COOLED AND UNCOOLED PHOTOVOLTAIC PANELS MODELING BY USING GENETIC EXPRESSION PROGRAMMING

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Original scientific paper

The aim of this paper is to estimate the efficiency of photovoltaic (PV) panels with and without active cooling by using genetic expression programming (GEP). An active cooling system has been developed based on water spraying (non-uniformly) of PV panels, and we provide to increase the efficiency of PV panels. Panels is not cooled, the temperature of the panel is increased and the efficiency was calculated as 16.81%. When the panels are cooled, the panel temperature fell and the efficiency was calculated as 18.83%. GEP is preferred since it generates a mathematical function which fits to given experimental data. The test results indicate that for the model equations obtained, the determination coefficients (R^2) are very high. These good agreements confirm the validity of the developed GEP models.

Keywords: *Active cooling; photovoltaic; genetic expression programming; efficiency, GEP*

1 Introduction

PV system is one of the renewable sources of energy. PV cells are semiconductor devices that can convert sunlight into electricity. PV panels work best in certain weather conditions, but since the weather is always changing and as designers are installing PV panels all over the world in different climate regions, most panels do not operating under ideal conditions [1]. Most of the PV panels, it cannot convert to a full radiation into electricity. It is important to have a cooling system so that the PV system may produce power more efficiently that is the PV system should maximize its potential power production [2]. The efficiency of solar cells decreases with increasing module temperature. So it must be cooled to the solar cells. A typical value for PV efficiency loss with temperature is 0.5%/°C though this varies with the type of cell. Cooling of the solar cell achieved by both water and air [3-7].

Solar cells can be cooled with active and passive methods. An external power requirements of the active system is concerned. There is no external power requirement in the passive system. Active system used machines such as pumps and fans [1]. Usually a PV panel converts only 10-15% of the incident power to electricity, the rest power is largely rejected as heat [8-9].

Many studies related to the cooling of the PV panel. Royne et al. [10] have examined a PV cooling methodologies, for use under concentrated lighting, it is desirable for the temperature to be uniform across the cells. Skoplaki and Palyvos reviewed efficiency/power correlations on the temperature dependence of PV module electrical performance [11]. Sanusi et al. [12] investigated effects of ambient temperature on the performance of a PV solar system in a tropical area, Ogbomoso, Nigeria. Teo et al. [13] reported an active cooling system for PV modules. Developing a heat transfer model, they have done very harmonious work with the actual temperature profiles. Chinamhora et al. [2] have done effective work by cooling the front and back of a PV panel with water. Moharram et al. [14] a non-pressured cooling system has been developed based on spraying the PV panels by water once in a while. A cooling rate model has been developed to determine how long it will take to cool the PV panels by water spraying to its operating temperature. Dorobantu and Popescu [15] proposed a solution to increase efficiency PV panels. So they used a device that makes a water film on the surface of panels, obtaining simultaneously cleaning and decreasing the operating the temperature of the panel. Zhu et al. [16], have made water cooling to avoid distortion for high concentration of PV cells. Hybrid Photovolatic/Thermal (PV/T) solar system is one of the most popular methods for cooling the photovoltaics panels nowadays. Tonoi and Tripanagnostopoulus [17] have studied a study that an improvement of heat extraction can be achieved by low cost modifications of the channels of PV/T air system. Abdulgafar et al. [7] investigated a PV panel cooling by water immersion technique to improve the performance and the electrical efficiency of polycrystalline silicon panel. Ceylan et al. [18] analyzed a study that the PV module was placed on the front of the solar collector. The water was pre-heated in the PV module which was placed on the front of the solar collector. In this way PV modules were cooled.

Intelligent methods (adaptive-neuro fuzzy inference systems; ANFIS, artificial neural network; ANN, support vector machine; SVM etc.) are widely used in various areas of energy-related research [19-21]. Ghaderi et al. presented an economic model for energy efficiency programs in order to evaluate their impacts on the GEP problem [22]. GEP is one of the earliest problems in power systems industry and numerous techniques have been applied to solve the problem [23]. In this study, the efficiency of PV panel was modeled by using the GEP. This method helps us to obtain a mathematical equation from values obtained from experimental data. A mathematical function is not possible to obtain from other intelligent systems.

The rest of this paper is organized as follows. The experimental setup and methodology of GEP modeling are described in Sections 2 and 3, respectively. The experimental results and findings of GEP is presented in Section 4. The study conclusions are given in Section 5.

2 Experimental system

2.1 Experimental setup

An experimental setup has been developed to validate both cooled and no cooled panel models, experimentally, and to study the influence of cooling on the efficiency of

PV panels. The PV panel is installed in the Firat University in Elazig in Turkey. Two solar panels, each of that has a power of 150 W, have been used in experimental studies. An experimental system has been built up as shown in Fig. 1, and further details can be found Table 1. Solar cell system and cooling system are provided separately in Table 1. Two of PV panels with the same characteristics are provided the same terms and to stand in the same direction. The appearance of the temperature point on the panel is given in Fig. 2.

The cooled panel was made from seven point measurements (front side 6, 7 and 8 points, the back side 2, 3, 4 and 5 points), in without cooled panel is the two points (the front 9, the back side 10 point) temperature measurement are made. Also during the experiment, ambient temperature (1 point) and the solar radiation were measured. The open-circuit currents and voltage of two PV panels were measured. Water is sprayed using water nozzles, which are installed at the back side of the panels, as shown in Fig. 2.

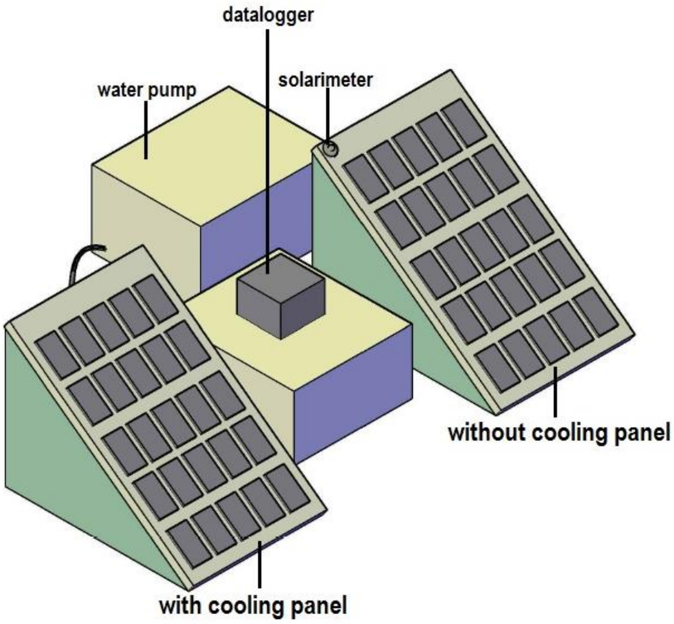

Figure 1 Experimental set-up

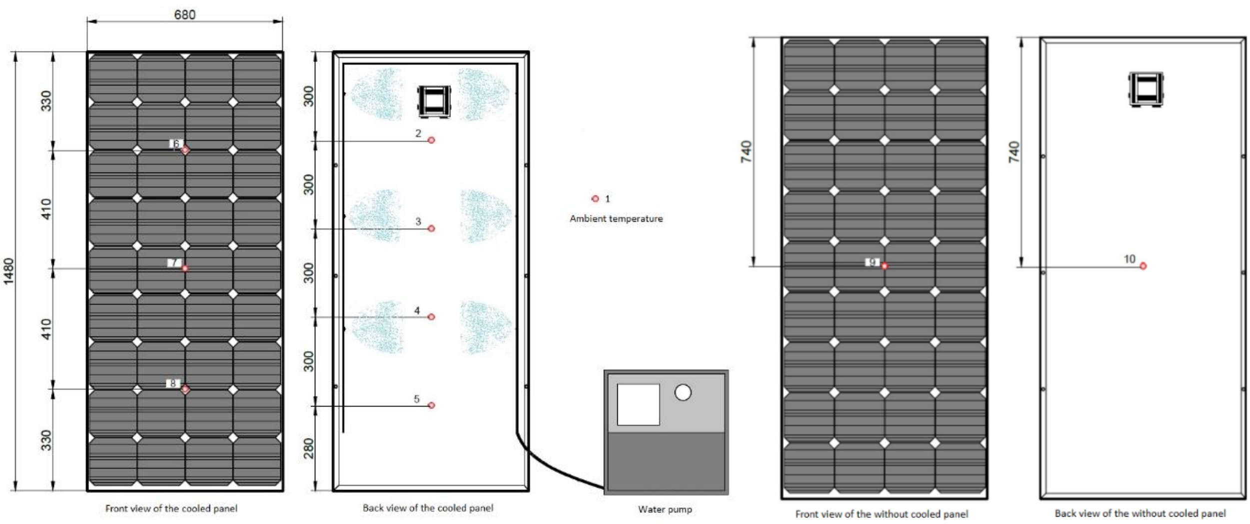

Figure 2 The view of the measured temperature point

Table 1 The main components specification and characteristics of the PV systems studied [24]

Systems	Element	Technical specification
Photovoltaic system	Solar cells	Model type: Bluesun 150W, BSM-150M monocrystalline; Solar cell type: Mono; Date: July 2012; 156X156 cell; Pm=150 W, Vmp=18.2V, Imp=8.25 A, Voc=21.9 V, Isc=8.77A; size: 1483x666x40; weight: 11.3 kg.
	Solar cell fasteners	UV protected multicontact solar cables and connectors; Power cable.
Cooling system	Pressure water pump	Manufacturer: Normist; type: RR-2; pressure: 70 bar; flow LPM:2; engine power: 0.75 HP, 0.55 kW; nozzle diameter: 0.2 mm; water inlet/outlet diameter: 9.525/12 mm, noise level: 78 dB.
	Distribution system	Manufacturer: Normist; hexagonal nozzle series: nozzle flow value: 0.075 lt/min (at 70 bar), clamps, pressure switch, pump regulator, terminating line, quickly drain, high pressure plastic pipe, low pressure plastic pipe plastic clips, quick fittings, purge.

2.2 Experimental analysis of the system

Cooling the solar panels has been performed to determine the influence of cooling. Cooling and without cooling of the solar panels were performed for two days in July 2014, and the experiment started from 08:00 am till 17:00 pm using a controlled water flow rate of 2 liter per minute.

The output power P of the PV panel is calculated using the measured maximum voltage and current values as follows:

$$P=V_p.I_p \tag{1}$$

where VP is the maximum voltage of panel and I_P maximum current of panel. The efficiency, η, of the PV panels is calculated by [14, 18],

$$\eta=\frac{P}{I.A} \tag{2}$$

where P (W) is the output power generated from the PV panels, A (m^2) is the panel surface area, and I (W/m^2) is the solar irradiance incident on the panels.

A pyranometer was used to capture the daily global solar irradiation. Temperature measurements are important in this experiment and therefore calibrated T-type thermocouples were utilized. The temperature distribution of the panels is measured using thermocouples located at the front and back of the panels. The output power, solar irradiance, and temperature are all monitored using a data acquisition system, employing Energy Systems Engineering Lab. All measurements are saved to an excel file for further calculation and analysis.

3 Genetic Expression Programming (GEP)

In 2001, Ferreira [25] proposed the GEP, which was developed to improve the genetic programming. Both GEP and genetic programming models apply the biological evolution concept for finding the best solution to a certain problem. The main difference between GEP and genetic programming is the implementation of chromosomes. The genetic programming utilizes a tree structure to represent a gene. These computer programs are complex tree structures that learn and adapt by changing their sizes, shapes, and composition, much like a living organism. Any mathematical description defined as figurative strings of fixed-length (chromosomes) in genetic algorithms is represented to be nonlinear entities of different size and shapes (parse trees). GEP computer program is encoded in linear chromosomes composed of genes structurally organized in a head and a tail. The head or tail domain of GEP genes (both normal and homeotic) is the basic building block of all GEP algorithms. However, gene expression programming also explores other chromosomal organizations that are more complex than the head or tail structure. Essentially these complex structures consist of functional units or genes with a basic head/tail domain plus one or more extra domains [26-27]. GEP algorithm flow chart is given in Fig. 3.

This algorithm arbitrarily makes up primary chromosome which denotes a mathematical function and then transform it into an expression tree as illustrated in Fig. 4. There is assessment between predicted values and actual values in subsequent step. . When preferred results in accord with fault criteria originally nominated are found, the GEP process is finished. If preferred error criteria could not be found, some chromosomes are chosen by method called roulette-wheel sampling and they are transformed to obtain new chromosomes. After preferred fitness mark is found, this method ends and then the knowledge's coded in genes in chromosomes are decoded for the best solution of the problem [28]. GEP model consist of two components called chromosomes and the expression trees. The chromosomes which may have one or more genes is coded some information using special language about the problem. Any mathematical model is coded in gene in chromosomes using bilingual and conclusive language called Karva Language. Expression trees and Karva Language are explained in details by [30-33]. Before the analysis, the user regulates the certain operator degrees that explain a certain possibility of a genetic material. It is suggested that the inversion rate and cross-over rate are 0.1 and 0.4, respectively. The mutation rate is ordinarily employed between the 0.001 and 0.1 [28].

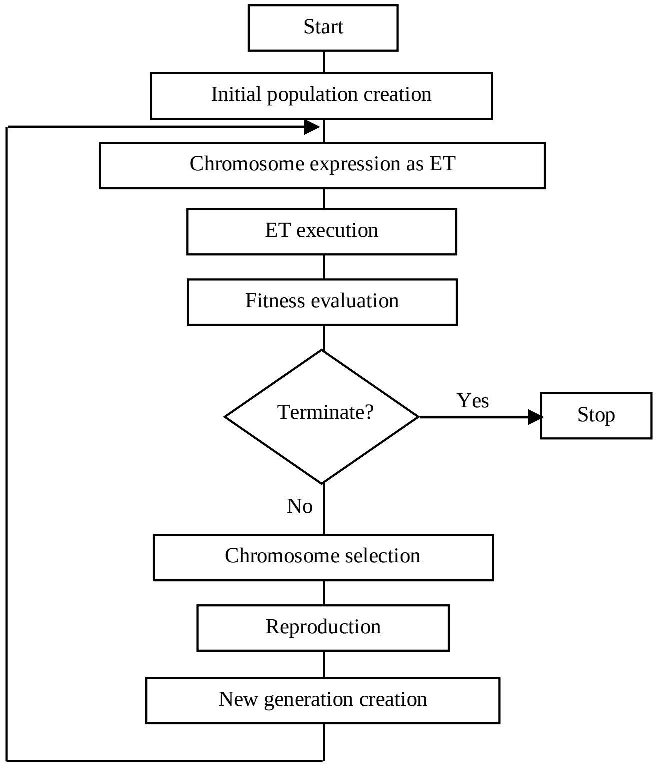

Figure 3 The algorithm of genetic expression programming [28]

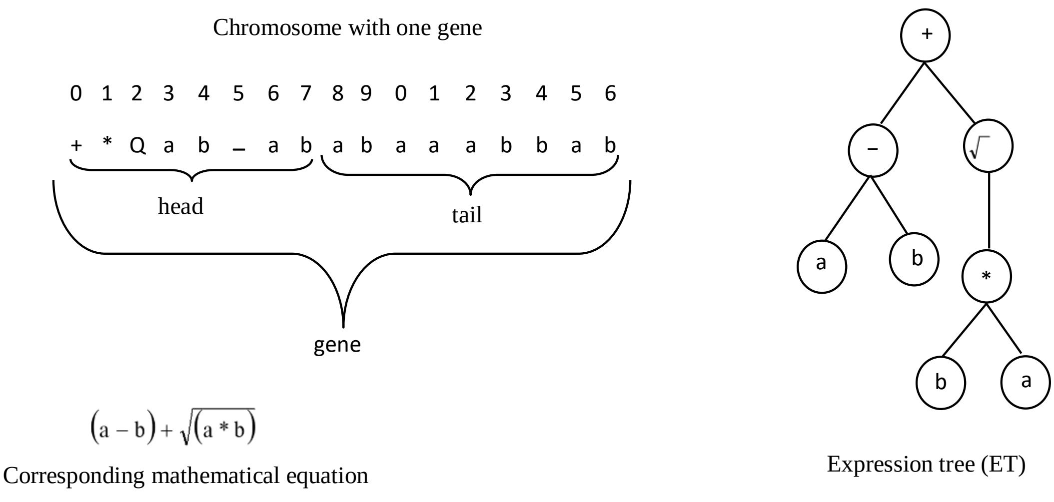

Figure 4 Expression of a chromosome with one gene and corresponding mathematical equation

Table 2 Typical electrical characteristics of BSM-150 PV module

Parameter	Variable	Value	Parameter	Variable	Value
Maximum power	*P*	150 W	Cell size	*Mm*	156x156
Power tolerance	%	+5	I_P temperature coefficient	*(%/°C)*	+0.1
Max-power voltage	V_P *(V)*	18.11	V_P temperature coefficient	*(%/°C)*	-0.38
Max-power current	I_P *(A)*	8.32	P temperature coefficient	*(%/°C)*	-0.47
Open-circuit voltage	V_{OC}*(V)*	22.51	I_{SC} temperature coefficient	*(%/°C)*	+0.1
Short circuit current	I_{SC}*(A)*	9.08	V_{OC} temperature coefficient	*(%/°C)*	-0.38
Max-system voltage	*VDC*	1000	NOCT-Nominal Operating Cell Temperature	*°C*	48±2
Cell efficiency	η_c *(%)*	≥17	Fill factor	%	≥73.3

The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:
• Illumination of 1 kW/m^2 (1 sun) at spectral distribution of AM 1.5;
•Cell temperature of 25°C or as otherwise specified (on curves).

4 Experimental and modeling results/discussions

The Bluesun BSM-150 PV panel was chosen for modeling, due is well-suited to traditional applications of photovoltaic. The BSM-150 panel enables 150 Watt of nominal maximum power, and has 36 series connected mono-crystalline silicon (4x9) cells. The key terms are shown in Table 2. A number of discrete data points are shown on the curves in Fig. 5.

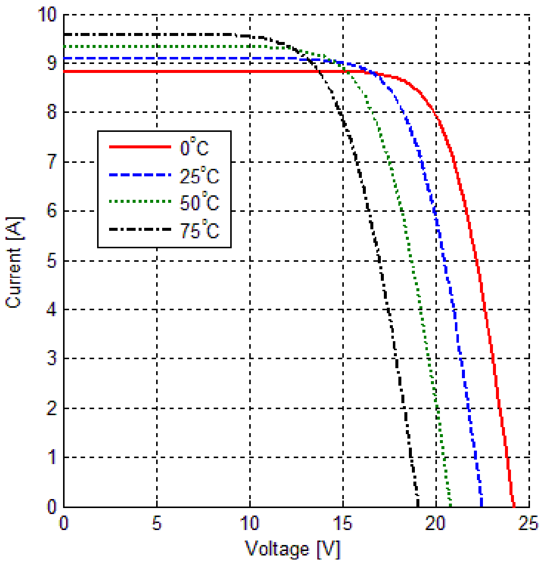

Figure 5 Matlab model I_P-V_P curves for various temperatures (BSM-150, G=1000 W/m^2, T=0, 25, 50, 75 °C)

These are points taken directly from the manufacturer's published curves, and show excellent correspondence to the model. For the BSM-150 the curves show, I_L changes from 9.08 to 9.35A (≈3%) as T changes from 25 to 75°C. Figure 6 shows power voltage curves for several temperatures, again the discrete data points taken directly from the manufacturer's published curves, and show excellent correspondence to the model. The cell efficiency and fill factor (FF) of BSM-150 photovoltaic unit are calculated as 17.12% and 73.71, respectively (according to the data of Table 2). It is shown with the cooled panel P1 and the without cooling panel display with the P2. In the experiment, PV current (A), PV voltage (V), temperature of panels and solar irradiation were collected. As the solar radiation increased, panel power and availability increased as well.

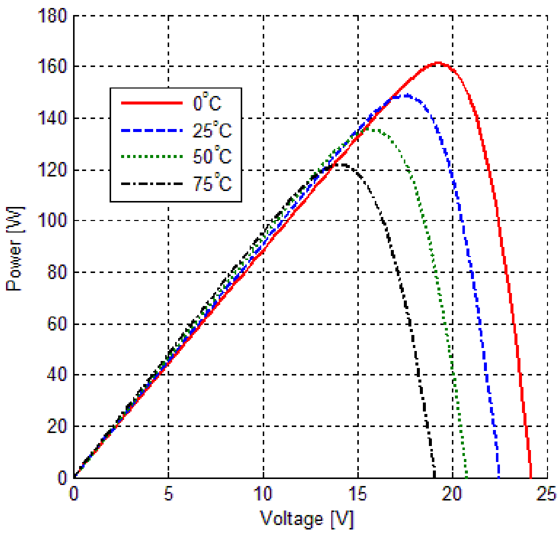

Figure 6 Matlab model P-V_P curves for various temperatures (BSM-150, G=1000 W/m^2, T=0, 25, 50, 75 °C)

The change in the solar radiation and panel voltage/current (I_P/V_P) were given in Fig. 7. Panel maximum voltage/current were changed according to solar radiation.

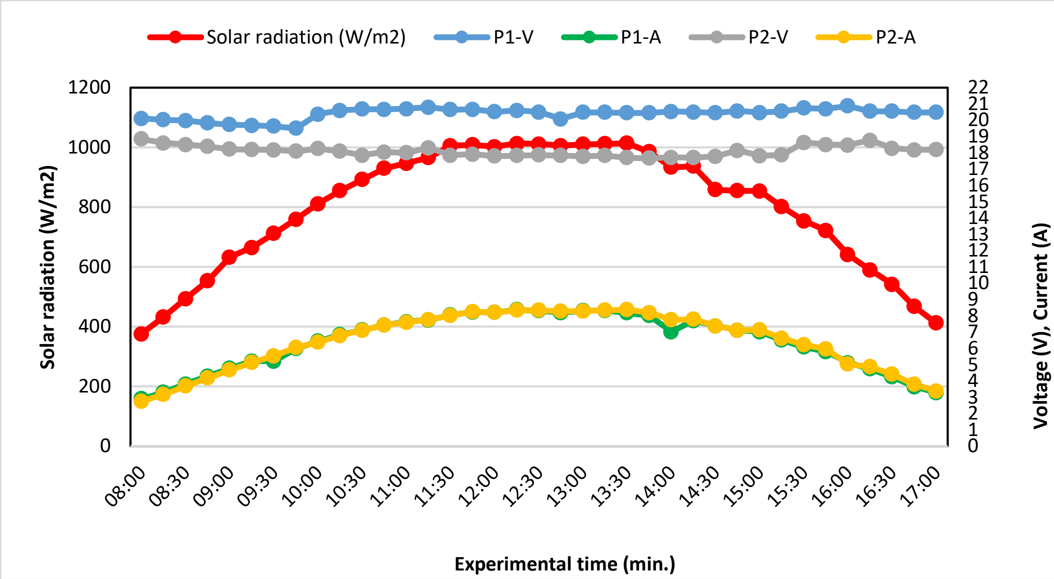

Figure 7 The solar radiation and voltage/current values on the days with a test

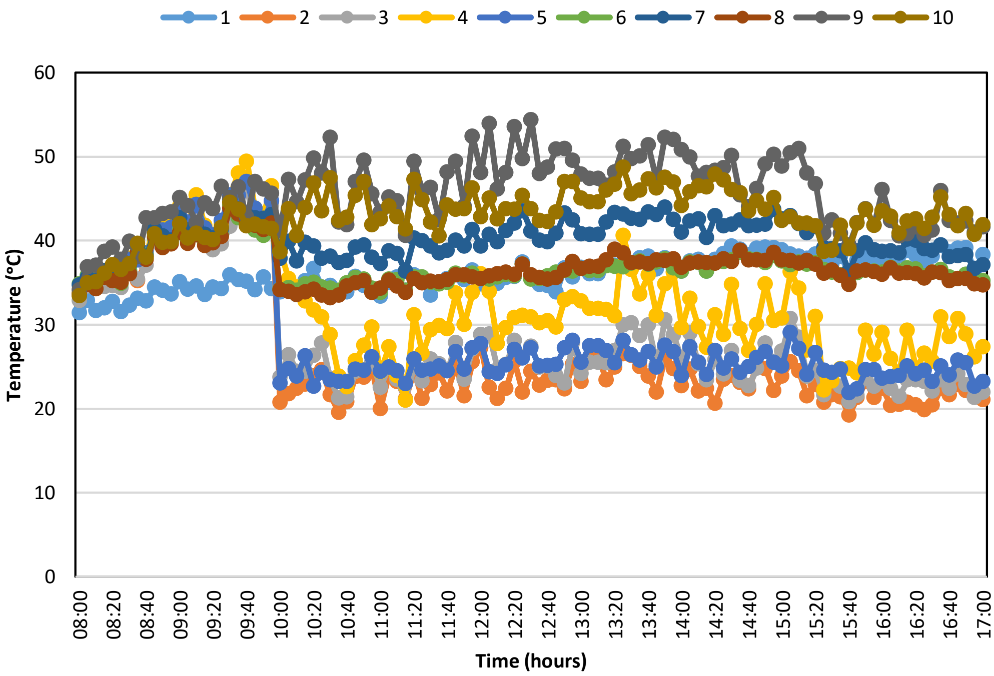

Figure 8 Graph of PV panel and ambient temperatures with time

The point of temperature in Fig. 2 are shown in Fig. 8. The cooled panel was made from seven point measurements (front side 6, 7 and 8 points, the back side 2, 3, 4 and 5 points), in without cooled panel is the two points (the front 9, the back side 10 point) temperature measurement is made. Also during the experiment, ambient temperature (1 point) was measured. Cooling experiments were started at 10:00 am. After that time, the average temperature of panels are in 40 °C, temperature fells to 20 °C.

Panel voltage/current increased and decreased in line with the solar radiation. Maximum power gains and panel efficiency in the system were calculated in Eq. 1 and Eq. 2, respectively. Without active cooling, the temperature of the panel was high and solar cells can only achieve an efficiency of 18.83%. However, when the panel was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of solar cells to between 16.81%. It can be clearly seen from Fig. 9 that as the solar panel temperatures increases, the solar PV panel efficiency decreases gradually. Experimental measurements of the efficiency and the module temperature of PV panels, during July 2014, are shown in Figs. 8-9.

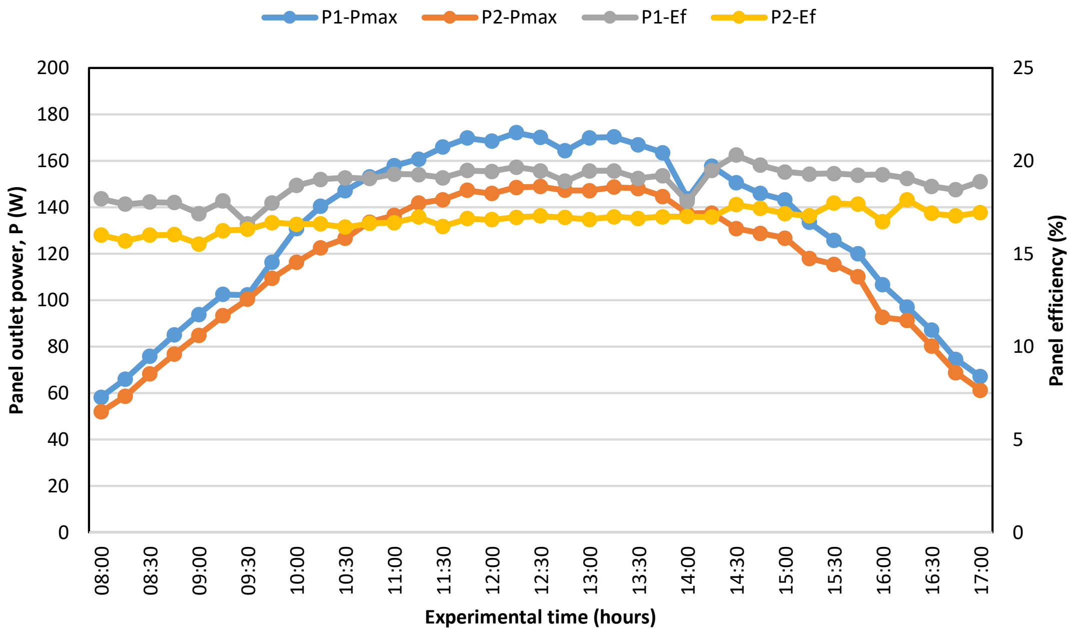

Figure 9 Variation of panel outlet power and panel efficiency

The experimental results in terms of the measured variables are shown by curves in Figs. 10-11. The data obtained from these tests are characterized by GEP model. Applying the employed GEP algorithm (Fig. 3), the GEP models have been developed beginning with the definition of terminal set (i.e. model variables) first, which is explained in detail above (Eq. (2)) as the independent (input) and dependent (output) variables. The dataset established from the experimental study was randomly divided into training and testing subsets where the testing test was not included within the training set [29].

In statistics, the mean absolute error (MAE) is a quantity used to measure how close forecast or predictions are to the eventual outcomes. The mean squared error (MSE) of an estimator measures the average of the squares of the "error". In an analogy to standard deviation, taking the square root of *MSE* yields the root-mean-square error or root-mean-square deviation (RMSE), which has the same units as the quantity being estimated; for an unbiased estimator, the *RMSE* is the square root of the variance, known as the standard deviation. Smaller the *RMSE*, the more reliable estimation. The *R* measures how successful the fit is in explaining the variation of the data. The value of *R* ranges from 0 to 1 and it will be one for exact prediction. The purpose of the GEP model is to provide low error and high correlation accuracy. Error and correlation coefficients calculated from the following equation [30-33]:

$$MAE = \frac{1}{N}\sum_{i=1}^{N} | X_m - X_p | \qquad (3)$$

$$MSE = \frac{1}{N}\sum_{i=1}^{N} \left(X_m - X_p\right)^2 \qquad (4)$$

$$RMSE = \left(\frac{\sum_{i=1}^{N}\left(X_m - X_p\right)^2}{N}\right)^{\frac{1}{2}} \qquad (5)$$

$$R = \sum_{i=1}^{N}\left(X_m\right)^2 - \left(\frac{\sum_{i=1}^{N}\left(X_m - X_p\right)^2}{\sum_{i=1}^{N}\left(X_m\right)^2}\right)^{\frac{1}{2}} \qquad (6)$$

where N is the number of data, x_m, x_p are the measured and predicted output values (efficiency), respectively.

This paper is aimed to generate the models for the prediction of PV panel efficiency. Two GEP models are generated for PV panels. For uncooled and cooled PV panels, two output equations are obtained. Eq. 7 is obtained for the uncooled PV panel and Eq. 8 is obtained for the cooled PV panel.

$$\eta = \left[\frac{(-2.214996xI}{A_P{}^2xV_P} + 2.749573\right]^3 + 9.321222286 + \left[cos\frac{(0.999827908xI)}{A_PxV_P}\right]^3 \qquad (7)$$

$$\eta = \left[CosV_Px\sqrt[5]{\frac{1}{V_P}\sqrt[4]{A_P}}\right] + Sin\left[Arctan(\sqrt[3]{ArctanV_P} + CosV_P)\right]^2 + \left[\frac{2A_PxV_P{}^2\sqrt[3]{V_P}}{I}\right] \qquad (8)$$

In two models; V_P, maximum voltage of PV panel, A_P, maximum current of PV panel, and I (W/m^2) is the solar radiation incident on the panels are model input parameters and η which indicates PV efficiency is model output parameter.

The predicted results from two models are compared with experimental results, as shown in Figs. 10-11

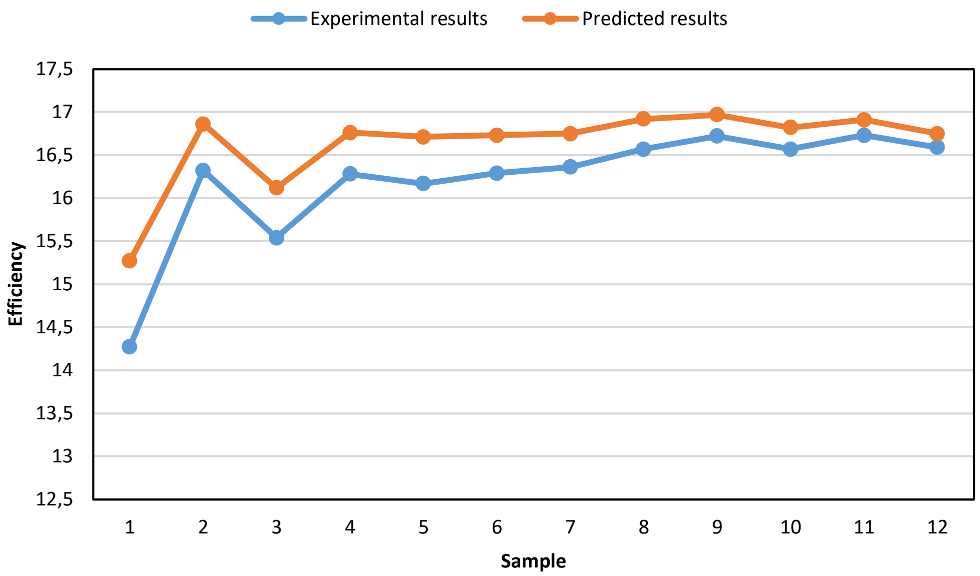

Figure 10 The predicted and measured values of efficiency for uncooled PV panel

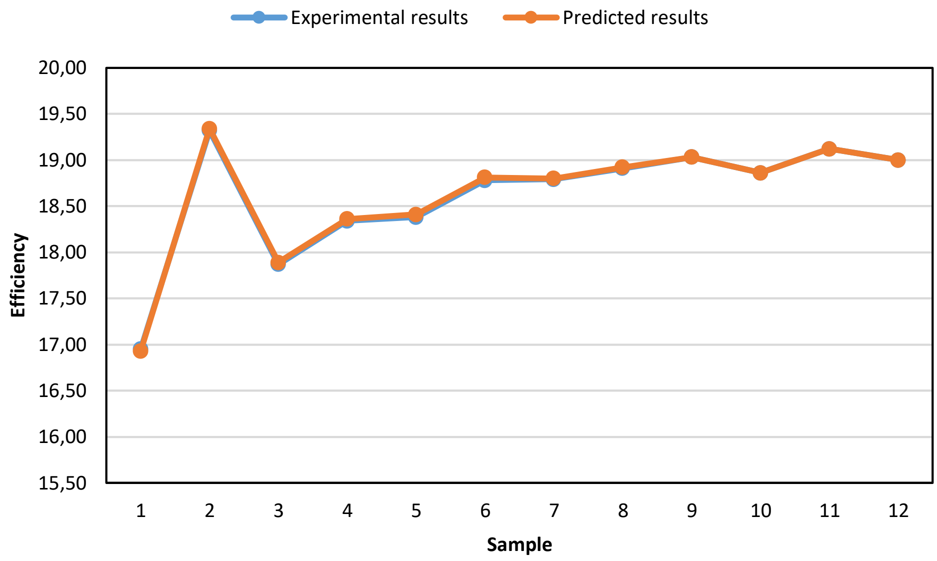

Figure 11 The predicted and measured values of efficiency for cooled PV panel

GEP models were developed according to laboratory data. The values of determination coefficient and error analysis results are presented in Table 3. All models were obtained high accuracy. The determination coefficient (R^2) values of GEP uncooled PV model and GEP cooled PV model were 0.969 and 0.999, respectively. It was observed from the test data that better results were obtained with GEP model. Additionally, the error distributions were also examined. The value of minimum square error (MSE) of each condition is calculated. MSE values of PV efficiency are 0.233667 and 0.0004924, respectively. From the determination coefficients of mathematical functions, it can be emphasized that GEP can be used for estimating the efficiency of PV panels successfully.

Table 3 Values of determination coefficient and error analysis results for PV panel

Statistical values	Uncooled PV panel	Cooled PV panel
R^2	0.969	0.999
MSE	0.233667	0.0004924
RMSE	0.483392	0.022189
MAE	0.430858	0.015468

5 Conclusion

Efficient use of energy plays an important role in energy security risks and emission reducing problems. In this paper, energy efficiency resources are modeled as efficiency PV panels (cooled/uncooled) to evaluate their impacts on GEP. The PV panel efficiency improved when it was cooled. It can be concluded from the literature survey that using water as a coolant is found to be more effective than using air. Thus, this research is to build a water-based cooling system to solve the solar panels overheating problem with the minimum amount of water and energy.

Without active cooling, the temperature of the panel was high and solar cells can only achieve an efficiency of 18.83%. However, when the panel was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of solar cells to between 16.81%.

The determination coefficient (R^2) values of GEP uncooled PV model and GEP cooled PV model were 0.969 and 0.999, respectively. Using the test results showed that GEP model yielded accurate results. GEP model using empirical equations with data obtained from experimental results have also been obtained. From all these results, GEP can be successfully used to estimate the cooled PV efficiency. Consequently, the GEP approach can be widely applied to help resolve many problems in energy systems engineering by reducing the time factor.

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