An Investigation of the Output Characteristics of Photovoltaic Cells Using Iterative Techniques and MATLAB® 2024a Software

Azem Hysa [1], Mohamed Metwally Mahmoud [2,*], Ahmed Ewais [3]
[1] Department of Applied and Natural Sciences, “Aleksander Moisiu” University, Neighborhood 1, Currilave Street, Durres, 2001, Albania
[2,3] Electrical Engineering Department, Faculty of Energy Engineering, Aswan University, Aswan 81528, Egypt
Email: [1] azemhysa@gmail.com, [2] Metwally_M@aswu.edu.eg, [3] ewaisa@aswu.edu.eg
*Corresponding Author

***Abstract*—This study investigates the characteristics of photovoltaic (PV) cells using iterative methods and MATLAB® 2024a software. Its main objective is to analyze the power-voltage (P-V) and current-voltage (I-V) characteristics for various series resistances and solar irradiation levels. The precision and dependability of this study are improved by the software utilized for numerical simulations and analysis. Since the PV cells are nonlinear, numerical techniques are favored in this situation to solve their nonlinear equations. In order to investigate different curves and their characteristics, the study makes use of numerical simulations, the single diode model, and the Newton-Raphson method (NRM), which is iterative and converges to an optimal solution of the problem to be solved. The behavior of PV cells under the variation of solar irradiance and different values of series resistance is described by the I-V and P-V characteristics. From the data, we notice that the influence of sun irradiance on PV cells, demonstrates that higher solar irradiance gives more current and power, and higher series resistance decrease the output power. The highest efficiency of a solar cell measured is roughly 47.1%. Future technical advancements in these crucial areas for humankind will result in further increases in the maximum efficiency of solar cells.**

Keywords*—PV Cells, Irradiation, Simulation, MATLAB 2024® Software, PV Characteristics

I. Introduction

The use of solar energy (SE) dates back to the 7th century. For example, through a magnifying glass that was used to focus a ray of sunlight on a certain point to light a cooking fire. In the 3rd century, people used a large mirror-reflected sunlight to light lanterns used in religious ceremonies [1]-[3]. The phenomenon of the photovoltaic (PV) effect (the conservation of light into electricity) was first observed by French physicist Edmund Becquerel in 1839 [4], [5]. He noted that the amount of electricity produced increases when the cell is exposed to sunlight [6], [7]. Afterward, in 1873, Willoughby Smith discovered that selenium could be a photoconductor [8], [9]. Three years later, William Grylls Adams and Richard Evans Day combined these two discoveries while noting that it was possible to produce electricity using sunlight [10], [11]. In 1883, American inventor Charles Fritts created the first fully functioning solar cell based on selenium [12], [13]. According to [14], PV cells (Fig. 1) comprise a semiconductor material - silicon - which is added substances, named doping to create a suitable means for establishing the PV effect, i.e. direct conversion of power linked to the solar radiation into DC electrical power. Furthermore, Castro (2008) states that the cell is the smallest element of the PV system, producing electrical power typically of the order of 1.5 Wp (corresponding to a voltage of 0.5 V and a current of 3 A) [14], [15].

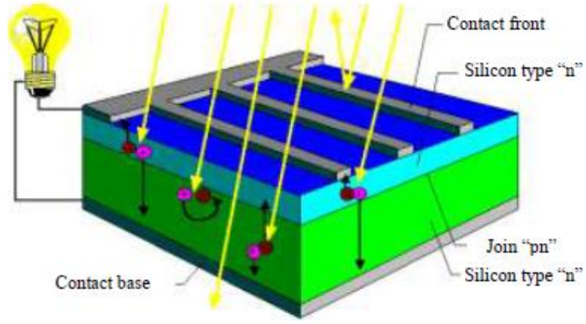

Fig. 1. The internal constitution of a typical PV cell [14]

Applications of PV cells are in solar power systems, off-grid power, and spacecraft. PV cells have been used in spacecraft to power instruments and systems because they are reliable and can work in outer space's abundant sunlight. Currently, space missions are very important because, as we know, it is a new field of research for exoplanets in which life is thought to exist. To carry out space missions, scientists send satellites to some special positions in space, which are called Lagrange points [16], [17]. To carry out these missions, SE is also used through solar panels that are installed in spaceships [18], [19]. PV cells were first used in space missions in the 1950s. In the 1950s, there was a significant development of space expansion and spacecraft technology, which began to be equipped with PV cells. The first such machines were the Vanguard I (1958), Vanguard II, Explorer III, and Sputnik-3 satellites (Wolfe 2018). In 1964, the US government agency responsible for the national spaceflight program, NASA, launched the Nimbus satellite, which was powered solely by a 470-watt photovoltaic panel array [20], [21]. Shortly after, the technology gradually began to be used in homes, factories, and public buildings.

Currently, the total installed solar PV power capacity in the European Union is about 160 GW [22], [23]. About 60% of this capacity is from residential and commercial rooftop installations [24], [25]. The cumulative installed capacity in the 171 European Union and Britain accounts for about 21%

of those worldwide [26], [27]. The number of solar PV cell power plants (some with storage) is growing yearly in more and more countries. In 2021, Germany had the leading market for PV elements with 5.3 GW of newly installed capacity. After Germany was Spain with 3.8 GW, then the Netherlands with 3.3 GW, Poland with 3.2 GW, and France with 2.5 GW [24], [28].

The level of SE radiation in Albania is quite high and its territory is suitable for installing PV elements. The territory of Albania is in the Western Balkans, part of the European continent. It is situated between latitudes 39o38' - 42o38' and longitudes 19o16' - 21o04' east [29], [30]. Most areas of Albania are exposed to more than 1500 kWh/m2 per year varying from 1185 to 1690 kWh/m2 per year [29], [31]. Albania is a country with great potential for SE due to its geographical location and favorable climate conditions. Albania's high levels of sunlight offer a chance for the nation to use PV technology to harness SE. Currently, the total installed capacity of SE in Albania is around 70 MW, which represents only a small fraction of the country's potential. Most of the existing solar power plants in Albania are small-scale installations, with a capacity of less than 5 MW [32], [33].

Several papers have proposed different models to study the PV cell output characteristics. The most used are; single and double diode models [34], [35]. In this study, we use the single-diode model. The characteristic current-voltage (I-V) is a non-linear equation with multiple parameters classified as follows: those provided by constructors, those known as constants, and the ones that must be computed. Sometimes, searchers develop simplified methods where some unknown parameters cannot be calculated. They are thus assumed constant [36]. Experimenting with PV cells in the laboratory is a time-consuming and costly task. So, to overcome this problem, numerical iterative methods and simulation techniques are used to simulate the behavior of PV cells under different conditions [37]. Output I-V and P-V characteristic curves and performance at different series resistance, shunt resistance, temperature, and solar irradiance are analyzed. Thus, this research work helps understand the behavior of the PV cell.

The remainder of this paper is organized as follows. Section II describes the methods used in this study. We use a single-diode model of the PV Cells and some numerical techniques, such as Newton's method and Newton-Raphson's method. In Section III, we describe our results and discussion, and our conclusions are presented in Section IV.

II. Material and Methods

The iterative Newton's method is used in several mathematical and engineering problems to find the numerical solutions of the nonlinear equations [38], [39]. This method is iterative and the iteration sequences converge to an optimal solution of the problem to be solved. However, this method can be introduced and discussed in a general context as the following equation:

$$x_{k+1} = x_k - \frac{f(x_k)}{f'(x_k)} \tag{1}$$

where, $x_{k+1} =$ the $(k+1)$estimate of the desired rootx_r, $x_k =$ the k_{th} estimate of the desired root $x_r f(x_k) =$, and the function $f(x)$ evaluated at $x = x_k f'(x) x = x_k$. This equation is repeatedly applied until $f(x_{k+1})$ is sufficiently close to zero and $x_{k+1} = x_k$ [40], [41].

A single diode represents the best model (Fig. 2), where IP, ID, and ISD denote the current through a shunt resistor, diode current, and the diode's reverse saturating current, accordingly. So, to obtain the equivalent circuit equations, mathematical analysis steps must be established [42]. By applying Kirchhoff's law in Fig. 2 a (for Rs = 0 and R_{sh}= 0), we have:

$$I = I_{ph} - I_D \tag{2}$$

The diode current is

$$I_D = I_0 \left(e^{\frac{V}{n_s V_T - 1}} \right), \tag{3}$$

Where

$$V_T = \frac{n k_B T}{e}, \tag{4}$$

And k_B=1.381×10-23 J/K is the Boltzmann's constant, e = 1.602×10-19 C is the electron charge, T is the operating temperature in Kelvin (K), I_0 is the saturation current of the diode. Substituting equation (3) into (2) we get the photovoltaic current in this form:

$$I = I_{ph} - I_0 \left(e^{\frac{V}{n_s V_T - 1}} \right) \tag{5}$$

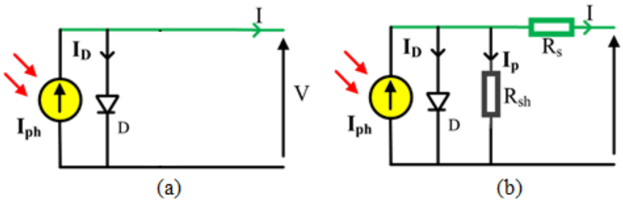

Fig. 2. (a) PV module approach without shunt and series resistance, (b) PV cell equivalent circuit for SDM [43]

The SDM configuration typically contains one diode (D) in parallel with a shunt resistor (R_{sh}) and photogenerated current (I_{ph}). This configuration, as manifested in Fig. 2 b, is put in series with another (R_S). The SDM current output (I) is mathematically formulated [44], [45]:

$$I = I_{ph} - I_D - I_p = I_{ph} - I_0 \left(e^{\frac{V}{n_s V_T - 1}} \right) - \frac{V + I R_s}{R_p} \tag{6}$$

where $I_p$is the shunt resistance current.

The photo-current I_{ph} is generated on the absorption of solar radiation by solar cells hence photo-current value is directly related to variation in solar irradiance and temperature and that is [46], [47]:

$$I_{ph} = \frac{G}{G_n} \left[I_{pvn} + K_i (T - T_n) \right] \tag{7}$$

where I_{pvn} is rated solar current at nominal weather conditions (25 ^oC and 1000 W/m^2) or short circuit current, K_i is short circuit temperature coefficient, G is solar irradiance in W/m^2, G_n is nominal irradiance in normal weather conditions (25 °C and 1000 W/m^2) and T_n is nominal temperature (298.15 K). The saturation current of the diode is.

$$I_0 = I_{on}\left(\frac{T}{T_n}\right)^3 exp\left[\frac{qE_g}{ak_B}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right] \quad (8)$$

where I_{on} is reverse saturation current of the PV cell for nominal temperature and irradiance values and E_g is band-gap energy of silicon. The reverse saturation current of the PV cell is:

$$I_{on} = \frac{I_{scn}}{\left[exp\left(\frac{V_{ocn}}{aV_{Tn}}\right)-1\right]} \quad (9)$$

where I_{scn} nominal SC is current, V_{ocn} is nominal OC voltage constant. We know that series resistance is very small then for an ideal solar cell there is no series resistance (no series losses) and no leakage to ground (no shunt resistance) therefore R_s and R_{sh} are neglected by putting $R_s = 0$ and $R_{sh} = \infty$. Shunt resistance has a significant effect on the operating characteristic curves of PV cells as low power output is recorded if the value of shunt resistance varies from 0.07 ohms to 1700 ohms [48], [49].
The bandgap energy E_g (in eV) for silicon:

$$E_g = 1.16 - 7.02\times10^{-4}\left(\frac{T^2}{T-1108}\right) \quad (10)$$

The power output can be expressed [29]:

$$P = \left\{I_{ph} - I_0\left[exp\left(\frac{e(V+IR_s)}{aN_sk_BT}\right)-1\right]-\frac{V+IR_s}{R_p}\right\}V \quad (11)$$

At the maximum power point (MPP), this equation becomes:

$$P_{mpp} = \left\{I_{ph} - I_0\left[exp\left(\frac{e\left(V_{mpp}+I_{mpp}R_s\right)}{aN_sk_BT}\right)-1\right]-\frac{V_{mpp}+I_{mpp}R_s}{R_p}\right\}V_{mpp} \quad (12)$$

The current-voltage characteristic equation of the equivalent circuit for the PV module arranged in Np parallel and Ns series can be described as [50], [51]:

$$I^m = N_pI_{ph} - N_pI_0\left[exp\left(\frac{\frac{V^m}{N_s}+\frac{I^mR_s}{N_p}}{aV_t}\right)-1\right]-\frac{\left(\frac{N_p}{N_s}\right)V^m + I^mR_s}{R_p} \quad (13)$$

where Np is the cell's parallel number; Ns is the cell's series number.

In this study, the Newton iterative method is used. This method is the most popular iterative method for a nonlinear function. The output current is computed iteratively [52], [53]:

$$I_{k+1} = I_k - \frac{\left[I_k - I_{ph} + I_0\,exp\left(\frac{V+IR_s}{aV_T}\right)-I_0\right]}{1+\frac{IR_s}{aV_T}+\,exp\left(\frac{V+IR_s}{aV_T}\right)}, \quad (14)$$

where, I_k present an k^{th} iteration and I_{k+1} presents the$(k+1)^{\text{th}}$ iteration. It is well known that PV module power equals to value that voltage multiplies current, and can be described as:

$$P = I^MV^M \quad (15)$$

On the other hand, the solution to the voltage at maximum power point (MMP) for the module with the Newton-Raphson method can be described as:

$$V_{k+1}^m = V_{k+1}^m - \frac{P'(V_k^m)}{P''(V_k^m)}, \quad (16)$$

where V_k is k^{th} an iterative voltage at MPP, V_{k+1} is $(k+1)^{\text{th}}$ an iterative voltage at MPP [54], [50].

III. RESULTS AND DISCUSSIONS

In this study, MATLAB® 2024a version is used to get the I-V and P-V characteristic curves of PV cells for different series resistances and different irradiance. MATLAB® is a software owned by MathWorks. This programming language is an environment designed for researchers for numerical calculations, and technical, scientific, and engineering calculations. MATLAB® has a high–quality graphical display environment. The version MATLAB® 2024b is around 90 % to 100 % reliable but the version MATLAB® 2024a is 100 %.

Table 1 shows the distribution of the global average daily solar irradiance in Razem, Peshkopi, Elbasan, Xarra, Sarande, Vlore, and Fier. From the data presented in Table 1, we see that the maximum solar radiation is in the city of Fier. The maximum value of solar radiation in this city is 7210 W/m^2. This value of solar radiation corresponds to the maximum power with a value of 338.528 W. Fig. 3 shows the power–voltage characteristic curve for G = 7210 W/m2, Gn = 1000 W/m2, a = 1.3, E_g = 1.12. Nominal OC voltage is constant Vocn = 32.9; Temperature voltage is constant Kv=-0.123; Temperature current constant Ki = 0.0032; No. of series conected cells is Ns = 54; Operating temperature is chosen T = 10 ºC, and Nominal temperature is Tn = 10 ºC. Some physical and environmental parameters used in this paper have been assumed to accomplish the work and they are shown in Table 2. For G = 6371 W/m^2, we have the maximum power of 313.998 W. This value of power corresponds to the maximum value of irradiance in the zone of the Razem. For G = 6448 W/m2, the maximum power is 316.34 W (City of Peshkopia, see Fig. 4).

Table 1. The daily average of solar radiation for some zones in Albania (W/m^2)

Zone	Razem	Peshkopi	Elbasan	Xarra	Sarande	Vlore	Fier
January	1699	1613	1884	1999	1940	1931	1941
February	2286	2331	2535	2636	2620	2618	2654
March	3165	3229	3340	3574	3523	3535	3596
April	4130	4328	4417	4679	4625	4757	4863
May	5154	5303	5422	5853	5764	5829	5990
June	5803	6152	6243	6703	6559	6753	6946
July	6371	6448	6520	6846	6768	6984	7210
August	5602	5674	5837	6088	6003	6117	6358
September	4327	4355	4515	4752	4667	4808	4824
October	2930	2978	3167	3282	3250	3293	3324
November	1814	1812	2009	2229	2177	2095	2146
December	1481	1403	1615	1789	1746	1680	1705

Another result shows that the maximum power of PV cells in the city of Elbasan is 318.496. In the zone of Xarra, the maximum power of PV cells is 328.381 W, etc. The effect of increasing irradiance while temperature was fixed is increasing the output and short circuit current, the output voltage almost not affected very much. For more about the current-voltage and power–voltage characteristic curves for parametric variation of series resistance Rs, shunt resistance R$_{sh}$, and various irradiation and constant temperatures [55]. The effect of increasing solar irradiance while the temperature was fixed is increasing the output and short circuit current, the output voltage is almost not affected very much. The increase in irradiance values, the values of the cell current, and the maximum power also increase proportionately, but cell voltage increases very less. This is because the open circuit voltage is logarithmically dependent on the solar irradiance, yet the short circuit current is directly proportional to solar irradiance.

Table 2. Photovoltaic Model Parameters

Parameters	Value
k_B	1.38065e^{-23} J/K
e	1.602e^{-19} C
I_{scn}	8.3 A
V_{ocn}	33.3 V
K_v	-0.125
K_i	0.00333
N_s	54
T	10 (ºC for many tests)
T_n	10 (ºC for many tests)
G	6371, 6448, 6520, 6846, 6768, 6984, 7210 (W/m^2 for many tests)
a	1.33
E_g	1.13
R_s	0, 0.05 Ω, 0.1 Ω, 0.15 Ω, 0.2 Ω, 0.25 Ω, 0.3 Ω, 0.35 Ω, 0.4 Ω, 0.45 Ω (for many test)

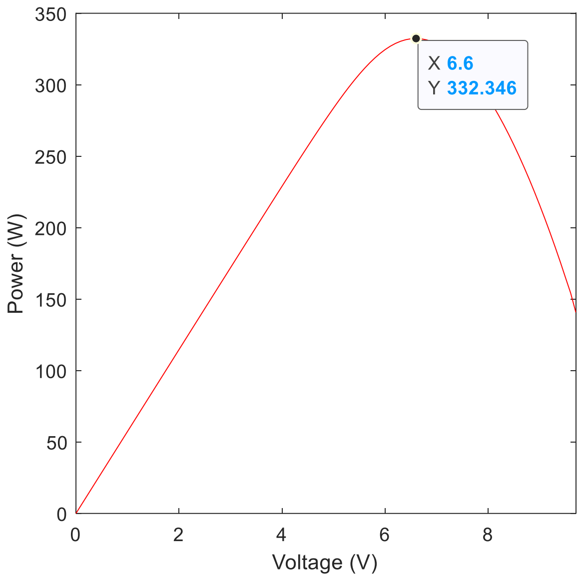

Fig. 3. P-V characteristic curves of PV cells for G = 7210 W/m^2

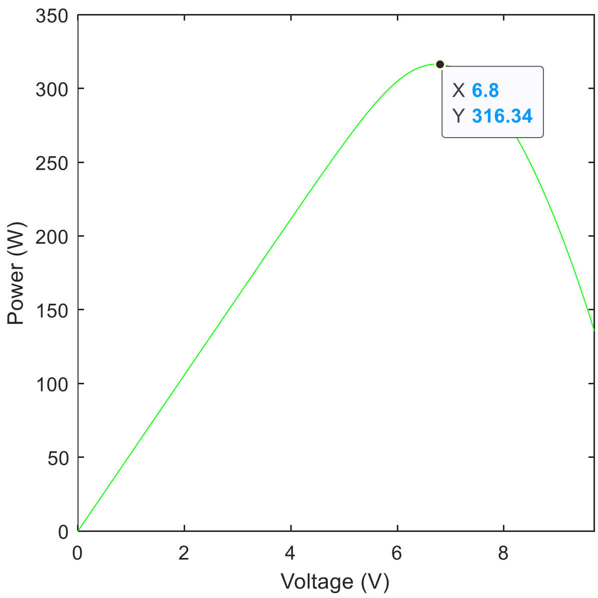

Fig. 4. P-V characteristic curves of PV cells for G = 6448 W/m^2

Fig. 5 and Fig. 6 show I-V and P-V characteristic curves for ten different values of R_s, respectively. As seen in these Figures, the variation of R_s affects the slope angle of the I-V characteristic curves resulting in a deviation of the MPP. It was shown that higher values of R_s reduce the power output of PVCs.

PV cells are very important in urban or remote areas and can power stand-alone devices, tools, and meters. The PV cells can meet the need for electricity for radio transmitters, parking meters, emergency phones, temporary traffic, lighting for roadways, space flights, etc. Research about the PVCs is important. Additionally, research is being conducted to improve the conversion efficiency of solar cells, including exploring strain engineering in two-dimensional materials and investigating the low efficiency of quantum dot PVCs. Oxford PVCs succeeded in developing a hybrid perovskite-silicon cell with an efficiency of more than 29% in 2020. However, scientists believe that much higher values are possible. Recently, the focus of the research has been to enhance efficiency by using innovative nanomaterials such as silicon nanowires, nanotubes, non-silicon materials, organic dies, and conducting polymers (third-generation PVCs) [56]. P-V characteristic curves for parametric variation of series resistance R_S shown in Fig. 6.

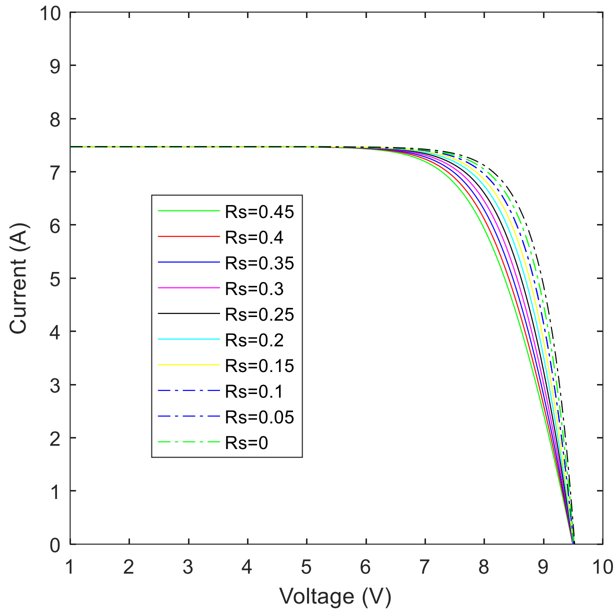

Fig. 5. I – V characteristic curves for parametric variation of R_S

Fig. 7 shows the current as a function of the voltage, demonstrating the nonlinear relationship in the PV cells. For this result we write a simple script in MATLAB. First, we define physical constants like the electron charge, the Boltzmann constant, and the temperature (T=29 ℃). Additionally, we set parameters for the PV cell like the ideality factor (n=1.33), the reverse saturation current (10^{-9} A), the series resistance (0.12 Ω), the shunt resistance (105 Ω), and the photocurrent (5.7 A). The photocurrent is also defined. The script simulates the I-V characteristics for a voltage range from 0 V to 1.1 V, using linspace to create a range of voltages. Since the I-V equation is nonlinear, the script uses a simple iterative method (NR) to find the current I corresponding to each voltage V. The iteration process refines the current estimate until the solution converges within a specified tolerance.

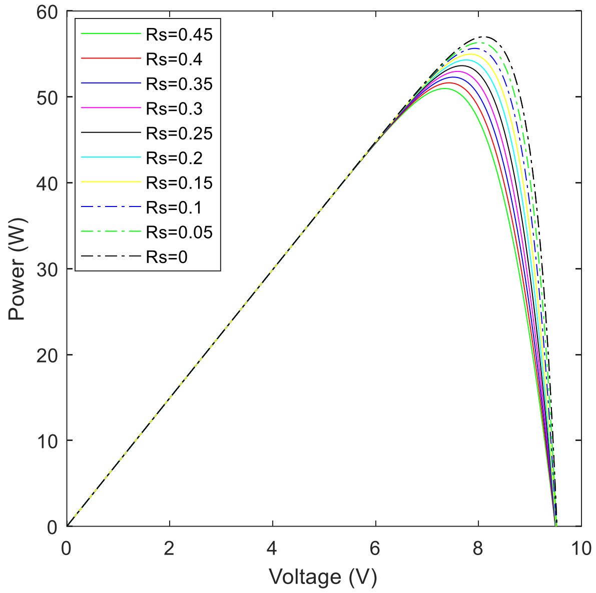

Fig. 6. P-V characteristic curves for parametric variation of series resistance R_S

The maximum power point (MPP), where the product of current and voltage is maximized, is also highlighted on the graph. The plot shows the current as a function of the voltage, demonstrating the nonlinear relationship. The script also calculates and marks the MPP, which is important for maximizing the efficiency of the PV cell.

Application of renewable energy sources is a relevant area of energy supply for urban infractucture. However, these systems require an improvement in their efficiency that can be achieved by introducing electric vehicles. They can accumulate, store and transfer surplus energy to the city's power grid. A solution to this problem is a smart charging infrastructure. The existing studies in the field of charging infrastructure organization for electric vehicles consider only models locating charging stations in the city or the calculation of their required number [57].

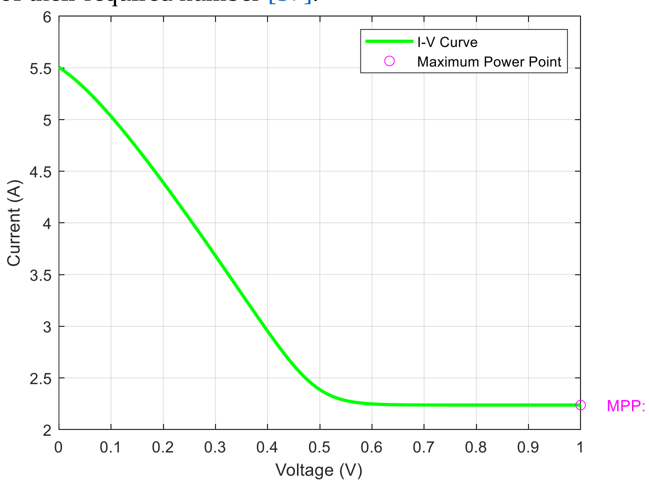

Fig. 7. 'I-V characteristics of a photovoltaic cell'

The maximum efficiency recorded for a third-generation solar cell is about 44%, but the studies have not yet been commercialized. Under laboratory conditions, a maximum value of 47.1% has so far been achieved [58]. These results and the study of the maximum efficiency or the maximum of the power PV cells is very important and can help us better understand the functioning of solar cells and helps us to better understand their function and their complexity of nonlinear dynamics. Photovoltaic technology continues to advance, with research focusing on improving efficiency, reducing costs, and developing new materials for higher performance in various environmental conditions. The maximum efficiency of PV cells, is of critical importance for several reasons, particularly in the context of renewable energy generation.

IV. Conclusions

PV-SE has been increasingly used to generate electric power from sunshine. Based on the data collected for solar radiation in Albania, it results that the maximum radiation intensity in W/m2 is in the city of Fier. This value is 7210 W/m2. The maximum power of 54 solar panels connected in series, which corresponds to this value is 338.528 W. The effect of irradiance (solar radiation) on PVCs, reveals that higher irradiance gives higher current and higher power. The higher values of R_s reduce the power output of PVCs. Maximizing the efficiency of PVCs is fundamental for improving the practicality, affordability, and environmental benefits of SE. It allows for greater energy production, reduces costs, and accelerates the transition to sustainable energy sources.

References

[1] S. Ashfaq *et al.*, "Comparing the Role of Long Duration Energy Storage Technologies for Zero-Carbon Electricity Systems," *IEEE Access*, vol. 12, pp. 73169-73186, 2024, https://doi.org/10.1109/ACCESS.2024.3397918.

[2] H. Soonmin, Hardani, P. Nandi, B. S. Mwankemwa, T. D. Malevu, and M. I. Malik, "Overview on Different Types of Solar Cells: An Update," *Applied Sciences*, vol. 13, no. 4, p. 2051, 2023, https://doi.org/10.3390/app13042051.

[3] M. Awad *et al.*, "A review of water electrolysis for green hydrogen generation considering PV/wind/hybrid/hydropower/geothermal/tidal and wave/biogas energy systems, economic analysis, and its application," *Alexandria Engineering Journal*, vol. 87, pp. 213–239, 2024, https://doi.org/10.1016/j.aej.2023.12.032.

[4] B. Chen, Z. Yang, Q. Jia, R. J. Ball, Y. Zhu, and Y. Xia, "Emerging applications of metal-organic frameworks and derivatives in solar cells: Recent advances and challenges," *Materials Science and Engineering R: Reports*, vol. 152, p. 100714, 2023, https://doi.org/10.1016/j.mser.2022.100714.

[5] N. F. Ibrahim *et al.*, "Operation of Grid-Connected PV System With ANN-Based MPPT and an Optimized LCL Filter Using GRG Algorithm for Enhanced Power Quality," *IEEE Access*, vol. 11, pp. 106859-106876, 2023, https://doi.org/10.1109/ACCESS.2023.3317980.

[6] B. C. Brusso, "A Brief History of the Energy Conversion of Light [History]," *IEEE Industry Applications Magazine*, vol. 25, no. 4, pp. 8-13, 2019, https://doi.org/10.1109/MIAS.2019.2908804.

[7] O. M. Kamel, A. A. Z. Diab, M. M. Mahmoud, A. S. Al-Sumaiti, and H. M. Sultan, "Performance Enhancement of an Islanded Microgrid with the Support of Electrical Vehicle and STATCOM Systems," *Energies*, vol. 16, no. 4, p. 1577, 2023, https://doi.org/10.3390/en16041577.

[8] N. F. Ibrahim *et al.*, "A new adaptive MPPT technique using an improved INC algorithm supported by fuzzy self-tuning controller for a grid-linked photovoltaic system," *PLoS One*, vol. 18, no. 11, pp. 1–22, 2023, https://doi.org/10.1371/journal.pone.0293613.

[9] N. F. Ibrahim, A. Alkuhayli, A. Beroual, U. Khaled, and M. M. Mahmoud, "Enhancing the Functionality of a Grid-Connected Photovoltaic System in a Distant Egyptian Region Using an Optimized Dynamic Voltage Restorer: Application of Artificial Rabbits

Optimization," *Sensors*, vol. 23, no. 16, p. 7146, 2023, https://doi.org/10.3390/s23167146.

[10] A. S. M. Sayem, A. Lalbakhsh, K. P. Esselle, J. L. Buckley, B. O'Flynn and R. B. V. B. Simorangkir, "Flexible Transparent Antennas: Advancements, Challenges, and Prospects," *IEEE Open Journal of Antennas and Propagation*, vol. 3, pp. 1109-1133, 2022, https://doi.org/10.1109/OJAP.2022.3206909.

[11] A. H. Elmetwaly *et al*., "Modeling, Simulation, and Experimental Validation of a Novel MPPT for Hybrid Renewable Sources Integrated with UPQC: An Application of Jellyfish Search Optimizer," *Sustainability*, vol. 15, no. 6, p. 5209, 2023, https://doi.org/10.3390/su15065209.

[12] K. A.V. S. Bashir, S. Ramesh, and K. Ramesh, "Solar cell-integrated energy storage devices for electric vehicles: a breakthrough in the green renewable energy," *Ionics*, vol. 28, no. 9. pp. 4065–4081, 2022, https://doi.org/10.1007/s11581-022-04700-6.

[13] M. Awad, M. M. Mahmoud, Z. M. S. Elbarbary, L. Mohamed Ali, S. N. Fahmy, and A. I. Omar, "Design and analysis of photovoltaic/wind operations at MPPT for hydrogen production using a PEM electrolyzer: Towards innovations in green technology," *PLoS One*, vol. 18, no. 7, p. e0287772, 2023, https://doi.org/10.1371/journal.pone.0287772.

[14] Y. F. Ma *et al*., "Review of roll-to-roll fabrication techniques for colloidal quantum dot solar cells," *Journal of Electronic Science and Technology*, vol. 21, no. 1, p. 100189, 2023, https://doi.org/10.1016/j.jnlest.2023.100189.

[15] N. F. Ibrahim *et al*., "Multiport Converter Utility Interface with a High-Frequency Link for Interfacing Clean Energy Sources (PV\Wind\Fuel Cell) and Battery to the Power System: Application of the HHA Algorithm," *Sustainability*, vol. 15, no. 18, p. 13716, 2023, https://doi.org/10.3390/su151813716.

[16] A. Hysa, "Non-linear dynamics of a test particle near the Lagrange points L4 and L5 (Earth-Moon and Sun-Earth case)," *EUREKA: Physics and Engineering*, vol. 2024, no. 1, pp. 3–10, 2024, https://doi.org/10.21303/2461-4262.2024.002949.

[17] A. Hysa, "a Study of the Nonlinear Dynamics Inside the Exoplanetary System Kepler-22 Using Matlab® Software," *EUREKA: Physics and Engineering*, vol. 2024, no. 2, pp. 3–12, 2024, https://doi.org/10.21303/2461-4262.2024.003257.

[18] A. Hysa, K. Peqini, and M. Hafizi, "A Study of the Linear and Nonlinear Dynamics of A Trojan Astrophysical Object Within Exoplanetary System HD 126053," *Journal of Natural Sciences*, vol. 36, pp. 148–175, 2024, https://jns.edu.al/a-study-of-the-linear-and-nonlinear-dynamics-of-a-trojan-astrophysical-object-within-exoplanetary-system-hd-126053/.

[19] R. Kassem *et al*., "A Techno-Economic-Environmental Feasibility Study of Residential Solar Photovoltaic / Biomass Power Generation for Rural Electrification: A Real Case Study," *Sustainability*, vol. 16, no. 5, p. 2036, 2024, https://doi.org/10.3390/su16052036.

[20] S. Arepalli and P. Moloney, "Engineered nanomaterials in aerospace," *MRS Bulletin*, vol. 40, no. 10, pp. 804–811, 2015, https://doi.org/10.1557/mrs.2015.231.

[21] A. T. Hassan *et al*., "Adaptive Load Frequency Control in Microgrids Considering PV Sources and EVs Impacts: Applications of Hybrid Sine Cosine Optimizer and Balloon Effect Identifier Algorithms," *International Journal of Robotics and Control Systems*, vol. 4, no. 2, pp. 941–957, 2024, https://doi.org/10.31763/ijrcs.v4i2.1448.

[22] A. Jäger-Waldau, "The Untapped Area Potential for Photovoltaic Power in the European Union," *Clean Technology*, vol. 2, no. 4, pp. 440–446, 2020, https://doi.org/10.3390/cleantechnol2040027.

[23] A. M. Ewias *et al*., "Advanced load frequency control of microgrid using a bat algorithm supported by a balloon effect identifier in the presence of photovoltaic power source," *PLoS One*, vol. 18, no. 10 p. e0293246, 2023, https://doi.org/10.1371/journal.pone.0293246.

[24] A. Starowicz, P. Rusanowska, and M. Zieliński, "Photovoltaic cell – the history of invention – review," *Polityka Energetyczna*, vol. 26, no. 1. pp. 169–180, 2023, https://doi.org/10.33223/epj/161290.

[25] O. M. Lamine *et al*., "A Combination of INC and Fuzzy Logic-Based Variable Step Size for Enhancing MPPT of PV Systems," *International Journal of Robotics and Control Systems*, vol. 4, no. 2, pp. 877–892, 2024, https://doi.org/10.31763/ijrcs.v4i2.1428.

[26] G. Masson *et al*., "A Snapshot of Global PV Markets - The Latest Survey Results on PV Markets and Policies from the IEA PVPS Programme in 2017," *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, pp. 3825-3828, 2018, https://doi.org/10.1109/PVSC.2018.8547794.

[27] M. N. A. Hamid *et al*., "Adaptive Frequency Control of an Isolated Microgrids Implementing Different Recent Optimization Techniques," *International Journal of Robotics and Control Systems*, vol. 4, no. 3, pp. 1000–1012, 2024, https://doi.org/10.31763/ijrcs.v4i3.1432.

[28] B. Benbouya *et al*., "Dynamic Assessment and Control of a Dual Star Induction Machine State Dedicated to an Electric Vehicle Under Short-Circuit Defect," *International Journal of Robotics and Control Systems*, vol. 4, no. 4, pp. 1731–1745, 2024, https://doi.org/10.31763/ijrcs.v4i4.1557.

[29] P. Mendrela, W. Stanek, and T. Simla, "Thermo-ecological cost – System evaluation of energy-ecological efficiency of hydrogen production from renewable and non-renewable energy resources," *International Journal of Hydrogen Energy*, vol. 50, pp. 1–14, 2024, https://doi.org/10.1016/j.ijhydene.2023.06.150.

[30] A. Fatah *et al*., "Design, and dynamic evaluation of a novel photovoltaic pumping system emulation with DS1104 hardware setup: Towards innovative in green energy systems," *PLoS One*, vol. 19, no. 10, p. e0308212, 2024, https://doi.org/10.1371/journal.pone.0308212.

[31] A. M *et al*., "Prediction of Optimum Operating Parameters to Enhance the Performance of PEMFC Using Machine Learning Algorithms," *Energy Exploration & Exploitation*, 2024, https://doi.org/10.1177/01445987241290535.

[32] L. Lluri, B. Gërmenji, E. Vyshka, and A. Myshketa, "The Use of Photovoltaic Technology in Albania: A Good Opportunity to Face the Energy Crisis," *Interdisciplinary Journal of Research and Development*, vol. 10, no. 2, p. 16, 2023, https://doi.org/10.56345/ijrdv10n203.

[33] M. M. Mahmoud, "Improved current control loops in wind side converter with the support of wild horse optimizer for enhancing the dynamic performance of PMSG-based wind generation system," *International Journal of Modelling and Simulation*, vol. 43, no. 6, pp. 952–966, 2023, https://doi.org/10.1080/02286203.2022.2139128.

[34] R. Chenni, M. Makhlouf, T. Kerbache, and A. Bouzid, "A detailed modeling method for photovoltaic cells," *Energy*, vol. 32, no. 9, pp. 1724–1730, 2007, https://doi.org/10.1016/j.energy.2006.12.006.

[35] M. M. Mahmoud *et al*., "Application of Whale Optimization Algorithm Based FOPI Controllers for STATCOM and UPQC to Mitigate Harmonics and Voltage Instability in Modern Distribution Power Grids," *Axioms*, vol. 12, no. 5, p. 420, 2023, https://doi.org/10.3390/axioms12050420.

[36] H. Bellia, R. Youcef, and M. Fatima, "A detailed modeling of photovoltaic module using MATLAB," *NRIAG Journal of Astronomy and Geophysics*, vol. 3, no. 1, pp. 53–61, 2014, https://doi.org/10.1016/j.nrjag.2014.04.001.

[37] V. Khanna, B. K. Das, and D. Bisht, "Matlab/simelectronics models based study of solar cells," *International Journal of Renewable Energy Research-IJRER*, vol. 3, no. 1, pp. 30–34, 2013, https://doi.org/10.20508/ijrer.v3i1.416.g6103.

[38] M. Louzazni, A. Khouya, K. Amechnoue, A. Gandelli, M. Mussetta, and A. Craciunescu, "Metaheuristic algorithm for photovoltaic parameters: Comparative study and prediction with a Firefly algorithm," *Applied Science*, vol. 8, no. 3, p. 339, 2018, https://doi.org/10.3390/app8030339.

[39] I. K. Argyros, "On the radius of convergence of Newton's method under average mild differentiability conditions," *Journal of Applied Mathematics and Computing*, vol. 29, no. 1–2, pp. 429–435, 2009, https://doi.org/10.1007/s12190-008-0143-3.

[40] B. T. Polyak, "Newton's method and its use in optimization," *European Journal of Operational Research*, vol. 181, no. 3, pp. 1086–1096, 2007, https://doi.org/10.1016/j.ejor.2005.06.076.

[41] P. Sinha *et al*., "Efficient automated detection of power quality disturbances using nonsubsampled contourlet transform & PCA-SVM," *Energy Exploration & Exploitation*, 2025, https://doi.org/10.1177/01445987241312755.

[42] L. Feng, J. Zhang, T. S. Kiong, K. Ding, N. Amin and F. U. Hamelmann, "Estimating Crack Effects on Electrical Characteristics of PV Modules Based on Monitoring Data and I–V Curves," *IEEE*

Journal of Photovoltaics, vol. 13, no. 4, pp. 558-570, 2023, https://doi.org/10.1109/JPHOTOV.2023.3275251.

[43] R. El-Sehiemy, A. Shaheen, A. El-Fergany, and A. Ginidi, “Electrical parameters extraction of PV modules using artificial hummingbird optimizer,” *Scientific Reports*, vol. 13, no. 1, 2023, https://doi.org/10.1038/s41598-023-36284-0.

[44] G. Xiong, J. Zhang, D. Shi, and Y. He, “Parameter extraction of solar photovoltaic models using an improved whale optimization algorithm,” *Energy Conversion and Management*, vol. 174, pp. 388–405, 2018, https://doi.org/10.1016/j.enconman.2018.08.053.

[45] V. J. Chin, Z. Salam, and K. Ishaque, “Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review,” *Applied Energy*, vol. 154. pp. 500–519, 2015, https://doi.org/10.1016/j.apenergy.2015.05.035.

[46] X. H. Nguyen and M. P. Nguyen, “Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink,” *Environmental Systems Research*, vol. 4, no. 1, 2015, https://doi.org/10.1186/s40068-015-0047-9.

[47] B. S. Atia *et al*., “Applications of Kepler Algorithm-Based Controller for DC Chopper: Towards Stabilizing Wind Driven PMSGs under Nonstandard Voltages,” *Sustainability*, vol. 16, no. 7, p. 2952, 2024, https://doi.org/10.3390/su16072952.

[48] A. Hysa, “Modeling and simulation of the photovoltaic cells for different values of physical and environmental parameters,” *Emerging Science Journal*, vol. 3, no. 6, pp. 395–406, 2019, https://doi.org/10.28991/esj-2019-01202.

[49] M. M. Mahmoud *et al*., “Voltage Quality Enhancement of Low-Voltage Smart Distribution System Using Robust and Optimized DVR Controllers: Application of the Harris Hawks Algorithm,” *International Transactions on Electrical Energy Systems*, vol. 2022, no. 1, p. 18, 2022, https://doi.org/10.1155/2022/4242996.

[50] L. Hichem, M. Leila, and O. Amar, “Comparative Study of Perturb-and-Observe and Fuzzy Logic MPPT for Stand-Alone PV System,” *Lecture Notes in Networks and Systems*, pp. 266–276, 2022, https://doi.org/10.1007/978-3-030-92038-8_27.

[51] S. R. K. Joga *et al*., “Applications of tunable-Q factor wavelet transform and AdaBoost classier for identification of high impedance faults: Towards the reliability of electrical distribution systems,” *Energy Exploration & Exploitation*, vol. 42, no. 6, pp. 2017-2055, 2024, https://doi.org/10.1177/01445987241260949.

[52] R. Herbazi, K. Amechnoue, A. Khouya, and M. Louzazni, “Investigation of Photovoltaic Output Characteristics with Iterative Methods,” *Procedia Manufacturing*, vol. 32, pp. 794–801, 2019, https://doi.org/10.1016/j.promfg.2019.02.287.

[53] I. E. Maysse *et al*., "Nonlinear Observer-Based Controller Design for VSC-Based HVDC Transmission Systems Under Uncertainties," *IEEE Access*, vol. 11, pp. 124014-124030, 2023, https://doi.org/10.1109/ACCESS.2023.3330440.

[54] A. Hassan, O. Bass, Y. M. Al-Abdeli, M. Masek, and M. A. S. Masoum, “A novel approach for optimal sizing of stand-alone solar PV systems with power quality considerations,” *International Journal of Electrical Power & Energy Systems*, vol. 144, p. 108597, 2023, https://doi.org/10.1016/j.ijepes.2022.108597.

[55] A. Hysa And M. Klemo, “Modeling and Simulation of Photovioltaic Cell with MATLAB for Different Temperature and Different Solar Radiation,” *Interdisciplinary Journal of Research and Development*, vol. 6, no. 2, p. 44, 2019, https://doi.org/10.56345/ijrdv6n204.

[56] M. B. Tahir, M. Abrar, A. Tehseen, T. I. Awan, A. Bashir, and G. Nabi, “Nanotechnology: the road ahead,” *Chemistry of Nanomaterials: Fundamentals and Applications*, pp. 289–308, 2020, https://doi.org/10.1016/B978-0-12-818908-5.00011-1.

[57] A. D. Gorbunova and I. A. Anisimov, “Assessment of the use of renewable energy sources for the charging infrastructure of electric vehicles,” *Emerging Science Journal*, vol. 4, no. 6, pp. 539–550, 2020, https://doi.org/10.28991/esj-2020-01251.

[58] A. Tartaraj and B. Trebicka, “Optimal Grading Scales for Enhancing Product Evaluation by Infomediaries,” *Interdisciplinary Journal of Research and Development*, vol. 10, no. 1, p. 59, 2023, https://doi.org/10.56345/ijrdv10n109.