Lightning arrester device

The invention relates to a lightning arrester device, consisting of a catching device that is connected via an electrical conductor to an earthing installation, the electrical conductor being surrounded by an insulation surrounded by a longitudinally continuous layer made of a weakly conducting material that preferably has a non-linear electrical behavior, at the end region of the layer facing the catching device, a connecting part made of an electrically conducting material, in particular metal, being arranged, by means of which the catching device and/or the electrical conductor is connected to the layer, and at the end region of the layer facing the earthing installation, a connecting part made of an electrically conducting material, in particular metal, is arranged, by means of which the electrical conductor and/or the earthing installation is connected to the layer surrounding the insulation.

Such a device is known from EP 1 760 855 B1.

In particular, the invention relates to possibilities of determining the condition of the insulation and the outer layer made of a weakly conducting material of an insulated arrester of an exterior lightning protection system.

The insulation, as well as the outer conductive layer, may be damaged by faulty transportation, wrong storage, or non-adequate assembly, and by an electrical breakdown during a lightning strike. Therefore, it is attempted to detect these damages at the occasion of the regular inspection of an exterior lightning protection

system or in particular after a recorded lightning strike.

Prior art describes such insulated arresters of an exterior lightning protection system, for instance, in the cited European Patent document, but also in IEC TS 62561-8. In Figure 1, an exemplary installation is shown. On building 1, for instance, a building body, a spaced catching device 4 with an insulator 2 is arranged that is connected to the connecting part 3 with the insulated arrester 6. The upper connecting part 3 thus connects the electrical conductor 6a to the outer conducting layer 6d of the insulated arrester 6. The insulated arrester 6 is connected, on the level of the building 1 (top), to an electrically conducting connection element 5, for instance, a holder, at an electrical bonding conductor of the building, or the like. Further holders 7 serve for the attachment of the insulated arrester 6. The lower connecting part 8 thus connects the electrical conductor 6a to the outer conducting layer 6d of the insulated arrester 6. A releasable disconnect terminal 10 connects, in the embodiment, the lower connecting part 8 to the electrical conductor 9 and thus establishes a connection to the earthing system of the building or to earth 12.

Figure 1a shows the installation in a side view.

An exemplary and preferred insulated arrester 6 is shown in Figure 2. Herein, the electrical conductor 6a is surrounded by a weakly conducting layer (inner conductive layer) 6b, followed by an insulation made of a high-voltage resistant insulating material 6c, again followed by a weakly conducting layer 6d that represents the outer conductive layer. An example of a connecting part is shown

in Figure 3. The figure shows the corresponding components in an exploded view and in the assembled condition.

An electrical equivalent circuit of such a design is shown in Figure 5 and forms the starting point for the explanation of the measuring means.

At the occasion of a lightning strike shown at the top by the stepped arrow, the largest part 17 of the lightning current will flow off into the catching device 4 over the electrical conductor 6a to remote earth 21. A very small part 18 only of the lightning current will flow off over the outer conductive layer R* (6d) of the insulated arrester 6 via symbolized connection cables 19 and 15 or over an electrical bonding rail 20 to remote earth 21.

As a consequence of damages or as a consequence of a breakdown of the insulation or the outer conductive layer 6d, the desired function of the insulated discharge of the lightning current is not obtained anymore, and part of the lightning current would then be able to enter into the building and cause damages there in electrical and electronic devices.

For this reason, there were attempts heretofore to detect possibly existing damages by a measurement when making the test as required in the mentioned standard.

Condition tests by measurements at high-voltage resistant, insulated arresters with high-voltage pulses, with surge-current pulses, or with a hybrid generator are considered too dangerous and not feasible due to the risk

for persons and the function of electrical and electronic equipment.

Therefore, there is a desire to be able to measure the insulation properties of an insulated arrester 6 on the earth side, i.e., at the bottom, without disassembly works at the catching device 4 on the roof or at the connecting part 3.

For this purpose, on the earth side, the connecting part 8 is removed, and the earth terminal 10 is interrupted so that there is free access to the electrical conductor 6a as well as to the outer conducting layer 6d. Thus, the measurement circuit common in prior art according to the equivalent circuit in Figure 6 is obtained. Herein, the insulation fault is drawn with the resistor R_F. According to prior art, it is attempted, with an insulation measuring device 22, which represents, with a voltage of approx. 1000 volts DC and a current limitation to a few milliamps, no risk for persons and equipment, to measure the insulation fault with the resistor R_F.

Investigations of insulated arresters with artificially introduced faults have shown that the accuracy of an insulation measurement and the accuracy of a fault location is very limited. This is caused by that on the side of the catching device 4, the electrical conductor 6a of the insulated arrester 6 and the outer conductive layer (6d) are connected to each other, as intended, by an electrical conductor 14.

As shown in Figure 6, the insulation measuring device 22 will indicate a value that is obtained from the resulting value of the resistors of the three holders R_H and

four sections of the outer conductive layer 6d (R*) and of the parallel connection of R_F and R* connected in series. The farther the insulation fault R_F is from the earth side, the less there is a possibility to measure the value of R_F in a meaningful way. To make this worse, the specific resistance of the outer conducting layer 6d (R*) has a strong temperature coefficient so that the specific resistance is changed in the temperature range from, for instance, –20 °C to +80 °C, by up to 300 %.

The resistance of an insulation fault R_F caused by an electrical breakdown of the insulation 6c, is in the range from several 100 kOhms to MOhms, the resistance of the outer conductive layer 6d is in the range from several kOhms/m. An unqustionable determination of an insulation fault with an insulation measuring device is, thus, not possible. A practicable way would be to interrupt the connection 14 between the electrical conductor 6a and the outer conducting layer 6d at the place of the upper connecting part 3. This would require, however, substantial efforts of assembly and thus cost.

Compared to this prior art, it is the object of the invention to develop a simple possibility, by means of which with possibly no intervention in the existing insulation, a corresponding examination of the exterior lightning protection system can be performed. In particular, it is intended to make disassembly of the connecting part at the transition to the catching device installed on a building unnecessary.

For solving this object, the invention proposes that the electrical connection between the electrical conductor and the conducting layer in the connecting part is

established serially by an adaptive switching element only, which in a normal operating condition, when there is no lightning strike, holds the electrical connection in a separated position (open position), and which in a lightning strike position is closed, due to the then occurring or exceeded response voltage of the switching element, and establishes the connection, wherein in the case of testing by measurement, an insulation or high-ohmic connection between the electrical conductor and the outer weakly or semi-conductive layer of the high-voltage resistant insulated arrester is effected, and in the case of potential differentials, such as during a lightning strike, a conducting connection between the electrical conductor and the outer semi-conductive layer of the high-voltage resistant insulated arrester is effected.

Preferably, it is further provided that the electrical connection between the electrical conductor and the conducting layer in the connecting part is established serially by an adaptive switching element only, which in a normal operating condition, when there is no lightning strike, holds the electrical connection in a separated position (open position), and which in a lightning strike position is closed, due to the then occurring or exceeded response voltage of the switch element, and establishes the connection, wherein, in the case of testing by measurement, an insulation or high-ohmic connection between the electrical conductor and the outer weakly or semi-conductive layer of the high-voltage resistant insulated arrester is effected, and in the case of potential differentials, such as during a lightning strike, a conducting connection between the electrical conductor and the outer semi-conductive layer of the high-voltage resistant insulated arrester is effected.

Advantageous implementations of the invention are defined in claims 3 to 14. Peculiarities of the implementation according to the invention are defined in claim 15. The possibilities for the arrangement and installation of measurement devices are defined in claims 16 to 20. Adaptive switching elements according to the invention are defined in particular in claim 21. A preferred and advantageous implementation is defined in claim 22.

According to the invention, a simple commercially available installation test device can be connected at the earth terminal and the outer conducting layer of the insulated arrester and provides then, by measurement of the insulation resistance, a unquestionable result concerning the condition of the insulation.

This measuring possibility is achieved by the introduction of an adaptive switching element between the inner conductor and the outer conducting layer of the insulated arrester. The adaptive switching element separates the outer conductive layer from the electrical conductor and enables the use of a commercially available insulation-measuring device with a voltage of about 100 to 2,500 volts and a measuring current of a few milliamps being non-hazardous for persons.

In case of a lightning strike, the adaptive switching element establishes an electrically conducting connection between the electrical conductor and the outer conducting layer of the insulated arrester and thus avoids the formation of harmful surface discharges.

In addition to the measurement of the insulation resistance, there is also the possibility of measuring the electrical loss factor tan δ and the capacity C as well as measuring electrical partial discharges and the location of an insulation fault with a usual cable fault location test device.

In the case of testing for damages of the outer conducting layer, it is required to interrupt the upper terminal of the outer conducting layer at the electrical bonding conductor and to establish instead an electrical connection from the uppermost end of the outer conducting layer to the electrical bonding conductor. Then, it is possible to supply a high-frequency current into the outer conductive layer. When there is a fault in the outer conductive layer, by the high-frequency current, an electromagnetic field is coupled into the insulation of the insulated arrester and is measured between the electrical conductor and the outer conductive layer of the insulated arrester with a microvoltmeter. On this occasion, insulation faults can also be detected, since they will also damage the outer conductive layer.

According to the invention, it is intended that damages at installed insulated arresters 6 can be detected even after a long time of operation, without interrupting the connection 14 between the electrical conductor 6a and the outer conductive layer 6d at the location of the upper connecting part 3. This possibility is explained in the following and shown in the drawing figures.

According to the invention, this requirement is solved by that the electrical connection 14 between the electrical conductor 6a and the outer conducting layer 6b

is interrupted at least in the connecting part 3, but preferably in the connecting parts 8 and 3, and an electrical connection is only achieved by an adaptive switching element 23, 24. The possible embodiments of an adaptive switching element are explained in the claims and in the description.

Figure 4 exemplarily shows the geometric arrangement of an adaptive switching element 13, which is contacted in the electrical connection between the connecting part 3 and the outer conducting layer 6d. In Figure 4, the catching device 4 with the connecting part 3 is shown. Below that, an adaptive switching element 13 is shown, which connects, according to the invention, the connecting part 3, which is connected to the electrical conductor 6a or to the catching device 4, to the outer conducting layer 6d of the insulated arrester 6.

The electrical equivalent circuit of an insulated arrester 6 with connecting part 3 or 8 and adaptive switching elements 23 or 24 is shown in Figure 7.

The adaptive switching elements 23, 24 must not deactivate the basic functions of the insulated arrester 6. Therefore, the following conditions apply for the adaptive switching elements 23, 24:

- In case of a lightning strike, the adaptive switching elements 23, 24 must be closed when their response voltage is reached. Thereby, the prevention of harmful surface discharges is secured. The adaptive switching elements 23, 24 must be able to carry the current through the outer conductive layer 6d. In case of an electri-

cal breakdown of the insulation 6c, the adaptive switching elements 23, 24 conduct a current limited by the partial resistance R* of the outer conductive layer and need to be dimensioned for this value.

- In normal operation, the switching elements 23, 24 for the condition check by measurement of the high-voltage resistant insulated arrester 6 with a measurement voltage being non-hazardous for persons and electrical components must not respond and must therefore be open. The measurement voltage must be below the response voltage of the adaptive switching elements 23, 24.

By means of adaptive switching elements 23, 24, it is then possible to unquestionably perform the measurement of the insulation resistance R_F with an insulation measuring device 22, with no disassembly of connecting parts 3, 8 or interruption of the earth line 9, 11 by means of a disconnect terminal 10 being required. Hereby, the measurement is substantially simplified and leads to the desired result of a precise determination of the insulation resistance. A risk for persons by influenced charging due to atmospheric electricity is excluded because of the always-existing electrical connection 19, 15 of the outer envelope layer 6d.

In addition to the measurement of the insulation resistance, further possibilities for additional diagnostics are made available by the integration of the adaptive switching elements:

- Measurement of the dielectric loss factor tan δ and of the capacity C,
- measurement of electrical partial discharges,
- detection and location of an insulation fault,
- detection of damage to the outer conducting layer.

The measurements of the dielectric loss factor tan δ and the capacity C with AC voltage provide information on production faults, the aging of electrical insulating materials and damages by electrical partial discharges. This measurement is made according to the scheme in Figure 7 between the end region 9 close to earth of the electrical conductor 6a and the weakly conducting outer envelope layer 6d, wherein the insulation-measuring device 22 is replaced by a commercially available network analyzer or a commercially available loss factor measuring bridge.

The localization of an insulation fault is of particular interest, beside the detection of an insulation fault. For this purpose, for the explanation in Figure 7, instead of the insulation measuring device 22, a cable fault location measuring device of conventional design is used, which enables fault localization.

Damages of the outer conductive layer 6e, as shown in Figure 8, may occur, for instance, by faulty transportation, storage, assembly faults, or damages after the assembly by other operations at the building and are harmful for the function of the high-voltage resistant insulated arrester 6 in case of a lightning strike. Even when the outer conductive layer 6d presents small damages 6e only, so that the insulating material 6c is exposed,

there is the risk of an electrical breakdown of the insulating material 6c in case of a lightning strike. There exists the desire, therefore, to determine such faults, in particular in the upper region near the catching device 4, since there is the highest voltage load. For the determination of such damages, the principle arrangement shown in Figure 9 with the circuit diagram shown in Figure 10 is proposed.

A high-frequency current 27 is conducted with a high-frequency generator 25 into the outer conductive layer 6d and back over the electrical connection 28 and the electrical bonding conductor 15 at the building 1. In the course of this, the electrical bonding conductor 19 shown in Figure 7 must be interrupted, and instead, the connection 28 shown in Figure 9 must be established. In case of a damage 6e, by the high-frequency current 27, an electromagnetic field 30 is irradiated into the space formed by the insulating material 6c and generates a voltage measurable with the microvoltmeter 22 between the outer conductive layer 6d and the electrical conductor 9 that is connected to the electrical conductor 6a. For reasons of signal integrity, it is proposed to perform the connection of the microvoltmeter 26 through a coaxial jack 29 in the lower connection element 8. For this kind of measurement, it is further necessary to open the earth connection in the disconnect terminal 10. Such a measurement also shows, in addition to existing assembly faults in the outer conductive layer 6d, an insulation fault in the insulation layer 6c, since in case of a breakdown of the insulation layer 6c, always the outer conductive layer 6d is damaged.

The proposed adaptive switching elements 23, 24 can be implemented with switching elements of usual design. Suitable are, *inter alia*:

- Varistors,
- cylindrical varistors,
- cylindrical varistors with a cylindrical opening for the insulated passage of the electrical conductor 6a,
- air spark gaps,
- gas-filled overvoltage arresters,
- anti-serially connected Zener diodes,
- thyristors,
- surface discharge air gaps,
- IGBT (insulated-gate bipolar transistors),
- other correspondingly effective electronic components.

These components can be accommodated, according to Figure 4, in an insulated housing 13.

Corresponding measurement devices can be activated permanently or for testing purposes only. In case of a permanent activation, a central monitoring process can be performed in a wireless or wired manner by a monitoring system, wherein corresponding measurement signals can also be remotely retrieved, for instance, through WLAN, and/or can be stored in a cloud and stored there in a retrievable manner.

As measurement devices can be used, for instance, the following devices:

- Cable fault location device 3M Dynatel 356DSP,

- impedance meter E4990A of the company Keysight Technologies, USA,
- insulation resistance meters MIT 2500 CALplus GmbH, Berlin, Germany,
- disturbance voltage meters FCKL 1528 of the company Schwarzbeck, Schönau, Germany,
- R_F and microwave R&SSMA100B signal generator of the company Rhode & Schwarz, Minden, Germany,
- measurement devices for partial discharges MPD 600, Omicron, Austria,
- capacity and loss factor meter CDAX 605, company Megger, Germany.

With regard to the special design of the respective lightning arrester device that is described in EP 1 760 855 B1, reference is made to the description therein including explanations in the subclaims 3 to 14. To avoid repetitions, reference is made to the disclosure therein of the patent specification in the description and to the description of the embodiment.

The invention is not limited to the embodiments, but is in many respects variable within the scope of the disclosure.

All individual or combined features disclosed in the description and/or the drawing are regarded as essential for the invention.

List of references

1 building
2 insulator
3 connecting part
4 catching device
5 electrically conducting connection part
6 insulated arrester
7 attachment holder
8 connecting part
9 electrical conductor
10 disconnect terminal
11 earthing conductor
12 earth

6 =
- 6a electrical conductor
- 6b weakly conducting layer
- 6c insulation made of high-voltage resistant insulating material
- 6d weakly conducting outer envelope layer
- 6e damage of 6d

13 adaptive switching element (23, 24)
6d = 5 R*
13 insulated housing with adaptive switching element
14 electr. conductor (connection between 6a and 6)
15 connection cable (6d)
17 lightning current
18 partial lightning current
19 connection cable (6d)
20 electrical bonding rail
21 earth
22 insulation measuring device
23 adaptive switching element (13)
24 adaptive switching element (13)

25 high-frequency generator
26 microvoltmeter
27 high-frequency current
28 electrical connection
29 jack
30 electromagnetic field

Patent claims

1. A lightning arrester device, consisting of a catching device (4) that is connected through an electrical conductor (6a) to an earthing installation (12, 21), the electrical conductor (6a) being surrounded by an insulation (6c), the insulation (6c) being surrounded by a longitudinally continuous layer (6d) made of a weakly conducting material, at the end region of the layer (6d) facing the catching device (4), a first connecting part (3) made of an electrically conducting material being arranged, by means of which the catching device (4) and/or the electrical conductor (6a) is connected to the layer (6d), and at the end region of the layer (6d) facing the earthing installation (12, 21), a second connecting part (8) made of an electrically conducting material being arranged, by means of which the electrical conductor (6a) and/or the earthing installation (12, 21) is connected to the layer (6d) surrounding the insulation (6c), wherein the electrical connection between the electrical conductor (6a) and the conducting layer (6d) in the first connecting part (3) is established serially by an adaptive switching element (13, 23) only, which in a normal operating condition, when there is no lightning strike, holds the electrical connection in a separated position (open position), and which in a lightning strike position is closed, due to the then occurring or exceeded response voltage of the switching element (23), and establishes

the connection, wherein, in the case of testing by measurement, there is an insulation between the electrical conductor (6d) and the outer weakly or semi-conductive layer (6d) of the high-voltage resistant insulated arrester, and in the case of potential differentials, such as during a lightning strike, there is a conducting connection between the electrical conductor (6a) and the outer semi-conductive layer (6d) of the high-voltage resistant insulated arrester, **characterized by that** the electrical connection between the electrical conductor (6a) and the conducting layer (6d) in the second connecting part (8) is established serially by an adaptive switching element (24) only, which in a normal operating condition, when there is no lightning strike, holds the electrical connection in a separated position (open position), and which in a lightning strike position is closed, due to the then occurring or exceeded response voltage of the switch element (24), and establishes the connection, wherein, in the case of testing by measurement, there is an insulation between the electrical conductor (6d) and the outer weakly or semi-conductive layer (6d) of the high-voltage resistant insulated arrester, and in the case of potential differentials, such as during a lightning strike, there is a conducting connection between the electrical conductor (6a) and the outer semi-conductive layer (6d) the high-voltage resistant insulated arrester.

2. The lightning arrester device of claim 1, **characterized by that** the insulation (6c) of a layer (6d) is surrounded by a polymer matrix and a particulate

filler material comprising zinc oxide powder, in particular doped zinc oxide varistor powder, or that the particulate filler material consists of a material of one or several other oxides or of carbides, nitrides, borides, chalcogenides, which lead to a material with distinct non-linear varistor properties, such as doped SnO_2, SiC.

3. The lightning arrester device of one of claims 1 or 2, **characterized by that** the material may contain, in addition to the (doped) ZnO filler material, still further filler materials, such as conducting or semiconducting filler materials with constant voltage-independent conductivity, additives for flame protection and/or processing and/or for stabilization against environmental influences, filler materials for mechanical reinforcement.

4. The lightning arrester device of one of claims 1 to 3, **characterized by that** the doped filler material is manufactured such that every filler material particle has, *per se*, a non-linear, varistor-like current (T)-voltage (U) characteristic, the transition from the insulating to the non-linear region can specifically be adjusted, and the non-linearity α is > 3.

5. The lightning arrester device of one of claims 1 to 4, **characterized by that**
   - the layer comprises a filler material proportion of doped ZnO in the range from 10 to 80 volume-%,
   - the layer comprises a filler material with particle sizes in the range from 4 to 160 µm,

- the particles may have a spherical shape or consist of fragments of full- and hollow-spheres or solid varistor ceramics,
- the layer comprises a polymer matrix of: silicone, EPDM, EPR, thermoplastic elastomer, mixtures of these elastomers, thermoplastics, or thermosets.

6. The lightning arrester device of one of claims 1 to 5, **characterized by that** the layer is adapted, with respect to its non-linear electrical behavior, for arresting lightning current voltages along the electrical conductor and fully or also segment-wise only surrounds the insulated conductor in the peripheral direction.

7. The lightning arrester device of one of claims 1 to 6, **characterized by that** the layer may be mono- or multi-layer, and that the conductivities of the individual layers may be different.

8. The lightning arrester device of one of claims 1 to 7, **characterized by that** the layer has a thickness in the range from 0.05 to 10 mm, preferably 0.2 to 5 mm.

9. The lightning arrester device of one of claims 1 to 8, **characterized by that** the layer is surrounded by an insulating or high-ohmic/semi-conducting protective layer.

10. The lightning arrester device of one of claims 1 to 9, **characterized by that** the insulated conductor (6) has different cross-sectional shapes, for example

round, flat, oval, and solid, or may consist of several partial conductors.

11. The lightning arrester device of one of claims 1 to 10, **characterized by that** the insulating layer and/or the additionally applied protective layer is configured as a mechanically supporting element, for example, as a glass fiber reinforced plastic material.

12. The lightning arrester device of one of claims 1 to 11, **characterized by** a continuous or modular device for lightning current arresting.

13. The lightning arrester device of one of claims 1 to 12, **characterized by that** the layer is extruded, shrunk, or painted.

14. The device of one of claims 1 to 13, **characterized by that** the adaptive switching element (13, 23) consists of one or more passive or active voltage-switching or voltage-limiting components.

15. The device of one of claims 1 to 14, **characterized by that** an insulation measuring device is temporarily or permanently connected at an earth-side connection terminal and at the earth-side outer semi-conductive or weakly conductive layer (6d), for the purpose of a measurement.

16. The device of one of claims 1 to 15, **characterized by that** a network analyzer or a loss factor measuring bridge is connected at the earth-side connection terminal and at the earth-side layer (6d), for meas-

urement of the loss factor tan δ and/or the capacity C of the high-voltage resistant insulated arrester (6).

17. The device of one of claims 1 to 16, **characterized by that** a partial discharge measuring device is connected at the earth-side connection terminal and at the earth-side layer (6d), for the purpose of measurement of partial discharges of the insulated arrester (6).

18. The device of one of claims 1 to 17, **characterized by that** a cable location measuring device is connected at the earth-side connection terminal and at the earth-side layer (6d), for the purpose of localization of an insulation fault of the insulated arrester (6).

19. The device of one of claims 1 to 18, **characterized by that** a high-frequency generator is connected between the layer (6d) and the closest access to the earthing system (11, 12) with separated disconnect terminal (10), the upper electrical bonding conductor is positioned at the upper end of the layer (6d) close to the catching device (4), and a microvoltmeter is connected between the conductor (9) and the layer (6d).

20. The device of one of claims 1 to 19, **characterized by that** as an adaptive switching element (13, 23)

- at least one varistor,
- at least one air spark gap,
- at least one gas-filled overvoltage arrester,
- anti-serially connected Zener diodes,

- thyristors,
- surface discharge spark gaps,
- IGBT (insulated-gate bipolar transistor),

is provided.

21. The device of one of claims 15 to 20, **characterized by that** the measuring device is permanently connected and communicates with a decentrally arranged central monitoring device that preferably can be remotely retrieved.

22. The device of one of claims 1 to 21, **characterized by that** the insulation (6c) is surrounded by a longitudinally continuous layer (6d) made of a weakly conducting material that has a non-linear electrical behavior.