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Photovoltaic module cell temperature estimation: Developing a novel expression

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ABSTRACT

Energy efficiency is one of the most important issues of today. The limited reserves of fossil fuels make the use of renewable energy sources more attractive. Photovoltaic panels are one of the ways to utilize solar energy, which is one of the renewable energy sources.

The instantaneous efficiency of photovoltaic panels is related to the cell temperature of the panels. In the current studies in the literature, there are empirical expressions that give the photovoltaic panel cell temperature, but the results obtained from these expressions do not overlap with each other. In order to obtain the instantaneous efficiencies of photovoltaic panels and, accordingly, the production values theoretically, there is a need for a global expression that gives the photovoltaic panel cell temperature. In this study, a global expression was developed that gives the photovoltaic panel cell temperature depending on the ambient temperature, solar radiation and wind speed. In addition, using the meteorological data of Kütahya for many years, expressions giving ambient temperature, solar radiation and wind speed were created.

1. Introduction

The limited reserves of fossil fuels make renewable energy sources more attractive day by day. While the world primary energy consumption was 581.51 exajoules in 2019, this value was 557.1 exajoules in 2020 (BP, 2021). The amount of renewable energy sources in primary energy consumption in 2019 was 28.82 exajoules (5 %), and in 2020, primary energy consumption from renewable energy sources was 31.71 exajoules (5.7 %) (BP, 2021). From renewable energy sources, 2,789.2 TWh of electricity was produced in 2019 and 3,147.0 TWh in 2020 in the world. While total solar energy production was 707.9 TWh (25.4 %) in 2019, total solar energy production was 855.7 TWh (27.2 %) in 2020 (BP, 2021).

Table 1 and Table 2 show the solar energy installed power and solar energy production values for 10 years between 2011 and 2020 (BP, 2021). When the tables are examined; It is seen that the installed PV power in the world has increased by 882 % in 10 years. Likewise, electrical energy production from PV systems has increased by 1,212 % over the 10-year period.

Fig. 1 shows Turkey's solar energy situation. While the total installed power was 7 MW as of the end of 2011, this value increased by 95,143 % and reached 6,667 MW at the end of 2020. Likewise, while electricity generation from solar energy was 2.86 GWh in 2011, this value increased by 378,732 % in 10 years and reached 10,834.6 GWh (BP, 2021).

Fig. 2 shows the unlicensed solar energy situation of Kütahya. While the installed power was 1 MW in January 2016, this value reached 116.32 MW as of March 2022. Likewise, when the production values are analyzed, the production that was realized as 42.86 MWh in January 2016 was realized as 15,099.81 MWh in March 2022 (EPDK, 2020).

In the literature, there are various sources about mathematical modeling of photovoltaic panels. Patel and Trivedi worked on the MPPT algorithm of the photovoltaic system with Boost converter. Perturbation & Observation algorithm was used in their studies (Patel & Trivedi, 2014). Little Judy and Karthika have detailed the effect of radiation and temperature on the parameters of the solar PV module. The study was carried out in the Matlab Simulink environment (Judy & Karthika, 2016). Meena and Sharma investigated the effect of solar radiation on the PV panel. MPPT technique was used in the study (Chandra Meena & Sharma, 2007). Jakhrani et al. developed an improved mathematical model for PV by combining analytical and numerical methods. The output current expression of the photovoltaic module was clearly determined by the Lambert W function, and the voltage was determined numerically by the Newton-Raphson method (Jakhrani et al., 2014).

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Table 1
Installed PV capacity (GW) (BP, 2021).

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America	5.71	8,96	13.05	17.94	2437	36,01	44.94	57.07	66.66	82.8
South&Cent. America	0.17	0.32	0.46	0.81	1.84	2.74	5.24	7.46	10.76	15.1
Europe	53.57	71.73	81.88	88.82	97.55	104.7	113.48	124.4	146.32	167.81
CIS	0.0	0.01	0.02	0.08	0.21	0.24	0.41	1.05	2.27	3.25
Middle East	0.21	0.27	0.51	0.8	0.97	1.48	2.11	3.33	5.48	6.52
Africa	0.27	0.32	0.66	1.56	1.93	2.97	4.69	7.1	8.28	9.51
Asia Pacific	12.11	19.84	39.11	61.58	90.59	143.16	213.59	282.51	341.0	422.58
Total World	72.04	101.45	135.68	171.59	217.46	291.3	384.45	482.92	580.76	707.5

Table 2
Solar generation (TWh) (BP, 2021).

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America	5.4	10.0	17.6	31.6	42.5	59.6	82.8	101.3	119.6	150.3
South&Central America	0.1	0.3	0.5	1.1	2.9	4.9	7.6	12.7	19.1	22.8
Europe	46.7	71.9	86.9	98.8	109.8	113.8	124.3	138.5	152.8	178.9
CIS	–	–	–	0.2	0.4	0.6	0.8	1.0	1.7	4.8
Middle East	0.2	0.4	0.7	1.3	1.8	2.8	3.9	6.0	11.9	16.4
Africa	0.6	1.0	0.8	1.9	3.6	5.1	6.9	8.3	10.9	12.4
Asia Pacific	12.2	17.5	32.3	62.8	95.3	141.5	219.8	309.1	392.0	470.3
OECD	60.5	91.9	121.0	159.6	195.5	229.4	278.4	325.8	378.8	455.7
Non-OECD	4.7	9.3	18.0	38.2	60.9	98.9	167.6	251.2	329.2	400.0
Total World	65.2	101.2	138.9	197.8	256.4	328.4	446.1	577.0	707.9	855.7

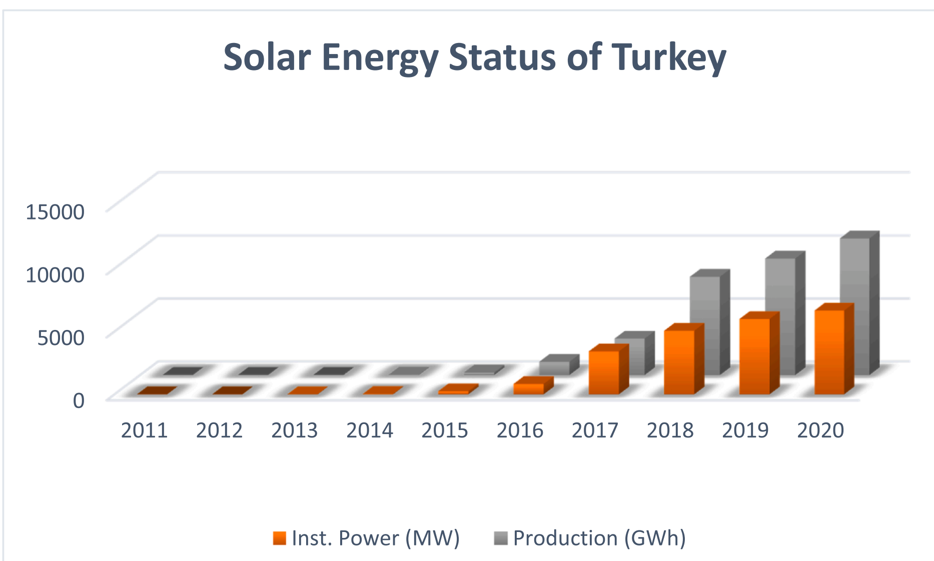

Fig. 1. Solar Energy status of Turkey (BP, 2021).

Dey et al. simulated the electrical properties of the PV panel in the Matlab Simulink environment. They simulated and examined the effects of radiation and light intensity on PV panel efficiency (Dey et al., 2016). Babu et al. made mathematical modeling of the PV panel by comparing two different MPPT methods (Babu et al., 2016). Saleem et al. examined the performance of the photovoltaic plant in real conditions before installation. In the study, a 180 W flexible solar panel was examined as an example model. I–V and P–V characteristics, an irradiance variation between 1000 and 400 W/m^2, ambient temperature variation between 15 and 70 °C were simulated. Modeling was carried out in Matlab Simulink environment (Saleem et al., 2020). Bellia et al. investigated the effects of solar radiation and ambient temperature on the PV panel. The studies were carried out in the Matlab Simulink environment (Bellia et al., 2014). Guerra and Iakovleva simulated the DSM-240-C PV panel in Matlab environment. Within the scope of the study, the effects of solar radiation and ambient temperature on the PV panel were investigated (Guerra & Iakovleva, 2019). Rodrigues et al. aimed to simulate and compare the characteristic current–voltage (I-V) and power-voltage (P-V) curves of equivalent circuits and equivalent circuits of the ideal PV cell model with five and seven parameters. Modeling was done in Matlab Simulink environment (Rodrigues et al., 2018). In order to increase the efficiency of PV panels, King et al. presented compressed air production and storage as a full system mathematical model consisting of panel temperature, panel cleaning and PV power generation (King et al., 2021). Palpandi and Prasanna examined the power output of a photovoltaic panel under different conditions. MPPT technique was also used in the study. Mathematical modeling is realized in Matlab software (Palpandi & Prasanna Moorthy, 2019). Nguyen and Nguyen investigated the simulation of PV cells, panels and arrays in the Matlab Simulink environment. Within the scope of the study, the DS-100 M model was chosen as the reference panel (Nguyen & Nguyen, 2015). Syed and Yazdani simulated the PV module in Matlab Simulink environment. The

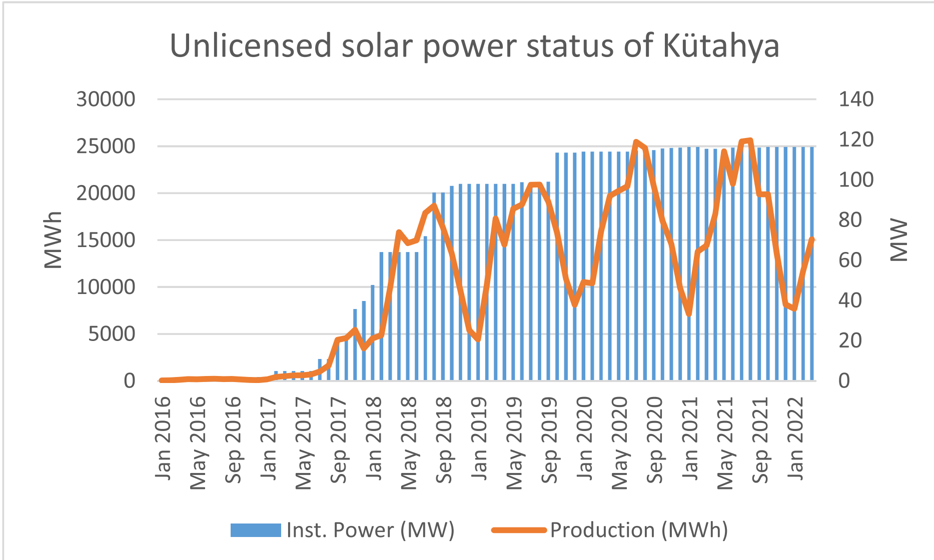

Fig. 2. Kütahya's unlicensed solar power situation (EPDK, 2020).

effect of radiation and temperature change on PV was investigated (Syed & Yazdani, 2014). Suthar et al. have developed mathematical models for PV cell, modules and arrays. Studies were carried out in Matlab software (Suthar et al., 2013). Apatekar and Mallareddy performed a mathematical modeling of a PV cell and investigated the effect of solar radiation on the cell (Apatekar & Mallareddy, 2013). Premkumar et al. have simulated parallel and series connected PV arrays. The studies were carried out in the Matlab Simulink environment and various environmental conditions were discussed (Premkumar et al., 2020). Rasheed et al. performed the mathematical modeling of the solar cell in Matlab environment. The obtained results were compared with the Newton Raphson Method (Rasheed et al., 2021). Zina et al. performed the mathematical modeling of the PV cell in the Matlab Simulink environment. With the model obtained, the power output values of the cell can be obtained depending on the radiation and ambient temperature (Zina et al., 2017). Chowdhury et al. simulated PV arrays in Matlab Simulink environment. Within the scope of the study, the effect of different environmental conditions on PV performance was investigated (Chowdhury et al., 2008). In her work, Jha performed mathematical modeling of PV arrays under partial shading conditions. The study was carried out in Matlab software (Jha, 2022). Jagathdarani and Jaiganesh created the mathematical modeling of the PV panel in Matlab software, and simulated the created model in LabView (Jagathdarani & Jaiganesh, 2015). Koçak created the relative depth map by modeling the reflectance values of Sentinel-2 images with multiple linear regression in his study (Koçak, 2022). Özçankaya and Batur used log diameter data for the estimation of the chest diameter of the stone pine tree in their study. In the study, a data set containing 266 data was used (Özçankaya & Batur, 2021). Dönük and Bindak, in their study with 312 teachers, examined the relationship between teachers' burnout levels, school climate perceptions and organizational commitment. The analyzes were carried out with one-way analysis of variance and multiple regression analysis (Dönük & Bindak, 2022). Doğan et al. developed Artificial Neural Networks model for the estimation of house prices in Keçiören district of Ankara province. 11 independent variables were used for the estimation. Within the scope of the study, 149 housing data were used (O. Doğan et al., 2022). Zorlu and Ünver investigated the relationship between the level of predicting English learning success, self-regulatory learning strategies and English self-efficacy belief. In studies with 542 students, simple and multiple regression analyzes were used (Zorlu & Ünver, 2022). Başar et al., in their study, optimized the thrust force in the drilling process of glass fiber reinforced polymer material with the Taguchi method and applied regression analysis for the estimation of the thrust force (Basar et al., 2020). Yıldıran and Kandemir used the multiple regression analysis method to estimate the yew stream flow data in their study (Yıldıran & Yerel Kandemir, 2020). Cansız et al. used artificial neural networks to determine the optimum number of vehicles on public transport routes, and also used regression analyzes to compare models (Cansız et al., 2020). Başara and Şişman created landslide susceptibility maps with logistic regression analysis using 10 different independent variables in their study (Başara & Şişman, 2022). Çıldır and Mutlu investigated the relationship between air pollutants and meteorological conditions in their studies. Regression analyzes were applied within the scope of the study (Çıldır & Mutlu, 2022). Doğan examined the estimation of the torsional strength values of beams in his study. Regression analyzes were performed using 7 different independent parameters (G. Doğan, 2022). Er et al., in their study, investigated the market value estimation of agricultural lands in Mezitli district of Mersin province. Multiple linear regression analysis was used in the study (Er et al., 2022).

2. Materials and methods

2.1. Datasets

Within the scope of the study, while the expressions giving the values of ambient temperature, solar radiation and wind speed were created, meteorological data obtained from the General Directorate of Meteorology of Turkey for many years were used (Mevbis, n.d.). While creating the expression giving the photovoltaic panel cell temperature, real photovoltaic plant data and other expressions in the literature were used (Lasnier & Gan Ang, 2017; Mondol et al., 2007; Risser & Fuentes, 1984; Ross & Smokler, 1986; Schott, 1985; Skoplaki et al., 2008; Tamizhmani et al., 2003).

While creating the expressions giving the values of ambient temperature, solar radiation and wind speed, a data matrix of 3,966x4 was used, and a data matrix of 2,691,780x4 was used to create the expression that gives the temperature of the photovoltaic panel cell.

2.2. Linear regression

The multiple regression model for the data set is expressed by the following equation (Kayaalp et al., 2015);

Table 3
Comparison of Generated Expression with Other Expressions.

Model	Empirical Expression	Percent Difference (%)
Risser and Fuentes (Risser & Fuentes, 1984)	$T_c = 3,81 + 0,0282.G_T + 1,31.T_{amb} - 1,65.V_W$	8.22 %
Schott (Schott, 1985)	$T_c = T_{amb} + 0,028.G_T - 1$	22.09 %
Ross and Smokler (Ross & Smokler, 1986)	$T_c = T_{amb} + 0,035.G_T$	−51.89 %
Mondol et al. (Mondol et al., 2007)	$T_c = T_{amb} + 0,031.G_T$	−20.04 %
Lasnier and Ang (Lasnier & Gan Ang, 2017)	$T_c = 30,006 + 0,0175.(G_T - 300) + 1,14.(T_{amb} - 25)$	173.53 %
Skoplaki et al. (Skoplaki et al., 2008)	$T_c = T_{amb} + \left(\frac{0,25}{5,7 + 3,8.V_w}\right).G_T$	−3.98 %
TamizhMani et al. (Tamizhmani et al., 2003)	$T_c = 0,943.T_{amb} + 0,028.G_T - 1,528.V_W + 4,3$	−48.35 %

$$Y_i = \beta_0 + \beta_1.X_{i1} + \beta_2.X_{i2} + ... + \beta_k.X_{ik} + \varepsilon_{ij}; \quad i = 1, 2, ...n \quad j = 1, 2, ...k \tag{1}$$

In this equation,
Y_i: refers to the i'th value of the dependent variable,
X_{ij}: refers to the i'th value of j'th independent variable,
B_j: refers to the j'th regression coefficient,
ε_{ij}: refers to the error term,
k: refers to number of independent variables.

After calculating the regression coefficients in the regression model with the least squares method, the following equation is obtained;

$$\widehat{Y}_i = \widehat{\beta}_0 + \widehat{\beta}_1.X_{i1} + \widehat{\beta}_2.X_{i2} + ... + \widehat{\beta}_k.X_{ik}; \quad i = 1, 2, ...n \tag{2}$$

2.3. Expressions

Within the scope of this study, ambient temperature, solar radiation and wind speed were mathematically modeled using the past meteorological data of Kütahya province. After obtaining the mathematical models of the ambient temperature, solar radiation and wind speed values, a global mathematical model was created that gives the photovoltaic panel cell temperature depending on the ambient temperature, solar radiation and wind speed.

In the literature, there are various expressions giving the photovoltaic panel cell temperature, and the theoretical results obtained from these expressions are different from each other. Within the scope of this study, a global expression that gives the cell temperature was created by using the expressions in the literature and the actual solar power plant data.

Using the long-term meteorological data of Kütahya province, the expression that gives the ambient temperature depending on the day and time is shared in Equation (3). In this expression, T_{amb} (°C) is the ambient temperature, n_d is the n'th day of the year, and n_h is the hour in the day in 24-hour units. The R^2 value of the expression was calculated as 80.47 %.

$$T_{amb} = -100,572461 + 0,101689513*n_d + 0,00195160285*n_d^2 - 0,0000306355524*n_d^3 + 0,000000216550535*n_d^4 - 0,000000000698535252*n_d^5 + 7,97106932E - 13*n_d^6 + 46,8720428*n_h - 10,5598686*n_h^2 + 1,25851515*n_h^3 - 0,0800119137*n_h^4 + 0,00257646748*n_h^5 - 0,0000332418934*n_h^6 \tag{3}$$

Table 4
Percentage Comparison of Theoretical Values and Actual Values.

Value	Percent Difference (%)
T_{amb} (°C)	−0.72795 %
G (W/m²)	−0.82639 %
V_w (m/s)	−0.26276 %
T_c (°C)	−3.98 %
P (kWh/m²)	1.8675 %

$R^2 = 0{,}8047$

Using the long-term meteorological data of Kütahya province, the expression that gives the solar radiation depending on the day and time is shared in Equation (4). In this expression, G (W/m²) is the solar radiation, n_d is the n'th day of the year, and n_h is the hour in the day in 24-hour units. The R^2 value of the expression was calculated as 66.71 %.

$$G = 8,57327012E + 04 - 2,41680385E + 03*n_d + 2,84111740E + 01*n_d^2 - 1,63468910E - 01*n_d^3 + 4,51277669E - 04*n_d^4 - 4,74435016E - 07*n_d^5 + 1,77607014E - 12*n_d^6 - 3,25232569E + 04*n_h + 4,84306344E + 03*n_h^2 - 3,54423317E + 02*n_d^3 + 1,28492149E + 01*n_d^4 - 1,90122636E - 01*n_d^5 + 2,32148744E - 04*n_d^6 + 9,14 \tag{4}$$

$R^2 = 0{,}6671$

Using the long-term meteorological data of Kütahya province, the expression that gives the wind speed depending on the day and time is shared in Equation (5). In this expression, V_w (m/s) is the wind speed, n_d is the n'th day of the year, and n_h is the hour in the day in 24-hour units. The R^2 value of the expression was calculated as 56.93 %.

$$V_w = 4,43491505E + 02 - 1,38884417E + 01*n_d + 1,54250299E - 01*n_d^2 - 8,03030187E - 04*n_d^3 + 2,08475742E - 06*n_d^4 - 2,22740581E - 09*n_d^5 + 3,68724339E - 14*n_d^6 - 1,83048578E + 02*n_h + 3,00652089E + 01*n_h^2 - 2,46167229E + 00*n_h^3 + 1,01398437E - 01*n_h^4 - 1,74913426E - 03*n_h^5 + 3,65425887E - 06*n_h^6 + 5,71 \tag{5}$$

$R^2 = 0{,}5693$

The expression giving the photovoltaic panel cell temperature is shared in Equation (6). This statement was created by using real photovoltaic plant data and data obtained from other statements in the literature. In this expression, T_c (°C) is the photovoltaic panel cell temperature, T_{amb} (°C) is the ambient temperature, G (W/m²) is the solar radiation and V_w (m/s) is the wind speed. The R2 value of the expression was calculated as 92.83 %.

$$T_c = 3,4631 + T_{amb} + 0,029345.G - 0,0051.G.V_w + 0,00027035.G.V_w^2 - 2,8467.V_w + 0,55022.V_w^2 - 0,0293.V_w^3 \tag{6}$$

$R^2 = 0{,}9283$

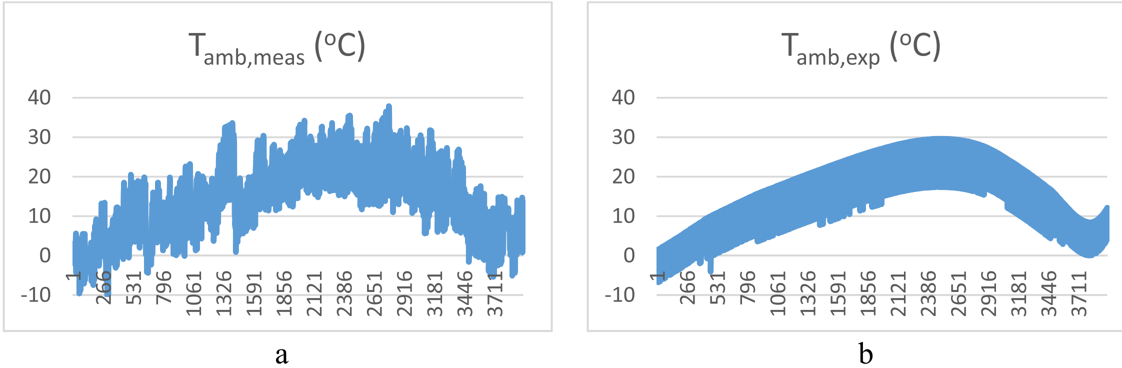

Fig. 3. Comparison of (a) Actual and (b) Theoretical Values of T_{amb}.

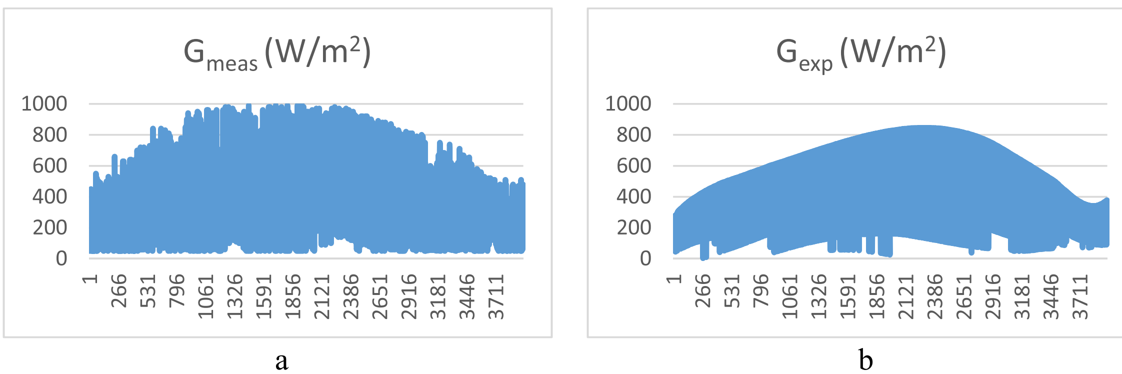

Fig. 4. Comparison of (a) Actual and (b) Theoretical Values of G.

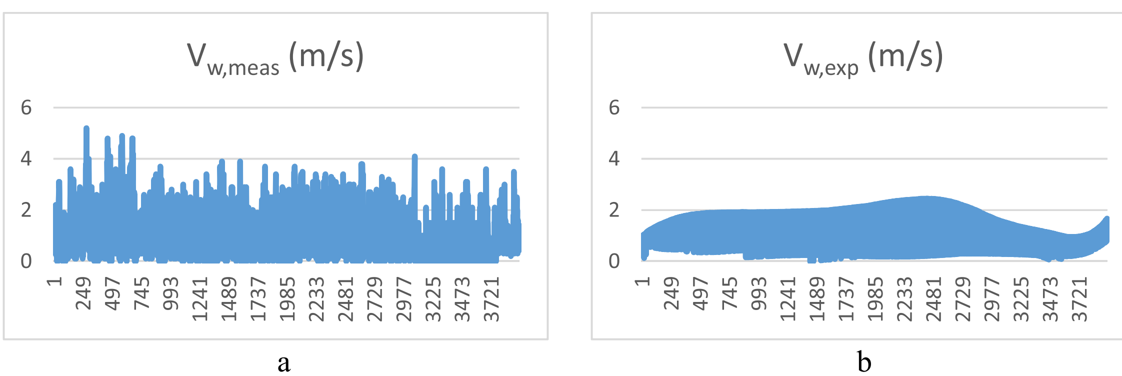

Fig. 5. Comparison of (a) Actual and (b) Theoretical Values of V_w.

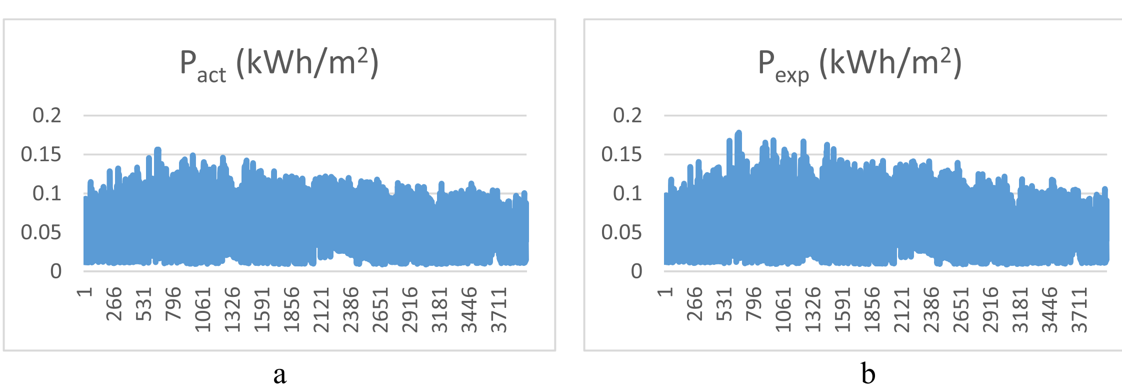

Fig. 6. Comparison of (a) Actual and (b) Theoretical Values of P.

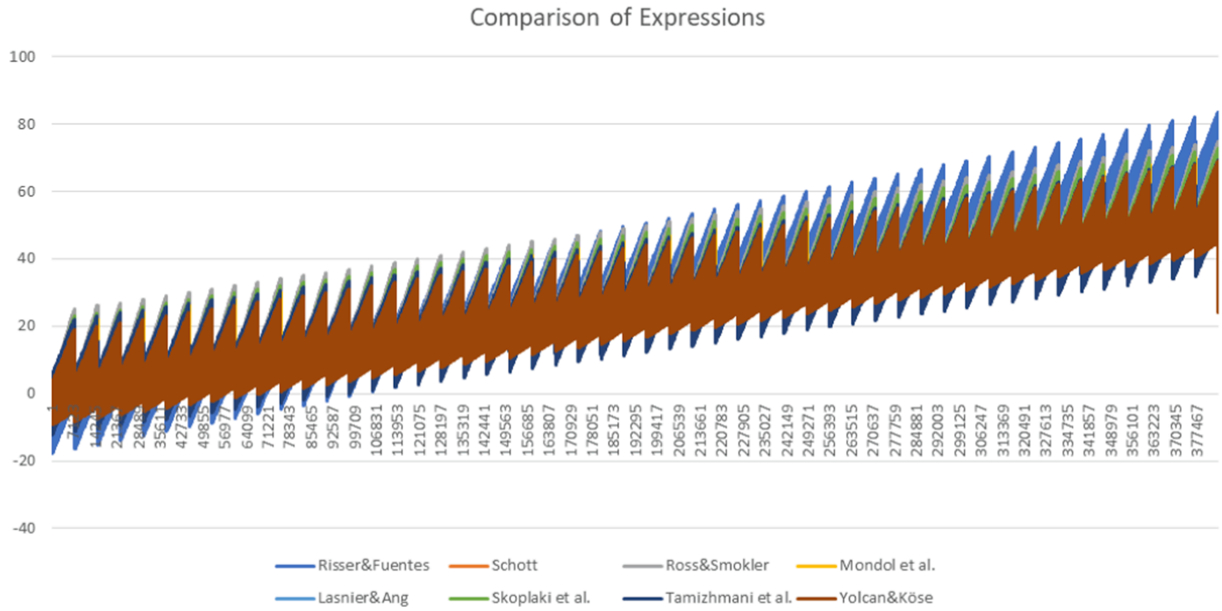

Fig. 7. Comparison of Expressions.

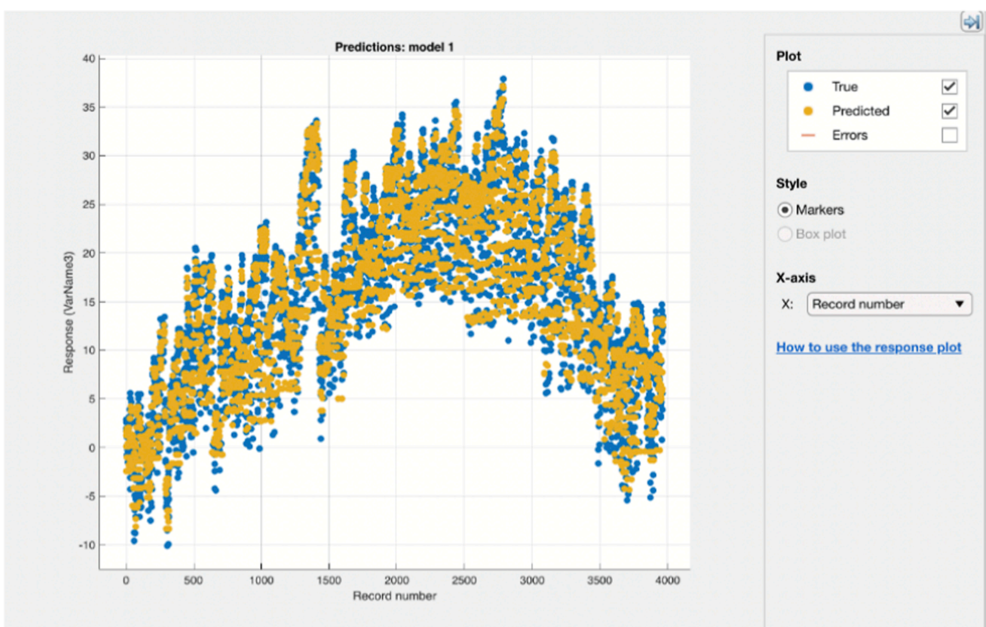

Fig. 8. Comparison of T_{amb} values with Fine Tree Method.

2.4. Validity of expressions

After creating expressions giving ambient temperature, solar radiation, wind speed and photovoltaic panel cell temperature, the validity of the obtained expressions was investigated. First, the percentage difference between the expression giving the cell temperature and the other expressions in the literature is shown in Table 3.

According to Table 3, the difference between the obtained expression and Risser and Fuentes (Risser & Fuentes, 1984) expression is 8.22 %, the difference between Schott (Schott, 1985) expression is 22.09 %, the difference between Ross and Smokler (Ross & Smokler, 1986) expression is −51.89 %, the difference between Mondol et al. (Mondol et al., 2007) expression is −20.04 %, the difference between Lasnier and Ang (Lasnier & Gan Ang, 2017) expression is 173.53 %, the difference between Skoplaki et al. (Skoplaki et al., 2008) expression is −3.98 % and dhe difference between Tamizhmani et al. expression is calculated as −48.35 %.

The percentage comparison of the values obtained with the generated expressions and the actual values is given in Table 4. Percentage difference was calculated by Equation (7). Theoretical photovoltaic production values were compared with the production values of a photovoltaic power plant using panels with P, CdTe panel technology.

As can be seen in Table 4, the difference between the calculated theoretical values and the actual values; It was calculated as −0.73 % for ambient temperature, −0.83 % for solar radiation, −0.27 % for wind speed, −3.98 % for photovoltaic panel cell temperature, 1.87 % for photovoltaic panel production value. The difference obtained as a result of comparing the results obtained from the created expression with the

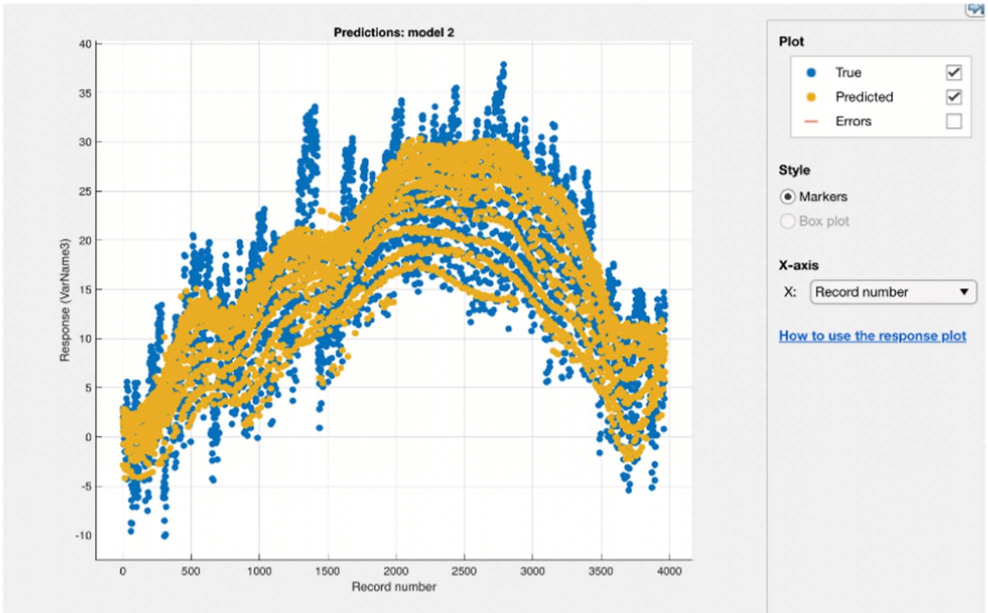

Fig. 9. Comparison of T_{amb} values with Fine Gaussian SVM Method.

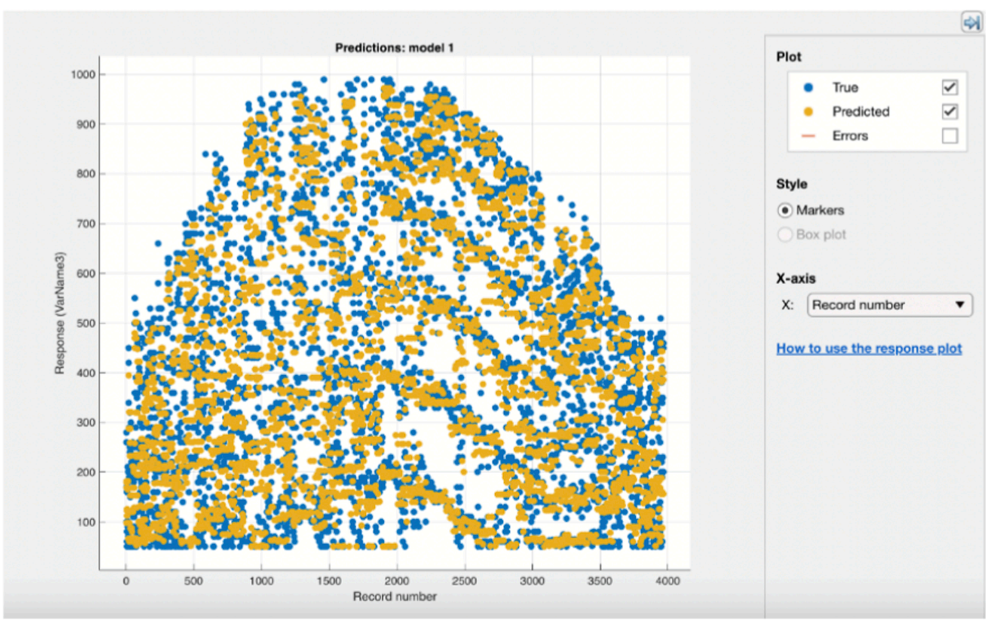

Fig. 10. Comparison of G values with Fine Tree Method.

actual data was found to be quite low. The difference between the created expression and the other expressions in the literature is relatively high. Calculating the difference as small in comparison with real data proves the validity of the statement created within the scope of the study.

$$Percent\ Difference\ (\%) = \frac{n_{theor.} - n_{actual}}{n_{theor.}} \quad (7)$$

For the ambient temperature, the graphical comparison of the actual data and the theoretical data is shared in Fig. 3. The values obtained with the expression created using long-term data were compared with the meteorological data of 2020. When Fig. 3 is examined, it is seen that the theoretical data and the actual data are consistent. The comparison was made for 365 days and graphed.

For the solar radiation, the graphical comparison of the actual data and the theoretical data is shared in Fig. 4. The values obtained with the expression created using long-term data were compared with the meteorological data of 2020. When Fig. 4 is examined, it is seen that the theoretical data and the actual data are consistent. The comparison was made for 365 days and graphed.

For the wind speed, the graphical comparison of the actual data and the theoretical data is shared in Fig. 5. The values obtained with the expression created using long-term data were compared with the meteorological data of 2020. When Fig. 5 is examined, it is seen that the theoretical data and the actual data are consistent. The comparison was made for 365 days and graphed.

For the photovoltaic electrical production for CdTe panel, the graphical comparison of the actual data and the theoretical data is shared in Fig. 6. The values obtained with the expression created using long-term data were compared with the meteorological data of 2020.

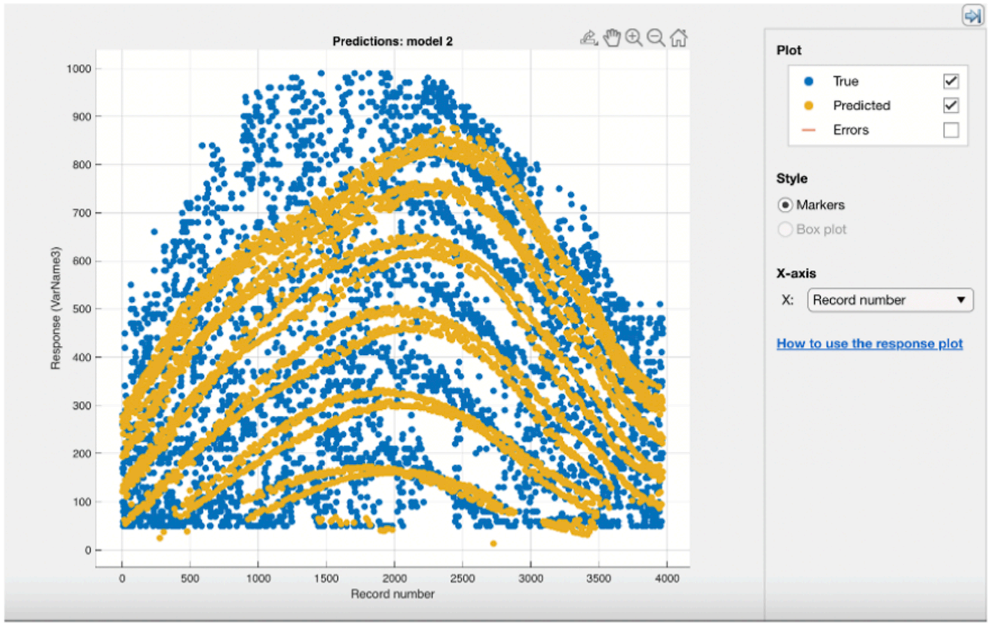

Fig. 11. Comparison of G values with Fine Gaussian SVM Method.

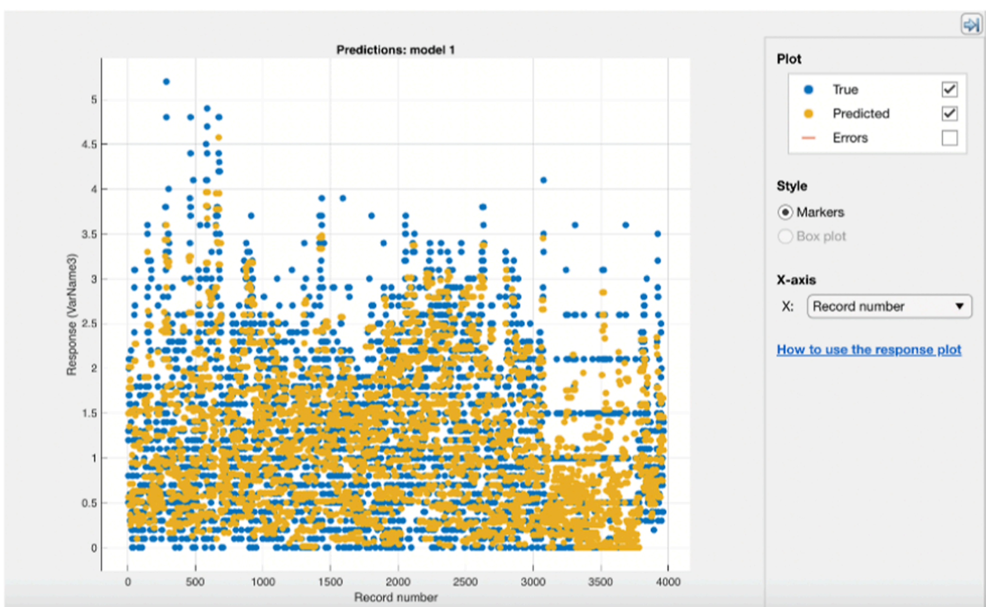

Fig. 12. Comparison of V_w values with Fine Tree Method.

When Fig. 5 is examined, it is seen that the theoretical data and the actual data are consistent. The comparison was made for 365 days and graphed.

Fig. 7 shows the graphical comparison of the most used expressions (Lasnier & Gan Ang, 2017; Mondol et al., 2007; Risser & Fuentes, 1984; Ross & Smokler, 1986; Schott, 1985; Skoplaki et al., 2008; Tamizhmani et al., 2003) in the literature on photovoltaic panel cell temperature and the expression created within the scope of this study. For the purpose of comparison, 7 different expressions in the literature and 384,540 different values for each of the expressions created in this study were compared. When Fig. 7 is examined, it is seen that the expression created within the scope of this study is consistent with other expressions.

At this stage of the study, the data were analyzed in MatLab (MathWorks, 2020) Regression Learner environment to check the consistency of the generated expressions. Fine Tree and Fine Gaussian SVM (MathWorks, 2020) methods were used for analysis.

Comparisons made with the Fine Tree Method for ambient temperature, solar radiation, wind speed and photovoltaic panel cell temperature are shown in Fig. 8, Fig. 10, Fig. 12 and Fig. 14, respectively. When the figures are examined, it is observed that the real data and the theoretical data are consistent.

Comparisons made with the Fine Gaussian SVM Method for ambient temperature, solar radiation, wind speed and photovoltaic panel cell temperature are shown in Fig. 9, Fig. 11, Fig. 13 and Fig. 15, respectively. When the figures are examined, it is observed that the real data and the theoretical data are consistent.

3. Evaluations and suggestions

In the current studies in the literature, there are empirical

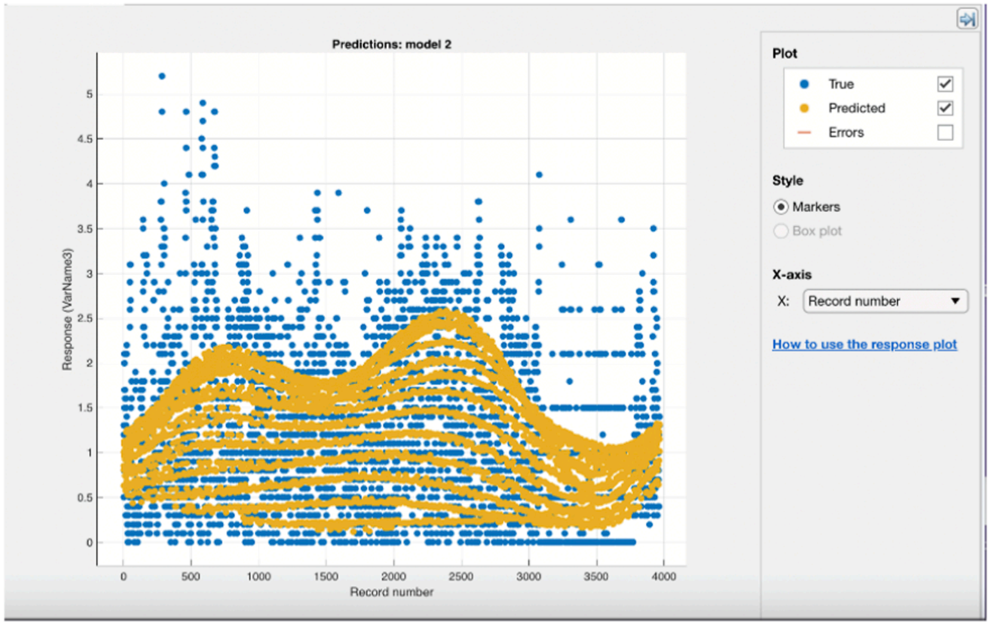

Fig. 13. Comparison of V_w values with Fine Gaussian SVM Method.

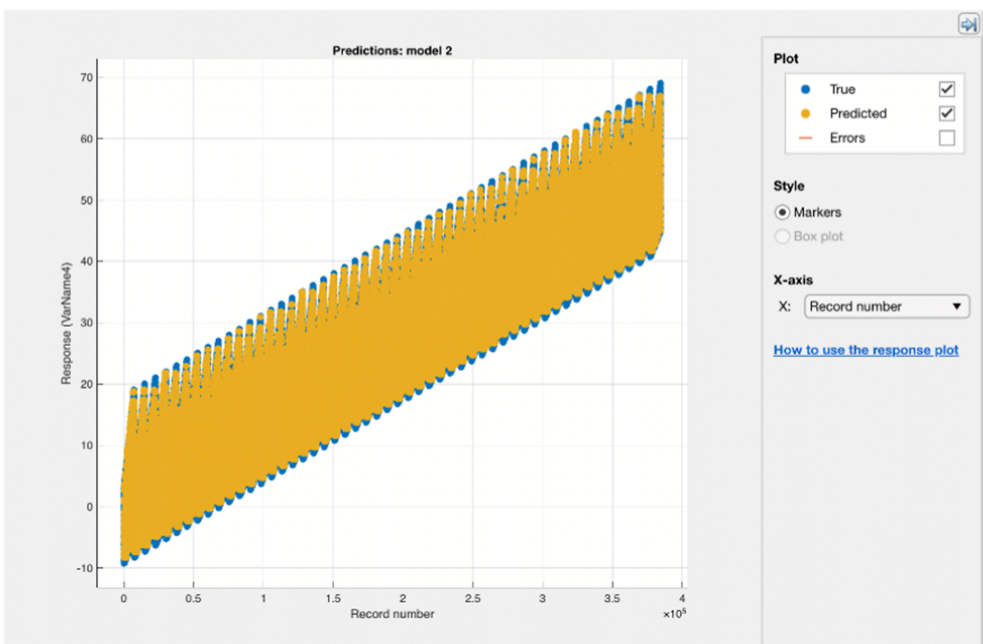

Fig. 14. Comparison of T_c values with Fine Tree Method.

expressions that give the photovoltaic panel cell temperature, but the results obtained from these expressions do not overlap with each other. In order to obtain the instantaneous efficiencies of photovoltaic panels and, accordingly, the production values theoretically, there is a need for a global expression that gives the photovoltaic panel cell temperature.

The instantaneous efficiency of the photovoltaic panel and the generation of electrical energy depending on the efficiency are related to the cell temperature of the photovoltaic panel. Within the scope of this study, a global expression that gives the photovoltaic panel cell temperature was created by using real photovoltaic plant data with the 7 most popular expressions in the literature that give the photovoltaic panel cell temperature. With the obtained expression, instantaneous photovoltaic panel temperature can be obtained depending on the ambient temperature, solar radiation and wind speed.

In addition, within the scope of the study, 3 different expressions have been created that allow us to theoretically obtain the ambient temperature, solar radiation and wind speed values depending on the day and hour by using the long-term meteorological data of Kütahya province. Although the expression for photovoltaic panel cell temperature is global, the expressions for ambient temperature, solar radiation and wind speed are valid for the province of Kütahya, but can be obtained for the desired region by using meteorological data together with the method in the study.

The validity of the generated expressions was made with Fine Tree and Fine Gaussian SVM regression methods in Matlab environment, together with the comparison of theoretical data and real data, and the

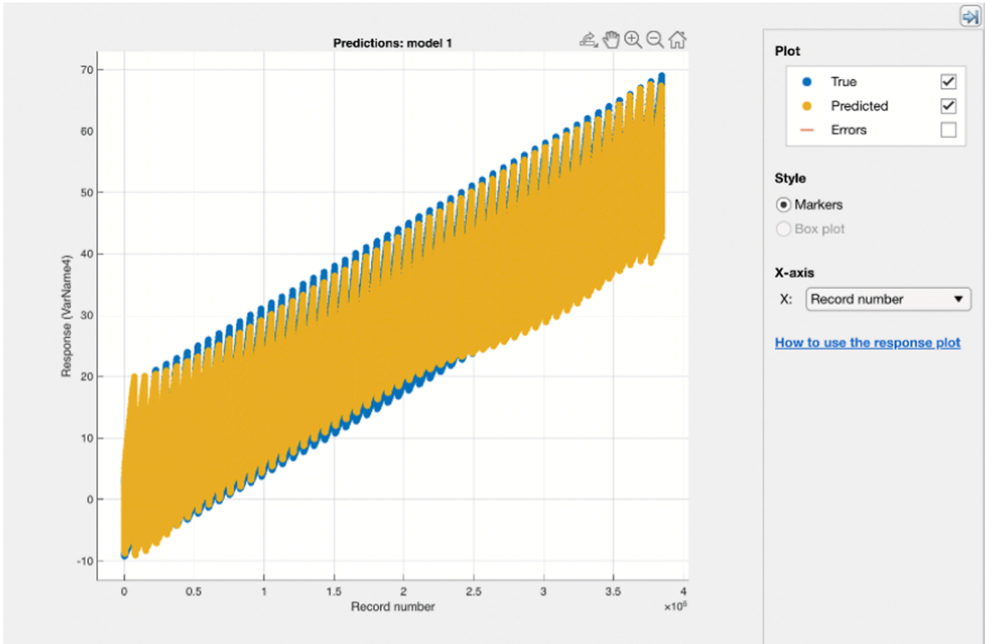

Fig. 15. Comparison of T_c values with Fine Gaussian SVM Method.

comparisons were shared numerically and graphically. When the comparison results are examined, it is seen that the expressions formed are quite consistent.

With the expressions obtained, instantaneous efficiency estimates of photovoltaic systems, electrical energy production estimates on the basis of the desired time and feasibility reports related to these can be obtained. In a world with limited fossil fuel reserves and global energy crises, one of the most important renewable energy sources, the importance and use of which is increasing day by day, is solar energy. With the expressions shared in this study, technical and economic analysis of photovoltaic solar energy systems at any scale can be made.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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