Production of electricity using photovoltaic panels and effects of cloudiness

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Abstract: The paper deals with atmospheric effects which have a negative effect on the production of electricity using photovoltaic panels. Especially on the cloudiness and its composition which affects the production of electricity in various ways. The introductory part of the paper is focused on atmospheric processes that lead to the formation of clouds, and cloudiness and its basic division. In the next part, the system that was used in the research, and also the methodology of collecting and analyzing measured data is described. The last part of the paper summarizes the experimental results of the research.

Key-Words: solar energy; efficiency; atmosphere; production; electricity; photovoltaic system; cloudiness

1 Introduction

Nowadays, there is an increasing development of photovoltaic power plants which serve as a source of clean energy for power, whether the large industrial enterprises or small houses. These photovoltaic plants convert sunlight to electricity by the various types of photovoltaic cells which differ both in used construction materials, efficiency and cost. Moreover, the increase of temperature is causing decrease of effectiveness of the photovoltaic panel. This phenomenon is a common property of photovoltaic panel. This declination of the efficiency and thus the production of electrical energy may vary according to the type of photovoltaic cell due to the increased surface temperature. The production of electric energy also affects the orientation, position, inclination, and the ambient climate conditions in which the photovoltaic panels are located.

In this post, we will focus mainly on the issue of the impact of changing climatic conditions for the production of electricity. These issues are often ignored while changing climatic conditions, in which the photovoltaic panels are located, may have significant impact on the total production of electricity in long time horizon. In particular, the incidence of various types of cloudiness which are formed during the day and at certain time intervals prevents impact of the direct solar radiation on the photovoltaic panels.

2 Processes leading to formation of cloudiness

From the surface of the water, soil and living organism, particles of water or ice evaporates into the atmosphere, and at a certain height above the ground surface gradually condensing into droplets or ice crystals that form clouds. Height, at which this process takes place, is variable and the boundary at which the water in the vapour phase transformed into liquid is called the dew point. This depends on the stability of the air and the percentage of moisture. The average particle size of water or ice crystals in a cloud is 0.01 mm [1, 2]. Clouds vary not only on the height in which is formed, but also on the appearance, properties and may consist of particles of different size and origin. Formation and development of the cloud is connected with the thermodynamic conditions occurring in the ambient atmosphere, and inside the cloud. Maximum water vapour concentration in the atmosphere is 4 percent, and if it is reached then we talk about a hundred percentage of humidity. The size of the droplets, that form clouds, is different depending on the types of individual clouds. Rain clouds (Nimbostratus) contain the largest droplets of size up to one hundred micrometers. The smallest droplets are about nine micrometers. These droplets are contained in the clouds of Cumulus type, and Stratus.

Basic international classification divides clouds into 10 cloud types. Given the observed differences in appearance and internal structure of the clouds, the clouds were further separated into 14 basic shapes. For this reason, the cloud observed in the sky may be labelled with the name of only one shape, which means that shapes of clouds are mutually exclusive. Certain shapes can also be found in several types of clouds. The clouds may also have particular characteristics, which are called varieties and distinction nine of them [3, 4]. These distinctive features are related to the different arrangement of cloud elements (for example the arrangement in the form of waves, etc.) and more or less translucency. The variety may again be common to several kinds of clouds. For some clouds, the withholding stripes, shreds of low clouds, etc. can occur directly in the cloud or outside the cloud. These certain characteristic traits are referred to as peculiarities clouds. The following Figure 1 shows ten basic types of cloud. [5]

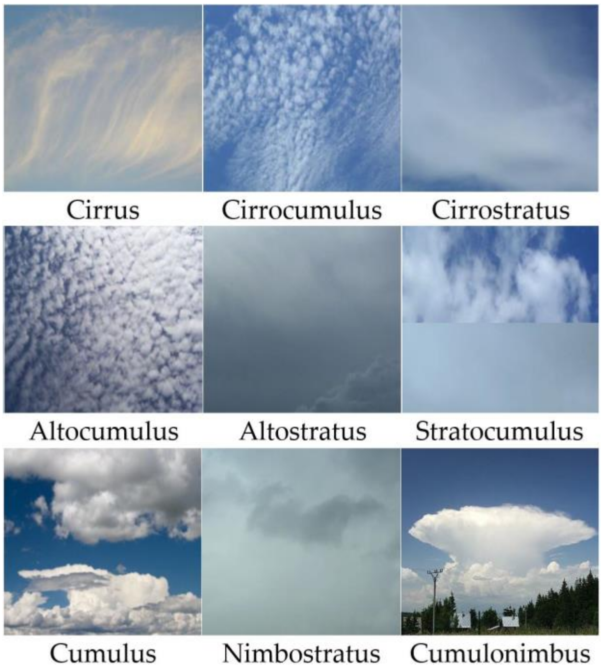

Fig. 1: Types of clouds. [5]

According to the altitude of its occurrence, the clouds are classified into three levels. The first level is low, which is up to 2 km from the earth's surface. Second level is medium (2-7 km) and last is high (5-13 km). Part of the sky covered with clouds is called cloudiness. [5] Cloudiness can be given in the eights (meteorologists) or in the tenths (climatologists) and expresses the fraction of the sky covered with clouds. Completely clear sky has zero cloudiness. If the sky is completely covered with clouds, the cloudiness is on code eight according to the scale used by meteorologists. Individual degrees of cloudiness used in meteorology are shown in following Table 1.

Table 1: The degree and brands of. [6]

Coverage x code	Meaning	Symbol
0/8 x 0	Sky completely clear	○
1/8 x 1	Sky completely clear	⦶
2/8 x 2	Almost sky completely clear	◔
3/8 x 3	Small cloudy	◔
4/8 x 4	Sky half cloudy	◑
5/8 x 5	Cloudy	◑
6/8 x 6	Cloudy	◕
7/8 x 7	Almost cloudy	◕
8/8 x 8	Sky completely cloudy	●
x 9	Sky obstructed from view	⊗

3 Description of the system

On the roof of the building FAI TBU is a small photovoltaic plant. The system consists of 9 photovoltaic panels with a total area of 11.25 m^2. The panels used, are of the type of polycrystalline photovoltaic cells. The producer of these panels has declared an energy efficiency of 15 % (for angle of the panels surface inclined from the horizontal one of 45° with the southeast azimuth of the normal direction to the panel surface). Installed panels are shown in figure 2.

Fig. 2: Photovoltaic panels.

Surface reaches 750 Wm^{-2}, the electric power produced by the panels should be P = 1265 W, based on the declared efficiency by the producer. The output DC voltage of the panels is converted by the AC voltage inverter in one phase AC current with the 230 V AC. This inverter is housed in the faculty laboratory of environmental engineering and energy efficiency is η_{euro} = 91.8 %. This value is measured under varying climatic conditions. Maximum efficiency was reached η_{max} = 93.5 % with the optimal measuring conditions (stable temperature conditions, nominal DC voltage and medium values of AC power). The rest of the converted energy is lost by the electrical conversion in the form of heat. [7,8]

4 Parameters validation

To determine the negative effects of different types of clouds on the electricity production of photovoltaic panels, we need to know their real effectiveness in operation. To verify this parameter, we need to know the total amount of energy produced by photovoltaic panels and the total amount of solar radiation that incident on the surface of the panels for longer period.

The total amount of solar radiation, that incident on the surface of the photovoltaic panels, can be measured directly by using a solarimeter device which is installed in the same angle as the panels. In this case, the energy of solar radiation that incident on the surface of the panels, which includes both direct and diffusion part of the radiation, is compared with the energy produced by the system.

The second option of the evaluation is to measure the solar energy by the solarimeter which is installed horizontally (the present case). The measured values of solar radiation by the solarimeter have to be then converted to the radiation that incident perpendicularly to the panels. This equation is given below according to CSN 73 0548 [7,9]. Solar declination is determined at 21st day of each month according to the equations (1) to (9):

$$\delta = 23{,}5\cos(30M). \tag{1}$$

where δ is solar declination [°],
M number of the month (1-12).

The solar declination δ is listed in table 1.

Table 2. Solar declination for each month.

Month	III	IV	V	VI	VII	VIII	IX	X
δ [°]	0	12	20	24	20	12	0	-12

The height of the sun above the horizon, h, for 50° north latitudes is given by the following equation:

$$\sin h = 0.766\sin\delta - 0.643\cos\delta\cos(15\tau) \tag{2}$$

where τ is solar time [h].

Solar azimuth, α in degrees, is determined from the north in a clockwise direction by the equation (3):

$$\sin\alpha = \frac{\sin(15\tau)\cos\delta}{h} \tag{3}$$

The angle between the perpendicular of the surface and the direction of the rays, Θ, is determined by the relationship (4):

$$\cos\Theta = \cos h\cos\alpha + \cos h\sin\alpha\cos(\alpha-\gamma) \tag{4}$$

The relation for the vertical surface is (5):

$$\cos\Theta = \cos h\cos(\alpha-\gamma) \tag{5}$$

and for the horizontal surface (6):

$$\cos\Theta = \sin h \tag{6}$$

where γ is azimuth angle (solar azimuth) [°],
α angle between the surface and the horizontal plane taken on the side acing away from the sun [°].

The intensity of direct solar radiation is determined as follows (7):

$$\dot{I}_D = \dot{I}_0 \exp[-0.097z(\sin h)^{-0.8}] \tag{7}$$

where $\dot{I}_D$ is intensity of direct sol radiation [Wm^{-2}],
$\dot{I}_0$ the solar constant, 1350 Wm^{-2},
z coefficient of air pollution.

For each month, these levels of pollution (Table 3) are recommended to use.

Table 3. Values of pollution by month.

Month	III	IV	V	VI	VII	VIII	IX	X
z [-]	3.0	4.0	4.0	5.0	5.0	4.0	4.0	3.0

The intensity of diffuse solar radiation, $\dot{I}_d$ in Wm^{-2}, is determined as follows (8):

$$\dot{I}_d = \left[\dot{I}_0 - \dot{I}_D - (1080 - 1.4\dot{I}_D)\sin^2\frac{\alpha}{2}\right]\frac{\sin h}{3} \tag{8}$$

The total intensity of solar radiation, $\dot{I}_C$ in Wm^{-2}, is calculated as (9):

$$\dot{I}_C = \dot{I}_D + \dot{I}_d \tag{9}$$

The theoretical intensity of solar radiation incident on both horizontal surface and the surface of the panels is calculated for each day and hour of the year using these relations. Based on this calculation, data obtained from the horizontally placed solarimeter are converted to the perpendicular direction of the panels and then we can evaluate the total energy incident on the panels. The energy efficiency of a photovoltaic system, η, is calculated according to an equation (10): [9,10,11]

$$\eta = \frac{P_m}{P_{rad}} = \frac{P_m}{\dot{I}_C \cdot A_C} \tag{10}$$

where P_m is performance of a PV panel [W],
P_{rad} power of the incident radiation [W],
$\dot{I}_C$ total intensity of solar radiation [Wm^{-2}],
A_C area of the photovoltaic cell [m^2].

5 Measurements

Collecting of meteorological conditions occurred at the placement of photovoltaic panels from October 2015 to January 2016. For this purpose, the weather station on the building of FAI was used which provided data on the average outdoor temperature and global solar radiation. Furthermore, the cloud amount occurring in Zlin was observed. This information was obtained from the Czech Hydrometeorological Institute (CHMI) that publishes this information on their website in the form of graphs. This includes a summary of the percentage coverage of the different types of cloudiness for high, medium, low and the total cloud cover for each hour occurring at the placement of photovoltaic panels. These data from graphs were regularly read out and written to the database. The last part of the record is complemented by information on the amount of electricity produced by photovoltaic panels.

The following table 4 shows the average values of the individual types of cloudiness occurring in each month of 2015 along with production of electricity of photovoltaic panels and the amount of solar radiation incident on a horizontal plane.

Table 4. Cloud occurrence in individual months of 2015.

Month	Coverage cloudiness [%]				Solar	PV
	Low	Med	High	Overall	[W/m^2]	[kWh]
Jan	56.28	49.62	30.11	77.53	26.39	1.27
Feb	43.01	44.57	40.18	69.92	73.62	2.82
Mar	40.01	42.17	41.39	66.35	115.12	4.84
Apr	44.26	31.17	29.16	54.18	203.11	7.02
May	31.28	39.25	30.05	46.23	202.02	6.86
Jun	18.98	22.16	25.28	40.66	274.57	8.23
Jul	23.64	19.66	22.47	41.81	271.81	7.74
Aug	22.38	27.93	29.31	44.75	226.50	7.27
Sep	42.37	35.12	29.18	53.25	146.66	5.49
Oct	40.23	44.49	42.19	68.61	80.73	3.11
Nov	34.06	46.63	42.88	68.81	52.14	2.65
Dec	45.40	35.14	30.65	62.25	23.27	1.32

In the months of December and January, resulting values of production of electrical energy, global solar radiation and the degree of the sky clouded were adjusted for days in which power were not produced due to unfavourable weather conditions. Especially in days when the solar panels were covered with a thick layer of frost or snow, which made it impossible to produce electricity for a significant part of the day. Table 5 details the values of electrical energy production for selected day in the month of November.

Table 5. Production of electricity in different parts of the day.

Time	Coverage cloudiness [%]				Solar	PV
	Low	Med	High	Overall	[W/m^2]	[kWh]
6:00	85	20	78	97	3.29	0.002
7:00	93	35	70	98	66.12	0.038
8:00	96	60	63	99	185.68	0.153
9:00	98	86	65	100	302.35	0.267
10:00	96	83	60	99	264.07	0.202
11:00	98	95	62	100	291.49	0.246
12:00	95	92	0	99	352.93	0.336
13:00	95	96	0	100	156.84	0.114
14:00	90	97	0	100	155.75	0.117
15:00	95	85	0	99	237.43	0.199
16:00	75	85	5	96	414.25	0.378
17:00	75	70	30	95	325.83	0.075
18:00	40	65	40	84	119.87	0.025
19:00	9	25	30	60	0.58	0.002
AVG	81.43	71.00	35.93	94.71	205.46	0.154

Figure 3 shows the dependence of production of electric energy and cloudiness in selected date in 2015 (degree of cloudiness in percentage).

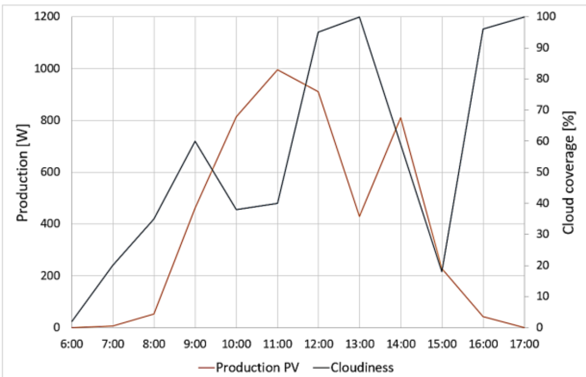

Fig. 3: The dependence of electrical energy production and cloudiness.

The dependence of the total production of electricity for cloudiness and intensity of the sunlight in the month of November is shown in Figure 4 (sky coverage is expressed in the eights).

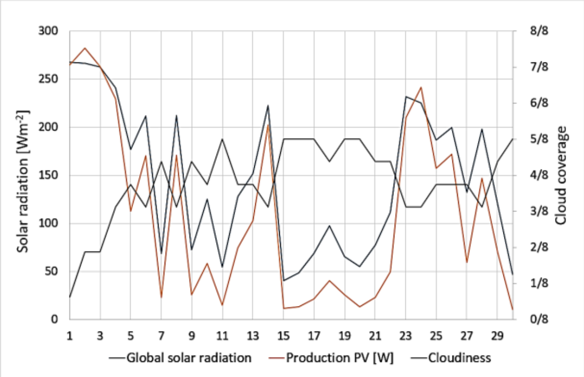

Fig. 4: The dependence of the total cloudiness on production electrical energy.

In 2015, the photovoltaic power plant produced 1,786 kW of electricity. The highest electricity production was recorded in June, because of the clouds cover was the lowest (see Table 4). Figure 5 shows the production of electricity in 2015.

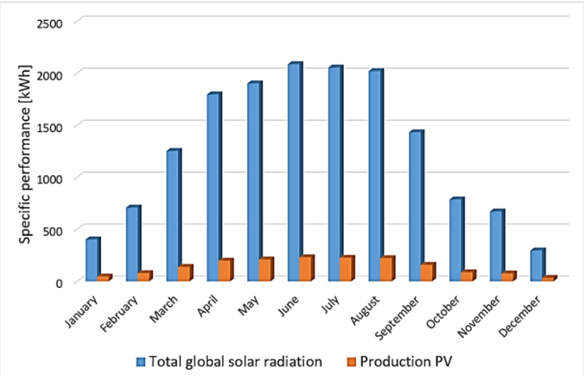

Fig. 5: Production electricity in 2015.

6 Results

From the measured values, which are listed in table 4, the occurrence of cloudiness in the different parts of the year, showing that the overall power production in individual months affects irradiance photovoltaic modules. On the other hand, the individual cloudy days do not affect the overall production of electricity. Decisive in this case, that the average value of the solar radiation and the lighting time of photovoltaic panels which are different each part of the year. Table 5 lists grade cloud cover, solar radiation and the amount of electricity produced by photovoltaic panels for each hour. These values were measured for each day in months. From these data, the values of the percentage coverage of the sky by different types of cloudiness, solar radiation intensity and the amount of electricity produced had been selected only 12 hours for each day of the month. All these values had been summarized in the database and linear regression was used to determine the effects of the percentage coverage of the sky clouds on the production of electricity photovoltaic panels. The results showed that the production of electricity by photovoltaic panels at the same percentage sky coverage of clouds is random. These measured data cannot determine the dependence between cloudiness and the production of the electricity. The same procedure was applied to determine the dependence of the cloudiness on the intensity of the global solar radiation incident on a horizontal plane. Even in this case, it showed that the intensity of the solar radiation is random and these measured data cannot define the dependence between the cloudiness and the light intensity on the horizontal plane.

7 Conclusion

In our case, the determination of the percentage of the dependence between cloudiness and the production of the electricity of photovoltaic panels cannot be determined from the collected data in number of reasons. The measurement of the percentage of coverage cloudiness can determine what cloud cover it is whether it is high, medium or low, but we cannot determine the strength of cloud cover, type and density of clouds, which are in various heights. This information is clearly essential for determining the influence of individual kinds of cloudiness on the production of electricity by photovoltaic panels, because the strength and type of cloud very substantially affects the transmittance of sunshine through the cloud. Based on the results, it is impossible to determine the effect of different types of clouds on electricity production of photovoltaic panels. The measured data shows that the most negative effect on the daily production of electricity is low cloud cover, because it prevents the passage of most of sunlight. Other climatic conditions that affect the production of electricity are ambient temperature, humidity (mist) the degree of air pollution and the wind, which increases heat dissipation from the surface of photovoltaic panels in clear days, and thus increases efficiency.

Further research will focus on determining the passage of the solar radiation different types of clouds. On the basis of these results, model that will determine exactly how clouds influence production of photovoltaic power plants will be created.

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