric field sensitivity. Calibration is needed for each diameter of the plate. Under the bottom plate a signal amplifier, micro controller and transceiver boards are located. The lower plate also works as a shield to prevent the electric circuit from electric interference with the measurements.

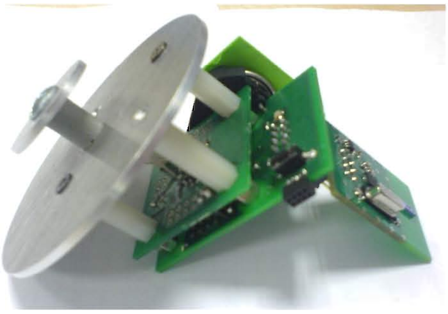


Fig. 3. Sensor for electrical field measurement

Nordic Semi transceiver nRF24L01 is used along with MSP430F2234 micro controller, which includes a 10bit ADC. The transceiver operates in 2.4 GHz ISM frequency band with transmission speed up to 2Mb/s and range up to 100m. The nRF24L01 is configured and operated through a Serial Peripheral Interface (SPI). The embedded baseband protocol engine (Enhanced Shock Burst™) is based on packet communication and supports various modes from manual operation to advanced autonomous protocol operation. The radio front end uses GFSK modulation. It has user configurable parameters such as frequency channel, output power and air data rate.

Micro controller's internal 10bit ADC is used to convert analog signal to digital. The internal OP is used to amplify the analog signal for the ADC. This allows changing signal gain using software, thus reducing number of external components needed for signal conditioning. Sensors are calibrated using a homogenous electrical field, which is produced by a large 1.5x1.5m parallel-plate capacitor with 0.5m between the plates. An AC power source is connected to the metal plates generating an electric field due to the voltage difference [1].

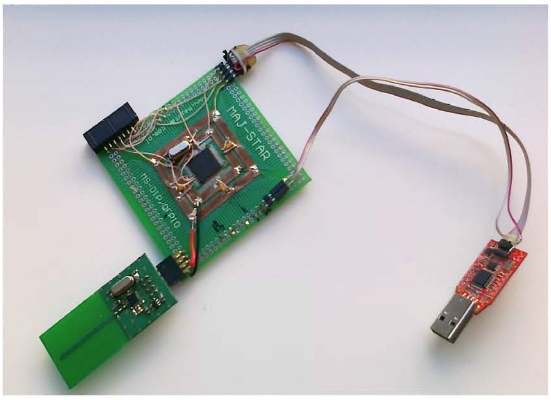


Fig. 4. Master device

ADC operates in DMA mode with sampling frequency of 1 kHz storing up to 96 bytes in the micro controller's memory. When the sampling operation is completed the sensor waits for a predefined time window to send data to PC. Each sensor sends 32 bytes in one data package. Three data packages are sent. Data package length is selected in software and based on data amount stored in MCU memory.

Master device that is connected to a PC consists of three blocks:

1. Microcontroller module;
2. Transceiver module;
3. UART to USB converter.

MSP430F5437 microcontroller is used in combination with Nordic Semi nRF24L01 transceiver. The micro controller has 16k RAM, which was the main reason for using this particular one because all data is stored there before transmission to the PC. Texas Instruments USB to UART converter is used to connect master board to PC. Data transmission speed is 9600kb/s.

Protocol design

The transceiver has configurable protocol settings. The wireless modules work independently: each sensor has its own unique identification number, but all sensors send data using one frequency channel and share one address. This approach is chosen because of its simple structure and deployment.

Communication between the sensor and master board is bidirectional. The master device sends commands to the sensors and gathers data from them. “Start” command is implemented to serve as a synchronization trigger. Synchronization is performed before each new start sample operation. Figure 5 illustrates timing diagram for both master and sensor devices. Initially, sensors are set to receive mode (RX) and are waiting for a start command from the master. The master device coordinates sensor behavior and initially is set to transmission mode (TX). One operation cycle from command reception to the end of data transmission takes 150ms. One cycle of sensor operation consists of the following actions:

1. Start command reception and time synchronization;
2. Configuration to RX mode;
3. Start sampling;
4. Data transmission to master device;
5. Configuration to RX mode.

Sensor timing and wireless data transmission protocol is configured and managed by MSP430 microcontroller through Serial Peripheral Interface (SPI).

When the start command is received all sensors start two timers, one for ADC other for time division communication. Timer 1 interrupt triggers ADC to sample data at 1 kHz sampling frequency. The second timer is counting all transmission cycle 50ms dividing it into thirteen 3ms time windows for each sensor to transmit data to master device.

The master device is waiting for data from sensors once a command has been sent. After 150 ms are elapsed master device compares count of received and lost packages and sends data to PC. Information about measured data is displayed on Lab View graphical user interface.

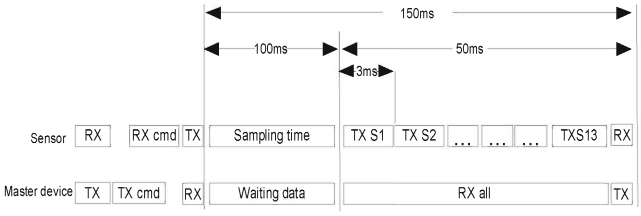


Fig. 5. Wireless sensor communication protocol timing diagram

Measurements and results

Experimental measurements were performed under 110kV power transmission line outdoors in a clear field. The conductors were located 10m above ground and the distance between them was 8m. The sensors were placed on plastic tubes at the height of 1.9m above the ground with 3m between them. Measurements were taken simultaneously from all sensors. Fig.6. illustrates measured field strength at 13 points. Fig.7. illustrates spectrum of the measured signals.

Heights of the conductors were calculated at 14.5, 9.9, 11.5m and distance between the wires at 12, 7.7m based on the measurements. The accuracy was approximately 15%.

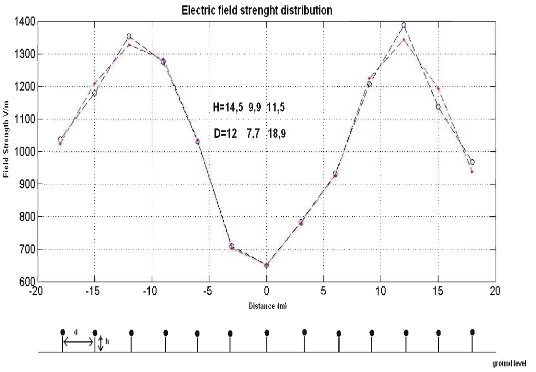


Fig. 6. Measured electric field intensities from thirteen equidistantly spaced sensors

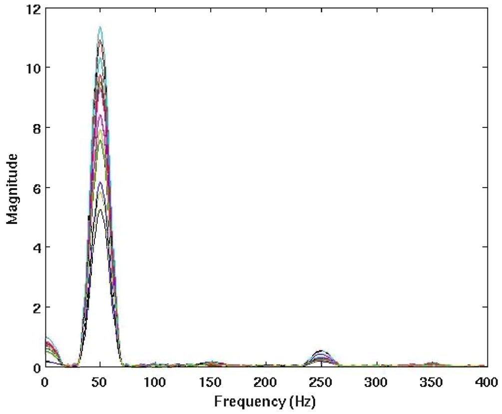


Fig. 7. Spectrum of acquired signals from thirteen sensors

Conclusions

We have developed a system for non-contact diagnostics of power lines, enabling simultaneous measurements of electric field density using capacitive sensors. Time synchronization for all sensors was used to ensure simultaneousness of measurements essential to the results. The geometry and voltages of the three-phase line can be determined from the measurements. The accuracy of diagnostics depends on layout of the conductors and number of sensors. Thirteen sensors were used in this work, however, number of sensors can be increased to twenty or more by modifying the software as needed.

The main sources of errors are the swing of the conductors and the ground with high specific resistance (very dry or snowy ground). For example, if the conductors are sagged in summer conditions, errors may increase [4]. Optical methods can be used to locate wire position and sensor placed at those points, improving the precision. Measurements where the sensors are located higher, increase the precision and reduce the interference from ground surface condition (relief, humidity).

Future work

It is planned to expand the system to twenty sensors thus increasing the measurement precision. Also, we plan to determine optimal parameters such as the sensor elevation above the ground for better deployment configuration.

Acknowledgements

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This paper describes the design of a system for measuring electrical field using distributed sensors that have wireless communication capability. The design includes development of the sensor node hardware, the communication protocol and software. The major constraint for the system is to minimize the interference with the electrical field that is measured, which was one of the reasons for choosing wireless rather than wired connectivity between the sensors. The system was tested with 13 sensor nodes, however, it is designed to be scalable for more. A possible application is to measure the electric field under high voltage lines for diagnostic or monitoring purposes. Ill. 7, bibl. 4 (in English; abstracts in English and Lithuanian).

A. Severdaks, G. Supols, M. Greitans, L. Selavo. Paskirstytojo elektrinio lauko matavimas taikant bevielio ryšio tinklą // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 1(107). – P. 7–10.

Aprašyta elektrinio lauko matavimo sistema, projektuojama ir kuriama taikant bevielio ryšio tinklą. Sistemą sudaro jutiklis, ryšio užmezgimo ir palaikymo protokolas, programinė įranga. Palyginti su laidine sistema, pasirinktas bevielio ryšio tinklas yra mažiau veikiamas elektrinio lauko. Matavimai atlikti su trylika bevielių jutiklių. Prie projektuojamos sistemos galima prijungti ir daugiau nei trylika tokio tipo jutiklių. Ši sistema gali būti taikoma aukštosios įtampos elektros linijų stebėsenai ir diagnostikai. Il. 7, bibl. 4 (anglų kalba; santraukos anglų ir lietuvių k.).

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