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NEW METHOD TO COMPARE INDOOR AND OUTDOOR TEMPERATURE COEFFICIENTS OF PHOTOVOLTAIC MODULES

Ali ŞENTÜRK[*]
Rüştü EKE[*]

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Abstract: In this study, a new method is presented to compare the indoor and outdoor temperature coefficients of photovoltaic module. Precise input of temperature coefficients introduced in the simulation is very essential to obtain accurate results about the actual performance of photovoltaic module/array. Thus, it is important to specify which type (indoor or outdoor) of the temperature coefficient is more accurate in simulating the actual performance. The short circuit current, the open circuit voltage, the output peak power and produced energy are considered as actual performance indexes. New method proposed in this study, simulates the actual performance for both indoor and outdoor temperature coefficients and compares with actual performance measured at field to decide which type of temperature coefficient is more accurate.

Keywords: Temperature Coefficient, Photovoltaic Module, Photovoltaic Array, Photovoltaic Performance

Yeni Bir Yöntemle Fotovoltaik Modüllerin İç ve Dış Sıcaklık Katsayılarının Karşılıştırılması

Öz: Bu çalışmada, fotovoltaik modüllerin iç ve dış ortamda elde edilen sıcaklık katsayılarının karşılaştırılması için yeni bir yöntem ortaya konmuştur. Fotovoltaik modüllerin/örgülerin gerçek performanslarının doğru bir şekilde simüle edilebilmesi için doğru sıcaklık katsayılarının kullanılması oldukça önemlidir. Bu yüzden, gerçek performansın simülasyonunda hangi tip sıcaklık katsayılarının (iç veya dış) daha doğru sonuçlar vereceği belirlenmelidir. Kısa devre akımı, açık devre gerilimi, maksimum çıkış gücü ve üretilen enerji gerçek performans parametreleri olarak kabul edilmişlerdir. Bu çalışmada ortaya konan yeni yöntem, gerçek performansı iç ve dış ortam sıcaklık katsayıları için simüle etmekte ve hangi tip sıcaklık katsayılarının daha doğru olduğunu belirleyebilmek için dış ortamda ölçülen gerçek performansla karşılaştırmaktadır.

Anahtar Kelimeler: Sıcaklık Katsayısı, Fotovoltaik Modül, Fotovoltaik Örgü, Fotovoltaik Performans

1. INTRODUCTION

The photovoltaic (PV) phenomenon provides clean and efficient energy to all humanity. Forecasting the energy produced (E) by PV arrays is important for to analyze their economic viability and inspect their operation (Rodrigues et al., 2016). PV arrays are formed from identical PV modules that electrically connected in series-parallel combinations. Once knowing the PV module's performance, it is possible to calculate the PV array's one (Rus-Casas et al.,

[*] Department of Physics, Faculty of Science, Muğla Sıtkı Koçman University, 48120,Turkey
Correspondence Author: Ali ŞENTÜRK (alisen@mu.edu.tr)

2014; Şentürk and Eke, 2015; Tian et al., 2012). The energy produced by PV modules and thus PV arrays mainly depends on irradiation and temperature as well as the secondary parameters such as operating period, orientation, montage type and etc. (Huld and Gracia Amillo, 2015). According to method of calculating the output peak power (P_M), there are two ways to simulate the energy produced by PV modules; direct and in-direct methods (Chenni et al., 2007; Ciulla et al., 2014; Humada et al., 2016; Rus-Casas et al., 2014; Tossa et al., 2014). In direct methods, P_M is usually calculated directly from empirical expressions. In indirect methods, at first, a current-voltage (I-V) curve of PV module is obtained by means of a single or double diode models and then corresponding P_M is extracted from this curve (Nassar-eddine et al., 2016). Finally, the produced energy (E) is calculated from P_M which is obtained either by means of direct or indirect methods (Jack et al., 2015; Rus-Casas et al., 2014).

Regarding the direct and indirect methods, to calculate the energy produced by PV modules, the actual electrical parameters; short-circuit current (I_{SC}), open-circuit voltage (V_{OC}) and output peak power (P_M), are needed to be know (Hussein et al., 2004). The actual electrical parameters (I_{SC}, V_{OC} and P_M) mainly depend on the module temperature (T_M), the irradiation (G) that expose on PV module and their reference electrical parameters (I_{SCREF}, V_{OCREF}, and P_{MREF}) that given in PV module datasheet. The reference electrical parameters are rated under Standard Test Conditions (STC) that cover irradiation level, module temperature and spectral distribution with value of 1000 W/m^2, 25 °C and AM1.5, respectively. The irradiation dependence of the actual electrical parameters could be expressed with explicit formulations i.e. no need additional information to be known(Ismail et al., 2013; Skoplaki and Palyvos, 2009). On the other hand, the temperature dependence of these electrical parameters is described by concept of temperature coefficient (Osterwald et al., 1987). Actually, the temperature coefficient of I_{SC}, V_{OC} and P_M that denoted with a symbol α, β, and γ, respectively, are obtained from complex expressions that need many physical parameters to be known. Many studies have been performed to obtain the theoretical values of the α, β, and γ (Cuce et al., 2013; Dupré et al., 2015b; Jiang et al., 2012; Perraki and Kounavis, 2016; Singh and Ravindra, 2012). However, previous studies reveal that these temperature coefficients nearly take constant values under various operating conditions where PV modules are deployed outdoor (Dupré et al., 2015a; Makrides et al., 2009; Osterwald, 1986; Osterwald et al., 1987; Perraki, 2013).

Usually, PV module manufacturers supply the temperature coefficients which are evaluated at laboratory under particular constant conditions (1000 W/m^2 and AM1.5); namely called as indoor temperature coefficients (α_{IN}, β_{IN}, γ_{IN}). On the other hand, most of small-scale PV module manufacturers are not able to evaluate these temperature coefficients (TCs) due to high cost equipments (Paulescu et al., 2014). Thus to overcome this matter, the outdoor measurement procedure must be performed to obtain these necessarily temperature coefficients which are namely called as outdoor TCs ($\alpha_{OUT,}$ β_{OUT}, and γ_{OUT}).

Still there is a dilemma about which type of temperature coefficients; the indoor or outdoor, are more accurate to simulate/calculate the actual performance of PV modules(Dubey et al., 2015). In traditional way, the indoor and outdoor TCs are compared directly with each other as taking into account the indoor TCs as true one (Dupré et al., 2015b). Indoor and outdoor TCs obtained at two different locations were compared for several commercially available PV modules in study reported elsewhere in (Makrides et al., 2009). The different types of outdoor temperature coefficients were evaluated and compared with each other in studies reported elsewhere in (Fanney et al., 2006; Granata et al., 2011). However, there is not certain judgment in literature that indoor TCs are absolutely true or accurate. The more accurate TCs are, the more accurate actual electrical parameters to be calculated and consequently the more accurate produced energy to be simulated (Dupré et al., 2015b; Mihaylov et al., 2016). Thus, precise simulation of the energy produced by PV modules or arrays depends on introducing the accurate temperature coefficients which in turn allows to predict sensible payback time of PV arrays formed by PV modules (Nassar-eddine et al., 2016; Şentürk and Eke, 2015).

In this study, a new method is presented to compare the indoor and outdoor TCs. The actual performance of PV module and array is simulated both for the indoor and outdoor TCs. Then simulated performances are compared with actual (measured) ones to clarify which TCs (indoor or outdoor) are more accurate in simulating the PV performance. The indoor TCs are taken from a PV module datasheet whereas the outdoor TCs are evaluated by means of shading procedure at field.

2. METHODOLOGY

2.1. Actual Performance of PV Module

In this study, P_M, I_{SC}, V_{OC} and E are considered as the actual photovoltaic performance parameters i.e. the actual performance (Hussein et al., 2004). The irradiation (G) and module temperature (T_M) dependence of P_M, I_{SC}, V_{OC} and E are defined with well known expressions given below (Skoplaki and Palyvos, 2009). These expressions are valid for both PV module and array.

$$P_M = \frac{P_{MREF} G}{G_{REF}} (1 + \gamma (T_M - T_{REF})) \tag{1}$$

$$I_{SC} = I_{SCREF} \frac{G}{G_{REF}} (1 + \alpha (T_M - T_{ref})) \tag{2}$$

$$V_{OC} = V_{OCREF} \left(1 + \beta (T_M - T_{REF}) + \frac{N_S n k_B T_M}{q V_{OCREF}} \ln \left(\frac{G}{G_{REF}} \right) \right) \tag{3}$$

$$E = \int P_M dt = \int \frac{P_{MREF} G}{G_{REF}} (1 + \gamma (T_M - T_{REF})) dt \tag{4}$$

Where n is the ideality factor of individual solar cell, N_S is the number of individual solar cells connected electrically in series within a PV module, k_B is the Boltzmann constant, q is the charge of electron, G_{REF} is the reference irradiation (1000 W/m^2), T_{REF} is the reference module temperature (25 ^{o}C), P_{MREF} is the reference peak power, I_{SCREF} is the reference short-circuit current, V_{OCREF} is the reference open-circuit voltage . In addition, G and T_M are the irradiation and module temperature, respectively, which correspond to the operating conditions where a PV module is deployed outdoor.

2.2. Indoor and Outdoor Temperature Coefficients

Indoor TCs are evaluated by manufacturers at controlled laboratory conditions and are given in PV module datasheet (Dubey et al., 2015). On the other hand, outdoor TCs are evaluated at field considering particular constrains (Dubey et al., 2015; Emery et al., 1996). Because of many challenges in evaluating outdoor TCs, these constrains provides to obtain reliable and repeatable results (Dubey et al., 2015; Mihaylov et al., 2016). Outdoor TCs of any photovoltaic module (α_{OUT}, β_{OUT}, γ_{OUT}) are calculated from temperature dependent I-V curve measurements that conducted a day with conditions of stable sunshine around solar noon (high than 800 W/m^2) and at calm wind speed (less than 2 m/s). Shading procedure is utilized to create temperature gradient on a PV module. First of all, a PV module is shaded with an opaque cover until it's temperature reaches near the ambient temperature. Then, I-V curves of a PV module are scanned with sampling interval (1 or 5 minutes) as the module temperature (T_M) rises due to removing a cover until the T_M reaches in thermal equilibrium with environment where a PV module is deployed (Emery et al., 1996). The I_{SC}, V_{OC}, and P_M parameters are extracted from the T_M dependent experimental I-V curves. After that, the normalized I_{SC}, V_{OC},

and P_M parameters are sketched with respect to the normalized module temperature, according to Table 1. The linear functions are fitted to the scattered data. Finally, the slopes of these functions correspond directly to the outdoor TCs of these parameters ($\alpha_{OUT,}$ β_{OUT}, γ_{OUT}) (Figure 1) (Makrides et al., 2009).

Table 1. Axes information to evaluate outdoor temperature coefficients.

Normalized Parameter (Vertical Axes)	Normalized Temperature (Horizontal Axes)	Meaning of Slope (ppm/^oC)
$\frac{G_{REF}\, I_{SC}}{G\, I_{SCREF}}$	$T_M - T_{REF}$	α_{OUT}; the TC of short-circuit current
$\frac{V_{OC}}{V_{VOCREF}}$	$T_M - T_{REF}$	β_{OUT}; the TC of open-circuit voltage
$\frac{G_{REF}\, P_M}{G\, P_{MREF}}$	$T_M - T_{REF}$	γ_{OUT}; the TC of output peak power

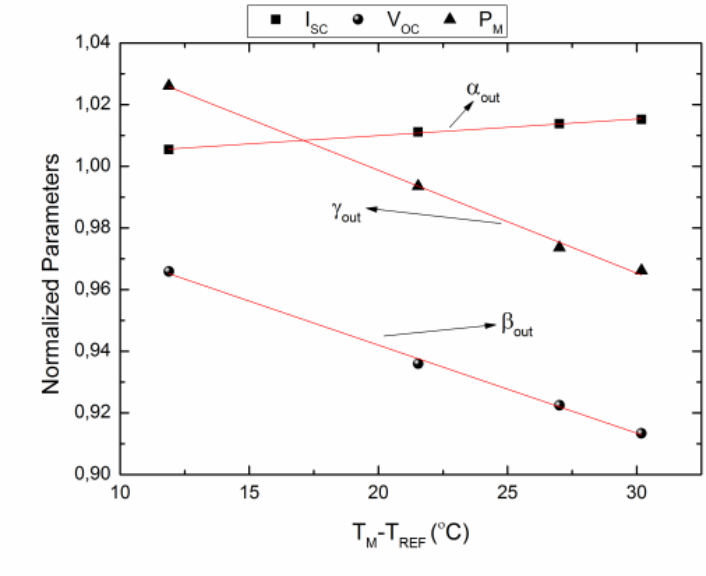

Figure 1:
The calculation of outdoor temperature coefficients.

2.3. New Comparison Method for Temperature Coefficients

The actual performance (P_M, I_{SC}, V_{OC} and E) is simulated for same operating conditions (G and T_M), but for different type of the temperature coefficients; indoor and outdoor TCs, using Eqs. (1)-(4). Then, the indoor and outdoor performances are compared with the actual performance measured at field by means of root mean square error approximation (RMSE) described below.

$$RMSE(\%) = 100\frac{\sqrt{N\sum_{I=1}^{N}(F_{SIM} - F_{MEAS})^2}}{\sum_{I=1}^{N} F_{MEAS}} \tag{5}$$

where, F_{MEAS}, F_{SIM}, and N are actual (measured) values, simulated values and number of data, respectively. The new method proposed here to compare temperature coefficients is shown in Figure 2.

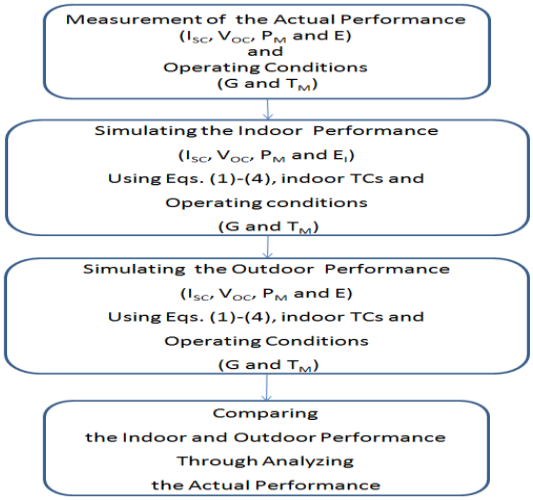

Figure 2:
The new method to compare the indoor and outdoor temperature coefficients.

The indoor performance and outdoor performance indicate which type of temperature coefficients; indoor or outdoor, respectively, are used to simulate the actual performance.

3. MATERIAL

Since the main actor of PV market is crystalline silicon (Si) based PV modules, the back contact single crystalline Si PV module was selected as device under test (DUT). Current - voltage (I-V) curves of the DUT were traced using a multi-channel measurement system. Kipp-Zonnen CM11 model type pyranometer was used to sense the irradiation (G) that exerted on the DUT. The temperature of DUT (T_M) was sensed via pasting four probes thin film Pt-100 temperature sensor on the back surface of DUT with thermal conducting paste and the temperature sensor was covered with insulating tape. Datasheet values of the DUT are listed in Table 2. In this study, the ideality factor of DUT is considered as 1.2 which is valid for a single crystalline silicon based PV modules (Bellia et al., 2014). It is note to remember that, the temperature coefficient that supplied in PV module datasheet are called as indoor ones ($\alpha_{IN,}$ β_{IN}, and γ_{IN}).

Table 2. Datasheet parameters of DUT.

Parameter	Value
N_S	32
P_{MREF} (W)	100.0
I_{SCREF} (A)	6.0
V_{OCREF} (V)	21.6
α_{IN} (ppm/°C)	600
β_{IN} (ppm/°C)	-2800
γ_{IN} (ppm°/C)	-3800

4. RESULTS AND DISCUSSION

Averaged outdoor TCs of the DUT were calculated from numerous I-V measurements during annual period of 2014. In this study, these TCs are called as outdoor ones. The

calculation procedure of outdoor TCs is well described in Section 2.2. The indoor and outdoor TCs are given in Table 3.

Table 3. Indoor (α_{IN}, β_{IN}, γ_{IN}) and outdoor (α_{OUT}, β_{OUT}, γ_{OUT}) temperature coefficients of DUT.

Temperature Coefficient	Value (ppm/°C)
γ_{IN}	-3800
α_{IN}	600
β_{IN}	-2800
γ_{OUT}	-3690
α_{OUT}	585
β_{OUT}	-2690

To obtain the actual performance of DUT, numerous experimental I-V curves were scanned each day through annual period from January 2015 to December 2015 at field with sampling interval of 5 minutes. To show effectiveness of the new method, only 12 days with different sky profile (clear, cloudy and partly cloudy) were selected which each day correspond to each month of the annual period. The actual values of I_{SC}, V_{OC}, and P_M were extracted from the experimental I-V curves of selected days. The simulated values of I_{SC}, V_{OC}, and P_M were calculated using Eqs. (1)-(3) and experimental data of G and T_M , for both the indoor (α_{IN}, β_{IN}, and γ_{IN}) and outdoor (α_{OUT}, β_{OUT}, and γ_{OUT}) TCs which were depicted in Table 3. The actual and simulated values of I_{SC}, V_{OC} and P_M were sketched versus local time but only three of them are shown in Figures 3-5. In these figures, "indoor TCs" and "outdoor TCs" indicate which type of TCs is used to simulate I_{SC}, V_{OC} and P_M.

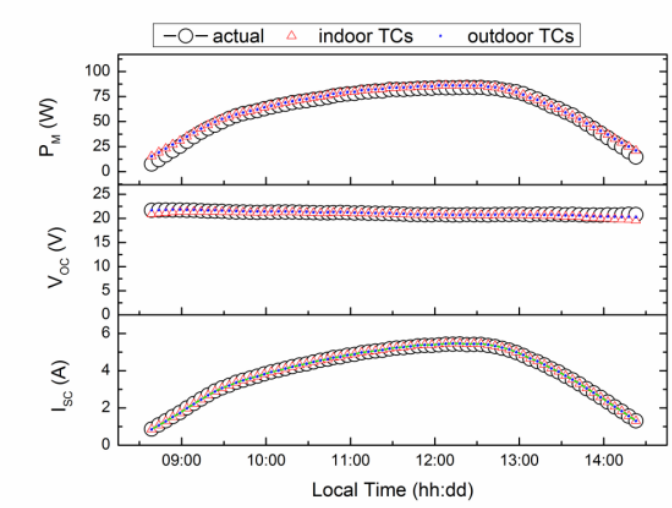

Figure 3:
Actual and simulated (indoor and outdoor TCs) curves at 08.01.2015.

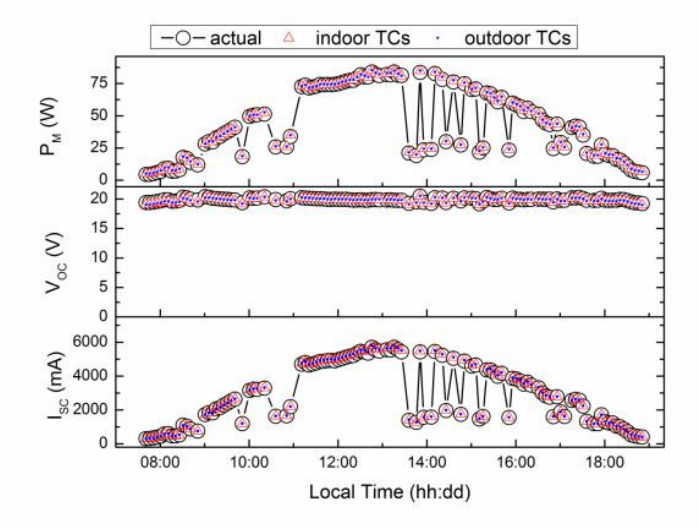

Figure 4:
Actual and simulated (indoor and outdoor TCs) curves at 06.09.2015.

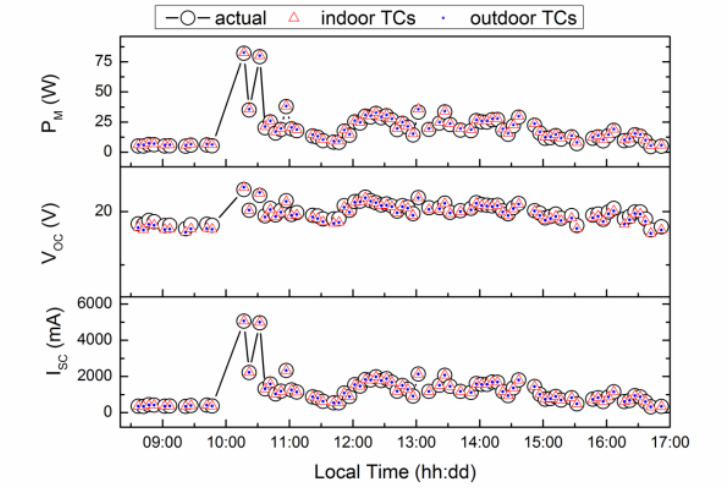

Figure 5:
Actual and simulated (indoor and outdoor TCs) curves at 15.10.2015.

For all the 12 days, simulated (indoor TCs and outdoor TCs) curves match well with actual ones. The RMSE values of simulated parameters were calculated and shown in Table 4.

Table 4. Error values of simulated I_{SC}, V_{OC} and P_M for indoor and outdoor TCs.

Measurement Date	RMSE of I_{SC} (%)			RMSE of V_{OC} (%)			RMSE of P_M (%)		
	Indoor TCs	Outdoor TCs	|Diff.| (%)	Indoor TCs	Outdoor TCs	|Diff.| (%)	Indoor TCs	Outdoor TCs	|Diff.| (%)
08.01.2015	0.6	0.6	0.0	1.7	1.6	0.1	4.6	4.6	0.0
07.02.2015	0.6	0.6	0.0	0.5	0.6	0.1	7.3	7.3	0.0
26.03.2015	1.5	1.5	0.0	0.8	0.9	0.1	3.0	3.2	0.2
14.04.2015	1.7	1.7	0.0	0.6	0.6	0.0	1.3	1.5	0.2
29.05.2015	2.0	2.0	0.0	0.6	0.6	0.0	4.9	5.0	0.1
27.06.2015	1.9	1.9	0.0	0.7	0.7	0.0	2.7	2.9	0.2
26.07.2015	2.1	2.1	0.0	0.5	0.6	0.1	2.9	3.2	0.3

07.08.2015	2.8	2.8	0.0	0.5	0.5	0.0	2.9	3.3	0.4
06.09.2015	1.6	1.6	0.0	0.6	0.6	0.0	1.6	1.7	0.1
15.10.2015	0.4	0.4	0.0	0.5	0.5	0.0	5.4	5.4	0.0
17.11.2015	1.7	1.7	0.0	0.7	0.7	0.0	2.0	2.0	0.0
02.12.2015	1.1	1.2	0.1	0.7	0.7	0.0	2.4	2.4	0.0

The actual (E_{ACT}), indoor TCs (E_{INDOOR}) and outdoor TCs ($E_{OUTDOOR}$) energy values were calculated from actual P_M-local time curves, indoor TCs P_M-local time curves and outdoor TCs P_M-local time curves, respectively, according to the Eq.(4). The calculated energy values (E_{ACT}, E_{INDOOR}, $E_{OUTDOOR}$) and corresponding error values are shown in Table 5.

Table 5. Measured, simulated and error values of produced energy for indoor and outdoor TCs.

Measurement Date	E_{ACT} (Wh)	E_{INDOOR} (Wh)	$E_{OUTDOOR}$ (Wh)	RMSE of E_{INDOOR} (%)	RMSE of $E_{OUTDOOR}$ (%)	|Diff.| (%)
08.01.2015	353.9	365.6	365.8	3.3	3.4	0.1
07.02.2015	211.8	224.3	224.3	5.9	5.9	0.0
26.03.2015	459.8	469.1	469.8	2.0	2.2	0.1
14.04.2015	678.7	686.8	688.5	1.2	1.4	0.3
29.05.2015	240.1	251.1	251.4	4.6	4.7	0.1
27.06.2015	472.9	484.5	485.7	2.5	2.7	0.3
26.07.2015	563.2	578.4	580.3	2.7	3.0	0.3
07.08.2015	401.7	413.5	415.1	2.9	3.3	0.4
06.09.2015	483.4	489.8	490.9	1.3	1.6	0.2
15.10.2015	158.8	166.8	166.8	5.0	5.0	0.0
17.11.2015	414.4	421.6	422.7	1.7	2.0	0.3
02.12.2015	394.8	407.3	408.2	3.2	3.4	0.2

The PV array (Figure 6) with 8.4 kW_P rated output peak power that located in the campus of Muğla Sıtkı Koçman Üniversity is used also to verify the effectiveness of the new comparison method. The details of the PV array is well described elsewhere in (Eke and Senturk, 2012).

Figure 6:
PV array at Mugla Sıtkı Koçman University campus (Eke and Senturk, 2012).

Since the PV array is formed from 84 numbers of identical DUTs, the indoor and outdoor TCs are assumed valid for the PV array. The operating conditions (G and T_M) were taken from a

data-logger that integrated into the PV array (Eke and Senturk, 2012). One day was selected to test the new method. Since data-logger does not store actual values of I_{SC} and V_{OC} of the PV array, only the P_M and E values were simulated for both the indoor and outdoor TCs using Eq.(1) and Eq.(4), respectively, and corresponding operating conditions (G and T_M). The simulated (indoor and outdoor TCs) and actual values of P_M were sketched versus local time and shown in Figure 7.

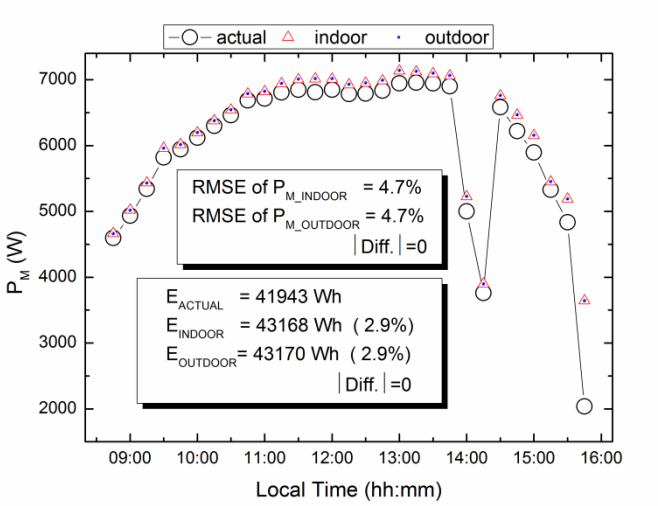

Figure 7:
Actual, simulated and error values of PV array.

The error value of output peak power of the PV array, shown in Figure 7,was 4.7% for both the indoor and outdoor TCs. The actual and simulated energy values of the PV array denoted with E_{ACTUAL}, E_{INDOOR} and $E_{OUTDOOR}$ were calculated 41943 Wh, 43168 Wh, and 43170 Wh, respectively. The error values of E_{INDOOR} and $E_{OUTDOOR}$ were calculated which is 2.9% for both. The actual and simulated produced energy values and corresponding error values are shown inset Figure 7.

To see difference of the indoor and outdoor TCs clearly on simulating the actual performance, the absolute differences (|Diff.|)were calculated between the error values of the indoor TCs and outdoor TCs. The RMSE and absolute difference values, shown in Table 4, Table 5 and Figure 7, indicate that there is not significant discrepancy between the indoor and outdoor TCs as simulating the actual performance of PV module and PV array at field. In some measurements, discrepancies were observed for absolute differences (|Diff.|) of simulated parameters (see Table 4 and Table 5). These discrepancies could be attributed with the outdoor TCs evaluation procedure where operating conditions are not exactly invariant as the indoor procedure. Since the maximum absolute difference is 0.4% (marked with grey in Table 4 and Table 5), these discrepancies are trivial.

5. CONCLUSION

In this study, a new method is presented to compare the indoor and outdoor temperature coefficients. Different from the conventional comparison method, the novelty of new method is to use the actual performance (I_{SC}, V_{OC}, P_M and E) as decisive index to compare the indoor and outdoor TCs. The new method is validated for the back contact mono-crystalline Si PV module and PV array at field. It is concluded that both indoor and outdoor TCs could simulate the actual performance of PV module and PV array almost with same accuracy. Thus despite they have been evaluated at fixed laboratory conditions, the indoor temperature coefficients are quite enough to simulate the actual photovoltaic performance at field. Since manufacturers of PV

modules always provide these temperature coefficients in PV module datasheet, it is not necessary to obtain and utilize the outdoor TCs as simulating the actual performance of PV module or PV array. Because obtaining outdoor temperature coefficients is cumbersome process where all external parameters vary with respect to time.

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REFERENCES

1. Bellia, H., Youcef, R. ve Fatima, M. (2014) A detailed modeling of photovoltaic module using MATLAB, *NRIAG Journal of Astronomy and Geophysics*, 3, 53–61. doi:10.1016/j.nrjag.2014.04.001

2. Chenni, R., Makhlouf, M., Kerbache, T. ve Bouzid, A. (2007) A detailed modeling method for photovoltaic cells, *Energy*, 32, 1724–1730. doi:10.1016/j.energy.2006.12.006

3. Ciulla, G., Lo Brano, V., Di Dio, V. ve Cipriani, G. (2014) A comparison of different one-diode models for the representation of I–V characteristic of a PV cell, *Renewable and Sustainable Energy Reviews*, 32, 684–696. doi:10.1016/j.rser.2014.01.027

4. Cuce, E., Cuce, P.M. ve Bali, T. (2013) An experimental analysis of illumination intensity and temperature dependency of photovoltaic cell parameters, *Appied Energy*, 111, 374–382. doi:10.1016/j.apenergy.2013.05.025

5. Dubey, R., Batra, P., Chattopadhyay, S., Kottantharayil, A., Arora, B.M., Narasimhan, K.L. ve Vasi, J. (2015) Measurement of Temperature Coefficient of Photovoltaic Modules in Field and comparison with Laboratory Measurements, doi:10.1109/PVSC.2015.7355852

6. Dupré, O., Vaillon, R. ve Green, M.A. (2015a) Physics of the temperature coefficients of solarcells, *Solar Energy Materials and Solar Cells*, 140, 92–100. doi:10.1016/j.solmat.2015.03.025

7. Dupré, O., Vaillon, R., Green, M.A., Dupr, O., Vaillon, R. ve Green, M.A. (2015b) Experimental assessment of temperature coefficient theories for silicon solar cells, *IEEE Journal of Photovoltaics*, 1–5. doi:10.1109/JPHOTOV.2015.2489864

8. Eke, R. ve Senturk, A. (2012) Performance comparison of a double-axis sun tracking versus fixed PV system, *Solar Energy*, 86, 2665–2672. doi:10.1016/j.solener.2012.06.006

9. Emery, K., Burdick, J., Caiyem, Y., Dunlavy, D., Field, H., Kroposki, B., Moriarty, T., Ottoson, L., Rummel, S., Strand, T. ve Wanlass, M.W. (1996) Temperature dependence of photovoltaic cells, modules and systems, *Twenty Fifth IEEE Photovoltaic Specialist Conference*, doi:10.1109/PVSC.1996.564365

10. Fanney, A.H., Davis, M.W., Dougherty, B.P., King, D.L., Boyson, W.E. ve Kratochvil, J. A. (2006) Comparison of Photovoltaic Module Performance Measurements, *Journal of Solar Energy Engineering*, 128, 152. doi:10.1115/1.2192559

11. Granata, J.E., Boyson, W.E., Kratochvil, J.A., Li, B., Abbaraju, V., Tamizhmani, G. ve Pratt, L. (2011) Successful Transfer Of Sandia National Laboratories Outdoor Test Technology To Tüv Rheinland Photovoltiıc Testing Laboratory, *Photovoltaic Specialists Conference (PVSC) 37th IEEE*, 003132–003137

12. Huld, T. ve Gracia Amillo, A.M. (2015) Estimating PV module performance over large geographical regions: The role of irradiance, air temperature, wind speed and solar spectrum, *Energies*, 8, 5159–5181. doi:10.3390/en8065159

13. Humada, A.M., Hojabri, M., Mekhilef, S. ve Hamada, H.M. (2016) Solar cell parameters extraction based on single and double-diode models: A review, *Renewable and Sustainable Energy Reviews*, 56, 494–509. doi:10.1016/j.rser.2015.11.051

14. Hussein, H.M.S., Ahmad, G.E. ve El-Ghetany, H.H., (2004) Performance evaluation of photovoltaic modules at different tilt angles and orientations, *Energy Conversion and Management*, 45, 2441–2452. doi:10.1016/j.enconman.2003.11.013

15. Ismail, M.S., Moghavvemi, M. ve Mahlia, T.M.I. (2013) Characterization of PV panel and global optimization of its model parameters using genetic algorithm, *Energy Conversion and Management*, 73, 10–25. doi:10.1016/j.enconman.2013.03.033

16. Jack, V., Salam, Z. ve Ishaque, K. (2015) Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review, *Applied Energy*, 154, 500–519. doi:10.1016/j.apenergy.2015.05.035

17. Jiang, J.-A., Wang, J.-C., Kuo, K.-C., Su, Y.-L., Shieh, J.-C. ve Chou, J.J. (2012) Analysis of the junction temperature and thermal characteristics of photovoltaic modules under various operation conditions, *Energy*, 44, 292–301. doi:10.1016/j.energy.2012.06.029

18. Makrides, G., Zinsser, B., Georghiou, G.E., Schubert, M. ve Werner, J.H. (2009) Temperature behaviour of different photovoltaic systems installed in Cyprus and Germany, *Solar Energy Materials and Solar Cells*, 93, 1095–1099. doi:10.1016/j.solmat.2008.12.024

19. Mihaylov, B., Betts, T.R., Pozza, A., Mullejans, H. ve Gottschalg, R. (2016) Uncertainty Estimation of Temperature Coefficient Measurements of PV Modules, *IEEE Journal of Photovoltaics*, 6, 1–10. doi:10.1109/JPHOTOV.2016.2598259

20. Nassar-eddine, I., Obbadi, A., Errami, Y., El Fajri, A. ve Agunaou, M. (2016) Parameter estimation of photovoltaic modules using iterative method and the Lambert W function: A comparative study. *Energy Conversion and Management*, 119, 37–48. doi:10.1016/j.enconman.2016.04.030

21. Osterwald, C.R. (1986) Translation of device performance measurements to reference conditions, *Solar Energy Materials and Solar Cells*, 18, 269–279. doi:10.1016/0379-6787(86)90126-2

22. Osterwald, C.R., Glatfelter, T. ve Burdick, J. (1987) Comparison of the Temperature Coefficients of the Basic I-V parameters for Various Types of Solar Cell Devices, *Energy Conversion*, 188–193.

23. Paulescu, M., Badescu, V. ve Dughir, C. (2014) New procedure and field-tests to assess photovoltaic module performance, *Energy*, 70, 49–57. doi:10.1016/j.energy.2014.03.085

24. Perraki, V. (2013) Temperature Dependence on the Photovoltaic Properties of Selected Thin-Film Modules, *International Journal of Renewable and Sustainable Energy*, 2, 140. doi:10.11648/j.ijrse.20130204.12

25. Perraki, V. ve Kounavis, P. (2016) Effect of temperature and radiation on the parameters of photovoltaic modules, *Journal of Renewable and Sustainable Energy*, 8, 13102. doi:10.1063/1.4939561

26. Rodrigues, S., Torabikalaki, R., Faria, F., Cafôfo, N., Chen, X., Ivaki, A.R., Mata-Lima, H. ve Morgado-Dias, F. (2016) Economic feasibility analysis of small scale PV systems in different countries, *Solar Energy*, 131, 81–95. doi:10.1016/j.solener.2016.02.019

27. Rus-Casas, C., Aguilar, J.D., Rodrigo, P., Almonacid, F. ve Pérez-Higueras, P.J. (2014) Classification of methods for annual energy harvesting calculations of photovoltaic generators, *Energy Conversion and Management*, 78, 527–

536. doi:10.1016/j.enconman.2013.11.006

28. Singh, P. ve Ravindra, N.M. (2012) Temperature dependence of solar cell performance-an analysis, *Solar Energy Materials and Solar Cells*, 101, 36–45. doi:10.1016/j.solmat.2012.02.019

29. Skoplaki, E. ve Palyvos, J.A. (2009) On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. Sol. Energy 83, 614–624. doi:10.1016/j.solener.2008.10.008

30. Şentürk, A. ve Eke, R. (2015) Predicting the energy yield of a photovoltaic system from an individual photovoltaic module, *Physica Status Solidi C,* 3, 1280–1282. doi:10.1002/pssc.201510087

31. Tian, H., Mancilla-David, F., Ellis, K., Muljadi, E. ve Jenkins, P. (2012) A cell-to-module-to-array detailed model for photovoltaic panels, *Solar Energy*, 86, 2695–2706. doi:10.1016/j.solener.2012.06.004

32. Tossa, A.K., Soro, Y.M., Azoumah, Y. ve Yamegueu, D. (2014) A new approach to estimate the performance and energy productivity of photovoltaic modules in real operating conditions, *Solar Energy*, 110, 543–560. doi:10.1016/j.solener.2014.09.043