White Paper

Register and measure lightning currents using the magneto-optic effect

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1 Overview

This document describes the operating principle of the magneto-optic effect for monitoring and measuring the intensity of surge currents in lightning strikes. An example is then used to describe the use of a lightning monitoring system in a wind power plant, a monument, and a power transformation substation.

This document is aimed at those who wish to gain a basic understanding of the physical principle of the effect. Furthermore, the reading material may be of interest in order to gain an idea of the potential suitability of the system for preventive maintenance.

2 Lightning monitoring on exposed objects

Lightning strikes can cause severe damage and destruction to buildings and systems. In the case of residential or commercial buildings, which are frequented regularly, such damage is immediately noticeable. The extent of the damage can be evaluated quickly and precisely. Immediate repair and recommissioning of important system functions can prevent consequential damage.

As a general rule, it is not possible for employees to continually monitor exposed objects or those with a large surface area, such as wind power plants or other power plants, switchgear systems or railway systems. Damage or destruction is often only monitored once consequential damage has occurred.

For this reason, intelligent monitoring systems are used increasingly that permanently monitor the different function states in a system and send the results directly to a central control unit. This enables an immediate response in the event of a malfunction and prevents consequential damage as well as long downtimes.

Indeed, up to now, there was no measuring system which could be used to reliably detect and evaluate lightning strikes on a system. As such, there was no damage or fault reporting of such events.

3 New monitoring technology with the Faraday effect

A new monitoring and measuring system utilizes the Faraday effect and the magneto-optic effect in order to analyze the level and flow direction of surge currents in lightening arresters. As such, the signals are transmitted between the sensor and evaluation unit by means of a light signal in a fiber optic cable. In contrast to signal transmission via copper cable, this has the key benefit that lightning currents, which occur in the vicinity of the measuring system, are unable to influence the light signal or couple into the transmission path. This means that the evaluation unit electronics feature a reliable and EMC-protected signal.

3.1 Structure of the measuring section

The measuring section consists of a transparent medium (dielectric) with polarizers or polarizing filters at either end. The measuring section is positioned at an angle of 90 degrees to the current flow direction in the down conductor. In this way, the propagation direction of a light wave in the measuring section lies parallel to the magnetic field of the surge current in the down conductor.

3.1.1 Dielectric

The dielectric consists of a weakly or non-conductive substance. The substance is non-metallic, generally non-magnetic, and as such can be in a gaseous, liquid or even solid state. As a general rule, the charge carriers cannot move freely. They are usually subjected to electric or electromagnetic fields.

3.1.2 Polarizers

Polarizers are filters which polarize electromagnetic waves. Using this method, corresponding filters generate either circular, elliptical or linear polarized light. A light wave is linearly polarized in order to use the Faraday effect in a lightning measuring system.

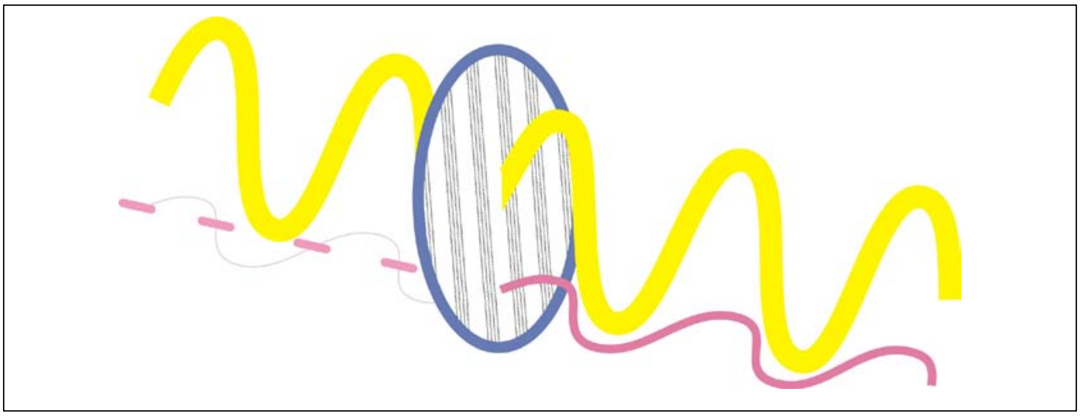


Figure 1
Linear polarizer

3.2 Magnetic effect on the plane of polarization

A light wave causes the electrons in the dielectric to oscillate. The magnetic field changes the movement of the electrons within the dielectric. This in turn influences the plane of polarization of the light. Depending on the magnetic field direction, in principle the plane of polarization can be rotated in any direction.

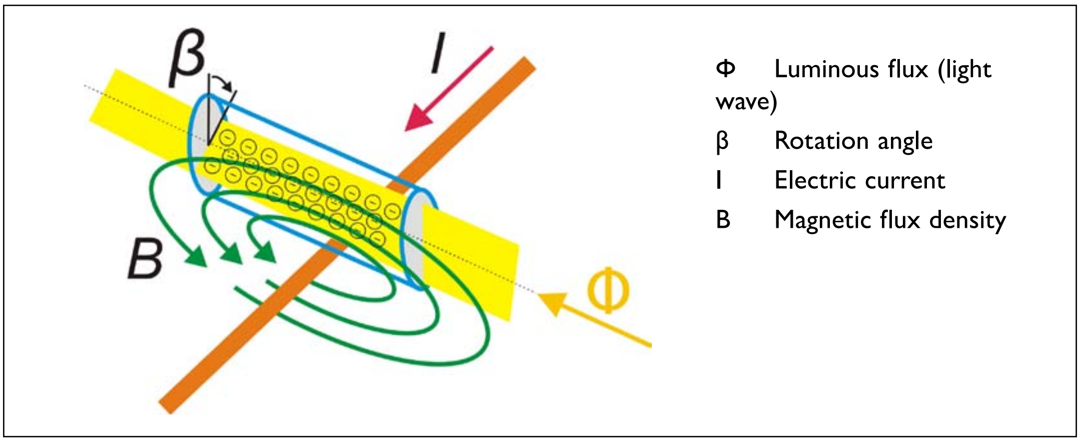


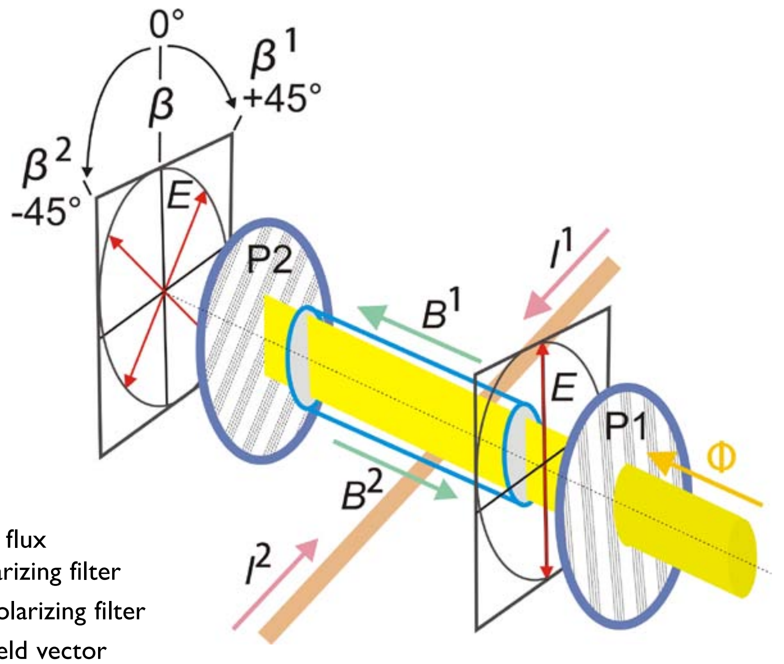
Figure 2
Schematic view of the magneto-optic effect

3.3. Magneto-optic effect in the monitoring system

A light beam of a specified light intensity is guided onto the measuring section via fiber optics. The polarizing filter at the input of the measuring section linearly polarizes the directed light. The light wave polarized in this way causes the electrons in the medium to oscillate and travels through the measuring section medium in the plane of polarization. The plane of polarization can be influenced magnetically.

The magnetic field of a surge current rotates the plane of polarization of the light wave within the medium around the longitudinal axis. The direction of rotation depends on the direction of the magnetic field lines and thereby the direction of the current flow. The greater the current, the greater the angle of rotation.

The second linear polarizing filter is positioned at the output of the measuring section at an angle of 45 degrees to the input polarizing filter. Only 50 percent of the light from an uninfluenced light wave thereby passes through the output polarizing filter. The amount of light that passes through the output polarizing filter is dependent on the rotation of the light wave. This results in a measurable light signal which can also be evaluated.



Φ	Luminous flux
P1	Input polarizing filter
P2	Output polarizing filter
E	Electric field vector
I1	Electric current to B1
I2	Electric current to B2
B1	Magnetic flux density to I1
B2	Magnetic flux density to I2
β1	Rotation angle to B1 and I1
β2	Rotation angle to B2 and I2

Figure 4

Graphical model of the Faraday effect

3.3.1 Measuring result and evaluation

Positive lightning results in clockwise rotation of the polarized light signal. The amount of light from the output value that passes through the second polarizing filter increases to more than 50 percent of the output value. When the angle of rotation of the light signal reaches 45 degrees, this corresponds to a 100 percent value for a positive lightning strike.

Negative lightning results in counterclockwise rotation of the polarized light signal. The amount of light that passes through the second polarizing filter reduces to less than 50 percent of the output value.

When the angle of rotation of the light signal reaches -45 degrees, this corresponds to a 100 percent value for a negative lightning strike.

The amount of light that makes it through the output polarizing filter is measured. The typical parameters of the monitored lightning surge current are derived from the progression of the amount of light over time. These are the maximum current strength, lightning current rate of rise, charge, and specific energy.

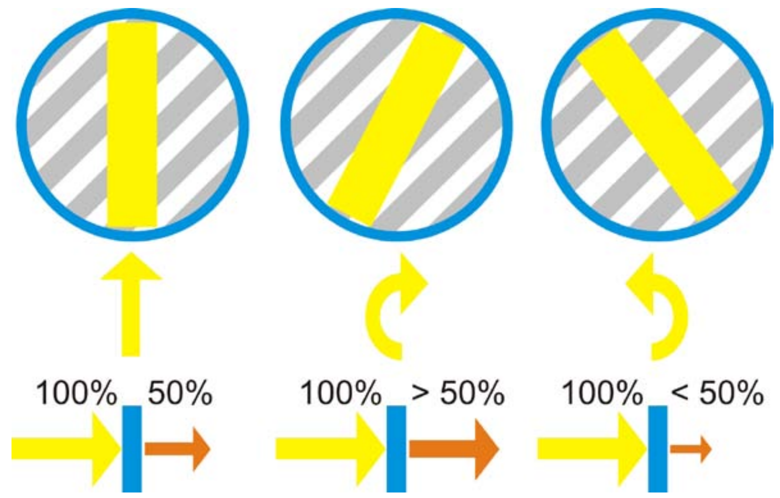


Figure 3
Change in the amount of light that passes through the output polarizing filter in the measuring section based on the input angle of the light beam.

3.3.2 Electric field vector E

The electric field vector describes the progression and the position of the affected or rotated light wave. The arrow here shows the light wave's direction.

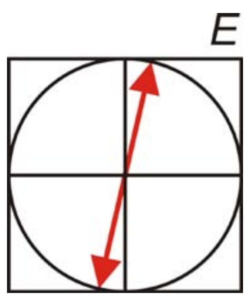
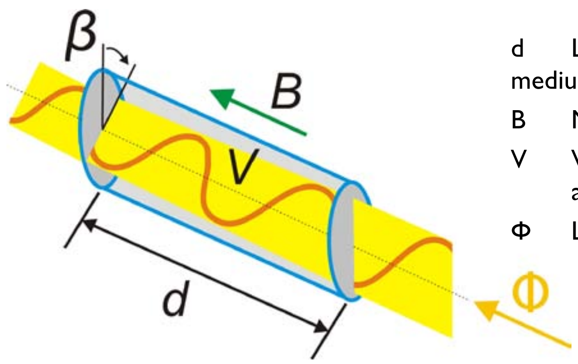


Figure 5
Electric field vector of a linear polarized light wave

3.3.3 Calculation of the angle of rotation β

- The angle of rotation β, about which the plane of polarization rotates, is calculated by:
  $\beta = V \times d \times B$



d Length of the light path through the medium

B Magnetic flux density

V Verdet constant, dependent on medium and wavelength

Φ Luminous flux

Figure 6
Schematic view of the parameters for calculating the angle of rotation β

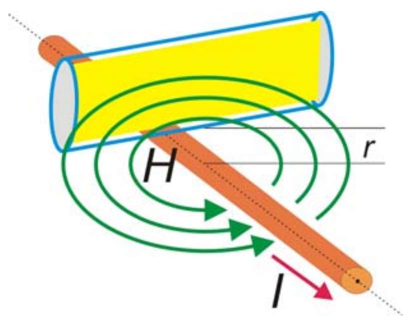
3.3.4 Verdet constant V

The Verdet constant is an optical constant for dielectrics. It describes the strength of the Faraday effect for the dielectric to be evaluated and the rotation per unit of the magnetic flux density. The medium and the length of the electromagnetic waves in the medium are influencing variables.

3.4 Installation of the sensor on a down conductor

In a circular magnetic field, the effective field strength depends on the depth of immersion of the sensor in the magnetic field of the current-carrying down conductor.

For the calculation, the immersion depth is defined via the radius. This means that the smaller the radius, the greater the field strength. It is therefore advisable to mount the sensor on the down conductor as tightly as possible, so that the effective field strength is as great as possible.



H Field strength [A/m]

r Radius [cm]

I Current [A]

Figure 7
Schematic view of the sensor installation

Figure 8
The measuring section is located in the front part of the sensor housing.

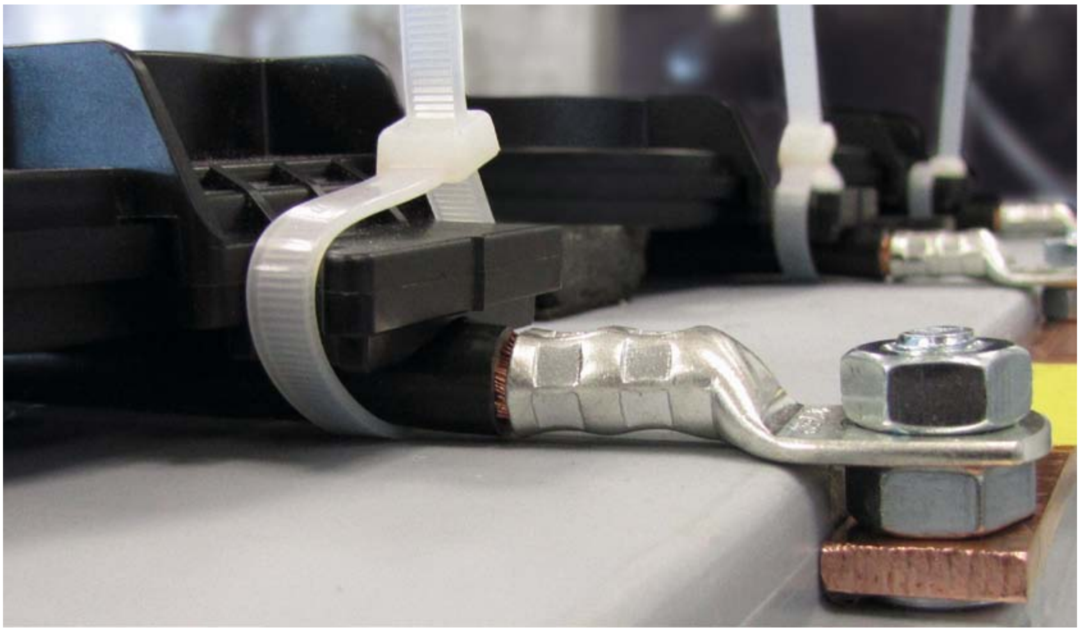


Figure 9
The sensor housing is firmly mounted and sealed on the down conductor using cable straps

3.4.1 Radius r

The radius describes the immersion depth of the sensor in the magnetic field and the monitoring of the effective magnetic field strength H. The measurement is calculated from the clearance from the outer edge of the sensor housing to the center line of the conductor.

This value must be determined during installation, as calibration of the monitoring system is based on this. This ensures the same measurement conditions for different system conditions.

3.5 System interfaces and signal transmission

The evaluation unit can be integrated into standard networks via the RJ45 Ethernet interface. An internal web server is used for accessing recorded data and configuring the system. The web interface is opened via the Internet browser of a PC connected to the system using IP addressing.

3.6 Remote monitoring

Lightning strikes on systems that are difficult to access or are remote, such as offshore wind parks, are impossible or extremely difficult to detect. The LM-S lightning monitoring system provides you with all the measuring data via an integrated web interface. This means that you can call up the load situation of the system at any time using remote access, e.g., on a smartphone.

Figure 10
Display of load values on a cell phone

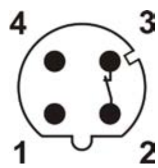
3.6.1 Preventive maintenance

The evaluated data allows you to precisely estimate the actual system load. The measuring results are always up to date and enable preventive maintenance to be carried out. If damage to the system is indicated, rapid measures can be initiated to prevent consequential damage. Downtimes can then be reduced or completely avoided. If the measuring results indicate minimum, uncritical system loads, this also saves unnecessary maintenance work or servicing.

3.7 Remote contact

The evaluation unit also has a switching relay with accessible remote contact. For each event, this N/C contact produces a short pulse, which can be evaluated by a counter. In this way, it is also possible to carry out a simple or additional evaluation of the number of lightning strikes on the system.

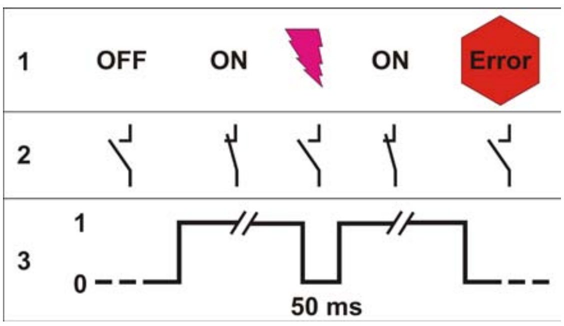
The relay contact only assumes its normal position once the system is started up. And in the event of a system malfunction, the relay drops out. In this way, the system readiness can be queried via the remote contact.



Remote connection:

M12 D-coded
2, 3 floating N/C contact
1, 4 not used

Figure 11
Connection diagram for remote contact shown in detail



Switching function of the remote contact:

1: System status
2: Remote contact
3: Switching signal

Figure 12
Remote contact

4 LM-S applications

Typical fields of application for the lightning monitoring system are all systems and buildings at risk of being struck being struck by lightning. This includes industrial plants, large buildings, antennas, energy distribution systems in the field of high and extra-high voltage technology as well as transport monitoring systems.

4.1 Wind power plant

The arrangement of the individual system components in, for example, a wind power plant, is shown here. A sensor is mounted on each lightning arrester on the rotor blades. The evaluation unit is located in a control cabinet in the hub. The signals are transmitted between the sensors and the evaluation unit via fiber optics. The Ethernet connection to the central controller is established via slip rings between the gondola and the observation deck. The evaluation unit works with 24 V DC.

If required, the remote contact can be connected to the controller. This makes it possible to signal every lightning strike or evaluate the number of events.

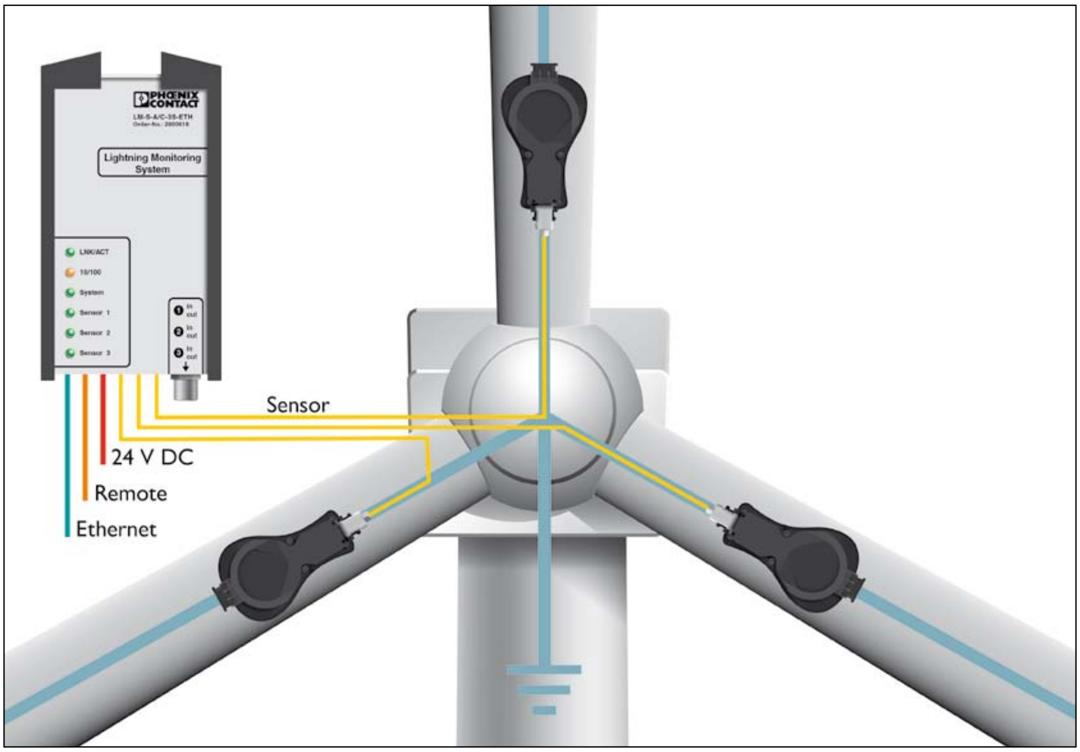


Figure 13
Schematic diagram of an LM-S application using the example of a wind power plant

4.2 Cultural monument

This application example shows how the lightning monitoring system is used at the Hermann monument in Detmold, Germany. The copper statue stands on a sand-lime brick base. Three grounding cables are connected to the base of the statue. This means that if the structure, which is over 53 meters tall in total, is hit by a lightning strike, the lightning surge currents are diverted to ground. The sensors are mounted on these down conductors. The evaluation unit is installed in a control cabinet inside the base.

In this application, early monitoring of potential damage to the system is not the key objective. However, due to the exposed location and the height of the structure, significant lightning strikes should be expected. The monitoring of these strikes is used to statistically evaluate lightning strikes and their strength. Such applications are of particular interest for lightning research.

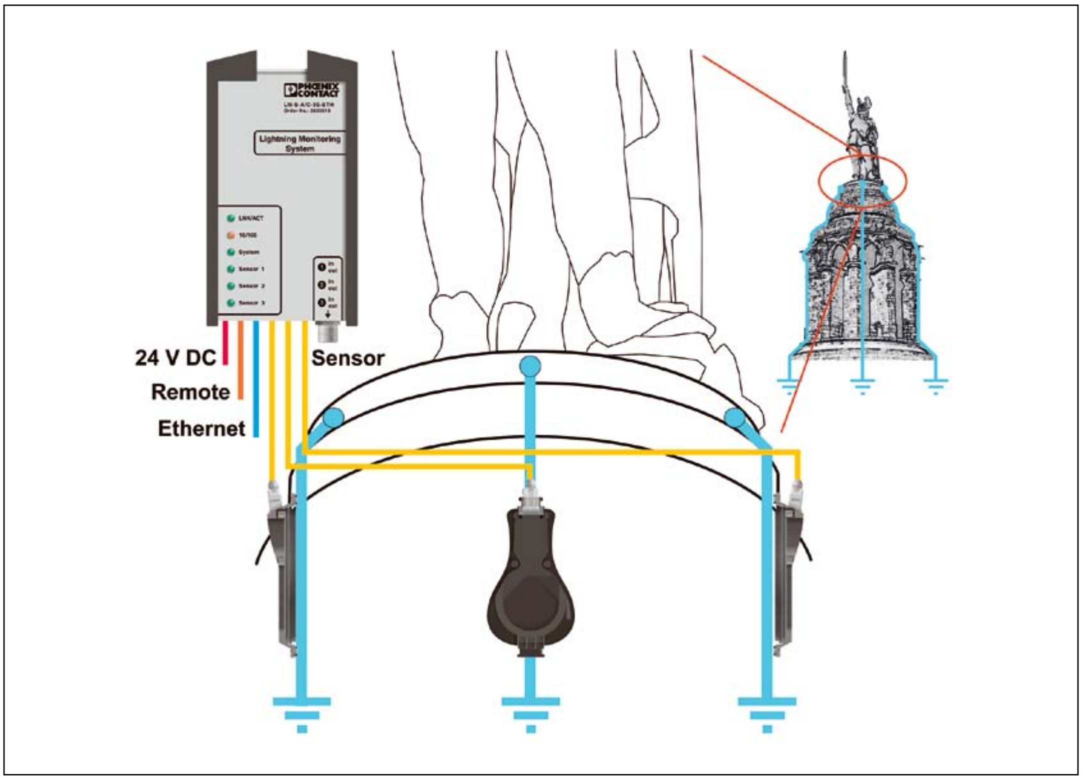


Figure 14
Schematic diagram of an LM-S application using the example of a cultural monument

4.3 Power transformation substation

Lightning strikes on high-voltage cables result in transformer loading in power transformation substations. Often surge protection elements are connected upstream of transformers. These direct the surge currents from coupled overvoltages to ground. In the past, spark gaps were normally used as protective elements. In recent years, varistors have become the preferred solution.

LM-S allows you to register and evaluate the actual load of the protective elements. This enables early monitoring of load limits and replacement of affected protective elements.

The sensors are installed on the down conductors between the protective elements and the ground. Fiber optics transmit the measuring signals to the evaluation unit, which is installed in a remote control cabinet.

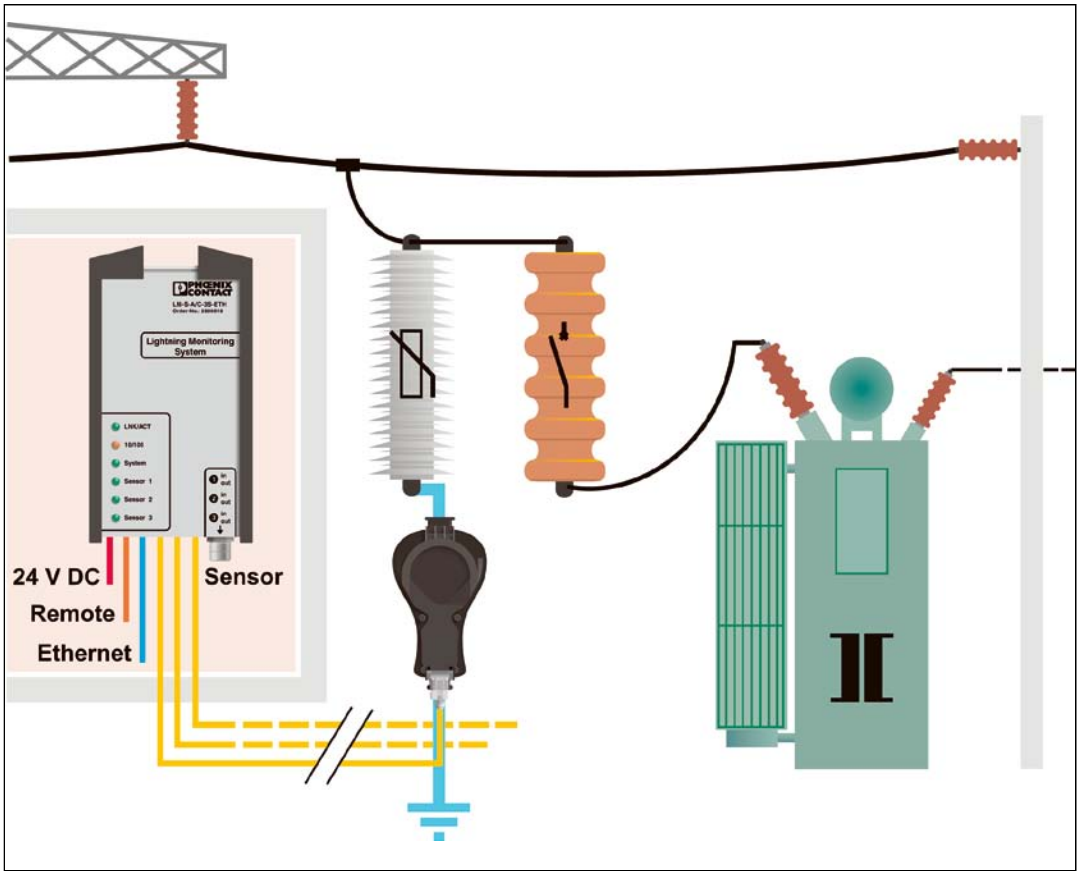


Figure 15
Schematic diagram of an LM-S application using the example of a power transformation substation

5 Technical data

5.1 General technical data	
Housing material	Metal
Mounting type	DIN rail: 35 mm
Width	77.60 mm
Height	156.00 mm
Depth	173.00 mm
Degree of protection	IP20
Ambient temperature (operation)	-30 °C ... 60°C
Permissible humidity (operation)	30 % ... 95 % (no condensation)
Altitude	Max. 4000 m

5.2 Typical characteristics	
Operation	Via web interface
Maximum storable data records	500
Supply voltage	24 V DC ± 4 V
Ethernet interface	
Transmission speed	10/100 Mbps
Connection method	RJ45
Fiber optic interface O/E module	
Number of ports	3
Connection method	B-FOC (ST®)

5.3 Remote indication contact	
Switching function	Öffner, 1-polig
Switching pulse per event	50 ms
Operating voltage: Maximum Umax DC	60 V DC
Connection method	M12 D-coded

5.4 Standards	
Electrical safety	EN 61326-1 2006

5.5 Product list for the creation of a lightning monitoring system with LM-S from Phoenix Contact			
	Evaluation unit with O/E module	LM-S-A/C-3S-ETH	2800618
	LM-S-LS-H sensor		2800616
	HCS cable (e.g., 10 m long) Cables with a recommended length of up to 200 m can be ordered in 1 m increments.	FOC-PN-HCS-1018/.../ PPCME / BFOC / 10,0	1402190
	O/E module LM-S-C-3LS		2800617

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