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Review Article:

Modeling and Simulation of Photovoltaic Modules

(Review, Critiques and Research Directions/Methods)

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1- Abstract

In this article review, some of the techniques and passageways to model the PV cells will be reviewed and manifested in several sections. The models will be presented mathematically, and then it will be simulated using various simulation environments, which was introduced in the literature of this field. The outcomes of the simulations and their comparisons will be reviewed and displayed in the last sections. This review's consequence is that PV modeling is essential for designing, sizing, and understanding solar systems' characteristics.

Keywords: *Simulation algorithm, Matlab, photovoltaic cells, Irradiation, temperature, modeling, and simulations.*

2- INTRODUCTION

The characterization of photovoltaic systems is crucial to get outstanding performance under different environmental situations. By comprehending the photovoltaic systems' characteristics, the system's simulation will be viable under several climate situations, such as different temperatures and irradiations.

The PV (Photovoltaic) system's performance depends on several variables, sequentially the I-V curve of each cell, each module, and the inverter used to convert the DC curve to the AC. A proper simulation of the system allows evaluating each component's performance and the whole system's performance. In the figure below, three-generation technologies are shown. The generations are according to a different parameter such as cost and material used for construction.
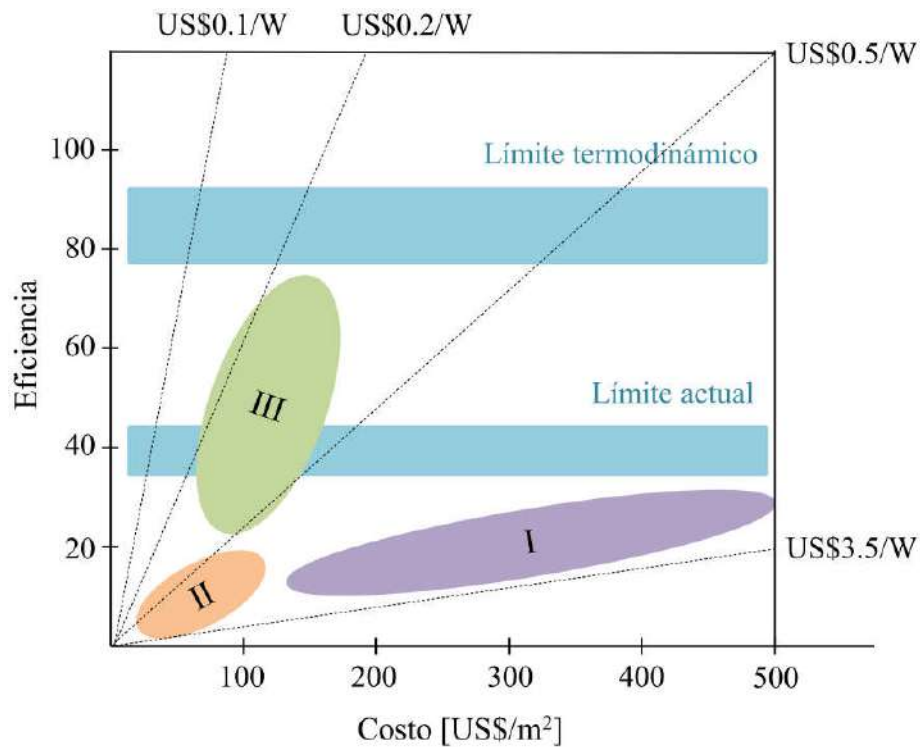
Figure 1:PV technologies

The figure above shows the following:

1. The first generation (I) is a crystalline silicon type.
2. The second-generation (II) is the Cadmium telluride type.
3. The third generation (III) is the hybrid cells (Organic and inorganic materials).

The third generation is the most used, and it has an efficiency of (14% to 20%) (Moreno, 2017).

With the availability and environment-friendly characteristics of PV cells, researchers are motivated to produce and develop a higher efficiency solar panel and more efficient power invertors that can extract 100% of power from the PV cells in the past decades.

(Mahmoud, Xiao and Zeineldin, 2012) proposed a simple and easy to model approach for implementing the simulations on PV systems. The work relies on the simplicity of the ideal models, and it gains accuracy by estimating the module parameters directly from the manufacturer datasheet.

(Park and Kim, 2013) analyzed the conventional three parameters of PV modeling algorithms by comparison, and they proposed a novel PV modeling algorithm that is accurate, fast, and can be applied for almost every type of PV cell. Simulations verify the proposed work.

(Manosukritkul and Titiroongruang, 2017) investigated a new model for estimation of PV power output (Pout) of the power plant in Thailand. The solar irradiance and temperature modules were used as the input of the model. This work was developed using one year of data from the plant and verified by comparing it to the measured data.

(Bendib *et al.*, 2018) they studied the single diode PV model and the model implemented under the LabVIEW environment. The proposed work shows the characteristics of current-voltage I-V and Power-Voltage P-V of PV generator under the simulation environment and at different temperature and solar irradiation conditions.

(Chedid *et al.*, 2014) presented a teaching method for modeling and simulating photovoltaic cells taking into account several constraints such as variation of temperature, Irradiation, and the serial and parallel connection between the modules and shading.

In this review paper, an investigation around the methods and approaches for modeling the Photovoltaic systems different aspects of modeling and simulations were presented in the next sections.

3- PV CELL MODELING

In this section, modeling and simulation of Photovoltaic (PV)cells will be presented, and the approach is based on equations that reflect the model's characteristics. PV systems can be modeled using several sub-circuit models. The model equations can be used to draw the current-voltage and power-voltage curves under several environmental constraints such as electrical connection type between cells, temperature, irradiations, and shade effect.

Photovoltaic cells use semiconductor materials to convert light photons to electric current. The fabrication of Photovoltaic cells is similar to diode production. When the photons of light hit the solar cells, electrons and holes

will be deposited on either side of the depletion layer. The electric field force pushes the holes to the P side and the electrons to the N side of the PN junction. When the electrons accumulate in the N side of the junction and the holes on the other side, a potential difference will be induced, and then the current will be passed to the load.

The Photovoltaic (PV) model can be simulated using several electric circuit models. The electric circuit models that are generally used are Single, double, and three diode models) see figure 2. The simplest model is a single diode model. This model consists of a current source that denotes Irradiation, a parallel diode for current fusion, and a series resistor representing the wire and contact resistances. This model can be improved by adding a shunt resistance to the circuit, makings it more accurate. This model can be further improved by adding a second diode in parallel to separate the saturation currents (Nguyen and Nguyen, 2015) (Bendib *et al.*, 2018) (Chedid *et al.*, 2014)(Perera and He, 2018).

The single diode model or the ideal model is shown in the figure below (Moreno, 2017)(Vinod, Kumar and Singh, 2018)(Villalva, Gazoli and Ruppert Filho, 2009):
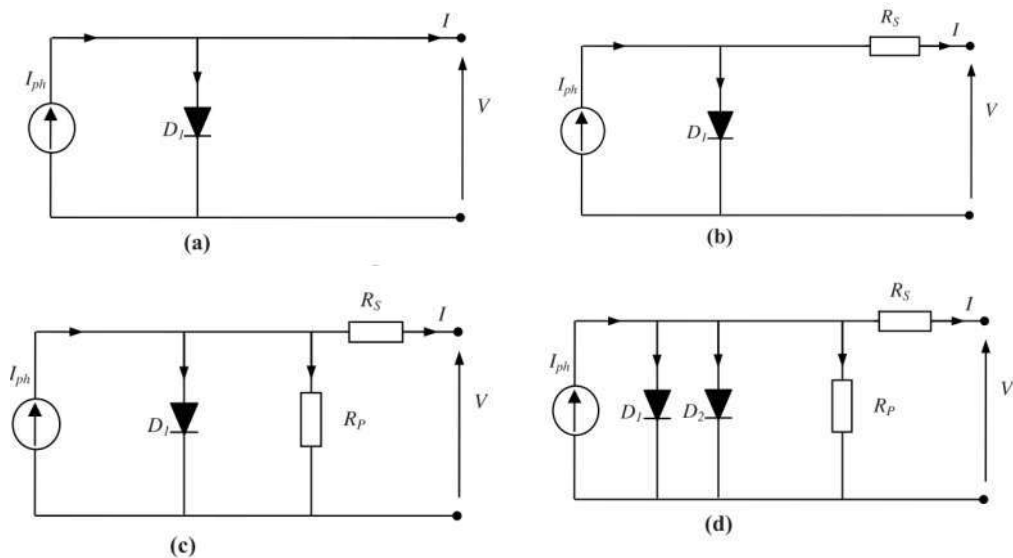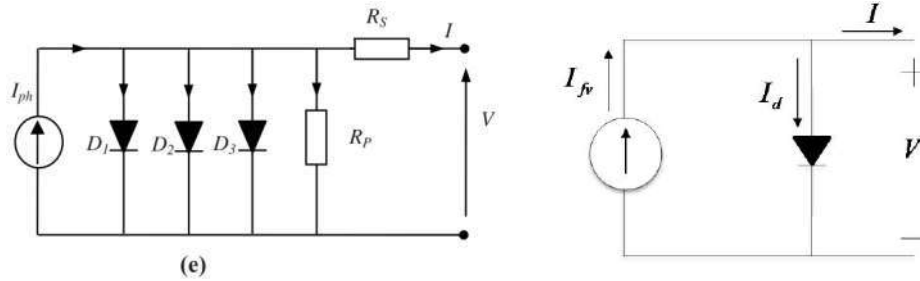
Figure 2: the ideal model of a Photovoltaic cell.

In figure 2, The single diode component is connected to the parallel current source. We can easily calculate the current (I), as shown below.

$$I = I_{fv} - I_d \qquad (1)$$

The output current equation is equal to the difference between photoelectric current (I_{fv}) and (I_d). This model does not consider the electric losses. The diode current (I_d) can be calculated by shockly equation:

$$I_d = I_0 \left(\exp \left(\frac{V_d}{m \cdot N_s \cdot V_T} \right) - 1 \right) \qquad (2)$$

The above equation shows that the diode's voltage is (V_d), and the (V_T) term is the thermal voltage, which is very important because it depends only on the temperature of the solar cell. The thermal voltage is a function of Boltzmann constant (k) and the electro charge q.

$$V_T = k \frac{T_c}{q} \qquad (3)$$

Now consider the electric loss in the model, and it can be represented as a series resistor R_s, as shown in Figure 2 (b). This resistor affects cell efficiency and module performance. The diode current (I_d) can be modified, and the effect of the series resistor will be included, as shown in the equation below:

$$I_d = I_o \left(\exp \left(\frac{V_d + IR_s}{m \cdot N_s \cdot V_T} \right) - 1 \right) \qquad (4)$$

The model can be extended more by adding the shunt resistor (R_p) in the circuit. See figure 2 (c). The equation (4) can be further modified to be like:

$$I = I_{fv} - I_o\left(\exp\left(\frac{V_d + IR_s}{m \cdot N_s \cdot V_T}\right) - 1\right) - \frac{V + R_sI}{R_p} \quad (5)$$

The circuit parameter R_s can be measured by open-circuit voltage V_{oc}, short circuit current I_{sc}, the voltage at the maximum power point V_m, and the current at maximum power point I_m.

The double diode model is shown in figure 2 (d), comprising two diodes, and a portion of the current will be through the second parallel diode (D_2). The model is more accurate as the defusion current and recombination took into account and considered. The current equation for the two diodes will be expressed as :

$$I_{d_1} = I_{o_1}\left(\exp\left(\frac{V_d + IR_s}{m \cdot N_s \cdot V_T}\right) - 1\right) \quad (6)$$

$$I_{d_2} = I_{o_2}\left(\exp\left(\frac{V_d + IR_s}{m \cdot N_s \cdot V_T}\right) - 1\right) \quad (7)$$

According to (Bendib *et al.*, 2018), the photocurrent at standard test conditions can be expressed in this way:

$$I_{ph} = \left(I_{sc\_STC} + K_i\left(T - T_{STC}\right)\right)\frac{G}{G_{STC}} \quad (8)$$

The saturation current (I_o) can be expressed under standard test conditions, and the equation is shown below. This current varies with cell temperature.

$$I_o = \frac{I_{sc\_STC} + K_i\left(T - T_{STC}\right)}{\exp\left(\left(V_{oc\_STC} + K_v\left(T - T_{STC}\right)\right)/aV_{th}\right) - 1} \quad (9)$$

K_i is the short circuit current coefficient, and the manufacturer gives it. K_v is the open-circuit voltage coefficient. If we consider N_p for parallel and N_s for series solar cells, we can write down the following equation :

$$I = N_P I_{ph} - N_P I_o\left(\exp\left(\frac{V + \left(N_S/N_P\right)R_S \cdot I}{N_S aV_{th}}\right) - 1\right) - \frac{V + \left(N_S/N_P\right)R_S \cdot I}{\left(N_S/N_P\right)R_P} \quad (10)$$

The above equation is complicated to solve, and therefore, numerical solutions will be applied to get the solution.

The flux of photons is a critical parameter to find the number of electrons due to the irradiation process because it directly impacts the current that will be produced in the solar cell. Also, it contributes to determining the photocurrent of the solar cell. The photon flux (ϕ) can be calculated from the equation below:

$$Photon\ Flux\ (\phi) = \frac{Number\ of\ Photons\ Hitting\ the\ Solar\ Cell\ Surface}{per\ second\ *\ per\ square\ meter} \quad (11)$$

The irradiance can be modeled by the photon flux and the wavelength of the photon wave.

$$Spectral\ Irradiance\ (F) = q\phi * \frac{E_p}{\lambda} \quad (12)$$

E$_P$ is the photon's distinct energy, and (λ) is the wavelength of the photon wave.

Taking into consideration the energy of the photon, which is the function of plank constant and speed of light, then the final equation for the (F) will be:

$$F = q\phi * \frac{1.24}{\lambda^2} \quad (13)$$

According to (Mahmoud, Xiao and Zeineldin, 2012) new approach for the PhotoVoltaic model was proposed, and a new mathematical equation was developed to calculate the PhotoVoltaic parameters. The output current can be expressed as :

$$I = I_{\text{ph}} - I_s \left[e^{\left(\frac{qV}{N_s K A T} \right)} - 1 \right] \quad (14)$$

The saturation current also can take the following form:

$$I_s = \frac{e^{\frac{|\beta|\Delta T q}{N_s KTA}} G[I_{\text{sc}} + \alpha\Delta T]}{(GI_{\text{sc}}/I_{rs} + 1)^{\frac{T_o}{T}} - e^{\frac{|\beta|\Delta T q}{N_s KTA}}} \quad (15)$$

The ratio of maximum power point the current and short circuit current can be calculated by:

$$\frac{I_m}{I_{sc}} = e^{\frac{qV_m}{N_s K T_o A}} - \left(\frac{I_{sc} - I_m}{I_{sc}}\right) e^{\frac{qV_{oc}}{N_s K T_o A}}. \qquad (16)$$

Then the PhotoVoltaic datasheet parameters and the above two equations (15) and (16) will be substituted in (14) to develop the new PV model, which shown below:
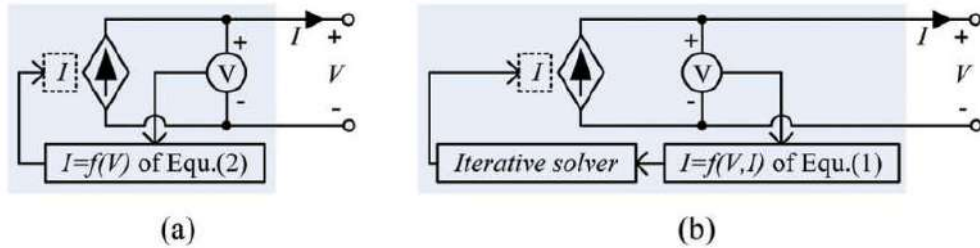

(a)   (b)

Figure 3: (a) the proposed model where I=f(v) (b) Single diode method with R_s and when I=f(V,I).

In (Manosukritkul and Titiroongruang, 2017) work, the model proposed for solar cells can be split into two phases; the first phase is to monitor the Irradiation from 0-350 (w/m²) and the second phase during 350-1000 (w/m²).
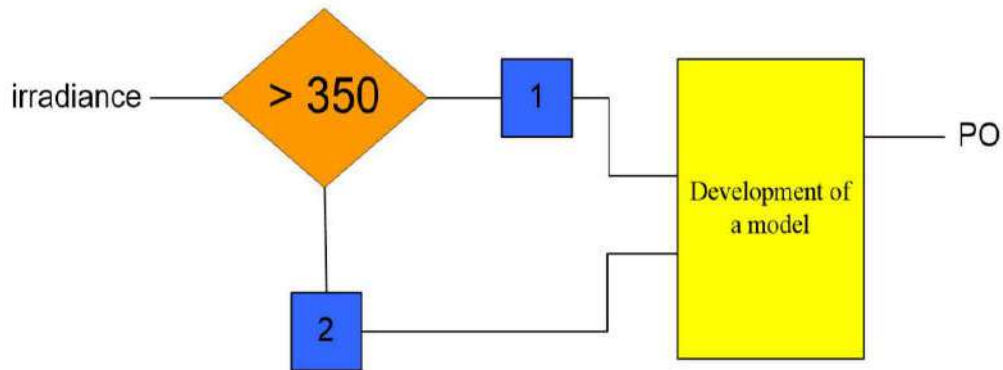
The model developed is shown in the figure below.

Figure 4: the developed model for solar cells.

In (Park and Kim, 2013) work, a new Photovoltaic model was proposed and promising to have minimum errors for different Photovoltaic decomposition types and less computation time. The model is based on the single diode model. The model created based on the following equations:

$$v_t = \frac{I_{sc}R_s - V_{oc}}{n_s \ln[\frac{n_s v_t R_s}{(I_{sc}R_{sh} + I_{sc}R_s - V_{oc})(R_{sh} - R_s)}]} \qquad (17)$$

$$v_t = \frac{I_{sc}R_s - V_{oc}}{n_s \ln[\frac{n_s v_t R_s}{(I_{sc}R_{sh} + I_{sc}R_s - V_{oc})(R_{sh} - R_s)}]} + R_s \quad (18)$$

$$v_t = \frac{V_{MPP} + I_{MPP}R_s - V_{oc}}{n_s \ln[\frac{n_s v_t (R_{sh} + R_s - R_{MPP})}{(I_{sc}R_{sh} + I_{sc}R_s - V_{oc})(R_{sh} - R_s)}]} \qquad (19)$$

$$R_{s\_max} = \frac{V_{oc} - V_{MPP}}{I_{MPP}} \qquad (20)$$

$$R_{s\_step} = \frac{R_{s\_max}}{1000} \qquad (21)$$

$$v_t = \frac{1.25kT}{q} \qquad (22)$$

$$R_{sh} = \frac{N_2 R_s{}^2 + N_1 R_s + N_0}{D_1 R_s + D_0} \qquad (23)$$

$$N_0 = R_{MPP}(V_{MPP} - n_s v_t)$$
$$N_1 = n_s v_t - I_{sc}R_{MPP} \qquad N_2 = I_{sc} - I_{MPP}$$
$$D_0 = I_{sc}I_{MPP} - V_{MPP} - n_s v_t \qquad D_1 = I_{MPP} - I_{sc} \qquad (24)$$

The algorithms were presented for the above equations, which will be presented in the next section.

4- SIMULATION OF THE PHOTOVOLTAIC MODELS:

In the previous section, several models and equations were presented for single diode and double diode methods taking into account several constraints such as the temperature, Irradiation, and other factors mentioned previously. Most of the models rely on the single diode method and simplify the calculations' convenience parameters. In this section, the models presented will be simulated, and the results will be shown in the next section.

1. Simulink Model for PV and Subcircuit Models

According to (Perera and He, 2018), the photon flux in equations (12) and (13) can be simulated using Simulink in Matlab. The Simulink model for photon flux is shown below.
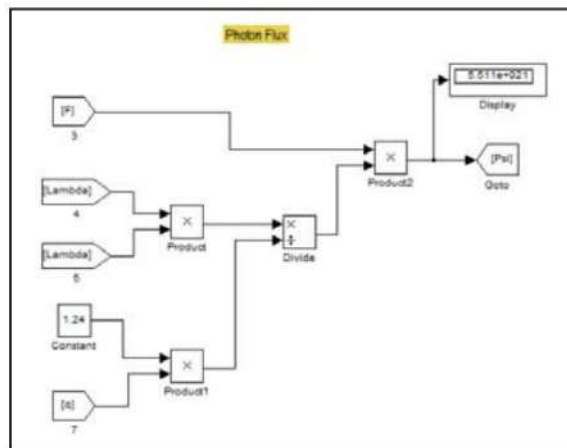

Figure 5: the photon flux simulations in Simulink.

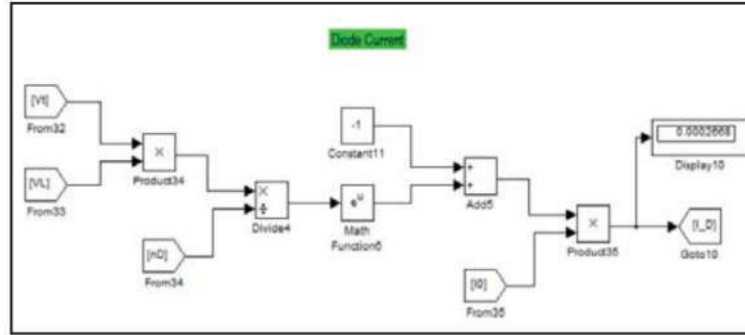The diode current in equation (4) can be simulated in Simulink, and the model can be shown below:

Figure 6: the diode current model

The model parameters can give the diode current modeled by shockly, which is the current passing through diodes. Practically, the diode equation contains the ideality factor, which shows the diode's deviation from ideality.

The series and shunt resistance (R_s, R_{sh}) contain the resistances from a semiconductor material, metallic contact, interconnection, and other parts resistances.
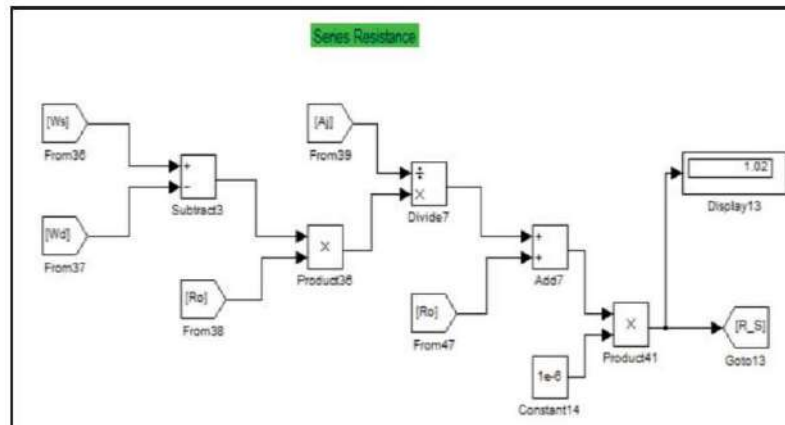

Figure 7: Series and Shunt resistance simulation.

One of the essential factors that measure the quality of the Photovoltaic cell is the Fill Factor. The Fill Factor can be used to calculate the maximum power of the solar cell using short circuit current and open-circuit voltage (I_{sc}, V_{oc}). The open-circuit voltage occurs when the current of the output is zero, or no load is connected to the cell, and the short circuit current will occur when the maximum current is drawn from the solar cell.
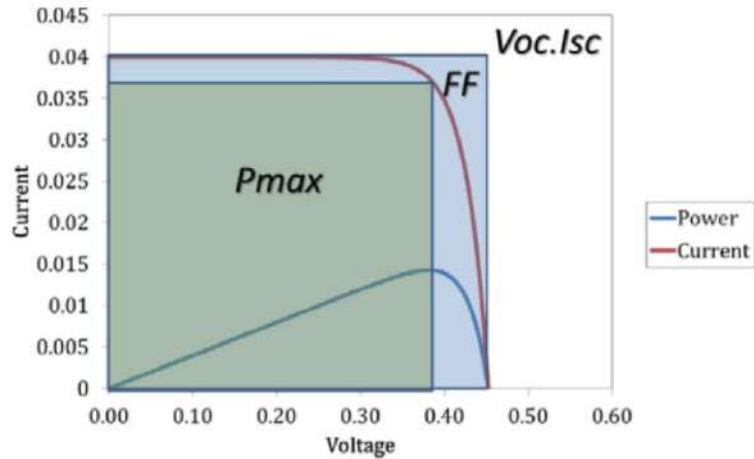
Figure 8: Graphical interpretation of Fill Factor.

The Fill factor equation can be found in (Perera and He, 2018), and the higher quality of the Photovoltaic cell required an immense Fill Factor value.
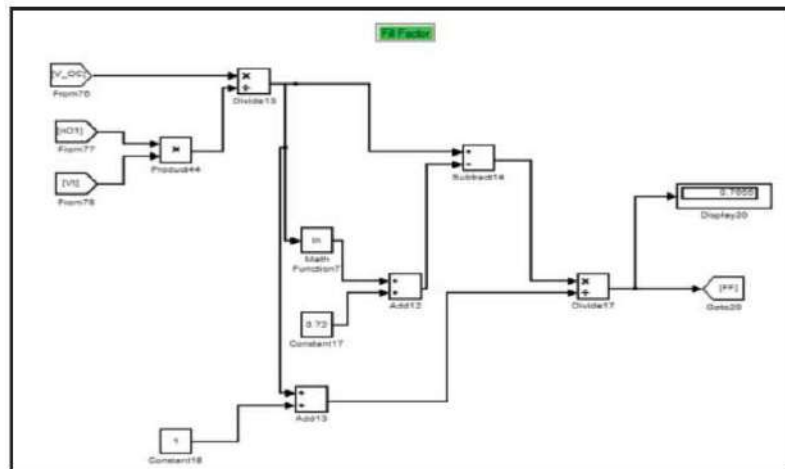

Figure 9: Simulink model for the Fill Factor parameter.

2. Simulation using Matlab codes

In (Chedid *et al.*, 2014), Photovoltaic cells' characteristics were simulated using Matlab codes. The characteristics of solar cells swayed by Irradiation, temperature, electrical connections, and shade. By Utilizing Matlab codes, it will be possible to examine the effect of different P-V and V-I curves parameters.

To be able to draw the V-I and P-V curves, also to be able to investigate the effects of temperature, Irradiation, and shading, the following Matlab code can be used.

```
Choose the data according to the solar panel being
simulated (Isc, Voc, Imp, Vmp, Kv, Ki, and the number of
cells in series to create the desired model).

Choose the nominal temperature (after changing to
Kelvin).
Set a matrix having different values of irradiance.

For j = 1:n
(n is the number of elements taken in the matrix)

        Let Vt = k*T/q
        I01=(Isc+(Ki*DeltaT))/(exp((Voc
        +(Kv*DeltaT))/((a1)*Vt))-1)
        I02=(Isc+(Ki*DeltaT))/(exp((Voc
        +(Kv*DeltaT))/((a2)*Vt))-1)
        Set a voltage vector from 0 to a maximum voltage
        specifying the step taken

        For i = 1: length(v)

            I(i) = Isc – Io1*(exp((V(j)+I(j)*Rsd)/Vt/a1)-
            1)-Io2*(exp((V(j)+I        (j)*Rsd)/Vt/a2)-1)-
            (V(j)+I (j)*Rsd)/Rpd-I(j)
            Find the value of I for every value of
            irradiance
        End

Draw the figure for I-V characteristics
Draw the figure for P-V characteristics using P = V *I to
perform element by element multiplication for the current
and the voltage

End
```

Figure 10: Matlab code for calculating Irradiation and temperature effects.

The shading effect is a normal and common issue that impacts the performance of the Photovoltaic system. When the cell is shaded, instead of generating current, it will draw current from the neighboring cells, and it acts as a load rather than a generator. The issue can be solved by connecting the diode between the cells to overcome the issue of shading.

When the shading is to be calculated in the Photovoltaic model, the shunt resistance will be neglected because the value of this resistance tremendous, and it can be considered an open circuit. The following Matlab code calculates the effect of shading.

```
Define:
    -   Number of sub-arrays in each group
    -   Number of shaded modules in each sub-array
    -   Number of un-shaded modules in each sub-array
        that are divided into the number of subgroups
        based on the illumination on each
    -   The illumination (in sun) on each shaded or un-
        shaded module in each group
    -   Temperature on each of the sub-groups
    -   Number of modules in parallel in each group

For k = 1:1:|G|
(k stands for the group number, |G| is the number of groups)

  I=0
  x=0
  V=0.001                              (taking    initial
values)
  while(V>0)
      increase I by a very small step
      x=x+1
      for j = 1: number of sub-arrays
           the voltage in the subassembly = number of
modules in subassembly * voltage of each module

        Where: -  voltage of the module is found using
equation (6)
                 -  $V_T$ is found using equation (2)
                 -  $I_L = I_{sc}$ * illumination
      End

       V=sum of voltages of subassemblies in series

         When x>2
         the deviation from last array voltage = Vprev - V;
          if this deviation is more than 4
   decrease I by a very low fraction (0.0009)
       for j = 1: number of subassemblies
            the voltage in the subassembly = number of
modules in subassembly * voltage of each module
       End
       V=sum of voltages of subassemblies in series
  End
End

         Vprev=V;

         voltage(k,x)=V;
                    % voltage of a group
         current(k,x)=I*N(k);
                    % total current from group
         power(k,x)=volt(k,x)*curr(k,x);
                    % power from group
  End
End

Fill elements of V, I, and P in arrays
         V_array = min(V of the three groups in parallel)
         I_Array = sum(I)
         P_Array                  =                 sum(P)
where P = V.*I
plot(voltage, current);
          %to plot IV curve
plot(voltage, power);
          %to plot PV curve
```

Figure 11: Matlab code for calculating the shading effect.

3. Simulation using LabView.

In (Bendib *et al.*, 2018) LabView environment is used as a drag-drop visual programming paradigm. Any complicated physical component can be simulated using the LabView. The LabView programs are known as Visual Instruments. In this study, Suntech solar module was used to be simulated in the program. The simulated module under Labview is shown below.
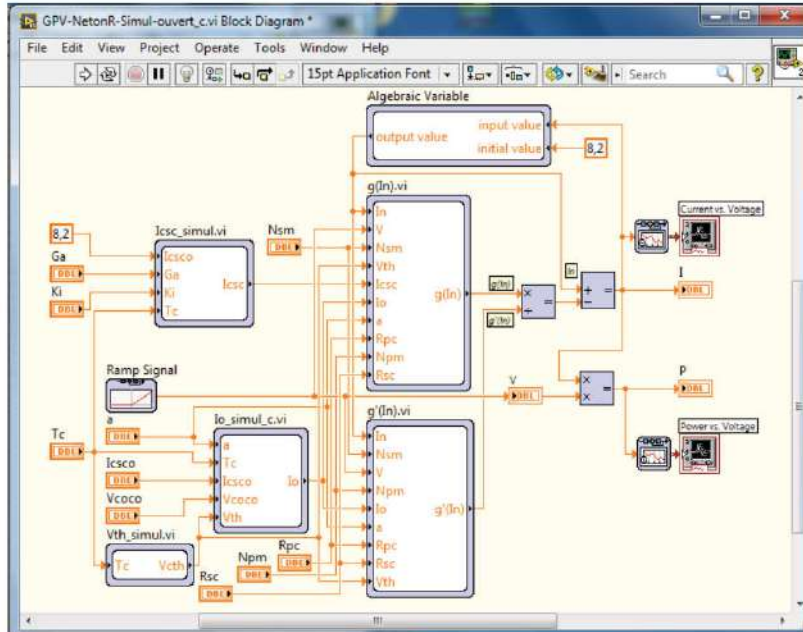
(a)
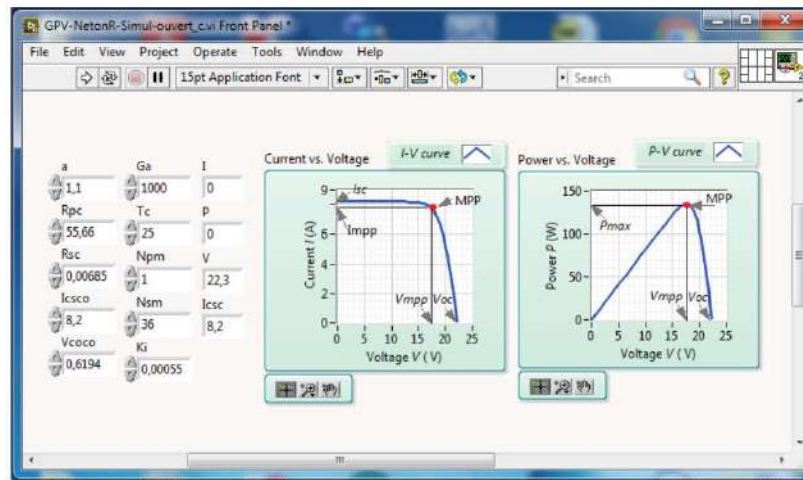
(b)

Figure 12 : (a) block diagram of the simulated module and (b) the PV generator module front panel in LabView

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The Photovoltaic module is a module that comprises 36 solar cells and provides 135 watts.

4. Simulation Algorithms

In (Park and Kim, 2013), some of the algorithms used in the Photovoltaic module simulation were presented. The following are the algorithms used in simulating the modules of solar.

A. Villalva algorithm:

In this Algorithm, the voltage is determined in R_s-R_{sh} selected pair. The value of current I(v) and P(v) are found in steps then if the Pmax is not matched, the process will continue for another iteration of R_s-R_{sh}. The Algorithm will stop when the values are matched.

This type of Algorithm's disadvantage is its dependence on trial and error for finding the value of the diode quality factor. The user should adapt the value of the diode quality factor out of the Algorithm to concide the V-I curve provided by the fabricator. According to the diode quality factor (a), the I-V curve difference is presented in the figure below.
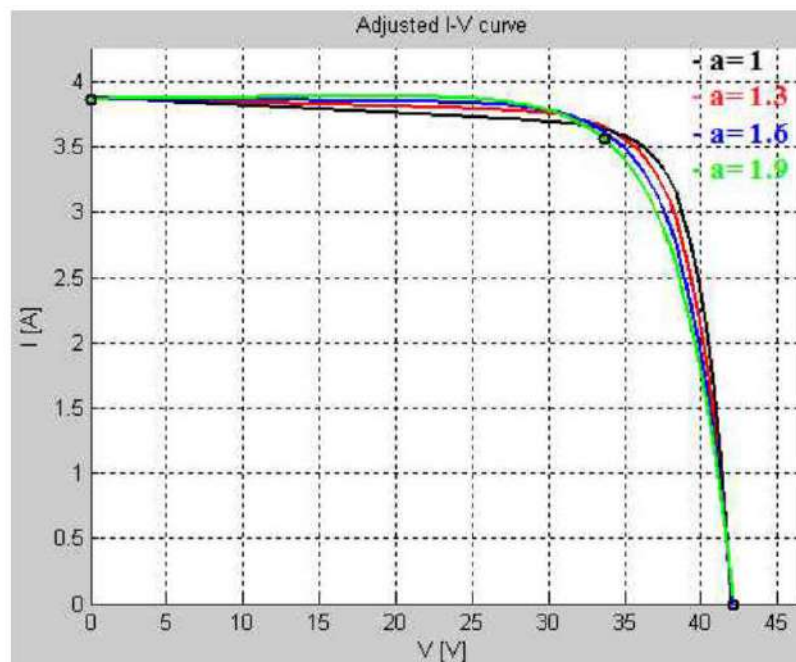
Figure 13: Different values for I-V curve for different values of diode quality factor (a).

The value of (a) is unknown, so one should manually adjust and change it. This process is painful and time-consuming.

B. Pedro algorithm

In this Algorithm, the diode quality factor will be assigned automatically by the Algorithm until a suitable value is calculated. The disadvantage is that the series resistor and the shunt resistor should be found separately, and reaching the solution is problematic.

C. Wagner algorithm

In this Algorithm, the extraction of the parameters will be finished from the first iteration, but because the numerical Algorithm was written primarily for the Cr-Si type, the change to another type causes the program to have severe errors.

D. In (Park and Kim, 2013) work, a new algorithm (**Named K1, K2, and K3**) was proposed due to the disadvantages of the previously mentioned algorithms. The Algorithm promises small errors when switching between different Photovoltaic decompositions, and it requires less computation time.

The work of the Algorithm can be summarized in steps as follows:
1. The R_s value will be from 0 to R_{s_max} by R_{s_step} interval.
2. The values of R_{sh} and v_t will be calculated from step (1).
3. R_{s_max} and R_{s_step} will be determined using the equations (20) and (21).
4. The value of Vt will be updated according to the equations (17),(18), and (19).

The complete flow diagram of the proposed Algorithm is shown below:
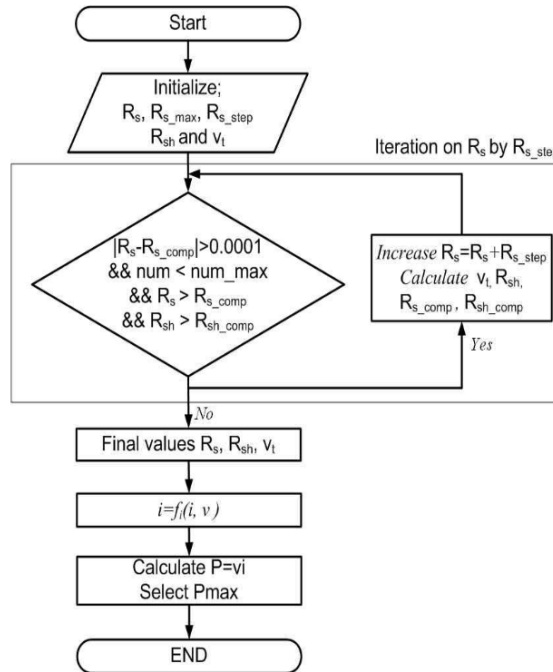
Figure 14: Flowchart of K1, K2, and K3 Algorithm

Comparing this type of Algorithm and the other types mentioned above will be presented in the next section.

5- RESULTS AND CONCLUSIONS

In this segment, the simulations' outcomes and the algorithms exhibited in the preceding sections will be conferred. At the end of this section, the conclusion of the studied papers will be granted.
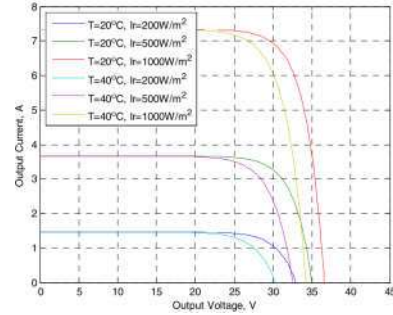
1-Results

In (Moreno, 2017), the impact of temperature on solar systems' operation was examined, and the V-I curve was constructed and compared for each situation. Sixteen solar cell modules were used for this experiment.

The results constructed under 20 C° and 40 C° for different values of irradiations, as shown below.
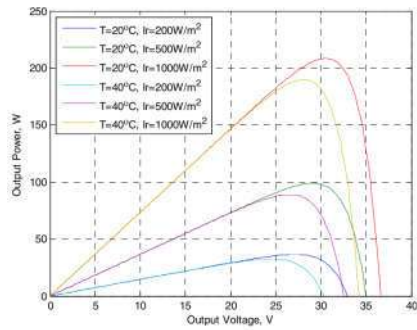
(a) P-V curve

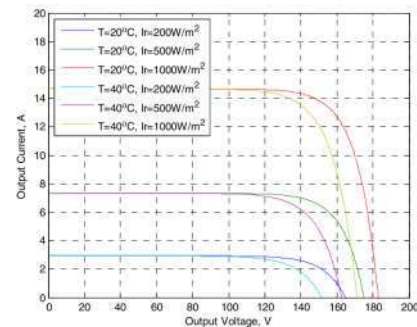(b) I-V curve
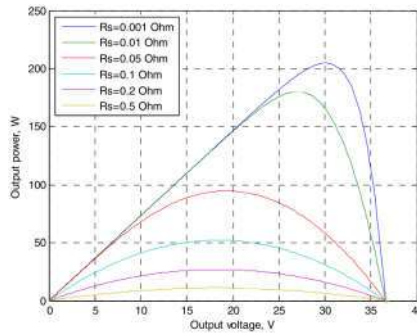
(c) P-V curve for Rs=0.001 to 0.5
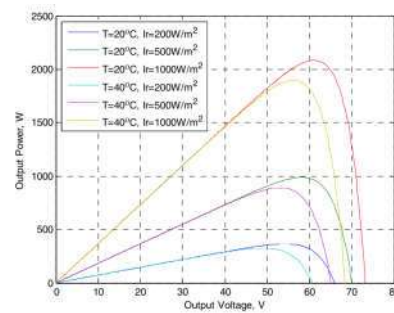
(d) P-V curve for ten modules of 60 cells(5 strings).
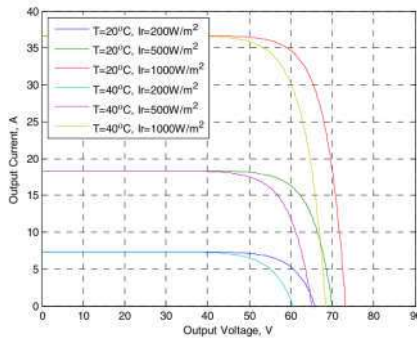
(e) I-V curve for ten modules of 60 cells (5 strings).
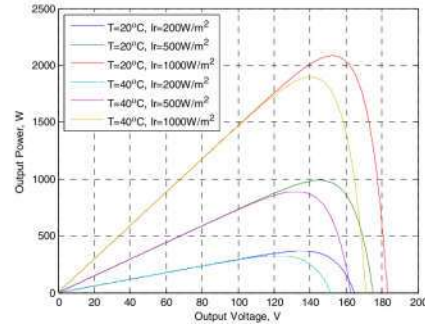
(f) P-V curve for the ten modules (2 strings).

(g) I-V curve for the ten modules (2 strings).

Figure 15: The P-V and I-V characteristics for different temperatures, irradiations, and connection configurations.

Figure (15)-a, the cells' power is 100 watt under 500 W/m2 irradiation for the sixty modules used in the experiment. However, when the temperature increased to 40 C°, the power will decrease to 95 watts. Figure(15)-b shows the I-V curve for the sixty solar cells. Figure(15)-c shows the change in R_s and its impact on P-V curve characteristics. The Rs value changes the maximum power point value, so it crucial to investigate it. The maximum power is excellent and exceeds 200 watts at R_s= 0.001 ohms, and it is minimum below 50 watts at R_s=0.5 ohms.

Figure (15)-d and (15)-e shows the P-V and I-V curves for ten modules, each of sixty cells connected In the following configuration:
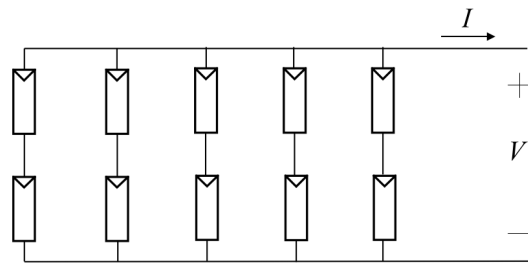
Figure 16: parallel configuration of ten modules

Again, the power out from the modules will decrease with the decrease of temperature.

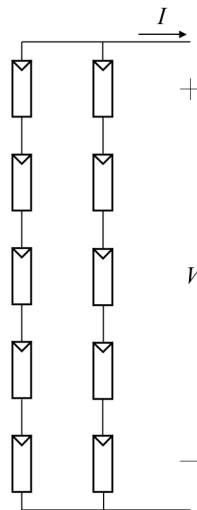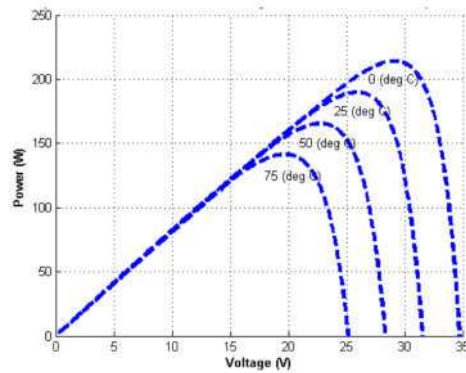The configuration changed to be connected in this way shown below:

Figure 17: Series connection of ten modules.

The modules are connected in two string configurations, and each module is sixty cells. The P-V and V-I curve concerning this configuration shown in Figure (15)-f and g. The configuration shown above depicts that the current will be maximum in the five-string, and in the two string configuration, the voltage will be maximum.
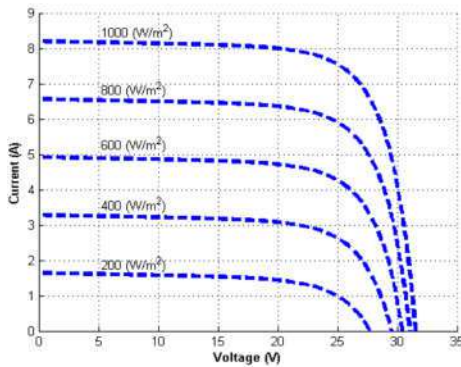
In (Chedid *et al.*, 2014), a simulation of the two diode model was presented using Matlab codes. The effects of Irradiation, temperature, and shading were studied and presented. The results of the Matlab codes are shown in the figure below:
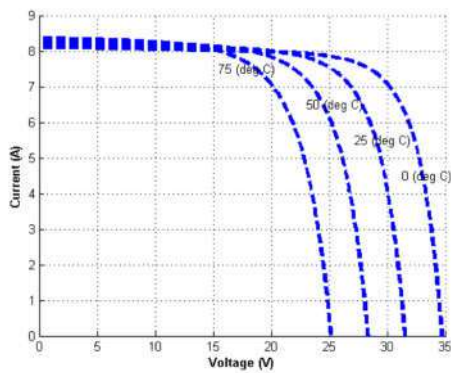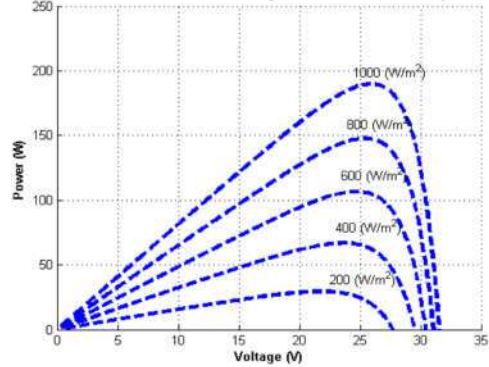

(1) The effect of temperature on the V-I curve.   (2) The effect of temperature on the P-V curve.

(3) The effect of Irradiation on the V-I curve.   (4) The effect of Irradiation on the P-V curve.
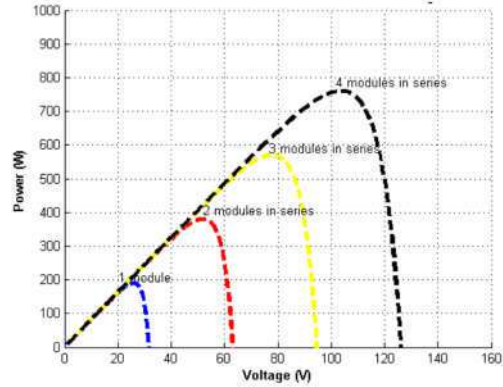
Figure 18: the effect of temperature and Irradiation on the V-I and P-V characteristics

The above curves are produced by the Algorithm shown in Figure 10. The results in Figure 18 show that when the temperature increases, the voltage will drop accordingly, but the current change is significant. On the other side, the power will drop with a decrease in voltage. Irradiation's effect is positive on the current and power so that when the irradiation increases, the current and power increase. In this work, the effect of connecting the
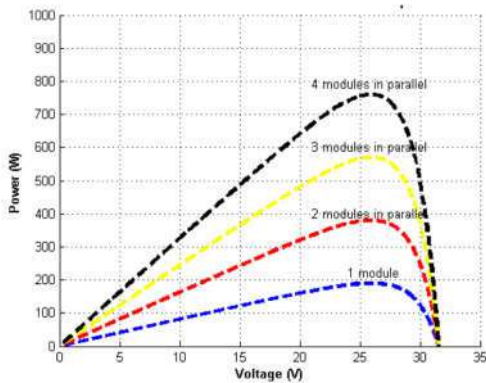
modules in parallel is investigated and simulated. The results can be summarized in the following figure.
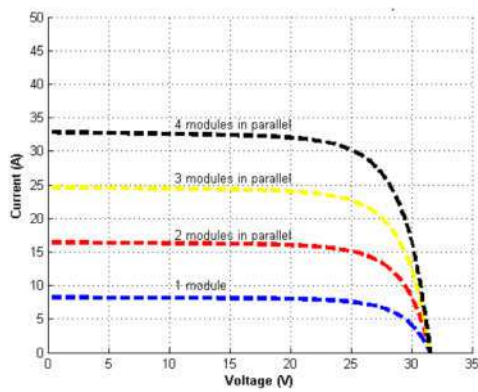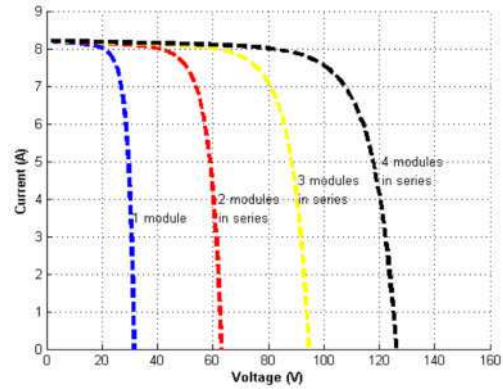

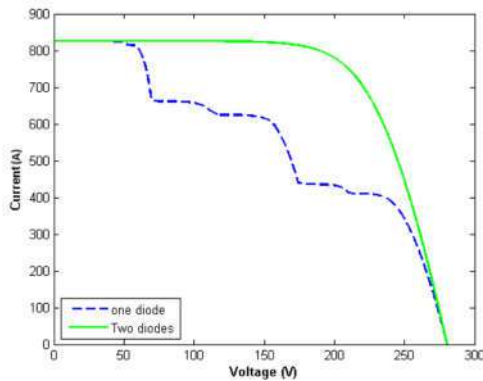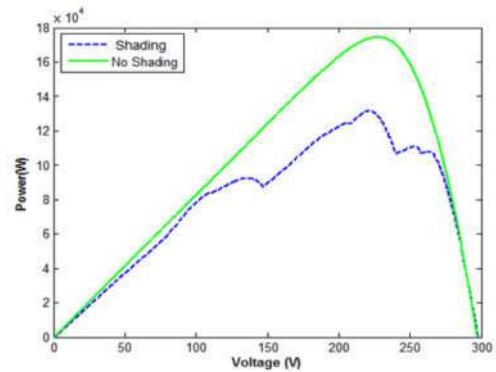(1) Parallel modules V-I curve   (2) Series modules P-V curve

(3) Parallel modules P-V curve   (4) Series modules V-I curve

(5) Shading and un-shading effect on V-I curve   (6) Shading and un-shading effect on P-V curve

*Figure 19: The connection configuration and shading effect on the P-V and V-I curves.*

From the curves shown in Figure 19, it shows that the parallel connection of modules results in cumulating the current to be increased with the power for the same value of voltage while the series connection results in increasing

the voltage and power for the same value of current. When the shading is considered, the effect will be the curves shown in Figure (19) numbers five and six. The I-V and P-V curves are drawn for both shading and no shading effects. The results show that the shading will decrease the magnitudes of current, voltage, and power. It depends on the amount of Irradiation on the modules.

The shading effect can be further investigated, and the following curves can be produced for the effect of shading on the parallel and series connection of the modules. Let suppose that four modules are connected in parallel, and one of them is shaded with a 20-degree temperature, and the other three modules are not shaded with 45-degree temperature. The Irradiation is assumed to be one sun.
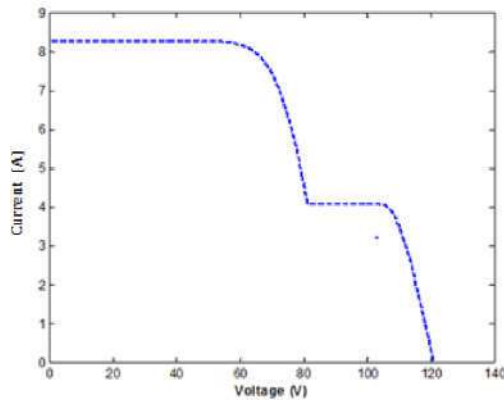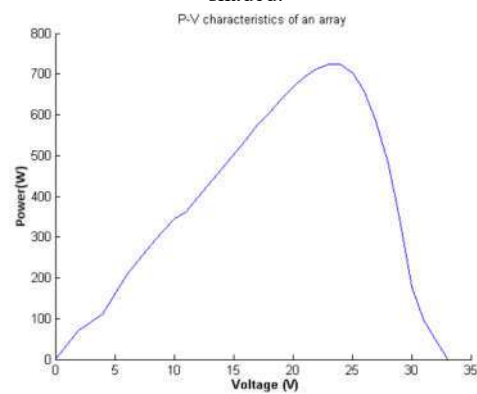

(1) V-I curve for four modules in series one shaded.
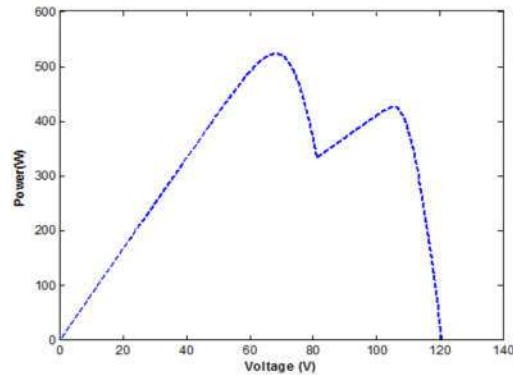
(2) P-VI curve for four modules in series one shaded.
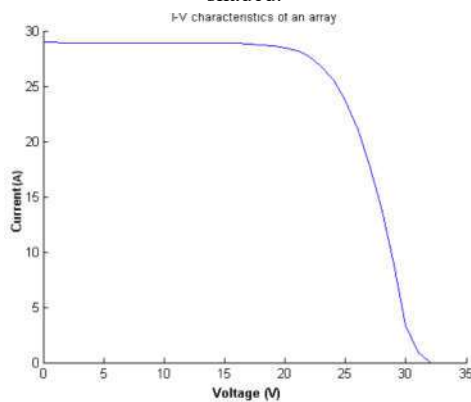
(3) V-I curve for four modules in parallel one shaded.

(3) P-V curve for four modules in parallel one shaded.

The modules' series connection is more sensitive for the shading that the parallel connection as it shows no ripples in the curves.

In (Bendib *et al.*, 2018), the Suntech solar module simulation was presented under the LabView environment program. Thirty-six polycrystalline solar cells were connected in series and tested in the simulation environment. The simulation of the work is shown in Figure 12 (a) and (b). The solar cells usually deliver 135 watts. The curves and tests were produced using the LabView, and the results for various parameter changes and their effects on P-V and V-I can be shown in the following figure.
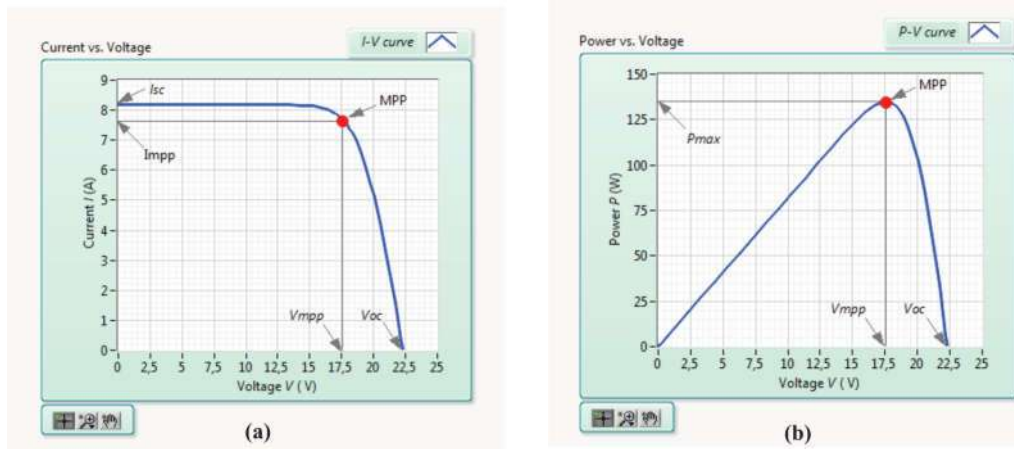

Figure 20: The characteristic of Photovotaci under standard conditions.
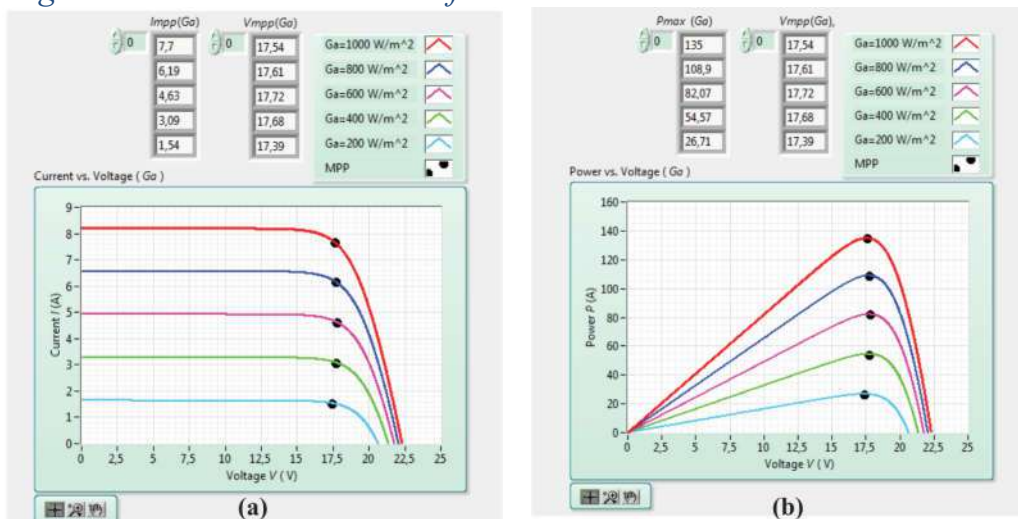

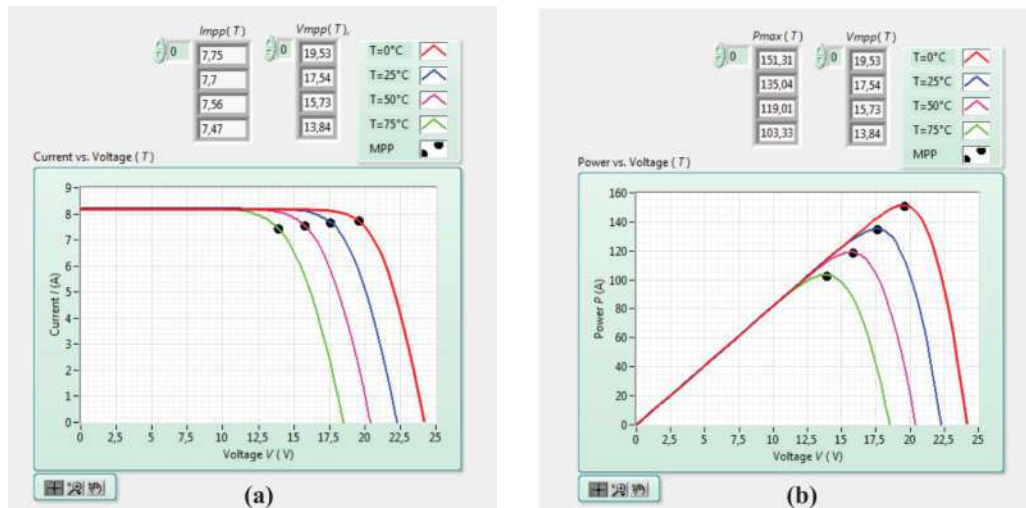Figure 21: Irradiation effect on the Photovoltaic solar cells

Figure 22: The effect of various temperature values on the Photovoltaic characteristics.

In Figure 20 (a) and (b), the curves show the V-I and P-V characteristics under the typical conditions (25 C_o and Irradiation of 1000 w/m^2). The results show that Irradiation has a crucial impact on the solar module's power and current. The current and power will decrease with the Irradiation level Figure 21 (a) and (b).

In Figure 21 (a) and (b), when the temperature is the altering parameter, the results presented show that the voltage will drop according to the temperature increase for the same current level. Besides, the power will drop with the drop in voltage and an increase in the temperature.

The simulation was also performed under the real situation, and Labview produced curves; it shows that the current and power will be increased when the Irradiation is high for the same value for voltage.

In (Mahmoud, Xiao and Zeineldin, 2012), a new and straightforward approach for simulating the Photovoltaic modules was presented. New mathematical models were presented, and the simulation and the results were compared to the preceding approaches for testing the proposed approach's validity and performance. The simulations are based on a single diode type module, and the results can be shown in the figure below.
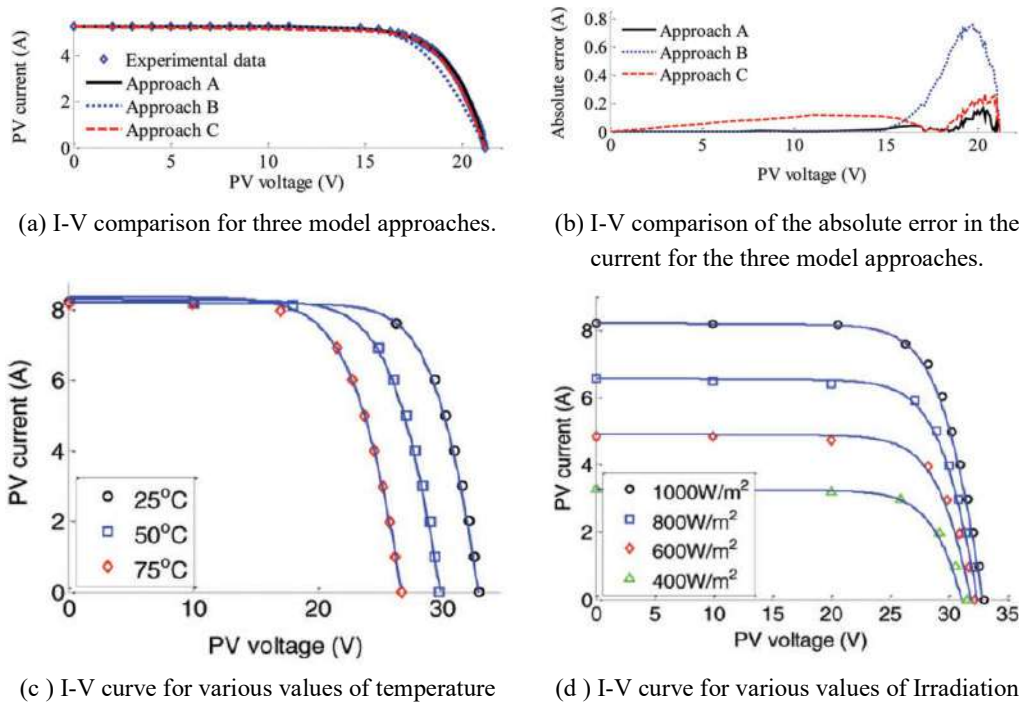
(a) I-V comparison for three model approaches.

(b) I-V comparison of the absolute error in the current for the three model approaches.

(c) I-V curve for various values of temperature

(d) I-V curve for various values of Irradiation

Figure 23: Comparing the three models approached in terms of absolute error, temperature, and Irradiation.

The data show that the simulated data approaches closely to the experimental measurements. The proposed approach simulation has reasonable accuracy levels with less processing time and root-mean-square deviation than the preceding approaches.

In (Manosukritkul and Titiroongruang, 2017) work, a new simulation model was proposed for estimating the power out from the plant in Thailand. The solar Irradiation and the temperature were used as the input for the simulated model. The simulation was performed based on one year of data collection. The error was found to be 1.11 after comparing the results with the practical measurements. The results are shown in the figure below:
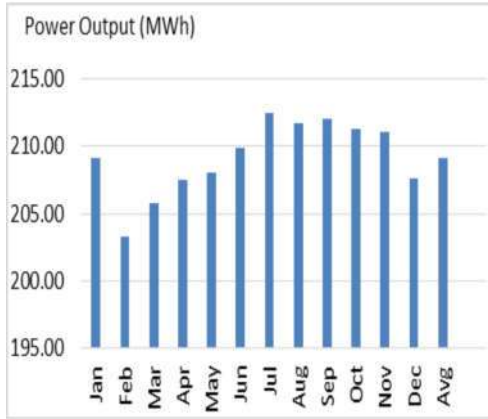
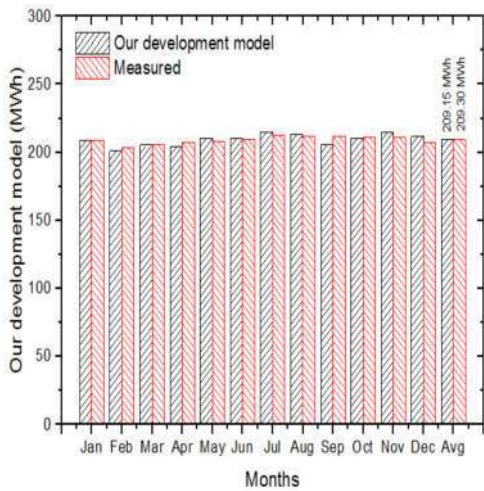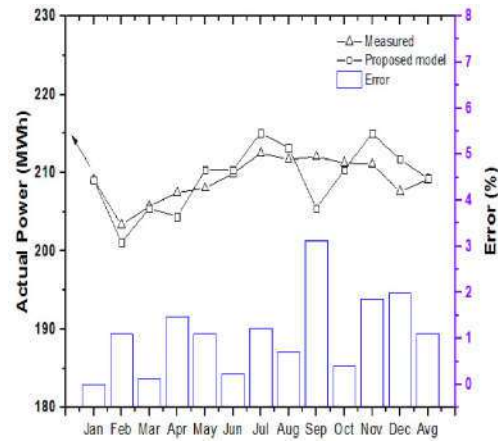(a) Measure power output   (b) The final yield
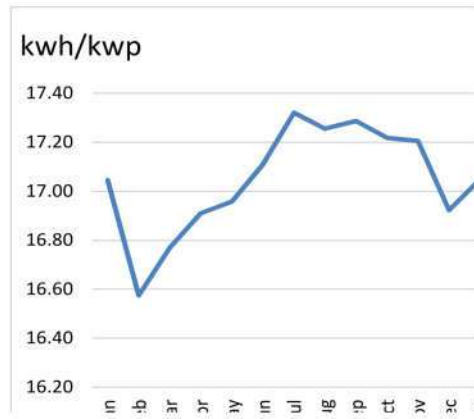
(c) Comparing one-year data measurements with the developed model   (d) Measurement of error and comparison of the measured and proposed model values.

Figure 24: Measurement of power output, the final yield, and error.

It can be seen clearly that the power output of the plant is decreasing during the February month because of rain. Figure 24 (a) shows the measured power out for the plant for one year. The final yield is shown in (b), and it depicts the capability of power out for each day. The developed power out in (MWh) compared to the plant power out measured over one year, and the result shows that the two data are close, and the average is almost the same see (c). Finally, the error between the actual power and the proposed model power is compared in figure 24 (d).

In (Park and Kim, 2013) study, several algorithms were presented with their advantages and disadvantages were depicted. The work proposed a new algorithm named (K1, K2, and K3) or K-algorithms. The proposed

Algorithm was implemented and compared to the preceding algorithms. The results can be summarized in the figures below.

a)   b)
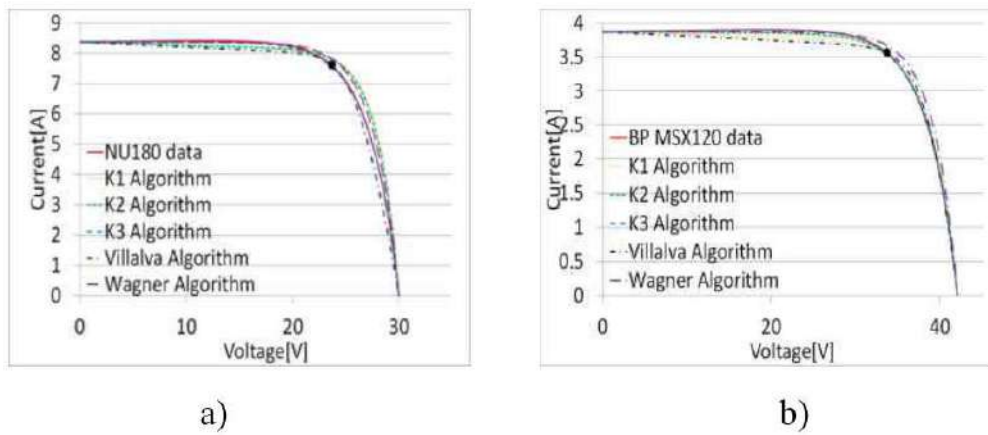
Figure 25: comparison of K-algorithms and the preceding algorithms

Figure 25, simulation for Cr-Si type photovoltaic cells; NU180 and BP MSX120 of Photovoltaic cells are presented. There is a significant error between the compared Algorithm as compared to the solid line.

a)   b)

Figure 26: comparison of K-algorithms and the preceding algorithms

The results in Figure 26 (a) and (b) show that the K-algorithm is close to the solid line while the other algorithms are far from the solid line.
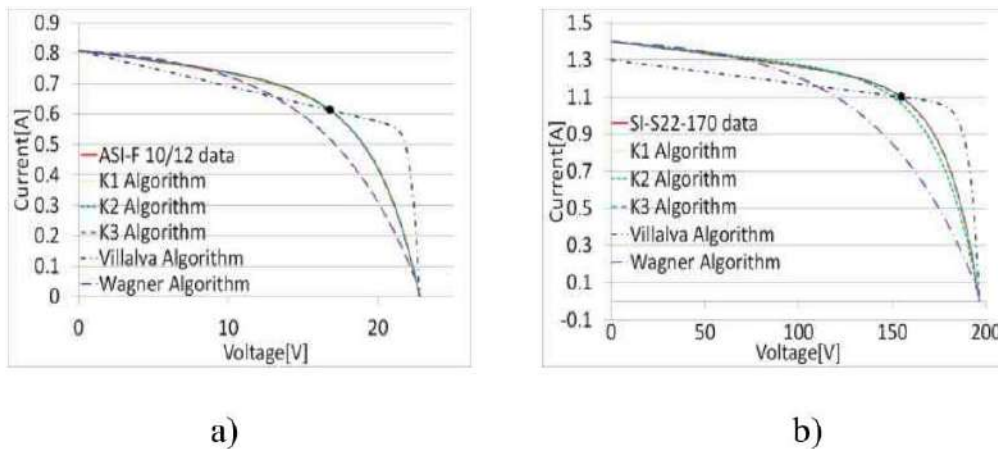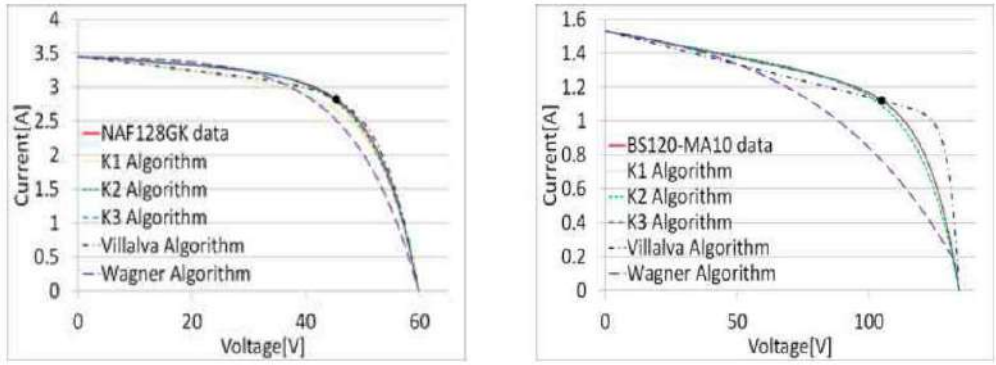
Figure 27: comparison of K-algorithms and the preceding algorithms

Figure 27 (a) and (b) show that the K- algorithm results are very close to the solid line and the other curves, which shows a large deviation from the solid line.
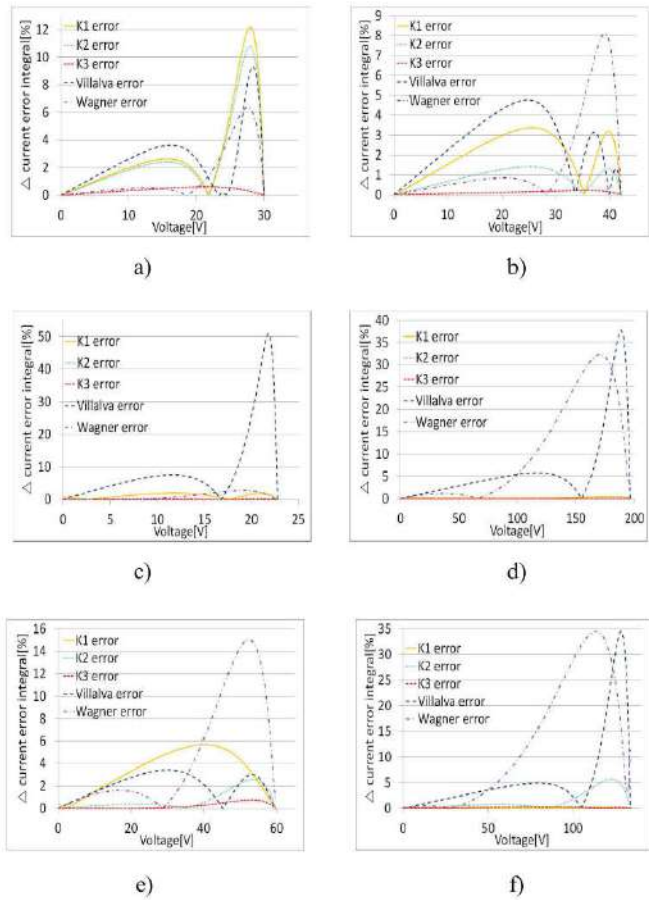

Figure 28: Comparison of the curves extracted from each Algorithm for error integration and the curve provided by the manufacturer

The results in Figure 28 (a – f) extracted from the Algorithms and the proposed Algorithm are compared to the manufacturer's curve. From the tables constructed in the study, it is clear that the error integration for K-algorithm is minimal amount comparing it to the previously used algorithms. The average integration error for the K3 Algorithm is 0.27, while it is 2.40 and 12.64 for the Villava and Wagner algorithms. The processing time for the K algorithms is fair but not faster than Villava. The K3 Algorithm is the fastest among the three K-algorithm types. The outcome is that the K3 Algorithm is the best performing algorithm as compared to K1 and K2.

2- Conclusions

The conclusions for this article review can be summarized in the following points:

(a) In (Moreno, 2017), the importance of studying the Photovoltaic cells' characteristics and the whole system of modules is presented. The results showed that the maximum power point would change 10 percent when the temperature changes from 20 to 40 degrees. This study is significant for selecting the inverter and battery size for any solar system.

(b) In (Chedid *et al.*, 2014), an in-depth study was presented for investigating the effects of several parameters on the photovoltaic modules. Curves produced by Matlab codes presented temperature, Irradiation, shading, and connection types on V-I and P-V. The study aims to help students understand the effects of the mentioned parameters on the solar module characteristics.

(c) (Bendib *et al.*, 2018) the investigation was performed under different simulation environments, and the same characteristics were studied under the effect of temperature, Irradiation. The simulation program utilized in this study is LabView. Moreover, the effect of the mentioned parameters was tested under the real atmospheric situation compared to the simulation results.

(d) In (Mahmoud, Xiao and Zeineldin, 2012), the work performed to compare three different approaches with the proposed approach presented in work in terms of altering temperature, Irradiation, and absolute error current value. The experimental data showed the

effectiveness of the proposed approach over the preceding approaches.

(e) In (Manosukritkul and Titiroongruang, 2017), the new approach compared to the measured data collected throughout one year inside Thailand's power plant. The error between the power out and the measured power out from the simulation model is 1.11.

(f) In (Park and Kim, 2013) work, three new fresh, fast, and accurate algorithms were presented and compared to the past algorithms used for modeling the photovoltaic cells. Different types of photovoltaic cells were used in the simulations, and for every type, the algorithms were used to extract the error integration values. The values and the results were compared to the curve provided by the manufacturer. The results showed that the K3 Algorithm is the best performing algorithm among all the primary types.

6- REFERENCES:

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