Computer Applications in Electrical Engineering
Vol. 13 *2015*

Protection of photovoltaic systems against the impact of atmospheric discharges

Dariusz Kurz
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3A, e-mail: dariusz.kurz@put.poznan.pl

In the study the attention was paid to the problem of protection of photovoltaic systems against the impact of direct and indirect atmospheric discharges (lightning). Relevant standards were quoted according to which the lightning protection system shall be executed as well as the standards applicable for equipment used in the lightning protection. Protection angle and rolling sphere methods were described in order to determine the protection zones and the height of vertical air terminals. The method of determining the minimum clearance between the elements of the PV and lightning protection systems was indicated along with the types of the used surge arresters. Various protection methods were indicated depending on the type of the system.

KEYWORDS**:** photovoltaic microsystem, lightning protection system, vertical air terminal, horizontal air terminal, clearance, surge arrester, rolling sphere method, protection angle method

1. Introduction

Due to exposed location and large occupied area, the photovoltaic systems increase the risk of overvoltage for household electrical equipment as well as for themselves. The life of PV panels is usually guaranteed for 20 years by their manufacturer, hence in this period the system should operate without any problems. The owners of photovoltaic systems should ensure to properly secure them against external disturbances, in particular against the impact of atmospheric discharges (lightning strokes). In case of damage of the system and the need to replace its elements, the incurred capital expenditure will not pay back within the planned period during the lifecycle of the system and will reduce the planned profits. In spite of the fact that there are methods to completely protect the PV system against the lightning, the use of proper preventive measures may considerably limit the risk of potential damage.

2. Legal regulations

The relevant provisions in the following applicable standards shall be considered in the process of selection and designing of the lightning protection and system [4]:

- PN-EN 61173:2002 “Overvoltage protection for photovoltaic (PV) power generating systems – guide”. This standard defines detailed rules to be met by the lightning system of the photovoltaic systems;
- PN-EN 62305-1:2011 “Protection against lightning – Part 1: General principles”. This standard includes general requirements to be met for the purposes of protection of the building structure containing the systems, equipment and persons working in the facility against the lightning;
- PN-EN 62305-2:2012 “Protection against lightning – Part 2: Risk management”. The standard covers the procedure designed for calculating the discharge risk in the building structures or systems by earth lighting discharges, which allows to select the appropriate protection measures in order to reduce the risk to the level which does not exceed the threshold value;
- PN-EN 62305-3:2011 “Protection against lightning – Part 3: Physical damage to structures and life hazard”. This document defines the requirements concerning protection of building structures against physical damage with the use of Lightning Protection Systems (LPS) as well as protection of persons against stroke with contact and step voltage near the LPSs. It also includes detailed requirements concerning minimum dimensions of individual elements of the Lightning Protection Systems depending on the used material;
- PN-EN 62305-4:2011 “Protection against lighting – Part 4: Electrical and electronic systems within structures”. It includes the information concerning designing, systems, inspection, maintenance and testing of the protection devices of the LMPS system concerning electrical and electronic equipment within building structures, capable of reducing the risk of continuous damage caused by lightning electromagnetic pulse;
- PN-HD 60364-7-712:2007 “Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Photovoltaic (PV) power supply systems”. The document concerns the electrical photovoltaic systems of the power supply systems, including alternating current modules.

Also, the elements of the lightning protection system should meet the requirements defined in standards from PN-EN 62561-1:2012 to PN-EN 62561-7:2012 “Lighting protection system components (LPSC)”.

Apart from the applicable legal acts, the standards developed in other countries, e.g. in Germany, may constitute some indicator for the investors (obviously with the observance of the law applicable in a country in which the PV system will be located) along with the requirements of insurance companies and banks. In case of photovoltaic systems with rated power over 10 kW the insurers require the lightning protection system executed in protection level III as well as internal surge protection. In case of the free-standing system it is necessary to use the surge protection equipment and the equipotential system [6].

3. Lighting protection system

In case of the photovoltaic microsystem installed on the roof of the building, proper distribution of the lighting protection air terminals shall be ensured in order to provide proper safety of the system. The air terminal system is defined on the basis of one of the three methods:

- mesh method (used for flat surfaces),
- protection angle method (used for simple-shaped buildings),
- rolling sphere method (appropriate in every case).

While using the rolling sphere method, the safety zone is defined by virtually rolling the sphere with the appropriate radius on the system surface. In places on the plane of the system's elements in which there is no contact with the sphere there is no hazard of direct lightning stroke (Fig. 1). For protection level III the sphere radius should amount to 45 m [1, 6].

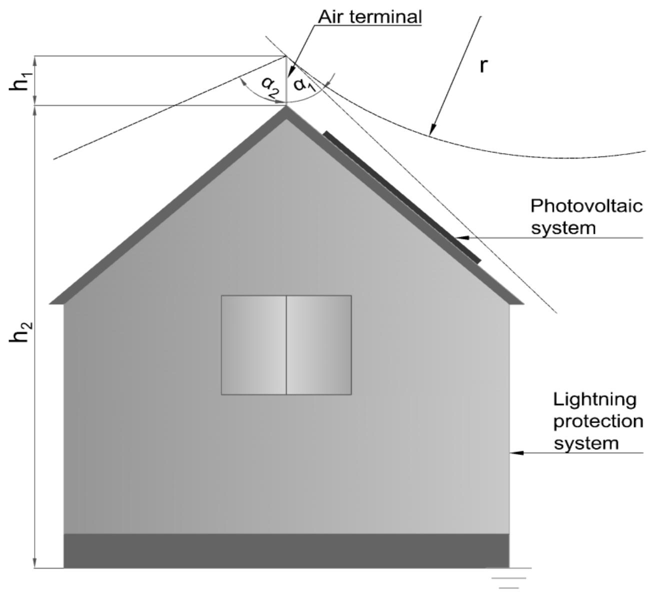

Fig. 1. Determination of protection zone of the lightning protection system for the photovoltaic system on the roof using the rolling sphere method and protection angle method [1, 6]: r – sphere radius [m], h_1 – length (height) of the vertical air terminal [m], h_2 – distance of the highest located point of the roof from the ground surface [m]

The safety zone determined with the use of protection angle method is defined by the virtual field of the cone determined at given angle α. This angle depends on the height of air terminal h and protection class, which was shown in Figure 2.

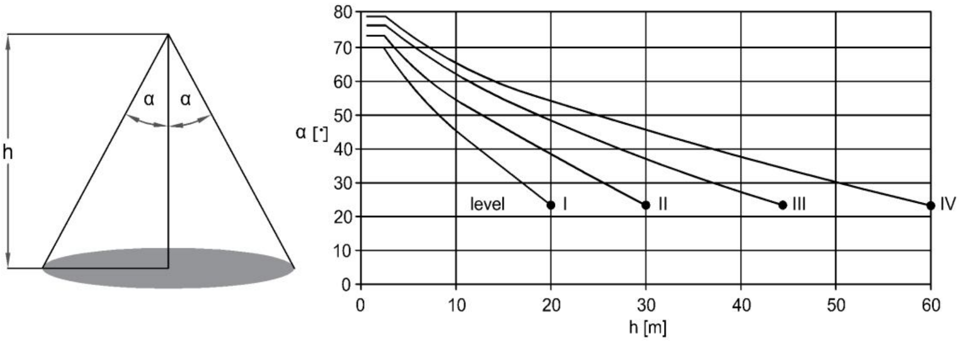

Fig. 2. Determination of protection angles depending on the height of air terminal *h* and the required protection level [3, 5, 6]

Designers of the PV and lightning protection systems must agree a lot of aspects with one another. The designer of the photovoltaic system would wish to use the roof surface for installation of PV panels as much as possible. Also, while planning the Lightning Protection Systems (LPS), the safe clearance shall be ensured between the elements of the LPS and the PV panels. In case of no mutual communication and coordination of works problems connected with safe use of the system may appear. The distance used between the elements of the PV system and the lightning protection is necessary due to protection of the elements of the photovoltaic system against flashovers or electric arcs from vertical air terminals and horizontal lightning protection systems (Fig. 3).

The required clearances are determined in line with standard PN-EN 62305-3:2011 on the basis of formula 1 [3, 4, 5, 6]:

$$S \geq k_i \cdot \frac{k_c}{k_m} \cdot l \tag{1}$$

where: S – minimum clearance [m], l – length measured along the air terminal wire or the down conductor from the point of considered contact to the point of the closest bonding [m], k_i, k_c, k_m – coefficients, the values of which were specified in Table 1.

For the example presented in Figure 4, the required clearance of PV modules from the lightning system air terminals was determined, and the lengths of the air terminals amount to $l_1 = 2$ m, $l_2 = 7$ m, $l_3 = 24$ m. All the terminals run in the air, hence the coefficient $k_m = 1$, while for LPS protection class III the coefficient $k_i = 0.04$. In case of typical lightning protection systems for the single family houses with hoop iron earthing (type B of earthings) the coefficient k_c is divided in half along with the distribution of the lightning current in the next nodes.

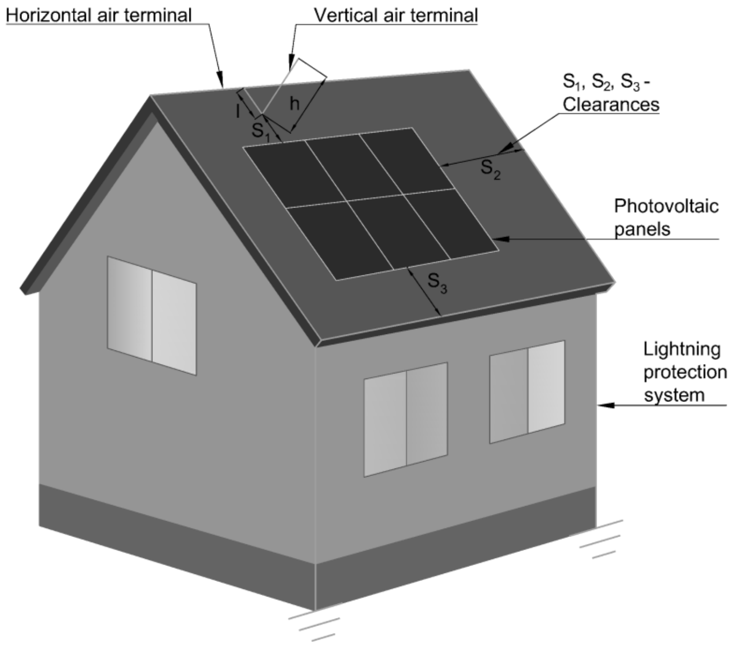

Fig. 3. Determination of clearances from the photovoltaic system [6]

Table 1. Values of the coefficient in the equation defining the clearance [3, 4, 5, 6]

Coefficient	**Value**	
k_i – depending on protection class LPS	0.08 – for LPS class I 0.06 – for LPS class II 0.04 – for LPS classes III and IV	
k_m – depending on the material of the clearance	1 – for the air 0.5 – for concrete, brick 0.7 ÷ 0.8 – for the used spacers (the values given for manufacturers of spacers)	
k_c – depending on the distribution of current in LPS conductors	Earthing system type A	Earthing system type B
	1 – vertical air terminal and 1 down conductor, 0.66 – horizontal air terminal and 2 down conductors, 0.44 – network of air terminals and 4 or more down conductors	1 – vertical air terminal and 1 down conductor, 0.5 to 1 – horizontal air terminal and 2 down conductors, 0.25 to 0.5 – network of air terminals and 4 or more down conductors

Therefore, the values of coefficients k_c for the presented example will amount to $k_{c1} = 1$ (as the whole lightning current flows on route l_1), $k_{c2} = 0.5$ (due to distribution of the current in node l_1/ l_2 into two equal parts, hence half of the lightning current flows on route l_2), k_{c3} = 0.25 (due to distribution of the current in nodes l_2/ l_3, similar as in nodes l_1/ l_2, hence one fourth of the lightning current flows on route l_3). Considering the above-mentioned air terminal sections formula 1 was converted to formula 2.

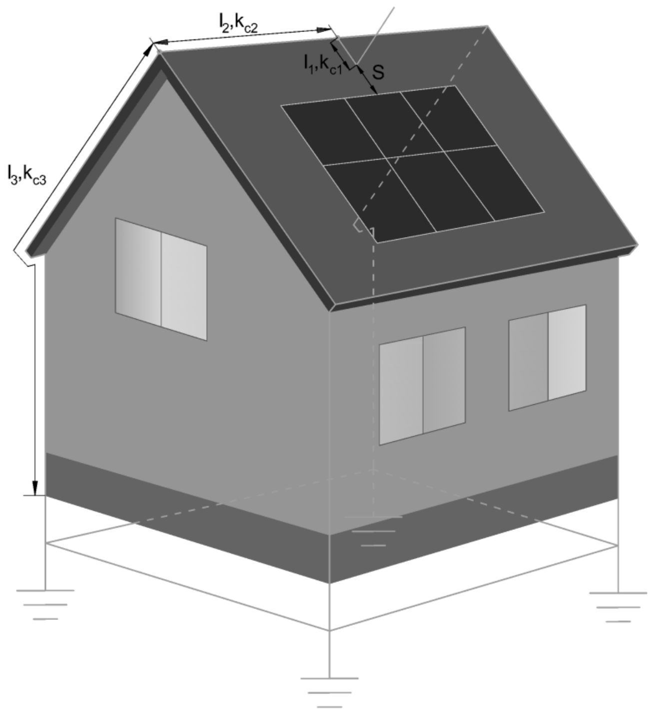

Fig. 4. Determination of clearances from the photovoltaic system [6]

$$S \geq k_i \cdot \frac{k_{c1} \cdot l_1 + k_{c2} \cdot l_2 + k_{c3} \cdot l_3}{k_m} \tag{2}$$

$$S \geq 0{,}04 \cdot \frac{1 \cdot 2 + 0{,}5 \cdot 7 + 0{,}25 \cdot 24}{1} \geq 0{,}46\ m$$

Usually the sufficient clearance S amounts from 0.4 to 1 m. The problem appears when the required distance between the elements of the PV and lighting protection system cannot be ensured, for example due to steel structure of the roof or its covering, or complete filling of the roof surface by the PV panels. In order to secure the photovoltaic panels against the jump of the electric charges from the photovoltaic system the bonding between metal frames of the panels shall be executed with the use of air terminal system [6].

4. Protection against indirect impact of atmospheric discharges

The significant aspect of protection of photovoltaic systems is their protection against direct electric and electromagnetic impact which arose after the lightning stroke in the close neighbourhood. In such a situation, electric and electromagnetic couplings may occur which may lead to damage of the inverter. The hazards which arose due to surge impulse may be eliminated or reduced using lightning protection measures, for example earthings, potential equalization, use of proper Surge Protective Devices (SPD) on the DC and AC side, screening as well as by proper cable routing.

In order to protect the photovoltaic system against indirect consequences of the lighting stroke, one can distinguish two cases [1, 6]:

a) Keeping clearances between the lightning protection and photovoltaic system or the building without lightning protection system (Fig. 5).

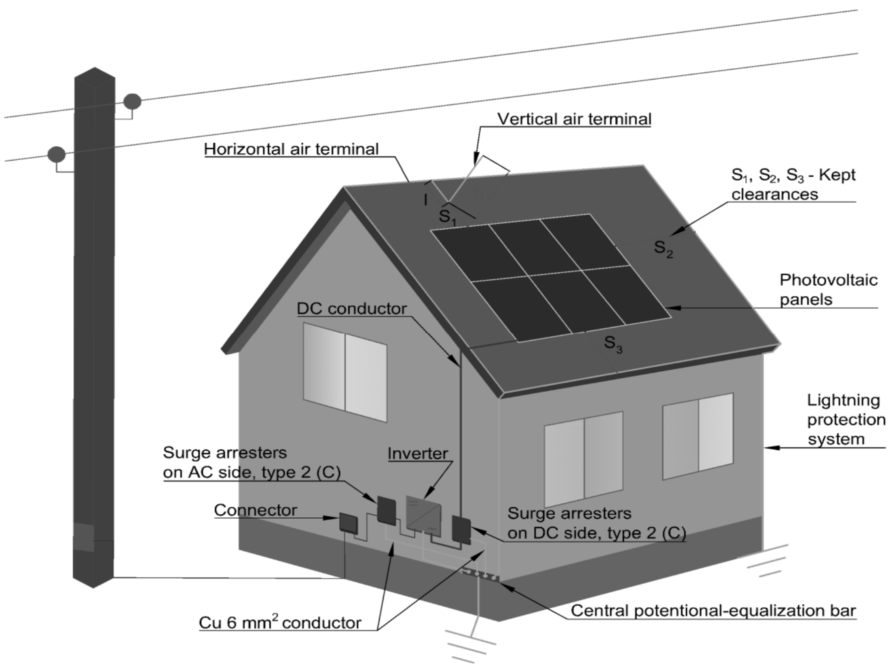

Fig. 5. Schematic diagram of protection of the PV system against direct consequences of atmospheric discharges keeping clearances or lack of lightning protection system [1, 6]

In case of keeping the minimum clearances between the elements of the photovoltaic and lightning protection system or lack of the lightning protection system, the impact of the part of lightning protection on conductors of the system on the DC side is not foreseen. The appropriate protection level will be ensured by surge arresters of type 2 (C) on the DC side (photovoltaic generator) and AC side (low voltage electrical system) connected with the protective conductor with the section of minimum 6 mm^2 to the central potential-equalization bar.

b) No possibility to keep clearances between the lightning protection and the photovoltaic system (Fig. 6).

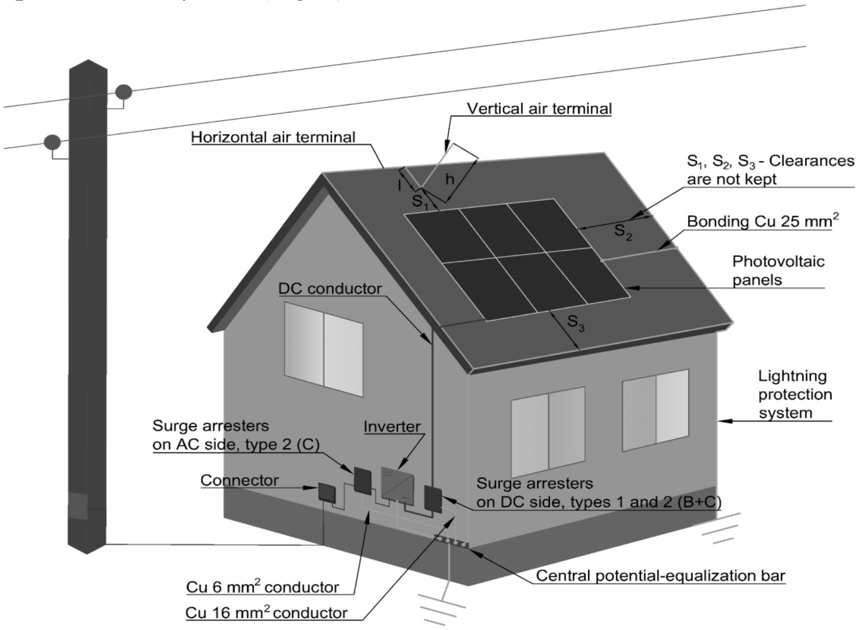

Fig. 6. Schematic diagram of protection of the PV system against direct impact of atmospheric discharges are not keeping clearances [1, 6]

In case of failure to keep the minimum clearances between the elements of the photovoltaic and lightning protection systems impact of the part of the lightning current on the direct current conductors on the DC side shall be assumed. Relevant level will be ensured by the use of surge arresters of type 1 and 2 (class B + C) on the DC side and type 2 (class C) on the AC side. The surge arrester of type 1 shall be connected to the potential-equalization bar using the conductor with the section of minimum 16 mm^2.

While selecting the surge arresters you should remember not to exceed their maximum continuous operating voltage which is determined from dependence (3) [6]:

$$U_{CPV} \geq U_{OC} \cdot 1{,}2 \tag{3}$$

where: U_{CPV} – maximum continuous operating voltage [V], U_{OC} – open circuit voltage of PV panels [V].

5. Surge arresters

SPD surge arresters of type 1 provide protection against direct impact of lightning currents and switching overvoltage. They also ensure potential equalization in all the systems entering the building. SPD surge arresters of type 2 provide protection against induced atmospheric overvoltage and switching overvoltage [1, 4, 6].

DEHN and CITEL surge arresters deserve special attention from among the companies available on the market that specialise in manufacturing of protections for photovoltaic systems.

The series of DEHNguard surge arresters executed according to the SCI technology patented by the company (with the incorporated fuse inside the module) increases the reliability of failure-free operation of the system. Surge arresters of type 2 with the SCI technology are executed in the form of a system of internal connections Y which is resistant to mistakes and consists of three varistor poles and three attached combined disconnecting and shorting systems (Fig. 7).

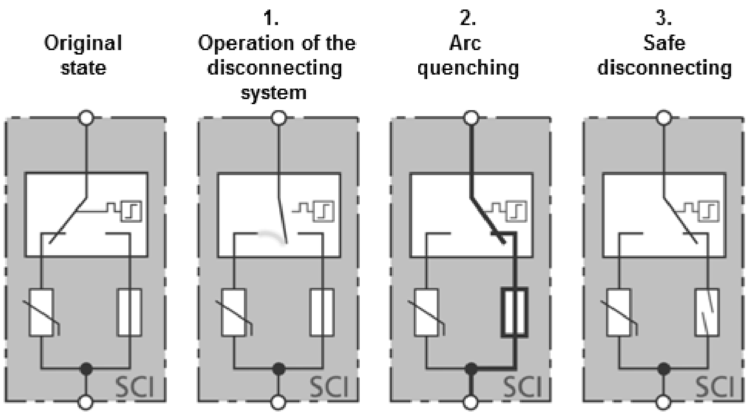

Fig. 7. Operation diagram of a three-degree DC switching system of DEHNguard arrester type 2 with the SCI [7]

The electric arc does not occur during disconnection of the arrester due to the use of a special fuse designed for the PV system in the system shorting the module. The risk of fire in case of overload and damage of the arrester was also limited to minimum owing to the use of the switching system.

The DS50VGPVS series of CITEL surge arresters of type 2 (Fig. 8) provides protection in the form of a gas arrester. It includes disconnecting devices with double protection as well as Y connection system resistant to failures and protected against confusing the poles.

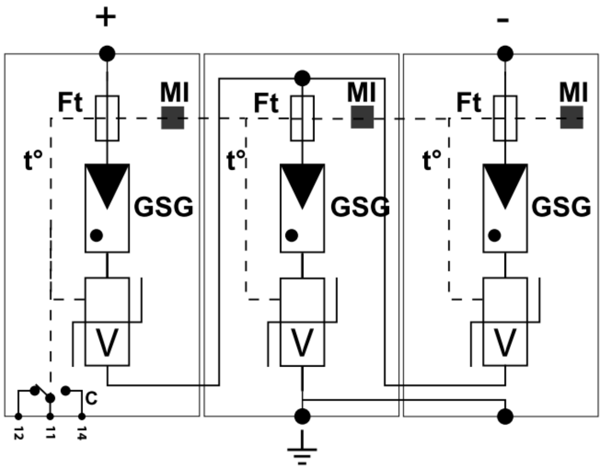

Fig. 8. Construction diagram of CITEL arrester of type 2, series DS50VGPVS [8]:
GSG – gas arrester, V – block of high-power varistors, Ft – thermal protection, t° - thermal disconnecting device, C – remote signalling contact, Ml – signalling of damage

CITEL surge arresters of type 1 + 2, series DS60VGPV, executed in VG technology (with gas arrester and varistor connected in series). Compared to the arrester presented in Fig. 8 they do not have the GSG gas arrester in the middle part.

Surge arresters of type 1 executed in the spark-gap technology (such as e.g. DEHNventil or DEHNshield) have lightning equipotential bonding and provide overvoltage protection of the converters. Surge connecters of type 1 executed in varistor technology do not have the switching function, but only the characteristics of voltage limitation.

6. Conclusions

The properly designed lightning protection system enables protection of the photovoltaic system against the impact of atmospheric discharges. The properly selected and distributed systems of horizontal and vertical air terminals together with down conductors, bonding and earthing system provide relevant protection for the elements of the photovoltaic system. The lightning protection system should be executed by the qualified designer in line with the applicable law and standards. The elements of the PV system shall be placed in the protected space keeping the appropriate clearance. If it is not possible to keep the distance, the bonding between structural elements of the photovoltaic system and the elements of the lightning protection system (or the roof) shall be executed.

Also, the essential elements of protection of the photovoltaic systems against indirect impact of atmospheric discharges are SPD surge arresters which should be located on the DC and AC side of the system. The arrester class shall be selected depending on the installation method and type of the system. The section of the conductor connecting the surge arrester with the potential-equalization bar shall be selected depending on the arrester class, while the length of the connecting conductor should not exceed 0.5 m.

References

[1] Haberlin H., Photovoltaics. System Designed and Practice, John Wiley & Sons Ltd., 2012.

[2] Maksymiuk J., Aparaty elektryczne w pytaniach i odpowiedziach [Electrical devices in questions and answers], Wydawnictwa Naukowo-Techniczne, Warszawa, 1997.

[3] Standard PN-EN 62305:2011 "Lightning protection"

[4] Polish Committee for Standardization, http://pkn.pl, as of 15.01.2015.

[5] Sowa A., Ochrona odgromowa obiektów budowlanych zgodnie z zaleceniami zawartymi w normach serii PN-EN 62305 [Lightning protection of building structures in line with the recommendations included in standards of series PN-EN 62305], http://www.dos.piib.org.pl/var/userfiles/Czytelnia/Ochrona-mat.szkol._2.pdf, as of 17.12.2014.

[6] Szymański B., Instalacje fotowoltaiczne [Photovoltaic systems], GlobEnergia, Kraków, 2015.

[7] http://www.dehn.pl/docs/publikacje/przepieciowa/ds109_fotowoltaiczne_pl.pdf, as of 08.09.2015

[8] http://www.jeanmueller.pl/pliki/katalog-citel-fotowoltaika.pdf, as of 08.09.2015

(Received: 15. 09. 2015, revised: 1. 12. 2015)