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A LIGHTNING CONDUCTOR MONITORING SYSTEM BASED ON A WIRELESS SENSOR NETWORK

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Abstract. Automated heating, lighting and irrigation systems are nowadays standard features of industrial and commercial buildings, and are also increasingly found in ordinary housing. In addition to the benefits of user comfort, automated technology for buildings saves energy and, above all, it provides enhanced protection against leakage of water and hazardous gases, and against fire hazards.

Lightning strikes are a natural phenomenon that poses a significant threat to the safety of buildings. The statistics of the Fire and Rescue Service of the Czech Republic show that buildings are in many cases inadequately protected against lightning strikes, or that systems have been damaged by previous strikes. A subsequent strike can occur within the period between regular inspections, which are normally made at intervals of 2–4 years. Over the whole of Europe, thousands of buildings are subjected to the effects of direct lightning strikes each year.

This paper presents ways to carry out wireless monitoring of lightning strikes on buildings and to deal with their impact on lightning conductors. By intervening promptly (disconnecting the power supply, disconnecting the gas supply, sending an engineer to inspect the structure, submitting a report to ARC, etc.) we can prevent many downstream effects of direct lightning strikes on buildings (fires, electric shocks, etc.) This paper introduces a way to enhance contemporary home automation systems for monitoring lightning strikes based on wireless sensor networks technology.

Keywords: lightning protection, lightning monitoring, wireless sensor networks, lightning counter sensor node.

1. Introduction

Lightning discharges are highly unpredictable and uncontrollable natural phenomena, and their direct and indirect effects can have destructive consequences for structures. Due to the low probability of a strike, owners and managers of buildings often neglect to ensure that they are safely protected from direct lightning strikes. The building is thus exposed to the risk of being struck by a lightning current without any protection. Other buildings are located in places where lightning strikes so frequently that a direct hit on the building is almost inevitable, and may even be repeated several times a year [1].

The only currently used protection systems for residential, commercial and industrial buildings involve conducting lightning discharges from the point of the strike through the catchment system safely into the ground. Safe operation of this system depends on the condition in which it is maintained. Statistics [2] indicate that a direct lightning strike can cause a fire or, more commonly, can destroy electrical appliances and consumer electronics even in a building with a protective conductor [3].

Our study addresses the issue of monitoring lightning strikes on buildings and processing this information online. A direct lightning strike can discharge a current of tens to hundreds of kA. The strike can have a considerable dynamic and thermal impact on components of the protection system. All kinds of mechanical joints are vulnerable. The conductive connection to the grounding system may be damaged, and the conductors and the catchment equipment itself may be mechanically and thermally damaged. Regular inspections of the lightning conductor system are covered in Annex E of ČSN EN 62305-3 ed. 2, which specifies periodic inspections at intervals of 2–4 years. The time intervals are defined according to the protection classification of the structure (commercial buildings are mostly in class II and class III) based on an analysis of the risk of harm as defined in ČSN EN 62305. In the Czech Republic, the applicable procedures are the ČSN EN 33 1500 standard with a valid change of Z4 and default inspection of ČSN 33 2000-6-61 ed.2 (332000) Electrical installations of buildings – Part 6-61: Revision – Initial revision. The ČSN EN 62305 standard is a translation of the European standard, so equivalent rules apply in the countries of the European Union. However, experience suggests that an interval of 2 to 4 years between inspections may be too long. When a building, its lightning conductor and grounding system are struck by lightning, the

Protection level	Visual inspection	Complete inspection	Critical situations[a] Complete inspection[b]
	Year	Year	Year
I and II	1	2	1
III and IV	2	4	1

[a] Lightning protection systems utilized in applications involving structures with a risk caused by explosive materials should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year. An acceptable exception to the yearly test schedule is in order to perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.
[b] Critical situations could include structures containing sensitive internal systems, office blocks, commercial buildings or places where a large number of people may be present.

Table 1. Maximum period between inspections of a Lightning Protection System adopted as IEC 62 305-3 [4].

Year	Cause	Number of fires	Ratio [%]	Damage [thousands of CZK]	Ratio [%]	Fatalities	Injuries
2012	lightning – W	13	0,06	8 953,0	0,31	0	1
	lightning – WO	30	0,15	10 727,0	0,37	0	5
2011	lightning – W	14	0,07	26 159,7	1,17	0	0
	lightning – WO	31	0,15	18 994,5	0,85	0	5
2010	lightning – W	13	0,07	3 041,00	0,16	0	0
	lightning – WO	24	0,13	6 912,30	0,35	0	3
2009	lightning – W	12	0,06	2 067,0	0,10	0	1
	lightning – WO	29	0,14	14 700,5	0,68	0	1
2008	lightning – W	9	0,04	1 385,00	0,04	0	1
	lightning – WO	32	0,15	10 455,00	0,32	0	1

Table 2. Lightning strikes on structures. Statistics for 2008–2012 [5]. Causes: W – buildings with protection, WO – building without protection.

protective system can be damaged to such an extent that it may not be able to provide protection against a subsequent lightning strike. If the owner or the operator of the building is not aware of the lightning strike, appropriate measures may not be taken.

The Czech Hydrometeorological Institute records the times and the localities in which storms have occurred, for the purposes of insurance companies and claimants. However, the system does not provide evidence of a direct lightning strike on a building - it only provides evidence of lightning discharges in the locality. In our proposed system, each conductor is equipped with a wireless sensor, which records the event of a lighting strike. This data is subsequently used to check the effectiveness of the catchment system and to indicate where improvements are needed.

2. Lightning and the catchment system

In the last five years, systems have appeared in industrial applications that can monitor the passage of the lightning discharge through the conductor when a building is struck. These systems are based on the principle of electromagnetic induction, or they work with non-electrical phenomena such as polarized light signals. However, these systems indicate the lightning strike only through a mechanical dial mounted directly on the conductor. As a part of our project, a wireless sensor module was prepared that provides online information about the state of the lightning current that is passing through.

3. Monitored building

The proposed solution was developed by implementing a wireless sensor into a device used commercially for making a statistical record of lightning strikes on lightning conductors. Most devices used for monitoring systems struck by lightning are passive devices. After the critical current passes (mostly 2–100 kA) they can detect the event by increasing the mechanical counter by one unit. The speed with which this change is evaluated depends on the operator or on the building. By contrast, our proposed system works online, and immediately after the building has been struck it provides information on the passage of the current through the conductor.

The monitored building is $5 \times 3 \times 4$ m in size, and is situated in the Šumava region in the Czech Republic. According to the isokeraunic map [6], it is located in an area with an average frequency of 30–35 thunder-

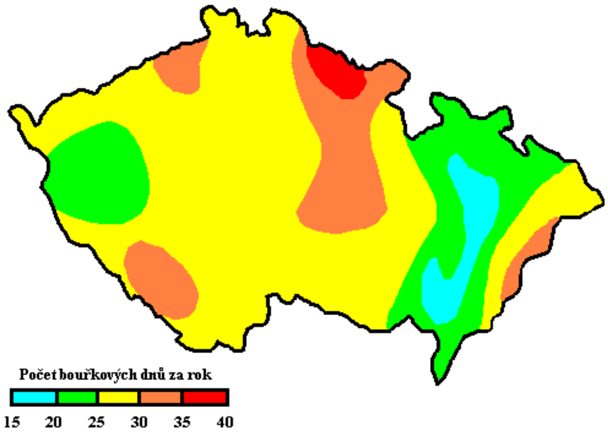

Figure 1. Isokeraunic map of the Czech Republic.

storm days per year (see Figure 1).

Number of days with thunderstorms per year

The advantages of the proposed solution are that instant information is obtained, and a rapid response can be made. The building can be disconnected from the networks, an engineer can be sent to make checks, and other actions can be taken to stabilize the structure. When information is received, an integral part of the response is to predict that there may be a fire, which can often arise as a direct result of a lightning strike. However, there is often a delay before a fire breaks out, and the time interval can be used to take measures to minimize its impact.

4. Description of the proposed solution

We present a modular solution that can be integrated into commercially-available instruments for registering lightning strikes. This paper describes the methodology for online transmission of information about lightning strikes, proposes a technological process for processing and evaluating the information, and describes the practical verification of a prototype.

5. Proposed system

The proposed system for monitoring the passage of a lightning current through a collection conductor is based on the following conditions:

- The device installation shall not affect the functionality of the building.
- The equipment must be easy to install on new and existing buildings.
- The device shall not significantly increase the budget for the construction of the lightning protection.
- The device must provide long-term maintenance-free operation between inspections, and should ideally be completely maintenance-free.
- The electronic part of the equipment should be protected from the effects of shock.

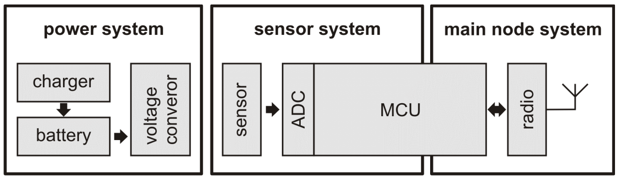

Figure 2. Concept of a sensor node [8].

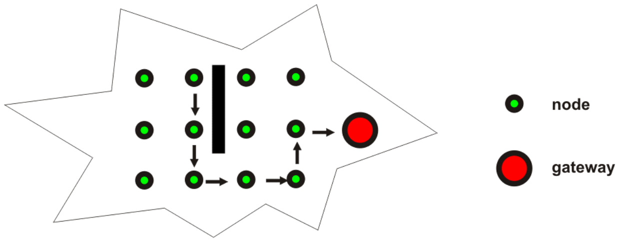

Figure 3. Mesh multi-hop routing [8].

Under these conditions, wireless transmission was the only option. At the time when the system was implemented, an appropriate Wireless Sensor Network (WSN) technology was available. WSN is a network of wirelessly interconnected sensors that monitor the surrounding physical phenomena (light, humidity, temperature, etc.). Wireless sensors transmit measured data to each other, or are able to preprocess the data when it is transferred through networks to the so-called sink node. The sink node, also called the gateway node, transmits the data to the control unit (PC), where it is processed and analyzed. On the basis of this information, action is taken and/or information about the status of the monitored environment is displayed or transferred [7].

The sensor node is the basic unit of the Wireless Sensor Network. The sensor node generally consists of a sensor, a computer, a power supply, and a radio module (see Figure 2).

The whole WSN system, i.e. computing performance, node performance and transmission protocols is expected to offer maximum energy saving and high flexibility. The node uses various levels of "sleep" when the performance of CPU, memory and the peripherals is controlled according to current needs (scanning parameters, data processing, communication, inactivity, etc.). These networks can consist of just a few nodes, though there is no theoretical limit to the quantities. The network can operate with the well-known star topology as the basic arrangement, but the biggest benefit of WSN is that it forms mesh type networks using multi-hop routing, see Figure 3.

For monitoring purposes, we used the Crossbow Iris development kit, which already supports mesh networking technology thanks to the MoteWorks technology. The properties of this series are summarized in Table 3 [9].

To capture the event when a discharge has occurred, we use the commercially available Dehn and Söhne lightning counter, enriched by the Iris node. The selected WSN technology ensures reliable data

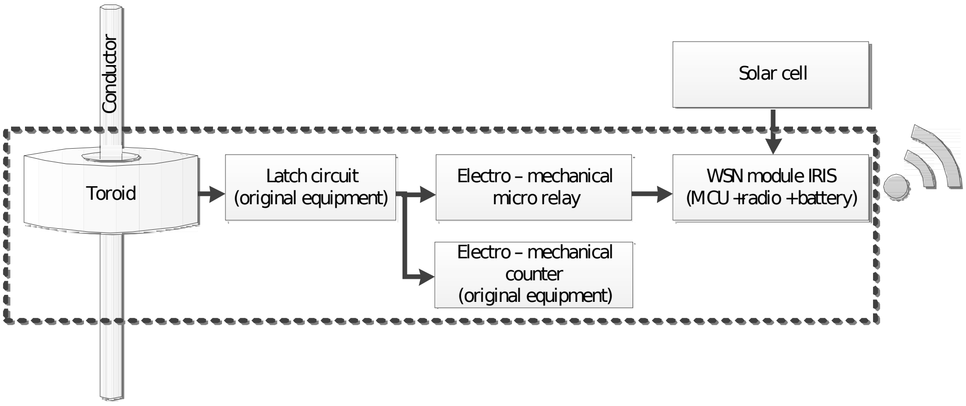

Figure 4. Lightning sensor node block diagram.

Processor performance	
Processor	Atmel ATMega 1281
Speed	8 MHz
Program flash memory	128 kB
Serial Flash	512 kB
RAM	8 kB
ADC	10 bit, 8 ch., 0–3 V input
Operating system	TinyOS 1.0
RF transceiver	
Frequency band	2.4 GHz ISM band, programmable in 1 MHz steps
Transmit data rate	250 kb/s
Outdoor range	> 300 m
Indoor range	> 50 m

Table 3. Iris development kit features.

transmission for periods of several years. When on battery power, the power supply battery needs to be replaced every few years. To enhance the lifetime of the system, we enriched the battery power system by a solar cell energy harvesting system, which operated reliably throughout the experiment.

The sensing element of the sensor node is a toroidal coil with wound threads, in which the voltage is induced during the passage of the lightning current. In our application, we connected the input of the mechanical counter to the micro relay. The micro relay serves primarily as a galvanic isolation element against voltage surges in the secondary circuit of the current sensing coil. The electronic equipment is therefore quite simple. It is basically a reference switch connected to the input of a simple microcontroller and a radio module. The block circuit diagram is shown in Figure 4.

The gateway is from the Iris set. It is used to connect with a PC via the USB. As the system is designed to be maintenance-free, we chose the power of the central node of the 230 V network (backup adapter). The digital output of the Iris gateway was applied to the digital input to the alarm with the GSM module (already installed in the house). The topology of the entire system is presented in Figure 5.

6. System Features

The deep sleep mode of MCU in the sensor node consumes 8 µA, while in transmit mode the current is almost 17 mA. Thus the concept is based on the deep sleep mode while waiting for an event. The event is a lightning discharge. A discharge activates the relay connected to a +3 V backup battery (CR2030). This voltage wakes up the node. After waking up, the node sends an "event message". The central node has radio communication continually powered-on, and when the message arrives it activates the GSM alarm input.

Features of the wireless system:

- nodes are inserted into the respective measurement points for the lightning conductor,
- selected communication of the mesh type for guaranteed transfer of discharge information,
- the electronics of the measuring node is stored inside a lightning counter, galvanically separated using an electromechanical relay
- the central node is connected to the GSM gateway of the house alarm
- the power supply is provided by a photovoltaic cell and the backup battery

7. Economic balance sheet of the proposed system

The components used in the test are relatively expensive, but the topology of the system is relatively inexpensive. Today, such a system could be based on nodes available in a WSN network. After that, the balance sheet would be as follows:

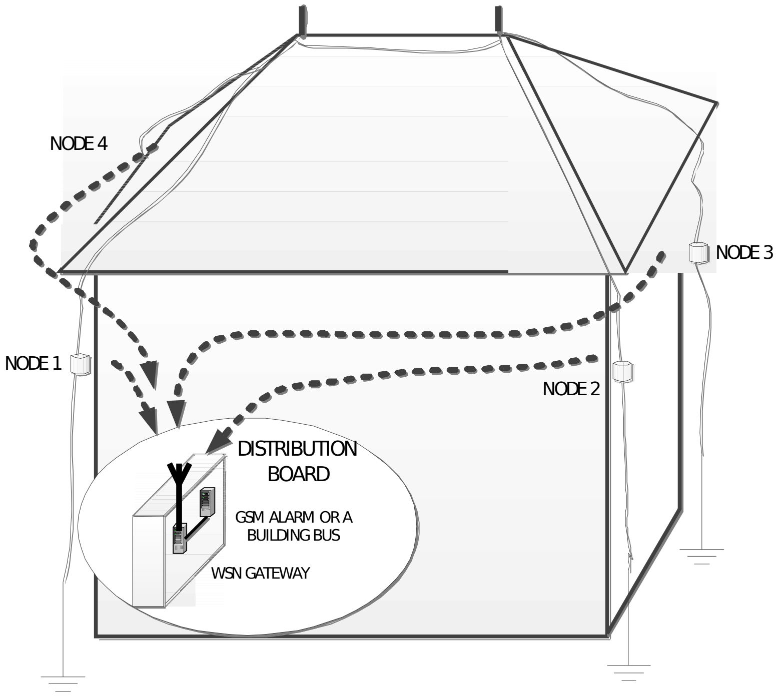

Figure 5. Monitoring system topology.

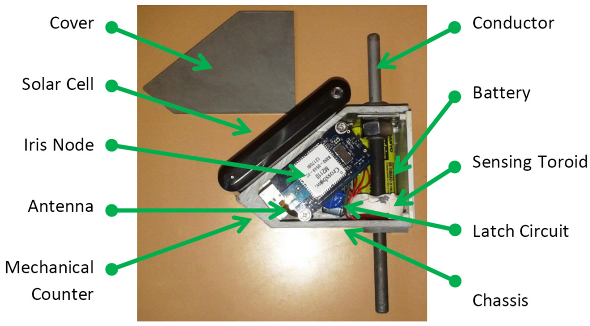

Figure 6. Lightning counter sensor node.

- The sensing part (coil and circuit switching relays) < USD 5
- Complete WSN node < USD 10
- Gateway (Ethernet, USB or GSM) < USD 20
- Mechanical Parts < USD 10

The total cost of the system is around USD 70. However the customer solution would be even cheaper (less than USD 50).

8. Summary

The system described above was implemented in the lightning conductor of a family house in the Šumava region in the Czech Republic, and for a period of one year the events were recorded and transmitted to the central unit. In the assembled module, the key parameters, mainly related to battery life, were verified. The authors suggest possible future possible extension with precise wireless monitoring of the grounding system itself, detecting the amount of current passing through the conductor. The WSN technology enables sensing of commonly measured physical phenomena. This paper has shown that high-quality lightning protection, especially with reference to disruption due to mechanical damage, is feasible.

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