Performance Calculation of Electrical Energy Output and Power Conversion Efficiency of Standalone PV System

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ABSTRACT

In this paper, an effort has been complete to inspect the performance calculation of a standalone solar photovoltaic (PV) array scheme based on electrical energy production and power conversion productivity. Shortened exact expressions for calculating performance catalogues using experimental measurements for complete PV system and its individual constituent sub modules on day, month and year basis have also been established. Investigates have been approved out on two components 40 Wp and 10 Wp standalone PV array and module scheme for weather condition of Salem (latitude: 11 390 N, longitude: 78 120 E and an altitude of 270 m above mean sea level). Specific performances of both constituent array and sub module were appraised and its consequence on the real performance of complete PV scheme has been offered. Mathematical calculation was approved out for a typical day in the month of 12th March 2014. It was observed from experimental results that day power transformation average and maximum efficiency of complete PV array were 62.48 % and 96.75 % correspondingly. For additional real performance calculation of PV array/module, on field investigational performance consequences have been associated with the rated (max.) results assessed at STC and also with the supreme performance results assessed for real weather conditions as gotten during research.

INTRODUCTION

Non-conventional technologies are considerably safer contribution a result to meet current growing demand of electricity power and numerous ecological and social harms related with nuclear and fossil fuels (Arvind Chel, G.N.Tiwari, 2011). Publics concentrates more and more attention to the good quality and nonconventional solar energy system, hence, researching, testing and predicting photovoltaic panel in instruction to put solar energy into complete use become an emphasis (Arvind Chel, G.N.Tiwari, Avinash Chandra, 2009). A photovoltaic panel or array contains of a group of solar modules or cells linked in parallel and/or series. Every of these cells is fundamentally a p-n diode that can translate the light (illumination) energy into electrical power (Rakhi Sharma, G.N.Tiwari, 2012). The components of photovoltaic panel delivered by builders are specified in the Standard Testing Conditions (STC) (G= 1000 W/m², T = 25 °C) (C. Armenta-Deu, 2003). These components at standard testing conditions do not really reflect the characteristics of photovoltaic panel in real application situations due to variation in temperature (T) and solar irradiance (G) around photovoltaic panel (Yoo Jae-Hyun, Gho Jeok-Seok, Choe Gyu-Ha, 2001). The electrical production of photovoltaic panel differ with atmosphere remarkably, the production power of photovoltaic panel variation with different G and T. These situations are not continuously typical of how photovoltaic array and modules function in the arena, and real performance is typically 85-90% of the STC. Prototypes that communicate the photovoltaic performance to G and T are well established (Heydenreich W, Muller B, Reise C, 2008). When irradiation of solar (G) rises, maximum power, short circuit current and transformation efficiency will rise (Luque A, Hegenhus S, 2002). In plus, according to the request of production power photovoltaic cells and/or modules are accumulated in dissimilar parallel series mixtures. Seeing the day’s usage of PV panel, many losses in array and the varying functioning situation, the strictures of photovoltaic panel and its performance catalogues cannot hold the track. So relying specially on the typical parameters of photovoltaic panel/array, photovoltaic scheme analysis will always be problematic to attain the favorite result. Investigation and improvement work on the PV technology is incessantly working on for several decades. Several innovative schemes and produces have

been put onward and their excellence assessed by professionals and academics. Certain studies can be establish in literatures for on field performing estimation of photovoltaic panel scheme and greatest of them are either required detailed statistics and difficult to use or typically limited to financial performance assessment. STC data can lead to an over estimate of the manufacture. Consistent information on the performance of dissimilar PV producers under actual functioning conditions is vital for precise product choice and precise calculation of their power invention (Deshmukh MK, Deshmukh SS, 2006). This paper to research the on field methodological performing of photovoltaic array and module, execution indices of a PV scheme such as electrical power production and real electrical efficiency of photovoltaic array and its constituent sub module have been designed from on field statistics after directing the test. Additional these real consequences are associated with nominal rated performing consequences, which can be valuable for some possible enhancements. For assessment insignificant rated execution outcomes have been modified or designed for similar ecological situations of photovoltaic functioning “T” and instance solar-“G” as gotten during research. For proposed photovoltaic array/sub module, to assess estimated value of on field concert on the day, month and year basis beneficial easy scientific classical have also been established using investigational parameters.

Analysis and Observation of 40 Wp Standalone Pscheme:

Fig.1 presents analysis and installation of 40 Wp PV structure for electrical and electronics engineering department at Government College of Engineering, Salem, Tamil Nadu, India. Sponsored by IIT, Bombay. This standalone photovoltaic structure of 40 Wp is equipped with four sub modules of rating 10 Wp each as shown in Fig.1. These sub models consists of 36 cells connected in series arrangement of multi and mono crystalline silicon materials. Ammeter, Voltmeter and Rheostat are major components of the testing 40 Wp PV scheme. The PV array mounted on a fixed metal supporting structure. On the basis of latitude of place (Salem) and for receiving the maximum solar illumination inclination of the frame in maintained at around 39°. In order to test the generated power form the 40 Wp PV array for the uses in battery storage, a connection was made between the PV panel and testing equipment making use of electric cable. The supply from the battery energy system is drawn only night time and when the power delivered by panel is less than the energy required by load. A PV structure is an integrated connection of array, modules and supporting components, the PV system designed to converter solar light energy to electrical power. Group of suitably connected cells/modules is combined and interconnected to form PV module/array. The photovoltaic panel may consist of number of sub modules/array for application convenience. The rating of single photovoltaic 10 Wp module with component are shown in Table-I. The solar cell ambient temperature coefficient β is 0.45 % / °C for mono-crystalline silicon material.

![Fig. 1: Experimental setup of PV array with direct load test system.](image)

Table-I: Specification of single PV module.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUE[UNITS]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak maximum power</td>
<td>10Wp</td>
</tr>
<tr>
<td>Peak maximum voltage</td>
<td>16.4V</td>
</tr>
<tr>
<td>Peak maximum current</td>
<td>0.610A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>21V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>0.700A</td>
</tr>
</tbody>
</table>

Experimental Calculation of Electrical Power and Energy Conversion Efficiency:

Performance catalogues such as electrical efficiency and energy production of photovoltaic array and module can be experimentally considered for proposed photovoltaic array and single PV module scheme with the help of established expressions specified below. These descriptions may also be realistic to analyze day,
month and annual performance catalogues of any type of photovoltaic array and module scheme, utilizing experimentally observed parameters (Chang Tian Pau, 2009).

**Electrical Energy Production of Photovoltaic Array and Module:**

The electrical power production is the product of the current and voltage. Total energy production of whole photovoltaic array will be the sum of the production from sub-modules (Iskander Charles, Scerri Edward, 1996). From research short circuit current and open circuit voltage of photovoltaic array and module are observed hourly from morning to evening throughout an entire day, then entire daily hourly electrical energy production from single PV module and array can be calculated. The total daily hourly energy production of complete PV system containing four sub modules is expressed by the equation. Single photovoltaic module power conversion efficiency is

$$E_{\text{PV module}} = \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{module}}$$  \hspace{1cm} (1)

For photovoltaic array containing four sub-modules the entire day hourly energy production can be described by the following equation:

$$E_{\text{PV array}} = \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m1}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m2}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m3}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m4}}$$  \hspace{1cm} (2)

For designing the estimated monthly electrical energy production, average day electrical energy production for a specific month is multiplied with the logged number of days in that month. Total estimated annual energy production can be intended by adding monthly electrical energy production over an annual. Equation.(4, 5) express total annual electrical energy production of PV single PV module, array.

$$\left( E_{\text{PV module}} \right)_{\text{annual}} = \sum_{n=1}^{12} \left( \left( E_{\text{PV module}} \right)_{n} \times D_{n} \right)$$  \hspace{1cm} (3)

$$\left( E_{\text{PV array}} \right)_{\text{annual}} = \sum_{n=1}^{12} \left( \left( E_{\text{PV array}} \right)_{n} \times D_{n} \right)$$  \hspace{1cm} (4)

Where, \(E_{\text{PV module}}\)_n is average daily electrical energy production of photovoltaic module for n^{th} month, and is gotten by taking average of total daily electrical energy production of observed for “n” no of typical days that n^{th} month. \(D_n\) is no of days in n^{th} month. Likewise annual electrical energy production from photovoltaic module, array can be expressed (Kannan R, et al., 2006).

**Electrical Power Transformation Efficiency of Photovoltaic Array and Single pv Module:**

Daily power transformation efficiency of array and single PV module for a typical day can be considered by taking the ratio of production energy of photovoltaic array and incident solar energy to array, similarly daily power transformation efficiency of single PV module can be calculated by taking the ratio of production energy of single photovoltaic module and incident solar energy to single PV module. Now the daily actual power transformation efficiency of complete photovoltaic array is the ratio of total electrical production of every photovoltaic module and total input incident solar energy on all the photovoltaic modules. Equation.(4) is utilized to calculate day power transformation efficiency for a typical day (Mayar D, Heidenreich M, 2003).

$$\eta_{\text{PV module}} = \frac{\sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{module}}}{\sum_{\text{hourly}} I_{1}}$$ \hspace{1cm} (5)

$$\eta_{\text{PV array}} = \frac{\sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m1}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m2}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m3}} + \sum_{\text{hourly}} (FF \times V_{oc} \times I_{sc})_{\text{sub m4}}}{\sum_{\text{hourly}} I_{2}}$$ \hspace{1cm} (6)

Where, \(I_1\) is the one average of hourly observed solar irradiation over the photovoltaic module area. \(A_{\text{module}}\). Here, \(A_{\text{module}}\) is area of PV module \times one.(1). Similarly \(I_2\) is the average of hourly measured solar radiation over the PV module-2 area. \(A_{\text{submodule2}}\). Here \(A_{\text{submodule2}}\) is area of PV module \times no of PV module in submodule2. If experimental data is obtained for “n” number of typical days of each month in a year then more approximate power transfiguration efficiency of photovoltaic module on the basis of monthly experimental data can be calculated by taking the ratio of net annual energy production from PV panel and an total input incident solar energy on the PV panel throughout a year. No of clear days in each month is recorded. Therefore, additional approximate power transformation efficiency of a photovoltaic module and an array on the annual basis by using measured monthly observation has been developed as follows.
Where \( I_{n} \) is the average of total daily hourly observed solar irradiation for any number of typical days during \( n^{th} \) month over the of photovoltaic module of area \( A_{module} \). Similarly \( I_{n} \) is the average of total daily hourly measured solar irradiation for any number of typical days day \( n^{th} \) month over the of PV submodule of area, \( A_{submodule} \).

**Performance Indices of pv Energy:**

**Estimation of Rated Day Electrical Energy Production:**

Approximation of photovoltaic energy production, power transformation efficiency of photovoltaic panel and its component sub module at minimal rating are valuable in reviewing the photovoltaic executions and conceivable enhancements. In a shortened way estimated supreme day energy production from photovoltaic array and single PV module can be designed mathematically by product the highest power of photovoltaic panel with equivalent hours of full sunlight \( E_{EFS} \) as expressed in Equation. (9). Peak power \( (P_{m}) \) from module and array is considered at standard test conditions (STC) as given by fabricator is expressed in Equation.(10), (11).

\[
E_{max} = P_{m} \times h_{EFS}
\]

\[
\text{Peak power (Pm) of single module} = \text{Peak power (Pm) of module} \times \text{one}
\]

\[
\text{Peak power (Pm) of array} = \text{Peak power (Pm) of module} \times \text{No. of module in a panel}
\]

Likewise supreme day output energy from photovoltaic panel can be also calculated by product the \( P_{m} \) of photovoltaic panel with \( h_{EFS} \). The STC can be stated by 100 mW/cm\(^2\) (equal to 1000 W/m\(^2\)) solar flux compatible to the typical reference AM 1.5 G spectrum, and temperature (T) 298.16 K (25°C). The usage of this flux value is exact suitable, as the efficiency in percent is mathematically equal to the power production in mW/cm\(^2\).

**Measurement of equivalent hours of complete sunlight \( h_{EFS} \):**

The \( h_{EFS} \) are demarcated by number of epochs of incident irradiation at a location, if intensity of irradiation is reserved fixed at its top value of 1 kW/m\(^2\), that stretches the similar energy received from sunrise to sunset. The \( h_{EFS} \) for specific day can be gotten by the graph, which demonstrations the hourly difference of solar radiation over photovoltaic surface for entire day. Integration of zone under the graph gives entire solar power received by the unit enhancement on that day. Supposing, integration of area under the graph of typical day difference of incident solar irradiation intensity on a flat unit zone surface is conveyed by \( N \) kWh/m\(^2\), then this can additional be expressed as fixed highest value of solar irradiation of 1 kW/m\(^2\) incident on receiving surface for \( N \) hours, then equivalent hours of full sunlight will be equal to \( N \) hours. The appearance is given by Equation. (12).

\[
\text{Total solar energy received by flat unit zone of panel (kW h/m}^2\) = peak solar intensity (1 kW/m\(^2\)) \times h_{EFS} \text{ (hours)}
\]

**Actual electrical power transformation efficiency of PV panel at STC:**

Power transformation efficiency at standard test conditions can be designed for component of photovoltaic panel (sub module1 and sub module4 independently). An appearance for calculating photovoltaic array and module power transformation efficiency at standard test conditions has been established as Equations. (13, 14), when array consists of four sub modules

\[
(\eta_{SCC})_{\text{array}} = \frac{\sum_{i=1}^{n} [FF \times V_{ocm} \times I_{scm} \times M_{s} \times M_{p} \times A_{submodule4}]}{[FF \times V_{ocm} \times I_{scm} \times M_{s} \times M_{p} \times A_{submodule4}]} \]

\[
(\eta_{SCC})_{\text{module}} = \frac{[FF \times V_{ocm} \times I_{scm} \times M_{s} \times M_{p} \times A_{submodule4}]}{[FF \times V_{ocm} \times I_{scm} \times M_{s} \times M_{p} \times A_{submodule4}]} \]

where \( V_{ocm} \) is open circuit voltage of module, \( I_{scm} \) is short circuit current of module, \( M_{s} \) represents no. of modules in series in a sub module and \( M_{p} \) represents no. of parallel strings of series connected modules in a sub module. FF is fill factor, \( I_{p} \) peak intensity with value of 1000 W/m\(^2\). All these parameters are observed at standard test conditions and delivered by producer specifications. Same established formula can be changed for ‘n’ number of sub modules of any given photovoltaic array (J.D. Mondol, Y.G. Yohanis, 2006).

**Temperature Effect on Nominal Rated Performance Indices of pv Module:**

The day production of a solar module/array depends on solar irradiation and photovoltaic working
temperature. Increase in the photovoltaic working temperature decreases panel peak energy production and photovoltaic module/array execution at standard test conditions. It is clear that actual assessment of photovoltaic working temperature of given site in order to transform the performance of photovoltaic panel from the normal rating temperature of 25°C to the panel executions at actual photovoltaic working temperature. Photovoltaic working temperature can be calculated using observed ambient temperature at given site and incident solar radiation on photovoltaic panel. Significance of containing the effects of photovoltaic working temperature in the photovoltaic electrical energy production and electrical efficiency are obtainable by Equations. (15) and (18) correspondingly (García-Valverde R, et al., 2009).

Estimation of Maximum Electrical Energy Output with pv Working Temperature Effect:
The power production of a photovoltaic panel is contingent linearly on the working temperature, reducing with $T_{OT}$. Effects of photovoltaic working temperature on photovoltaic electrical energy production can be articulated by the subsequent equation

$$\varepsilon_{PV} = P_m \times h_{EFS} \times [1 - \beta (T_{OT} - T_{STC})]$$

(15)

With essential correction functional to $h_{EFS}$, the result would be the UAO, in units of watt hour per peak watt per day. UAO is a chosen parameter for the sizing workout in contrast to parameters such as $h_{EFS}$ or global irradiation. UAO is given by the subsequent equation

$$UAO = h_{EFS} \times [1 - \beta (T_{OT} - T_{STC})]$$

(16)

Thus Eq.(15) can be altered for temperature corrected photovoltaic electrical energy production as follows

$$\varepsilon_{PV} = P_m \times UAO$$

(17)

Estimation of Power Transformation Efficiency with pv Operating Temperature Effect:
To show the significance and importance of containing the effects of photovoltaic working temperature in the photovoltaic electrical efficiency an existing linear expression for $T$ corrected photovoltaic electrical efficiency $\eta_{OT}$ is specified by

$$\eta_{OT} = \eta_{STC}[1 - \beta (T_{OT} - T_{STC})]$$

(18)

Where $\eta_{STC}$ is the photovoltaic electrical efficiency at standard test conditions, $\beta$ is module/array efficiency coefficient, $T_{STC}$ is reference temperature at standard test conditions for photovoltaic electrical efficiency, $T_{OT}$ is the average photovoltaic working temperature (M.M.H. Bhuiyan, M.A. Asgar, 2003).

Evaluation of Production Factor (PF):
One of the performing indices for assessing photovoltaic panel execution is production factor and can be distinct by ratio of real power harvest gotten from experimental consequences and potential power harvest gotten at minimal rating and working temperature at a specific site. Expression for PF is specified by the subsequent equation

$$PF = \frac{E_{PV\ module/array}}{\varepsilon_{PV}}$$

(19)

Simulation and Experimental Results and Discussion:
Simulation Characteristics of PV Modules:
It is evident that the output of the current source controller is depends on the load voltage and current and hence they are chosen as appropriate control inputs to this dependent current source. The model of the PV cell incorporating this modified equivalent circuit using an independent current source, a controlled current source, voltage and current measuring blocks and a few arithmetic blocks is shown in Fig.2(a). These arithmetic blocks are available in the existing libraries of Matlab Simulink. The developed model can be used to determine the characteristics of a module/array as it is evident that the characteristics of a panel, made up of identical cells, can be obtained by appropriately scaling the V-I characteristics of the individual cells. The dialog box of the developed PV model is shown in Fig.2(b). The model was developed and implemented in Matlab/Simulink based on equation; it contains a general model of a solar cell and a model of a photovoltaic generator. The model parameters are characteristics under normal conditions of the solar panel of short circuit, open circuit and optimum value of numbers connected in series and parallel. The various coefficient of current and voltage
depending only temperature. The variation of irradiance, temperature and both conditions were simulated using the simulator. The voltage and current characteristics, of 36 cells connected in series, were fed to the simulator and a MATLAB Simulink software application was implemented, to facilitate the change of the output power as a sine function of the irradiance and temperature (Arulmurugan, R., Suthanthira Vanitha, N., 2013). The simulator waveforms obtained using scope.

Fig. 2: (a) The modified circuit implemented in power system block set and (b) dialog box for developed PV module.

The individual and grouped modules of the panel simulation model are validated, and the results found from the complete model of the plant under dynamic conditions are discussed. The effects of radiation and temperature on the output of the individual and grouped solar module and array were simulated. The voltage vs. current (V-I) and voltage vs. power (V-P) characteristics of the individual and grouped solar module for radiation levels of 500, 750, 900 and 1000 W/m² and a constant cell temperature of 25 °C are shown in Fig.3(a), Fig.4(a) respectively. It can be seen the changes of radiation mainly affect the output current. Fig.3 (b), Fig.4 (b) shows the V-I and V-P characteristics when the temperature was adjusted. The module was adjusted to operate with a radiation level of 1000 W/m². Operating temperatures were varied at 0 °C, 25 °C, 50 °C, and 75 °C. It can be witnessed that the operating temperature mainly affects the output voltage of photovoltaic module. In common, it was observed a decrease of voltage for high radiation because of the resulting higher temperature of the module. The effect of lowering the level of radiation mainly disturbs the current module and has only a slight influence on the voltage of the module. The effect is greater on the current of the module because it reductions linearly with the decrease of radiation while the voltage of the module only reductions logarithmically with decreasing radiation.

Fig. 3: Curves I–V and P–V of the individual solar model for (a) constant T and different G. (b) constant G and different T
Experimental Analysis and Results:

The proposed experimental setup is revealed in Fig.1 and data were tested every hour during whole day of experimentation. Table-II shows experimental data collected on a typical clear day of 12th March 2014 at Omalur, Salem. The typical clear day hourly measurements of solar irradiance on panel, ambient air temperature, PV operating temperature, short circuit current, open circuit voltage for single PV module and array were being observed during investigation with the help used for the design of numerous performance specifies of 40 Wp photovoltaic array and 10 Wp single PV module respectively (Bhuiyan MMH, et al., 2000).
full sunlight ($h_{EFS}$) and photovoltaic working T (WT) of PV panel for a typical day. Great value of PV working temperature causes decrease in electrical efficiency of photovoltaic panel. Average hourly difference of solar radiation ($G_{avg}$) on specified photovoltaic panel located at Salem, omalur for classic day is exposed in Fig.6. Now solar radiation on complete photovoltaic array at some specific time has been intended by taking normal of measured radiation on array and sub module at that similar period. Addition of area under the graph (Fig.6) stretches complete solar energy collected by the unit zone on similar day and this was utilized to analyze equivalent periods of full sunlight ($h_{EFS}$).

Fig. 7: Hourly difference of open circuit voltage for PV array on 12th March 2014.

Table-II: Observed values of standalone PV panel for a typical day in 12th March 2014.

<table>
<thead>
<tr>
<th>Size of PV panel</th>
<th>Equivalent hours of full sunlight in hours</th>
<th>PV working temperature (WT) in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV array 40 Wp</td>
<td>4.5</td>
<td>32.58</td>
</tr>
</tbody>
</table>

Fig.7 and Fig.8 demonstrates the hourly variant of open circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$) for PV array and single PV module of the 40 Wp and 10 Wp respectively. The difference in the $I_{sc}$ is credited to the difference in the solar G because short circuit current is directly proportional to inward light strength. The comparatively lesser variation in open circuit voltage during the day is mostly due to T variations and mist cover. By nonstop observing of short circuit current and open circuit voltage of an array and single PV module, it is conceivable to directly notice any degradation in array and module performance and miscarriage can be readily sensed (Chel, G.N. Tiwari, A. Chandra, 2009).

Fig.8: Hourly difference of short circuit current for PV array on 12th March 2014.

Fig.9 displays the hourly variation of electrical power yield for PV array (40 Wp) and single PV module (10 Wp). Complete photovoltaic array output is the sum of the four sub modules production. From the test for a typical day supreme electrical power production of photovoltaic array (40 Wp) has been observed 37.36 W at 12:00 PM afternoon and electrical power yield of single PV module of 10 Wp has been gotten 9.339 W at 12:00 PM afternoon correspondingly. Total electrical energy production of array and single PV module were experimentally designed 24.9925 Wh/day and 6.2428 Wh/day correspondingly. Electrical energy production of complete standalone photovoltaic array and module of 40 Wp and 10 Wp was calculated by using Eq.(1). These practically designed performance values previously including the consequence of photovoltaic working T during the day of research as hourly observed parameters of
open circuit voltage and short circuit current are $T$ dependent. For popularization in experimental controls fill factor (FF) has been expected of value 0.67 as gotten from rated values.

Fig. 9: Hourly difference of electrical power production for PV array on 12th March 2014.

**Calculation by Result Enactment:**

The evaluation of real on field outcomes of performance indices with minimal rated (max.) outcomes, calculated by using producer specifications helps to evaluate real on field performance of photovoltaic panel. For real effective outcome calculation of photovoltaic array and module minimal rated execution indices, which are attained at standard test conditions by using Equations. (12) and (13,14) for day supreme energy production and day supreme power transformation efficiency correspondingly, have been modified for classic day photovoltaic working $T$ attained at specific location. $T$ modified supreme electrical energy production and $T$ corrected supreme photovoltaic electrical efficiency for photovoltaic array and module are assessed by using Equations.(15) and (18) correspondingly. The particulars of gotten results for real on field investigational performance indices of photovoltaic array and module with normal minimal rated performance indices and $T$ modified minimal rated performance indices achieved for a classic day have been offered in Table-III for day electrical energy production. Likewise Fig.10 obviously indicates the performance of day power transformation efficiency of proposed Photovoltaic array and single PV module. Table-III shows the experimentally designed unit array output (UAO) in Wh/Wp/day under outside field circumstances in assessment to projected supreme value of UAO using Equation,(17). From the current single module and array examination the performance indices such as intended day electrical energy production of photovoltaic single module and array, daily power transformation efficiency, UAO and production factor for panel of 40W were obtained. Compare to estimate $T$ corrected supreme performance outcomes of same panel and it’s clear that decrease in overall performance of complete photovoltaic panel (R.Arulmurugan and N.Suthanthiravanitha, 2014).

![Graph showing hourly electrical efficiency of PV array](image)

Fig.10: Day power conversion efficiency of photovoltaic array and single PV module.
Table III: Electrical energy, UAO for PV module for a typical day on 12th March 2014.

<table>
<thead>
<tr>
<th>Size of PV module (Wp)</th>
<th>Estimated maximum energy production at STC (Wh/day)</th>
<th>Estimated maximum electrical energy production with PV working temperature effect (Wh/day)</th>
<th>Estimated maximum value of unit array output (UAO) (Wh/Wp/day)</th>
<th>Fill factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV array (40 Wp)</td>
<td>180</td>
<td>179.18</td>
<td>4.678</td>
<td>0.680</td>
</tr>
<tr>
<td>PV module 10 Wp</td>
<td>45</td>
<td>44.79</td>
<td>4.479</td>
<td>0.680</td>
</tr>
</tbody>
</table>

Conclusion:
A general approach to modelling of a solar array and single module is presented, based on standard parameters. Two types of solar module material (mono-crystalline and multi-crystalline) have been assessed by this model. The results obtained by simulation and experimental show the consistency between the data and found the parameters given by the producers such as voltage, current and power. Theoretical evaluation shows that the parameter model is considered a very effective model for such a solar panel in general. An appropriate fixed angle position to search for the optimization point of maximum power is developed. The simulation results compared to experimental show that it is very efficient in terms of performance, the produce the following results have been drawn. Maximum working temperature of PV panel was found 33 °C at 12:00 noon when ambient temperature was measured 31.2 °C and solar radiation was 819.91 W/m². For a typical day maximum electrical power output of single PV module, array has been observed 9.675 W and 38.7 W at 5th sample respectively. The simplification in experimental calculations of fill factor has been calculated the value of 0.68 as obtained from rated values. The maximum and average electrical efficiency of PV array has been calculated from observation 96.75 % and 62.48 % correspondingly.

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REFERENCES


