A METHOD FOR DIMENSIONING THE LIGHTNING PROTECTION OF PHOTOVOLTAIC MODULES, PLACED ON THE ROOFS OF BUILDINGS

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ABSTRACT. The installation of photovoltaic modules on the roofs of buildings is appropriate, but the issue of their protection against the effects of lightning is becoming more and more relevant. The design of lightning protection implies different methodologies and constructive solutions. With static installation of photovoltaic modules, the design approaches used ensure effective protection according to the selected lightning protection level. Some manufacturers offer photovoltaic modules which allow adjustment of optimal vertical alignment to maximise solar radiation use depending on the geographical location and season. In this case, additional design checks and updates are required to guarantee the lightning protection zone.
The paper proposes a methodology, basic analytical dependencies are derived and the sequence of activities to solve the problem are shown.

Keywords: lightning protection, dimensioning, protection zone

МЕТОД ЗА ОРАЗМЕРЯВАНЕ МЪЛНИЕЗАЩИТАТА НА ФОТОВОЛТАИЧНИ МОДУЛИ, РАЗПОЛОЖЕНИ НА ПОКРИВА НА СГРАДИ

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РЕЗЮМЕ. Монтирането на фотоволтаични модули на покривите на сгради е удачно, но заедно с това става актуален въпроса за тяхната защита от действието на мълнии. При проектирането на мълниезащитата се използват различни методики и конструктивни решения. При статичен монтаж на фотоволтаичните модули използваните подходи за проектиране гарантират ефективна защита, съобразно избраното ниво на мълниезащита. Някои от фирмите производители предлагат фотоволтаични модули позволяващи завъртане на оптимален ъгъл с цел използване в максимална степен на слънчевата радиация в зависимост от географско разположение и годишен сезон. В този случай се налага да се направят допълнителни проектни проверки и актуализации, имащи отношение към гарантиране на защитната зона.
В тази статия е предложена методика, изведени са основните аналитични зависимости и е показана последователността от действия за решаване на посочения проблем.

Ключови думи: мълниезащита, проектиране, защитна зона

Introduction

During the last decades the use of renewable energy sources, such as sun, wind, tides, thermal springs, etc. has become particularly relevant. Without any doubt, the photovoltaic (PV) systems are the most popular among them, because they can be used not only in industrial companies, but also in everyday life. A number of leading companies (relevant to 2019), such as Trina Solar, Canadian Solar, Jinko Solar, JA Solar etc. develop and offer photovoltaic modules and power inverter equipment for obtaining of sinusoidal voltage, microprocessor control and interconnection with the power grid (website: www.power-technology.com).

Along with the large-scale studies with regard to these systems, the problem for the lightning protection of photovoltaic modules, and electronic power equipment interconnected to them remains completely unresolved.

There are a number of regulations and standards, dealing with lightning protection design of buildings, structures and open-areas, including international standards (IEC 62305-1, 2, 3, 4, 2010) and local Bulgarian regulations (Ordinance № 4 of 22nd December 2010 on the Lightning Protection of Buildings, External Equipment and Open Spaces). All of these regulations do not reflect the fact that the PV modules are tilted in order to efficiently absorb the solar radiation, and often their tilt angle is adjustable.

Another problem is related to the efficiency of grounding systems and the dissipation of lightning current through earth (Stefanov, Hristova and Atanasov, 2009).

The probability of direct lightning strikes is significant, because in most cases photovoltaic panels are placed on the roofs of buildings. This problem is particularly relevant for mountain areas with strong lightning activity.

The development proposed here is indicated to solve some existing problems in the following areas:

- Based on the constructional characteristics and requirements for the installation of photovoltaic systems, a method for protection against the effects of lightning has been offered;
- Analytical expressions have been derived, which can be used at the preliminary design stage ;

- An overall methodical sequence of activities to solve problems with lightning protection by the designer has been proposed.

Special points with regard to the installation of photovoltaic modules on the roofs of buildings

Photovoltaic modules have a rectangular shape with dimensions (***a*** x ***b***, Fig. 1) and are covered by a non-conductive or metal frame. They are mounted statically and are able to rotate in order to optimally absorb solar radiation. Figure 1 shows two variations of their attachment.

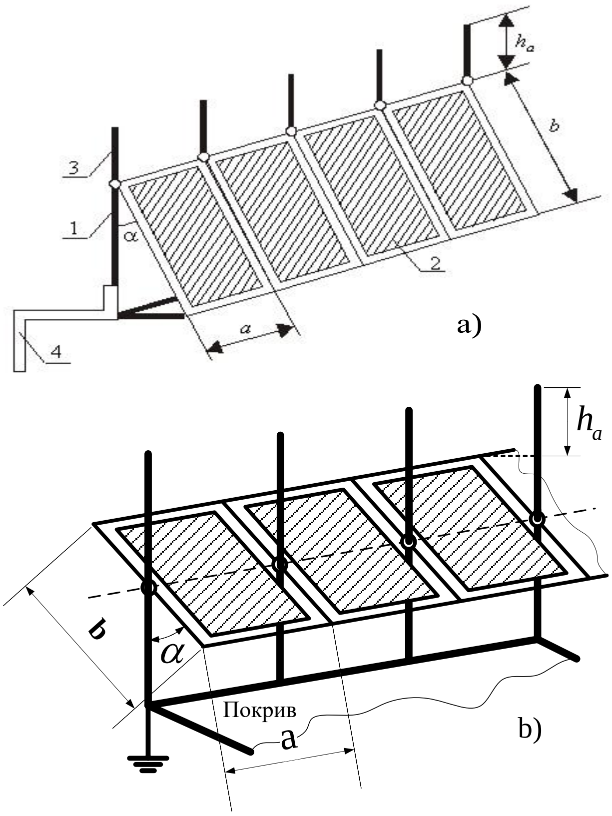

Fig. 1. Alignment of PV modules and installation of the lightning rods, where: a) upper suspension; b) suspension in the middle

The construction from Fig.1 consists of the steel frame 1 on which the PV modules 2 are fixed. In both cases in Fig.1 (upper suspension and suspension in the middle of PVs) rotation and locking of PV modules have been realized at a desired tilt angle. The vertical steel rods 3 are used in order to protect the PV modules against lightning. These rods are mounted on the metal frame by welding. The zinc-plated steel buss-bar 4 connects the metal frame with the grounding system. Using a lightning protection of this type is suitable since the lightning rods create a small and limited shaded area on the modules.

In our case of a lightning protection system, the following input parameters are used for designing needs:

- h_X - building height of the roof, on which the modules are installed;
- Geometric dimensions of the modules (***b*** - height; ***a*** - width);
- α - the maximum angle of tilt rotation relative to the vertical axis.

The main question that a designer should answer is related to defining the lightning rod's active height h_a in order to ensure effective protection of the modules from a direct lightning strike at the selected rotation tilt angle α .

Deriving of basic analytical dependencies needed for the lightning protection design

The protection of PV modules is realized by vertical lightning rods, located on the metal support frame (the connection is made by welding).

The protection area of a vertical lightning rod comprises a tent-shaped volume with a peak at the tip of the lightning rod. The wrapping curve of this volume is described by the equation (Petrov, Venkov, 2002):

$$r_x = \frac{1,6}{1+h_x/h}\left(h-h_x\right) p = \frac{1,6p\cdot h_a}{1+h_x/h} \qquad (1)$$

, where:

h_x – Height of the protected object;

r_X – Radius of the protection zone with a height h_X;

h_a – Active height of the lightning rods;

$h=h_a+h_x$

$p=1$ for $h\le 30$ m; $p=5,5/\sqrt{h}$ for $h>30$ m

This protection area has been determined experimentally with a reliability of protection up to 0.999. (Valchev, et al., 1980)

Equation (1) can be transformed precisely in relation to the active height h_a for the following cases:

- $p=1$ when $h\le 30$ m;

$$h_a = \frac{\left(r_x - 1,6h_x\right)+\sqrt{2,56h_x^2+9,6h_x r_x + r_x^2}}{3,2} \qquad (2)$$

- $p=5,5/\sqrt{h}$ when $h>30$ m;

$$h_a = \frac{\left(r_x - 1,6p\cdot h_x\right)+\sqrt{2,56p^2\cdot h_x^2+9,6p\cdot h_x r_x + r_x^2}}{3,2\cdot p} \qquad (3)$$

, where:

p - Length of the horizontal part of the structure on which the modules are arranged;

In dependencies (2) and (3), the radius of the protection area r_x is selected to be one half of the width of the photovoltaic module i.e. $r_x = \frac{a}{2}$.

Since PV modules are not located tight-close to each other and in order to provide overlapping of their protection areas it is necessary the value of r_x to be increased. For this purpose, we must take into account the length of the horizontal part of the structure on which the modules are arranged ***p*** and their number ***n***:

$$r_x = \frac{p}{2 \cdot n} \quad (4)$$

In dependences (2) and (3) it is necessary to add the height of the modules to the height of the building, i.e.:

$$h'_x = h_b + b \quad (5)$$

Fig. 2 illustrates the maximum allowable rotation angle $\alpha_{\max}$ of PV modules in order to guarantee efficient lightning protection.

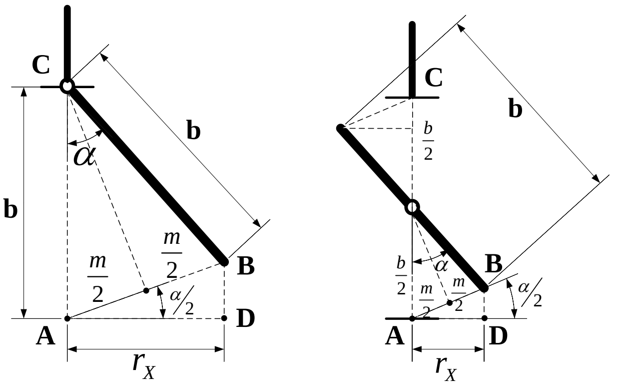

Fig. 2. Principle diagram of modules' rotation for the various cases of suspension, wherein:
a) upper suspension; b) suspension in the middle

For both cases the following analytical relationships are valid:

- For the case of Fig. 2 a) - From triangle ABC it is defined: $m = 2b \cdot \sin\left(\frac{\alpha}{2}\right)$, and from triangle ABD: $r_x = b \cdot \sin(\alpha)$. Then the maximum allowable angle of rotation $\alpha_{\max}$ is obtained as:

$$\alpha_{\max} = \arcsin\left(\frac{r_x}{b}\right) \quad (6)$$

, where $r_x \le b$

- For the case of Fig. 2 b) – Analogically, the maximum allowable angle of rotation $\alpha_{\max}$ is:

$$\alpha_{\max} = \arcsin\left(\frac{2 \cdot r_x}{b}\right) \quad (7)$$

, where $r_x \le \frac{b}{2}$

The obtained analytical expressions (6) and (7) allow the determination of the magnitude of the maximum allowable rotation of PVs $\alpha_{\max}$ for a predefined radius of the protective zone r_x (4).

In case $\alpha_{\max}$ is higher than required, r_x is additionally increased and calculations (6) and (7) are repeated. The final value for the active height of the lightning rod h_a is calculated by (3), where the chosen value for $\alpha_{\max}$ has to satisfy equations (6) and (7).

The protection area of a group of two lightning rods has substantially larger dimensions compared to the single rods' protection areas, taken together.

In our specific case, the lightning protection consists of vertical lightning rods, having the same heights and arranged in one and the same plane. Therefore, it can be concluded that the proposed method for lightning protection design has a significant coefficient of reserve, which guarantees a reliable protection of PV modules.

Example: *On a building roof PV modules are mounted with dimensions respectively: b = 1,5* m*; a = 1,2* m*, the number of modules n = 3 and the length of the support frame p = 4,2 m. The height of the building is* $h_X = 20$ m .

The lightning protection design will include the steps:

1) The corrected building height is:
$h'_X = h_X + b = 20 + 1,5 = 21,5$ m
2) The radius of protection area is:
$$r_x = \frac{p}{2 \cdot n} = \frac{4,2}{2 \cdot 3} = 0,7 \text{ m}$$
3) Using (2), the lightning rods active length will be:

$$h_a = \frac{(r_x - 1,6h_x) + \sqrt{2,56h_x^2 + 9,6h_x r_x + r_x^2}}{3,2}$$

$$h_a = \frac{(0,7 - 1,6 \cdot 21,5) + \sqrt{2,56 \cdot 21,5^2 + 9,6 \cdot 0,7 \cdot 21,5 + 0,7^2}}{3,2}$$

$h_a = 0,86 \text{ m} = 86 \text{ cm}$

4) For the maximum allowable rotation the angle $\alpha_{\max}$ is obtained:

- In case of upper suspension via (6):

$$\alpha_{\max} = \arcsin\left(\frac{r_x}{b}\right) = \arcsin\left(\frac{0,7}{1,5}\right) = 27,8°$$

- In case of suspension in the middle via (7):

$$\alpha_{\max} = \arcsin\left(\frac{2 \cdot r_x}{b}\right) = \arcsin\left(\frac{2 \cdot 0,7}{1,5}\right) = 43,03°$$

4) In case when the optimal rotation angle of PV modules exceeds $\alpha_{\max}$ the calculation procedure has to be repeated with a larger value for the protection radius r_x .

Conclusions

The proposed methodology for a lightning protection design of photovoltaic modules can be used in practice. The following conclusions with regard to it can be made:

- The vertical lightning rods appear to be suitable for lightning protection of PV modules located on the roofs of buildings. They are of relatively small dimensions, allowing their installation without extra reinforcement. Most often this is realized by welding. The installed lightning rods do not affect the overall lightning protection of the building;
- When the PV modules are installed with suspension in the middle, the active length of lightning rods is smaller, which

allows larger angles of PV modules' rotation. Therefore, for higher buildings, it is preferable PV modules to be suspended in the middle.

- The proposed methodology is based on derived analytical dependencies for the different variants of suspension of PV modules, allowing the determination not only of the geometric dimensions of the lightning rods, but also the evaluation of the impact of different angles of PV modules rotation.

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