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An empirical correlation of ambient temperature impact on PV module considering natural convection

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ABSTRACT

In this paper, the effect of the ambient temperature on the PV modules for different angles of inclinations and different intensities of the solar radiation on the surface of the PV module is considered by using empirical correlations for natural convection. An analytical model based on the energy balance equilibrium between the PV module and the environment conditions has been used. Also an expression for calculating the electric power of silicon PV modules in a function of the ambient temperature, the intensity of the solar radiation, the incident angle of the solar radiation to the surface of the PV module and the efficiency of the PV modules at STC conditions have been used. By comparing the obtained both results, it can be seen that the largest deviation between the power values obtained by the analytical model and expression is about (5 %). The results obtained indicates that in the case of a small number of PV modules corresponding to the required number for an average household, it is more economical to invest additional resources in increasing the PV module's surface area than in case of the PV module with sun tracking system.

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1. INTRODUCTION

The energy of solar radiation is the largest and inexhaustible source of energy on Earth available on all parts of its surface. Since this energy is free and does not affect environmental pollution, so, it is understandable why huge attention is paid to the systems for the exploitation of solar energy, especially in last two decades [1]. The direct conversion of the sun into electricity by means of PV modules today provides a small percentage of the world's electricity demand. The main reasons for this are the relatively high prices of the PV modules, but also their low efficiency, which, depending on the type of the commercial PV modules which ranges from 10 to 18% [2]. This means that more than 80% of the energy of the solar radiation that enters the surface of the PV module is converted into heat, while the smaller part is reflected. However, the International Energy Agency (IEA) predicts that by 2050, 45% of the world's energy will be produced from the Sun's energy [3]. It is well known that the efficiency of the PV module is greatly depends on its temperature. With the increase in the temperature of the PV module, the voltage of the PV module is reduced, resulting in a decrease in its efficiency. This problem is particularly pronounced in areas with a warmer climate such is our country (Iraq republic).

In this paper, the application of the analytical model considers the influence of the ambient temperature, the intensity of the solar radiation, the angle between the normal on the upper surface of the PV module and the incident solar radiation, the temperature of the PV module and its corresponding efficiency were analyzed. On the basis of the obtained results, the expression for calculating the electric power of the

PV module is proposed depending on the above mentioned parameters under the conditions of heat exchange between PV modules and ambient through natural convection and radiation. The process of heat exchange through natural convection and radiation between PV modules and the environment is modeled by empirical analytical model for the determination of temperature and electric power of PV modules.

There are many models in the literature for determining the temperature of the PV modules [4]. However, all models give different results for the same values of intensity of solar radiation and ambient temperature. These differences are due to the neglect of the influence of individual parameters, climatic conditions, PV module configuration and various approaches to problem solving. In this paper, an analytical model based on the equation of the energy balance between the received energy of the solar radiation, the part of this energy converted to an electric in the PV module and the exempted thermal energy from the PV module through natural convection and radiation is applied to determine the temperature of the PV module.

1.1. Literature review

There are a large number of papers in the literature dealing with the problem of the influence of different parameters on the performance of the PV modules. In [4], there is a constant decrease in the efficiency of the PV module relative to the value prescribed by the manufacturer for the temperature of the module of 25 ° C, when its temperature is higher than this value. This means that it is necessary to install a larger number of PV modules in order to achieve the required power in real conditions of exploitation in relation to the STC conditions of the PV module. A set of correlations is proposed for determining the required surface of the PV module for a certain power in the function of the ambient temperature, the intensity of the solar radiation and other construction parameters of the PV module and the same is applied to the climatic conditions in [5].

Mattei et al. [6] analyzed the performance of the PV module for three different variables: ambient temperature, intensity of solar radiation and wind speed without taking into account the effect of radiation and the angle of the PV module. In [7], an assessment was made of the individual influence of the intensity of the Sun's radiation, its spectrum and the temperature of different types of silicon PV modules on their performance. Skoplaki et al. [8] suggested semi empirical correlations for determining the efficiency of the PV modules and their power depending on the temperature of the ambient, the intensity of the solar radiation, the wind speed and the modes of PV modulation. However, the correlations in are recommended only for wind speeds greater than 1 m / s [9].

2. MATERIALS AND METHOD

In this paper, the specific PV module SUNTECH STP265 - 20 / Wem is made of polycrystalline silicon. Silicon Solar cells have been developed among the earliest and most used today. The PV module made of p-Si was chosen because today in the world about 60% of the electricity produced by PV modules is produced precisely in modules from p-Si [10, 11]. At today's level of development, most commercial Si modules have an efficiency of 15-18% and very uniform characteristics regardless of the manufacturer, so that the conclusions derived from the PV module whose data are given in Table 1.

Table 1. Characteristics of the SUNTECH STP265-20/WEM module [12-16]

Size	Value	Size	Value
Width [W] Height [*L*]	1.00 m 0.64 m	Absorption coefficient for the upper surface of the PV module (αS)	0.97
Maximum power at STC conditions [Pmax]	265 W	Coefficient of emission for the upper surface of the PV module (ε_{UF})	0.91
Efficiency degree for STC conditions [ηTref]	16.3%	Emission coefficient for the bottom surface PV module (ε_{DF})	0.85
Temperature coefficient [βref]	0.004 1/K	STC: Intensity of solar radiation 1000 W / m^2, PV module temperature 25℃, R, AM = 1.5	
Reference temperature [Tref	25 ℃		

The angels that determine the optimum panel position is demonstrated in Figure 1

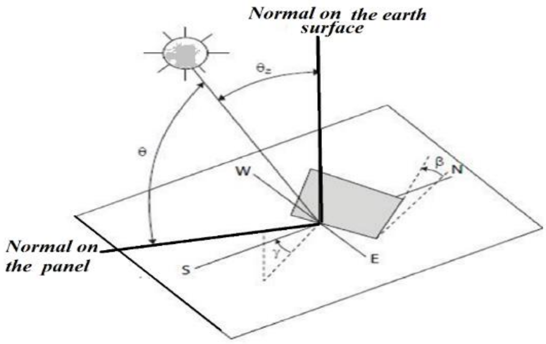

Figure 1. The angels that determine the optimum panel position [17]

3. MATHEMATICAL MODULE USED IN THE ANALYSIS

The model includes all the relevant values that affect the temperature of the PV module, which makes the results obtained by it very reliable. The model is described in detail and only the finite expression for calculating the temperature of the PV module in the case of heat exchange between this module and the environment through natural convection and radiation is given here [18-20]. Table 2 illustrate the parameters description indicated in the above equations.

$$T_{Pv} = \frac{(1+\eta Tref \cdot (\beta ref \cdot Tref-1))\alpha S \cdot Q + (hUF + hDF) \cdot Ta + (hr,UF + hr,DF) \cdot 0,0552 \cdot T_a^{1.5}}{h_{UF} + h_{r,UF} + h_{DF} + h_{r,DF} + \eta_{Tref} \cdot \beta_{ref} \cdot \alpha \cdot Q_S} \quad (1)$$

$$h_{r,UF} = \varepsilon_{UF} \cdot \sigma_{SB} \cdot \left(T_{PV}^2 + T_{Sky}^2\right) \quad (2)$$

$$h_{r,DF} = \varepsilon_{DF} \cdot \sigma_{SB} \cdot \left(T_{PV}^2 + T_g^2\right) \cdot (TPV + Tg) \quad (3)$$

$$Q = G \cdot \cos\delta \quad (4)$$

$$Tsky = Tg = 0,0552 \cdot T_a^{1.5} \quad (5)$$

$$\eta e = \eta Tref[1 - \beta ref(T - Ta)] \quad (6)$$

Table 2. Parameters description indicated in the above equations [21-24]

Parameter	Description	Unit
T_{PV}	The mean value of the PV modulus temperature.	[K]
α_S	The solar radiation absorption coefficient for upper surfaces of the PV module.	
Q	Component of solar radiation is normal on the upper surface of the PV module.	[W / m^2]
h_{UF}	Coefficient corresponding to the natural convection between the upper surface of the PV module and the air.	[W / (m^2 · K)]
h_{DF}	Coefficient corresponding to natural convection between the lower surfaces PV mod. and air.	[W / (m^2 · K)],
$h_{r,UF}$	Coefficient corresponding to the radiation between the upper surface of the PV module and ambient.	[W / (m^2 · K)]
Tg	The temperature of the earth.	[K].
ε_{UF}	Emission coefficient thermal radiation from Upper surface of the PV module.	
σ_{SB}	Stefan-Boltzmann constant.	[W / (m^2 · K4)],
G	Intensity of solar radiation (direct component).	[W / m^2]
Ψ	Angle of PV module inclinations in relation to the vertical	[°]
ε_{UF}	Emission coefficient thermal radiation from upper surface of the PV module.	
δ	Angle between the direction of the Sun rays and normal on the upper surface of the PV module.	[°]
η_{Tref}	Efficiency of PV modules at reference temperature T_{ref} and intensity of solar radiation of1000 W / m^2.	[%]
β_{ref}	Temperature coefficient that describes a decrease in the efficiency of the PV module with an increase in the PV module temperature above the reference value T_{ref}.	[1 / K]

More information on this module and the corresponding correlations used for modeling natural convection can be found in [19]. When in the iterative process the temperature of the PV module is calculated by (1) and its corresponding efficiency by (6), then the electric power of the PV module at its ends can be calculated as [25]:

$$Pel = \eta el \cdot \alpha S \cdot Q \cdot S \quad (7)$$

Where S is the active surface of the PV module in [m2].

4. RESULTS AND DISCUSSION

Using the above-described analytical model, the electric power generated by the PV module ***Pel*** at its connection ends for different ambient temperature values, the intensity of the sun's radiation and the incident angle of the sun radiation on the top of the PV module, as the most important parameters affecting the performance of the PV module will be calculated. On the basis of the performed analyzes, it was established that for different angles of the PV modulation of the ψ and the constant value of the intensity of the solar radiation on its upper surface G and the angle between the direction of the sun's irradiance and normal on the upper surface of the PV module δ, the electric power generated ***Pel*** by the PV module is slightly changed.

Therefore, all calculations are carried out for the same angle of (ψ = 60°), which is the optimum tilt angle of the PV module relative to the Tikrit city) and the angle δ changes in the range 0° ≤ δ ≤ 60° with a step of 10°. The change of the azimuth angle of the PV module slightly disturbs its electric power (only 4% in the case of the azimuth angle of the PV module of ± 45°),that means the azimuth angle of PV panels considered to be constant (azimuth = 0°). Such a small change is due to the fact that solar power is not obtained only directly from the un, but also by the diffusion of air through the atmosphere and the reflection of air from objects on the earth. Figures 2, 3 and 4 illustrate the electrical power in the panel output obtained by performing the previously described analytical algorithm (7)for different values of δ and for three values of G : (G = 200 W / m2), (G = 400 W / m2) and (G = 1000 W / m2).

Table 3 gives the mean values of the intensity of solar radiation on the horizontal surface of the location of the considered place, as well as the mean monthly value of values corresponding to the warmer part of the day when the PV modules are used are taken.

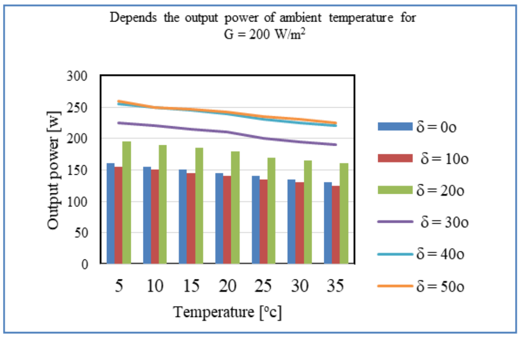

Figure 2. Power values of PV modules for different values of δ and when G=200 W/m2

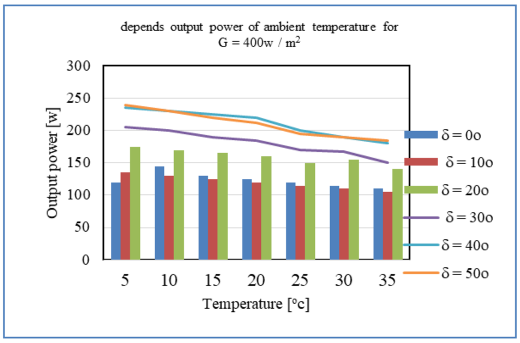

Figure 3. Power values of PV modules for different values of δ and When G = 400 W / m2

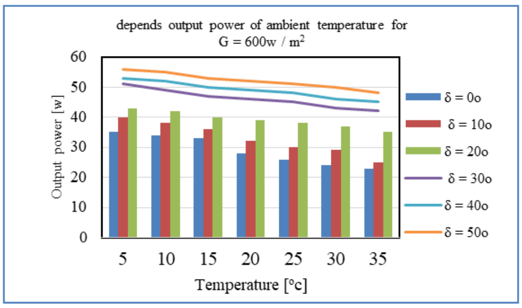

Figure 4. Power values of PV modules for different values of δ and When G = 600 W / m2

Based on the results obtained by performing the previously described analytical algorithm, which are shown in Figures 1, 2 and 3, a correlation is proposed for determining the power of the PV module in the ambient temperature function, the intensity of the radiation, degree of efficiency of PV module specified by the manufacturer under STC conditions and the inclined angle of the panel, the output power of the photovoltaic panel can also be calculated by using the following equation:

$$P_{el} = 0.0386 \,.\, \eta_{Tref} \cdot S \cdot \left[\frac{G}{1000}\right]^{0.92} .\, (cos\delta)^{0.9} .\, (245 \; - Ta\,) \tag{8}$$

In the (8), the degree of efficiency of PV modules under STC conditions ηTref is expressed in [%], intensity of solar radiation G in [W / m2], angle δ in [°] and ambient temperature Ta in [°C]. In this way, the (8) gives the electric power in [W]. By using the formula (8), an analysis of the electricity production of this system will be performed for two cases of the angle of inclination of the PV modules follows:

a) when the angle of inclusion of the PV module is constant.
b) when it changes for each month.

Table 2 gives the mean values of the intensity of solar radiation on the horizontal surface of the location of the considered place, as well as the mean monthly value of the angle at which the sun rays fall to the horizontal surface of the earth for the location of the Tikrit city (latitude: 29º57'47 ", longitude: 41º49'51"). For the temperature, the mean values corresponding to the warmer part of the day when the PV modules are used were taken.

Based on the data from Table 2 and using the formula (8) for a specific set of 8 PV modules of type AS-5M-200 W which have the characteristics (ηTref = 15.67%, Length = 1.58 m, Width = 0.808 m), the electrical power of the PV module can be calculated and then compared with the electrical output power results by the previously described module.

The proposed formula (8) will now be used to calculate the power of a series of PV modules used to supply the electrical power to the considered place. PV modules are mounted at an angle of 45°. The optimal value of the angle of inclination for the whole year for the considered location was obtained by multiplying the geographical width of the location at which the PV module is located at 0.9, while the optimal values of the inclination angles for each month are obtained so that the modules receive the highest energy of the sun's radiation in the period between 9 and 15 h when it is most intense.

The results are given in Tables 3, 4 and 5 which illustrate the expected electrical power generation for 8 PV modules (type AS-5M-200 W) obtained by using (8) for parameter values from Table 2 and two cases, in the first case when the inclination angle (Ψ) is constant, while in the second case when the angle of inclination (Ψ) is changing for each month of PV module.

Table 3. The mean values of solar radiation intensity on horizontal earth surface

Time	Parameter	Jan.	Feb.	Mart	Apr.	Maj	June	July	Avg.	Sep.	Oct.	Nov.	Dec.
6-9 h	G [kW/m^2]	0.02	0.05	0.11	0.23	0.24	0.30	0.33	0.24	0.17	0.12	0.03	0.03
	δ [°]	7.71	13.35	22.45	32.6	39.72	43.01	39.57	34.91	28.42	20.65	12.89	7.55
9-12 h	G [kW/m^2]	0.21	0.30	0.42	0.36	0.45	0.63	0.67	0.61	0.53	0.36	0.22	0.19
	δ [°]	23.67	31.67	42.15	53.56	62.17	66.27	64.33	57.32	47.43	36.37	26.81	22.03
12-15 h	G [kW/m^2]	0.24	0.34	0.43	0.46	0.52	0.58	0.63	0.60	0.45	0.33	0.22	0.19
	δ [°]	17.27	25.1	34.05	42.16	49.21	52.9	52.23	46.33	36.53	25.67	16.29	13.66
15-18 h	G [kW/m^2]	0.04	0.09	0.16	0.20	0.26	0.33	0.24	0.68	0.07	0.06	0.03	0.06
	δ [°]	8.71	15.55	26.45	33.2	41.62	45.01	41.27	36.21	29.62	22.65	42.89	9.85
	T_a [°C]	5	8	13	18	23	27	29	29	23	19	12	5

Table 4. Expected electrical power generation of 8 PV modules (type AS-5M-200 W) obtained by using (8) when the angle of inclusion (Ψ) is constant

Time		Output electrical power	Jan	Feb	Mart	Apr	Maj	Jun	Jul	Avg.	Sep	Oct.	Nov	Dec	Yearly production average
6-9 h	Ψ = (51°)	P[KW]	0.31	0.33	0.32	0.45	0.61	0.53	0.57	0.51	0.42	0.06	0.06	0.15	3.65 MWh /year
9-12 h		P[KW]	0.36	0.42	0.45	0.57	0.56	0.62	0.67	0.65	0.52	0.53	0.50	0.42	
12-15 h		P[KW]	0.31	0.36	0.50	0.63	0.64	0.65	0.62	0.52	0.50	0.42	0.48	0.45	
15-18 h		P[KW]	0.33	0.35	0.38	0.45	0.51	0.53	0.57	0.51	0.43	0.05	0.03	0.15	

Table 5. Expected electrical power generation of 8 PV modules (type AS-5M-200 W) obtained by using (8) when the angle of inclusion (Ψ) changes for each month

Time	Parameter	Jan.	Feb.	Mart	Apr	Maj	Jun	July	Avg.	Sep	Oct.	Nov.	Dec.	Yearly production
6-9 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	32	3.70 MWh / year
	P [kW]	0.07	0.18	0.36	0.61	0.82	0.90	0.84	0.68	0.49	0.33	0.14	0.08	
9-12 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.73	0.96	1.25	1.36	1.57	1.67	1.73	1.68	1.41	1.11	0.77	0.64	
12-15 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.79	1.08	1.31	1.36	1.49	1.62	1.73	1.66	1.31	1.03	0.71	0.06	
15-18 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.14	0.29	0.46	0.53	0.64	0.74	0.81	0.68	0.45	0.25	0.07	0.06	

From the results obtained in Tables 3, 4 and 5 and according to (8), it can be conclude that the electrical power of the PV module directly depends on the intensity of solar radiation and the degree of utilization of PV modules. It has also been confirmed that the maximum power of the PV module is in the case when it is inclined at an optimum angle (when the angle between the solar rays and the normal to the PV module is equal to zero). The member (245 - Ta) actually has the form (270 - (Ta + 25)), where 25 °C is added to the ambient temperature because it is the temperature of the PV module on which the manufacturer prescribes the characteristics under STC conditions. This is confirmed by the fact that for the temperature of the module is about 270 °C, the power generated by the PV module is equal to zero. Exponents 0.92 and 0.9 in formula (8) take into account the influence of different parameters / phenomena on the efficiency of the PV module, such as the separation of the boundary layer along the surface of the inclined PV module which depends on the angle of inclination of the PV module, the change in the emissivity of the upper surface of the PV module with the change in the incident angle and the intensity of the solar radiation. The optimal value of the angle of inclination for the whole year for the considered location was obtained by multiplying the geographical width of the location at which the PV module is located at 0.9, while the optimal values of the inclination angles for each month are obtained so that the modules receive the highest energy of the sun's radiation in the period between 9 and 15 h when it is most intense.

As shown in (8) is very simple and very useful for calculating the expected production of electricity and the techno-economic optimization of the PV system both static and those that have the ability to monitor the position of the sun. By comparing the obtained both results, it can be seen that the largest deviation between the power values obtained by the analytical model and formula (8) is about 4.6%. From the comparison of the results obtained for the two cases, it also can be seen that the difference in the annual production of electrical power in the case where PV modules do not have the possibility of changing the angle of inclination and the case when this angle is changed for each month, it is very small (only 50 kWh / year).

However, in order to monitor the position of the sun and adjust the angle of inclination of the PV module, among other things, an motor and a solar positioner is required. In the unidirectional monitoring system of the sun position, an additional mechanism for rotating the PV module is needed, and the maintenance costs due to more frequent system failures and higher own consumption for the operation of the engine are also higher. Therefore, in order to achieve the required power of the PV system, in this case, it is much more economical to invest in a larger number of PV modules with constant angle inclinations than in a unidirectional monitoring system for the position of the sun.

5. CONCLUSION

In this paper, the ambient temperature effect on the photovoltaic (PV) modules for different angles of inclinations and different intensities of the solar radiation on the surface of the PV module has been studied by using empirical correlations for natural convection. An analytical model based on the energy balance equilibrium between the PV module and the environment conditions has been used. The results obtained indicates that the power of the PV module depends on the ambient temperature. This dependence is linear in contrast to the dependence of the power of the PV module on the intensity of the sun's radiation and the angle between the sun's irradiance and the normal on the upper surface of the PV module.

The study also include a proposed formula (8) for calculating the power of the PV modules in function of the standard test conditions (STC) of the photovoltaic (PV) module (25 °C - 1000 W / m2). Formula applies to the worst case of cooling PV modules when the wind speed is zero. By comparing the obtained both results, it can be seen that the largest deviation between the power values obtained by the analytical model and formula (8) is about (5 %). Also, from the results obtained, It has been shown that in the case of a smaller number of PV modules corresponding to the required number for an average household, it is more economical to invest additional resources in increasing the PV module's surface area than in case of the sun tracking system. Of course, this applies to the ambient conditions of location at which the PV modules are being planned, especially in hot countries such as Iraq country.

REFERENCES

[1] Wang T, Wang S, Luo R, Zhu C, Akiyama T, Zhang Z. "Microencapsulation of phase change materials with binary cores and calcium carbonate shell for thermal energy storage". *Apply Energy*, vol. 171, pp. 113-9, 2016.

[2] Hachem F, Abdulhay B, Ramadan M, El Hage H, El Rab MG, Khaled M. "Improving the performance of photovoltaic cells using pure and combined phase change materials-experiments and transient energy balance." *Renew Energy*, vol. 107, pp. 567-75, 2017.

[3] Zhu L, Raman AP, "Fan S Radiative cooling of solar absorbers using a visibly transparent photonic crystal thermal black body." In: *Proceedings of the national academy of sciences*, pp. 12282-87, August 2015.

[4] Elbreki AM, Alghoul MA, Al-Shamani AN, Ammar AA, Yegani B, Alsanossi, Aboghrara M, Rusaln MH, Sopian K. "The role of climatic-design-operational parameters on combined PV/T collector performance: a critical review." *Renew Sustain Energy Rev*, vol. 57, pp. 602-47, 2016.

[5] Vishwanathan B, Reinders AHME, de Boer DKG, Desmet L, Ras AJM, Zahn FH, Debije MG, "A comparison of performance of flat and bent photovoltaic luminescent solar concentrators." *Sol Energy*, vol. 112, pp. 120-7, 2015.

[6] Correia SFH, Lima PP, Andre PS, Ferreira MRS, "Carlos LAD. High-efficiency luminescent solar concentrators for flexible wave guiding photovoltaics". *Sol Energy Sol* Cells, vol. 138, pp. 51-7, 2015.

[7] Popovici CG, Hudisteanu SV, Mateescu TD, Chereches NC. "Efficiency improvement of photovoltaic panels by using air cooled heat sinks." *Energy Procedia*, vol. 85, pp. 425-32, 2016.

[8] Wang Y, Zhou S, Hou H. "Cost and CO_2 reductions of solar photovoltaic power generation in China: perspectives for 2020." *Renew Sustain Energy Rev*, vol. 39, pp. 370-80, 2014.

[9] Correia SFH, Lima PP, Andre PS, Ferreira MRS, Carlos LAD. "High-efficiency luminescent solar concentrators for flexible wave guiding PV". *Sol Energy Mater Sol Cells*, vol. 138, pp. 51-7, 2015.

[10] Samir Kouro, Jose I. Leon, Dimitri Vinnikov, Leopoldo G. Franquelo, "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology", *IEEE Industrial Electronics Magazine*, vol. 9, no. 1, March 2015.

[11] R. Arulmozhiyal and K. Baskaran, "Implementation of a Fuzzy PI Controller for Speed Control of Induction Motors Using FPGA," *Journal of Power Electronics*, vol. 10, pp. 65-71, 2010.

[12] Pelin, Denis; Opačak, Milan; Pal, Matej, "PV Emulation by using DC Programmable Sources". *International Journal of Electrical and Computer Engineering Systems*. vol 8, no.1, pp. 11-17, 2017.

[13] Ayop, Razman; Tan, Chee Wei, "A comprehensive review on photovoltaic emulator," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 430-452, 2017.

[14] A. S. Gujari, M. M. Wagh, N. N. Shinde, "A technoeconomic feasibility of inverter selection for MegaWatt(MW) scale grid connected solar photovoltaic power plant¸" *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, pp. 282-288, 2017.

[15] Kataloški podaci modula BMU-250 proizvođača BISOL: http://www.bisol.com /files/ Datasheets/CRO/BISOL%20Produktna%20specifikacija%20BMU%20HR.pdf ; pristup 1.8. 2018.

[16] Sahay A, Sethi VK, Tiwari AC, Pandey M. "A review of solar photovoltaic panel cooling systems with special reference to Ground Coupled Central Panel Cooling System," *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 306-12, 2014.

[17] Royne A, Dey CJ, Mills DR, "Cooling of photovoltaic cells under concentrated illumination: a critical review." *Sol Energy Mater Sol Cells*, vol. 86, pp. 451-83, 2003.

[18] Jordehi AR, "Parameter estimation of solar photovoltaic (PV) cells, vol. 61, pp. 354-71, 2016.

[19] Tse K.-K., Chow T.-T. and Su Y, "Performance evaluation and economic analysis of a full scale water-based photovoltaic/thermal (PV/T) system in an office building," vol. 122,pp. 42-52, 2016.

[20] "Channel heat sinks in the application of ultra-high concentrator photovoltaic system". *Sol* Energy, pp. 314-27, 2017.

[21] da Cunha JP, Eames P, "Thermal energy storage for low and medium temperature applications using phase change materials-a review," *Appl. Energy*, vol. 177, pp. 227-38, 2016.

[22] Liu L, Su D, Tang Y, Fang G, "Thermal conductivity enhancement of phase change materials for thermal energy storage: a review." *Renew Sustain Energy Rev*, vol. 62, pp. 305-17, 2016.

[23] Su D, Jia Y, Alva G, Liu L, Fang G. "Comparative analyses on dynamic performances of photovoltaic–thermal solar collectors integrated with phase change materials," *Energy Convers Management*, vol. 131, pp. 79-89, 2017.

[24] D. S. Tasić, J. L.G. Peuteman, D. O. Klimenta, Lj. N. Andjelković, "The modelling of the angle of inclination effect on the convection of a flat plate: the photovoltaic module case," *Thermal science*, published online: Mar 2016, DOI: 10.2298/TSCI140821059P.

[25] Hu J, Chen W, Yang D, Zhao B, Song H, Ge B, "Energy performance of ETFE cushion roof integrated photovoltaic/thermal system on hot and cold days," *Apply Energy*, vol. 173, pp. 40-51, 2016.

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