THE USE OF PHOTOVOLTAIC PANELS

Milan JUS*

Faculty of Special Technology, Alexander Dubček University of Trenčín, Pri parku 19, 911 06 Trenčín, Slovakia
*Corresponding author E-mail address: milan.jus@tnuni.sk

Abstract
This paper presents a photovoltaic renewable energy source system focused on the use of photovoltaics in Slovakia and at near abroad. The experimental section contains measurements, where there is a tendency to choose the best solar panels for orientation in a southerly direction, and performance differences were found in uniaxial and biaxial performance monitoring panels.

Keywords: renewable energy, photovoltaic, photovoltaic cells, photovoltaic panels, photovoltaic technology

1 Introduction

Renewable energy sources (RES) are natural energy (NE) resources which have the potential partial or full recovery. They are quite abundant, widespread, locally available and mainly organic. This group includes solar, wind, hydro, geothermal, biomass and heat pumps. In coastal areas it is possible to use energy in the form of ocean tides, ocean currents, waves and thermal energy absorbed by the sea. Slovakia has the greatest potential for use of solar energy, wind energy and biomass. Spaces for larger hydropower plants in our performances are exhausted. It is therefore clear that solar radiation as a clean and renewable source of energy for humankind in the long term perspective. It is therefore both necessary and proper, given proper attention.

In this paper, attention is devoted to the analysis of the photovoltaic (PV) system, its advantages and disadvantages for the use of RES (renewable energy sources) in Slovakia during the months of January to March. The purpose of this paper is to resolve further issues most suitable inclination of the photovoltaic panel (PVP) from the horizontal surface.

The solar energy had greatest importance in remote areas where is not power grid. The same disadvantage appears to be a low DC voltage of around 12 ÷ 48 V, but the usual small appliances exist in version 12 ÷ 48 V and can be change for example by standard AC 230 V inverter. The disadvantage may not even be uneven sunlight or night, when the sun does not shine at all. All the energy produced in the world today could be produced in PVP spanning 1000 x 1000 km^2. The solar batteries can compensate uniform supply of solar energy. Solar batteries may be settled (classical - electrochemical) or more efficient way of energy storage in hydrogen produced by electrolysis of water. [1]

In Slovakia legislation has started in 2008. Regulatory Authority adopted decree 2/2008, which provided the first condition promotion of RES. Only in August 2009, parliament adopted a law on the promotion of renewable energy sources (no. 309/2009). [3], [4]

The following *Table 1* represents the repurchase value of solar energy. [5]

Table 1 *The repurchase value of solar energy*

Year	The repurchase value of solar energy
2010	0,43072 € (up to 100 kW)
	0,42512 €/kWh (100 kWp)
2011	0,38765 €/kWh (up to 100 kWp)
	0,38261 €/kWh (100 kWp)
2012	0,25917 €/kWh (for roof installation)
	0,19454 €/kWh (for all devices)
	0,119 €/kWh (from July 1st)

Solar radiation striking the Earth has an average value of 1,367 W/m^2, which represents the solar constant. Performance radiation passing through the atmosphere decreases, due to reflection, absorption or scattering. In fine weather, the intensity of radiation at midday value of about 1000 W/m^2. Solar radiation onto the ground consists of the direct and diffuse radiation. Direct radiation prevails on clear days, on a cloudy day, when the sun is not visible is light, diffraction in the clouds, or haze in the ozone layer, so hit the ground diffuse radiation. This implies that the composition and intensity of solar radiation depends on the weather, time of the year, time of the day and latitude. Total irradiation in kWh/m^2 per year we will receive the sum the energy content of direct and diffuse solar radiation for every day of the year. This value depends on the granularity of the country. In the south of Slovakia during the year it recorded the most sunlight, while at least in the north. The difference represents a value of approximately 15% [kWh/m^2].

In our latitudes is more than 3/4 of incident solar energy captured in from April to September when the sun is low on the horizon, the extended path of sunlight, resulting in a lower intensity of spectral composition of sunlight. [6], [7]

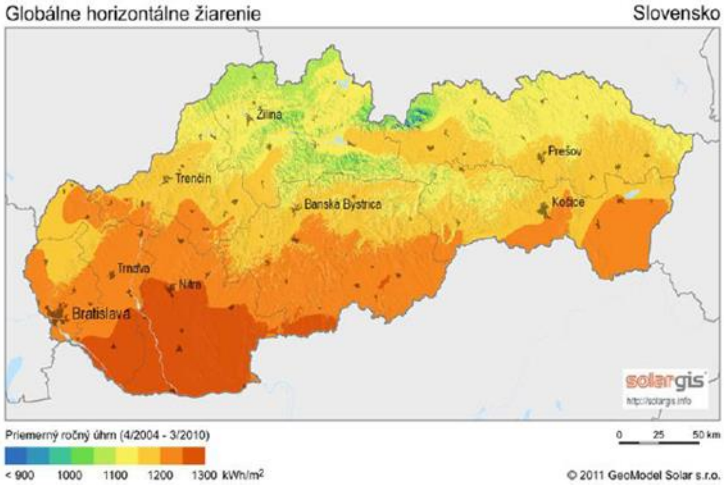

Fig. 1 *The global horizontal radiation*

2 The photoelectric effect

The conversion of electromagnetic radiation into electricity occurs in semiconductor solar cells. Semiconductor properties are the properties of metals and insulators. The conductivity of semiconductors such as conductivity metal, but they have some free electrons 10^{19} m-third Semiconductors differ from metal mainly temperature dependence of conductivity. The conductivity of metals after the temperature rises due to frequent precipitation of electrons with lattice decreases in semiconductor, on the contrary increases. The width of the band gap semiconductor is at less than 3 eV. According to the type of charge carriers are divided on its own semiconductors and extrinsic. Extrinsic semiconductor below the divided semiconductor of conductivity type P and N. [8]

Custom semiconductors have the final electron band fully booked and the following band is separated him from the prohibited zone. The temperature of semiconductor is 0 K, it is an insulator. If the temperature increases, increasing the oscillating energy of the atom lattice and at sufficient intensity oscillations of electrons, some of them can get into the conduction band. Electrons in the conduction band can move freely, the electrons in the valence band, which is not fully occupied, can move freely. In such a case it arises after the electron empty space that is positively charged - hole. The feature intrinsically conductive semiconductor is the amount equal number of electrons and holes, torn as electron leaves a hole in one.

P-type semiconductor containing the permitted energy levels in a restricted area where this provides an acceptor level.

If it is a semiconductor with conductivity of N-type and in a restricted area just below the conduction band is formed by donor level. Electrons that level are occupied with small increases in energy gets easily into the conduction band, which is free to move.

PN junction is situated between the dopant type semiconductor P-type and N-type. PN junction acts as a gate; it transmits the electrical current in one direction. Involvement can be permeable or inverse direction, so to flush one direction. Properties of PN junctions are used in semiconductor devices such as diodes, transistors, photodiodes, and others. [9]

3 Photovoltaic cell

FV cell presents essentially large-area diode in which PN passage is oriented perpendicular to the front face between the front and the rear. When the area to the impact of photons more energetic than the width of the band, these photons generates electron pairs - hole. Thus they transmit their energy and absorb up. In case of excess of power the kinetic energy transmitted in the form of precipitation of electrons to the screen, which is converted to heat, resulting in heating of semiconductor material. Couples electron - hole generated on P-N passes are separated by the electric field between the binding space charge. The holes are accelerated in the direction of the electric field and the electron reverse. Between the contacts of a solar cell appears a voltage and connection to the electric circuit, we can observe the flow of direct electrical current. FV article becomes a source of energy, so is the active component. [9]

In order to have a higher voltage, the PV cells associated with PV panels or solar modules and the daisy chain where all the solar cells through the same stream. The disadvantage of such a diagram, the resulting entity will deliver just such a current, which produces at least lighting or worst quality PV cell. In practice, the most commonly used solar cells with PN junctions on the basis of monocrystalline, polycrystalline or amorphous silicon. [2]

Photovoltaic cells under construction can be divided into:

1. Single crystal articles, consisting of a single crystal. Their articles are usually square or square with rounded or bevelled corners. Cell surface is dark blue to black, with fine crystal structure. Achieving average efficiency 15-17%. Shape of the article is determined during the production process. In the production of this kind are by immersing seeding of high-purity silicon melt pulls monocrystalline rod. It is cut to 0.3 mm thick plate of different geometric preferred design. The plates, which are already doped with P-type ingredients were steamed thin film phosphor. The settlement back contact layer and anti-reflective coating is applied, the articles are complete. Used on pitched roofs oriented to the south. They have the highest performance relative to square meter. Life of approximately 30 years, with a guaranteed 90% output after 10 years as the performance guarantee of 80% after 25 years. [7]
2. Polycrystalline cells are also called even more crystalline cells, recognizable characteristic sparkling blue and substantially crystalline structure plotted. It is produced by the silicon is heated in vacuum at 1500 °C and the graphite meld was gradually cooled to the freezing point. This generates polycrystalline blocks on the sides of 40x40 cm and a height of 30 cm. The blocks are cut into bars, and then to plate a thickness of 0.1 up to 0.3 mm. Then, the process is similar to that of monocrystalline cells. They used on pitched roofs, ground systems and vertical remains on the rise. They have less power per square meter than monocrystalline panels, with their positive the possibility of conversion and diffuse radiation. Their lifespan is 30 years, with a guaranteed 90 % output after 12 years as the performance guarantee of 80 % after 25 years. They are dominant in performance in the use of diffuse radiation that prevails in Central Europe. This technology achieves currently the best price / performance ratio. [7]
3. Thin-film photovoltaic technology has their own photovoltaic cell geometry. Thin film technologies emerge deposition of layers on semiconductor substrate, where there is a photovoltaic cell with a thickness of 1-5 microns on a support material (glass, metal, or plastic film). They exhibit a great savings in the consumption of starting materials. There technologies are used:
    a. Amorphous silicon 4.5 to 9.5%, with effect, which is achieved by the combination of several layers of microcrystalline silicon. Each layer is doped with other elements so that the total energy use of solar light spectrum was up. They are made up of three layers of semiconductor of one another. [10]
    b. CIGS - (copper, indium, gallium diselenide) with effect from 8.5 to 12.5%, it is to achieve the highest efficiency commercially produced solar panels.
    c. CdTe - (Cadmium) as 6 - 11%, it is achieved with the highest energy levels from all solar technologies, the low entry cost. [11]

    Their uses are found in the solar plant, which is not limited land area. The advantage is the possibility of installing them in the wrong orientation of the roof and the area where I often cloudy. Upon impact, diffuse light has the highest performance per watt installed. The disadvantage is the lowest power per m^2. With these systems it is necessary to have an area of 2.5 times the power of the crystalline panels. They have a lifetime 20 years with a guaranteed 90% output after 10 years as the performance guarantee of 80% after 15 years. [12], [13]

4 Measurement of the photovoltaic panels in diffuse radiation

To measure the solar panel was made with thirty six photovoltaic cells that were connected in series.

Measuring diffused radiation at cloudy conditions, the sun did not work during the day temperature in the range from 0.8 to 1.2 °C. The PV panel was mounted in a southerly direction - the active part, filmed panel uniaxially - vertically deflected from the horizontal base.

The first measurement was made out at zero angles - horizontally panel and continues with 10 degree incline photovoltaic panel. The first phase measurement is terminated after reaching the right angle between the panel and base horizontal. The response of diffuse radiation on the PVP was registered every hour, starting eighth and finishing seventeenth hour. The values detected by measuring instruments, are listed in Table 1 and Table 2.

From the measured data, it is clear that the position in which the PVP absorb the most energy is varied in the 30-40 horizontal degrees. Panel showed diffused radiation still "tolerable" results in the range of 0-50°. Outside this range of inclination panel data showed significantly lower profits, which it is in normal practice not usable. It is worth noting is the fact that out of a total possible gain 30 W, which provides panel according to the nameplate, was recorded during the day power summit at 12:00 AM and 30 degree inclination the power value only 4.68 W.

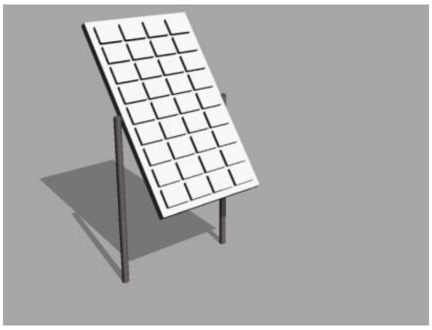

Fig. 2 *The model of photovoltaic panel [14]*

Table 1 *Measurement of the photovoltaic panel in diffuse radiation between 8:00 and 12:00*

Time	8:00			9:00			10:00			11:00			12:00		
α[°]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]
0	16,1	11,9	0,19175	31,2	14,8	0,46176	70,8	17,5	1,23617	155,2	19,4	3,01709	183,3	19,8	3,63117
10	17,4	12	0,20793	30,1	14,8	0,44488	72,6	17,7	1,28429	154,1	19,5	3,00803	199,6	20	3,994
20	18	12,1	0,21708	31,5	14,7	0,46305	71,9	17,7	1,26904	151,1	19,4	2,9253	211,7	20,2	4,28269
30	17,6	12	0,21138	32,6	14,8	0,48313	72,8	17,7	1,28638	153,9	19,6	3,01336	230,2	20,4	4,68687
40	13,9	11,7	0,16319	29,7	14,5	0,43095	65,9	17,5	1,14996	145,5	19,5	2,83871	212,3	20,3	4,31818
50	12,6	10,9	0,13709	27	14,2	0,38232	61,8	17,7	1,0951	132,9	19,3	2,57029	210,4	20,2	4,25639
60	11,6	10,6	0,12238	22,8	13,4	0,3062	55,4	17	0,93903	122,1	19,2	2,34554	209,6	20,3	4,26326
70	9,7	10	0,0971	20	12,6	0,2514	78,8	16,6	1,30887	103	19	1,95288	205,8	20,3	4,17362
80	10	9,63	0,0963	17,6	12,3	0,2156	43,3	16,1	0,69626	104	19	1,97288	191,2	20,3	3,88901
90	9,2	9,36	0,08611	16,1	11,8	0,1895	37,7	15,3	0,57794	86,8	18,4	1,59799	168,6	20,1	3,38717

Table 2 *Measurement of the photovoltaic panel in diffuse radiation between 13:00 and 17:00*

Time	13:00			14:00			15:00			16:00			17:00		
α[°]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]
0	125,4	18,9	2,3663	74,6	17,8	1,3249	43	16,4	0,70649	13,1	11,2	0,14607	0,064	0,81	5,2E-05
10	135,5	19	2,57315	76,1	17,8	1,35686	43,7	16,5	0,71974	13,7	11,4	0,15563	0,054	0,73	3,9E-05
20	135,8	19,1	2,58699	74	17,8	1,3172	42,1	16,4	0,69044	14,3	11,5	0,16502	0,049	0,69	3,4E-05
30	130,3	19	2,4757	76,2	17,9	1,36169	43,6	16,5	0,71722	14,8	11,7	0,17316	0,044	0,64	2,8E-05
40	124,7	19	2,36431	71,8	17,7	1,27158	40,8	16,1	0,65851	13,3	11,2	0,1483	0,041	0,6	2,5E-05
50	115	18,8	2,16545	65,8	17,5	1,15347	35,9	15,6	0,5604	12,5	10,9	0,13575	0,037	0,57	2,1E-05
60	104,2	18,7	1,94333	62,6	17,4	1,08799	32,1	15,1	0,48599	11,8	10,6	0,12473	0,034	0,52	1,8E-05
70	95	18,4	1,75085	57	17,1	0,97413	29	14,7	0,42485	10,2	9,88	0,10078	0,032	0,5	1,6E-05
80	81	18	1,45881	50,4	16,7	0,84118	25,2	14	0,3528	8,9	9,27	0,0825	0,029	0,47	1,4E-05
90	65,9	17,4	1,14798	36,1	15,8	0,57182	18	12,8	0,23058	6,4	8,32	0,05325	0,025	0,42	1,1E-05

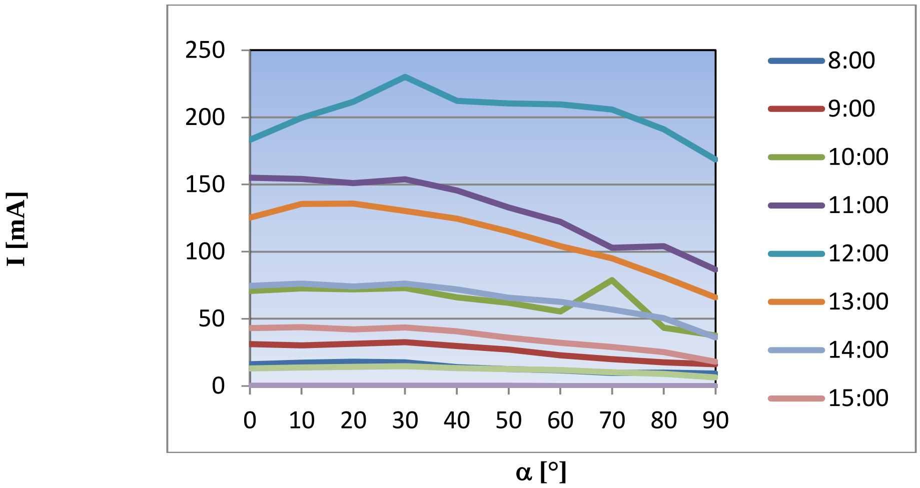

Fig. 3 *The measured current value I=f(α) for diffuse radiation*

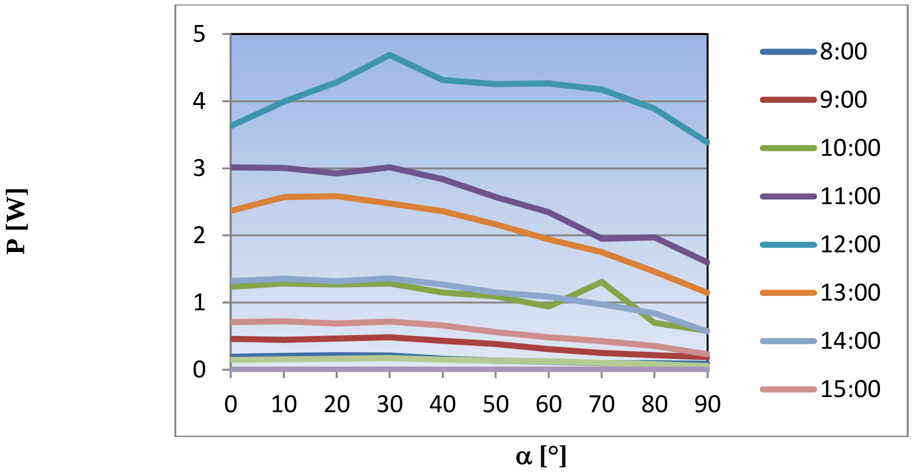

Fig. 4. *The measured power value P=f(α) for diffuse radiation*

5 Measurement of the photovoltaic panels under clear sky – direct radiation

Measurements carried out in clear weather, temperatures during the day range from -1.6 °C to 4.2 °C, the PVP mounted in a southerly direction, filmed panel uniaxially - vertically deflected from the horizontal base.

The measurements were carried out in clear weather, temperatures during the day range from -1.6 °C to 4.2 °C, the PV panel mounted in a southerly direction, filmed panel uniaxially - vertically deflected from the horizontal base.

Table 3 *Measurement of the photovoltaic panels under clear sky between 8:00 and 12:00*

Time	8:00			9:00			10:00			11:00			12:00		
α[°]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]
0	0,57	21	0,011959	0,51	20,8	0,010613	0,62	21	0,0130138	0,92	21,1	0,019384	0,99	20,8	0,020632
10	0,53	21	0,011109	0,59	21,9	0,012915	0,67	21,1	0,0141102	1,01	21,2	0,021382	1,07	21,1	0,022566
20	0,54	20,9	0,011308	0,59	21,8	0,012886	0,62	21,1	0,0130944	1,04	21,2	0,022069	1,17	21,2	0,024781
30	0,47	20,9	0,009828	0,57	21,7	0,012375	0,65	21,2	0,013767	1,12	21,3	0,023834	1,26	21,2	0,026712
40	0,34	20,6	0,00699	0,5	21,5	0,010765	0,69	21,2	0,0146418	1,04	21,1	0,021965	1,42	21,5	0,030459
50	0,3	20,4	0,006123	0,46	21,4	0,009835	0,78	21,4	0,0167232	1,09	21,2	0,023108	1,47	21,5	0,031561
60	0,27	19,9	0,005378	0,44	21,3	0,009385	0,73	21,4	0,0155928	1,14	21,4	0,02435	1,4	21,5	0,03003
70	0,17	19,5	0,003322	0,31	20,8	0,006451	0,6	21,2	0,012714	1,08	21,3	0,023004	1,45	21,5	0,031175
80	0,16	19,6	0,003139	0,3	20,8	0,006231	0,58	21,1	0,0122264	1,02	21,3	0,021706	1,27	21,3	0,027102
90	0,16	19,6	0,003138	0,19	20,2	0,00383	0,28	20,3	0,0056896	0,83	21	0,01743	0,96	21,1	0,020256

Table 4 *Measurement of the photovoltaic panels under clear sky between 13:00 and 17:00*

Time	13:00			14:00			15:00			16:00			17:00		
α[°]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]	I[mA]	U[V]	P[W]
0	1,18	21,7	0,025606	0,98	22,2	0,021717	0,58	21	0,0121858	0,22	20,2	0,004437	0,05	16,8	0,000841
10	1,27	21,7	0,027508	1,17	22,1	0,025845	0,73	21,3	0,0155417	0,31	20,5	0,006358	0,07	18	0,001262
20	1,39	21,6	0,030024	1,24	22	0,027305	0,85	21,4	0,0182155	0,34	20,7	0,007021	0,09	18,6	0,001672
30	1,46	21,5	0,031448	1,42	22	0,031254	1,08	21,7	0,0233928	0,36	20,9	0,007524	0,1	18,9	0,001893
40	1,58	21,5	0,033954	1,55	22	0,034023	1,22	21,8	0,026535	0,42	21,1	0,008854	0,13	19,2	0,002493
50	1,65	21,3	0,035079	1,66	21,8	0,036188	1,4	21,8	0,030548	0,45	21,3	0,009567	0,13	19,5	0,002532
60	1,65	21,2	0,034931	1,75	21,6	0,037853	1,44	21,8	0,0314208	0,54	21,3	0,011502	0,17	19,9	0,00338
70	1,63	21,1	0,034377	1,78	21,4	0,038145	1,53	21,8	0,0333846	0,64	21,4	0,013683	0,18	20,1	0,003618
80	1,5	21	0,03144	1,74	21,3	0,03701	1,56	21,8	0,0339456	0,63	21,4	0,013488	0,18	20,2	0,003631
90	1,17	20,5	0,024032	1,57	21,1	0,033049	1,53	21,7	0,033201	0,66	21,3	0,014084	0,18	20,3	0,003645

It is occurred when measuring are going at each change of rotation at the diffuse radiation. The measured data are listed in the table for each change of rotation. The measurement is performed every hour on a sunny day. The most favourable values were at 14:00 pm, at an inclination of 70 degrees. Circuit voltage was 21.43 V and short circuit current of 1.78 A, which corresponds to the theoretical performance of 38.15 [Wp]. In this case, the panel showed unstable power limits at the various stages tilt. In judges' panel hours just tilting at an angle of 0-30 ° panel reached the highest values. At mid-day panel exhibited excellence at an angle of 40-70 °. In the early evening hours he reached its peak at 60-90 °. When uniaxial Shooting, solar radiation incident on the solar panel at different angles and rarely perfect (upright). It is caused by solar altitude.

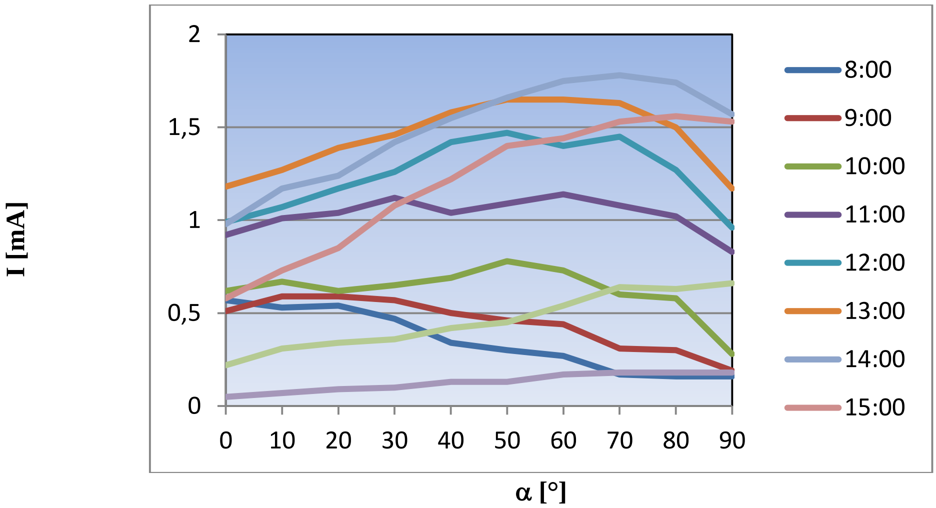

Fig. 5 *The measured current value I=f(α) for direct radiation*

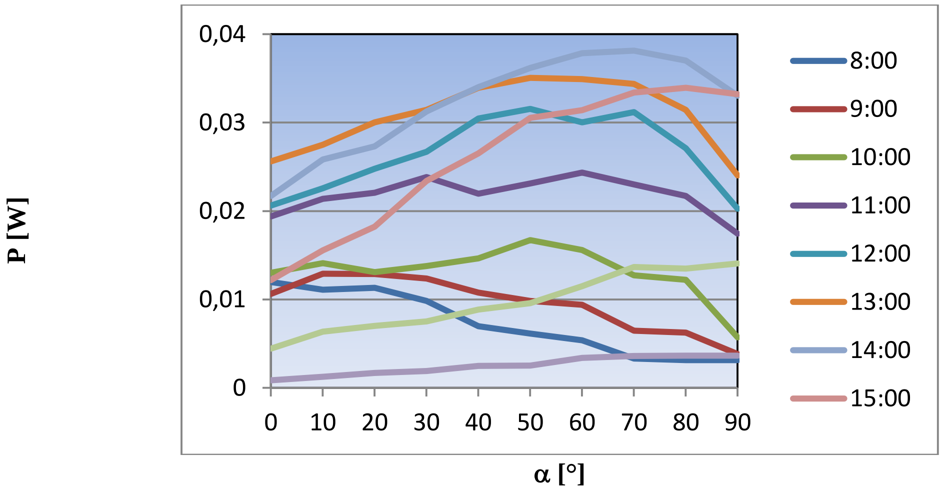

Fig. 6. *The measured power value P=f(α) for direct radiation*

6 Conclusion

Solar radiation that penetrates the atmosphere and reaches the Earth's surface is either reflects or absorbs. Photovoltaic is able to utilize radiation diffuse reflected or direct form of radiation, but other values of performance gain. The enormous growth of energy PV panels is observable in direct sunlight. In uniaxial vertical shooting panel he showed a nearly tenfold profits compared with diffuse radiation. The most effective system can be constructed by using the movable solar mechanisms follower the position of the sun (sun trackers). Loss of power occurs at contaminated surface and photovoltaic panels. For larger mounting surface, the panels involved in serial - parallel blocks, where the quality of the surface of one of the panels causes a decrease in performance of the entire unit, which constitutes a loss when the dust settled, pollen or faeces up to 23% on a branch. To maintain the purity of the panels need to constantly monitor their surface, ensuring long-term efficacy at highest level.

Acknowledgements

The paper was treated within the project no. ITMS 26220220083 "Research technological base for designing applications for renewable energy in practice" EU operational program "Research and Development".

Európska únia
Európsky fond regionálneho rozvoja
Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ
Podporujeme výskumné aktivity na Slovensku
Projekt je spolufinancovaný zo zdrojov ES
Operačný program
VÝSKUM a VÝVOJ

References

[1] M. Libra, V. Poulek: Fotovoltaika. Teorie i praxe využití solární energie. vyd. ILSA Praha, 2009, 160 s. ISBN 978-80-904311-0-2

[2] A. Bartoš, P. Coufal, E. Bullová: Sledujte budúcnosť vo fotovoltike. In SOLAR technika, 2/2010, vyd. Techpark, o. z., s. 70-71 ISSN 1338-0524

[3] P. Šimon: Viac svetla do nejasného stavu fotovoltiky na Slovensku. In SOLAR technika, 1/2010, vyd. Techpark, o. z., s. 40-41, 2010, ISSN 1338-0524

[4] P. Šimon: Prečo na Slovensku nehrozí český „solárny boom“. In SOLAR technika, 2/2010, vyd. Techpark, o. z., s. 36-38, 2010, ISSN 1338-0524

[5] Fotovoltaika na Slovensku. 2012 [online]. [cit. 2015-11-02]. Dostupný z: http://www.fotovolt.sk/fotovoltaika_na_slovensku.php

[6] Globálne horizontálne ožiarenie. [online]. [cit. 2015-11-02]. Dostupné z: http://sk.wikipedia.org/wiki/S%C3%BAbor:SolarGIS-Solar-map-Slovakia-sk.png

[7] R. Haselhuhn: Fotovoltaika. Budovy jako zdroj proudu. vyd. HEL Ostrava- Plesná, 2011. 176 s. ISBN 978-80-86167-33-6

[8] Fyzikální podstata fotovoltaické přeměny solární energie. [online] [cit. 2015-11-03]. Dostupný z: http://www.odbornecasopisy.cz/index.php?id_document=34990

[9] M. Libra, V. Poulek: Fotovoltaika. Teorie i praxe vyuţití solární energie. vyd. ILSA Praha, 2009, 160 s. ISBN 978-80-904311-0-2

[10] A. Klenovčáková, T. Brestovič: Možnosti využívania fotovoltaických článkov na výrobu elektrickej energie. [online]. [cit. 2015-11-03]. Dostupný z: http://www.asb.sk/tzb/fotovoltaika/moznosti-vyuzitia-fotovoltickych-clankov-na-vyrobu-elektrickej-energie-1669.html

[11] R. Čada: Srovnání a výhody tenkovrstvých technologií ve fotovoltaice. SOLAR technika, 1/2010, vyd. Techpark, o. z., s. 34-38, 2010, ISSN 1338-0524

[12] K. Drienovská: Fotovoltaické panely ich význam a použitie. [online]. [cit. 2015-11-03]. Dostupný z: http://www.enoviny.sk/print.phtml?cid=66995

[13] D. Vítek: Jak správně na fotovoltaiku aneb krok za krokem k optimálnímu výkonu. In SOLAR technika, 2/2010, vyd. Techpark, o. z., s. 10-12, 2010, ISSN 1338-0524

[14] M. Gombár: Demonštračný a testovací systém fotovoltaického obnoviteľného zdroja energie (OZE). Bakalárska práca. Trenčín: Trenčianska univerzita Alexandra Dubčeka v Trenčíne, Fakulta špeciálnej techniky, 2013, 62 s.