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Evaluation of degradation factor effect on solar panels performance after eight years of life operation

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Abstract

Most high-quality solar panel products suffer from performance degradation at an annual rate of 0.4–0.5% per year during their specified normal operational life of 25–30 years. This percentage increases in areas with hot climates and roof photovoltaic systems and varies according to the quality, guarantee and reliability of the solar panel manufacturers. The aim of this research is to assess the degradation rates of solar panels in the city of Baghdad and to determine their impact on the investment feasibility of residential systems under hot climatic conditions. In this research, an evaluation of performance of photovoltaic solar panels working in a 2 kWp system connected to the electrical grid was done under the operational climatic conditions in the evaluation area (Baghdad, Iraq). The degradation rate of all photovoltaic system modules during the operation time from 2015–2023 is equal to 4.74% (0.593% / year). For comparison, a new monocrystalline solar panel of power 185.94 Wp with an old solar panel of monocrystalline type of power 183.33 Wp (which previously was installed in 2015) were installed at the same tilt angle of 30^o, and evaluated during the operation months starting in March and ending in November of the year 2023. The degradation rates per year of an aged solar panel were determined to range from 0.441% to 0.850%, with an average value of 0.788% per year. After undergoing a correction process to align the maximum power values of the old and new solar panels, the corrected degradation rates per year values ranged from 0.391% to 0.684% per year, with an average value of 0.621% per year, which closely matches the degradation rate of all photovoltaic system modules at 0.593% per year.

Keywords: Solar panel performance; Evaluation of PV; PV operational life; Panel degradation rate

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1. Introduction

The topic of evaluating the performance of photovoltaic systems (PV), specifically the performance of solar panels during their operational life has become extremely important to focus an increased attention of photovoltaic solar energy researches. When investing in the solar photovoltaic energy field, many criteria must be taken into account to ensure the system's performance reliability. The most important criterion that specialists in the solar photovoltaic energy field care about is the solar panel's degradation, which reduces their production power and is included in the panel's nameplate [1,2]. Solar panel manufac-

Nomenclature

% $D.R$ – degradation rate in the performance of the solar panels, %
$I_{max.}$ – maximum current, A
$I_{s.c.}$ – current of short circuit, A
$P_{max\ (2015)}$ – max. output power of solar panels measured in 2015, W
$P_{max\ (2023)}$ – max. output power of solar panels measured in 2023, W
$P_{max\ (new)}$ – measured max. output power of new solar panel, W
$P_{max\ (old)}$ – measured max. output power of old solar panel, W
V_{max} – maximum voltage, V
$V_{o.c.}$ – voltage of open circuit, V

Abbreviations and Acronyms

CdTe – cadmium telluride
CIGS – copper indium gallium selenide
EVA – ethylene-vinyl acetate
PID – potential-induced degradation
PV – photovoltaic
UV – ultraviolet (radiation)

turers offer to their customers a warranty ranging from 25–30 years with about a 20% decrease in power. Recent studies have proven degradation rates of 0.6–0.7% annually [3].

Solar panel technology continues to develop until the degradation rate has commonly reached below 1% a year. Currently, despite the development of technology, rates of deterioration are inevitable. However, work can be done to reduce and slow down the degradation rate by choosing the solar panel's technical quality and providing appropriate environmental conditions for the solar system operation [4]. The typical degradation rate of silicon cell technology (Mono-Si, Poly-Si) is 0.4–0.5% / year, for thin film cell technologies (CdTe, CIGS) it is 0.5% / year. The appropriate degradation rate power for mono-crystalline silicon cells with back contact technology can be considered about 0.35% / year [5].

For example, the degradation rate in the solar panel's capacity is 0.8% in year two, which means that the solar panel's productivity will be at a rate of 99.2% of their total output; by the end of the 25-year operating life, the productivity rate will be 82.5%. The most durable solar panel with a degradation rate of 0.5% will have a productivity of about 87.5% of its production power upon its first installation [6]. To estimate the solar panel productivity of any system, one can simply multiply the degradation rate by the number of years required and subtract the result from the total value of 100% [7]. When the topic relates to the solar panel's degradation rate concept, it is necessary to look at the solar panel's performance warranty. Typically, a performance warranty is a 25-year warranty and will guarantee that your solar panels maintain a certain percentage of their original output each year. The panel's performance warranty period varies depending on the quality of the product, and this gives an idea of the solar panel's operational life [8,9].

Since solar panels installed in outdoor locations will be exposed to various and changing weather conditions such as solar radiation, high temperature, humidity, rain, etc., which have a significant effect on their performance over time [10,11]. Aging degradation is one of the main reasons for the decrease in solar panel power [12]. The first type of deterioration that affects the solar panel is the potential-induced degradation (PID). This deterioration occurs between the conductive solar panel parts and the grounding system as a result of the high voltage between conductive parts [13,14]. The second degradation that occurs in the solar panel is due to exposure to light that contains ultraviolet rays, which causes solar cell discoloration. This is known as light degradation [15,16].

Environmental factors contribute to increasing the solar panel's degradation, including high temperature, humidity, wind, and mechanical stress, which work to change the solar panel's physical specifications [17,18]. Common physical effects caused by environmental conditions, as previous studies have shown, are discoloration, corrosion, delamination, and cracking. Corrosion between solar cells and connections is caused by atmospheric humidity and leakage current. The delamination observed between the solar cells and the encapsulation material of solar panels is attributed to metal corrosion induced by high humidity levels. [19]. Optical transmission losses have an impact on the solar panel's productivity due to the discoloration caused by ultraviolet rays. Other effects that affect solar panel's productivity are dust storms and lightning strikes that strike the solar panel's metal parts [20].

There are several ways to diagnose defects in solar panels, such as visual inspection, conductivity testing, electrical insulation, and electrical luminescence, in addition to electrical specifications [21]. The solar panel's electrical specifications are tested individually to diagnose the current-voltage curve under normal solar radiation by using a curve tracer device. Appearance defects in the solar panel, such as cracks and discoloration for solar panel parts, can be diagnosed by visual inspection. The electroluminescence test is an important preliminary test to prevent the development of cell defects by applying a forward bias to the solar panel [22]. Defects in the packaging between the solar cells and the front glass cover with the filling glue material and defects in the back packaging with ethylene-vinyl acetate (EVA) cause discoloration in the solar panel. The EVA changes colour from light yellow to dark brown as the discoloration progresses [23].

The solar panel emits a low-intensity emission due to the electron-hole pair recombination. This emission is within the spectral region near the infrared 1000–1300 nm, which can be detected by a thermal camera [24]. The test environment varies according to the type of test. Electroluminescence test requires a dark environment within indoor tests, but it can be conducted in outdoor field conditions [25]. Thermal camera is used to inspect solar panel defects in large-scale solar power plants, by diagnosing temperature changes in the solar panels at the plant. Visual inspection is an effective method for identifying defects in a solar panel and has been supported by numerous research studies [26]. The US National Renewable Energy Laboratory announced in its 2017 report that degradation defects common in solar panels for the last 10 years were hotspots (33%) followed by ribbon discoloration (20%), glass breakage (12%), encapsulate discoloration (10%), cell breakage (9%) and potential-induced degradation PID (8%) [27].

The reason for these cases are the stresses to which the solar panel is exposed, in addition to humidity, ultraviolet (UV) radiation, temperature, wind, hail, and high system voltages as well as other factors such as broken interconnects, hot spots, corrosion, encapsulate discoloration and delamination [28]. The cause of solar panel failure is mainly related to the construction, packaging, design and operating environment [29]. Hot spots in the solar panel damage the solar panel as a result of the high solar cell temperatures due to the external shadow and the shadow that is formed as a result of interference between the solar cells within the solar panel or intermittent contacts between the cells and mismatch between them [30,31]. In this research, the degradation of the solar panel was measured after eight years of exposure of the solar panel to different conditions within a site of the city of Baghdad.

2. Materials and methods

In this research, an evaluation of the performance of solar panels for a photovoltaic system with a maximum power of about 2kWp connected to the electrical grid was conducted using the performance analyzer device (PV Analyzer model Solmetric PVA-600) during the year 2023 to evaluate the degradation occurring in the power produced by the solar panels of the system over eight years after their installation in the field.

Note that, this system was installed on the roof of the building at a Baghdad site, at a constant tilt angle throughout the year of 30°. The practical part included the following steps:

- The performance of the solar panels of the system as a whole was evaluated on 8/14/2023 and compared with the performance of the system's solar panels previously measured on 8/12/2015 according to the results documented in our previous research [17]. The solar panels of the system are shown in Fig. 1.

Fig. 1. The solar panels of the system 2 kWp.

- The evaluation results which were recorded previously in August 2015 and currently in August 2023 (after eight years of life operation of the system) by PV Analyzer model Solmetric PVA-600, were documented as shown in Fig. 2.
- To reinforce the obtained result in the second step, as shown in Fig. 3, a new solar panel with maximum power of 185.94 Wp (of monocrystalline type) with a fixed tilt angle of 30° was installed next to an old solar panel, also a product by the same factory, with maximum power of 183.33 Wp (of monocrystalline type), previously installed in 2015 at the same tilt angle.

a)

b)

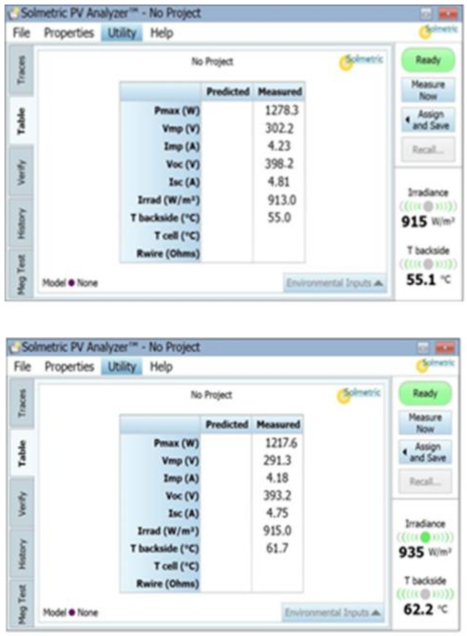

Fig. 2. System test results in August 2015 (a) and August 2023 (b) by PV Analyzer.

Fig. 3. New module and old module.

- After completing the installation of the new solar panel on the metal structure, performance evaluation readings were taken for the old and new solar panels at the same time by the performance analyzer device once every month, starting in March and ending in November of the year 2023.

The percentage of decrease in the total maximum output power of the solar panels of the system, which is called the degradation rate in the performance of the solar panels (% *D.R*) was calculated according to the following Eq. (1):

$$\% \, D.R = \frac{P_{\max(2015)} - P_{\max(2023)}}{P_{\max(2015)}} \times 100\,\%, \qquad (1)$$

where $P_{\max\ (2015)}$ and $P_{\max\ (2023)}$ denote the maximum output power of solar panels measured in 2015 and 2023, respectively.

Note that this slight difference in the maximum power values of the two solar panels and their dissimilarity is due to the tolerance imposed in the production of solar panels by the manufacturer. Table 1 explains technical specifications of the two solar panels at standard conditions, which were used in this research.

Table 1. Standard conditions test of the two solar panels.

Module specifications	PV Module (2015)	PV Module (2023)
P_{max}	183.33 W	185.94 W
$V_{o.c.}$	45.19 V	45.37 V
$I_{s.c.}$	5.41 A	5.51 A
V_{max}	36.43 V	36.62 V
I_{max}	5.03 A	5.8 A
Max. system voltage	1000 $V_{d.c.}$	1000 $V_{d.c.}$

3. Results and discussion

The obtained results from the evaluating process of the performance of all the system's solar panels via the performance analyzer device were documented for the years 2023 and 2015 in the same month in August, as shown in Fig. 2. As found from Fig. 2 using Eq. (1), the performance degradation rate of the solar panels (% *D.R*) for the total PV system during eight years of the system's operational life was calculated at 4.74%, and therefore the annual performance degradation rate of the system solar panels was equal to 0.593% / year (see Table 2), due to the system's panels being exposed to fluctuating environmental factors and continuous exposure to influential ultraviolet rays during this period.

Table 2. % *D.R* for the total PV system during eight years.

Time	P_{max} (total modules)	Total % *D.R* (8 years)	% *D.R*/year
12/08/2015	1278.3 W	4.74%	0.593%
14/08/2023	1217.6 W		

Figure 4 shows the incident solar radiation rates every month, starting in March and ending in November, whereas Fig. 5 exhibits the maximum output power from the two solar panels (new and old) recorded via the performance analyzer device for these months.

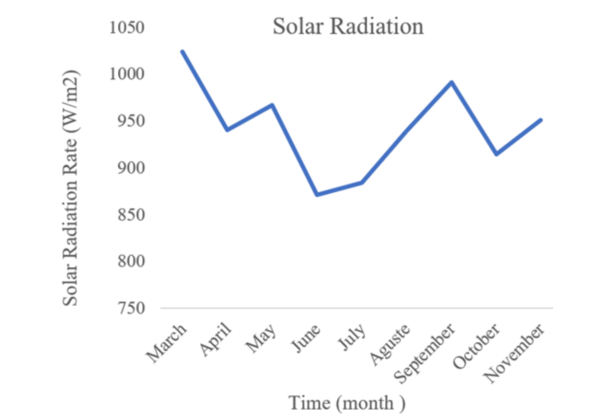

Fig. 4. The change of solar radiation rate with months.

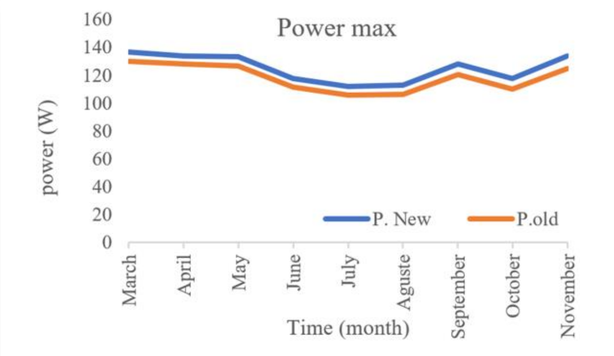

Fig. 5. Maximum output power of two solar panels.

The degradation rate % *D.R* and % *D.R* / year for the old solar panel which is selected from the PV system (of 2 kWp), was calculated monthly using Eq. (2):

$$\% \, D.R \; = \frac{P_{\max\,(new)} - P_{\max(old)}}{P_{\max(new)}} \times 100 \,\%, \qquad (2)$$

where $P_{\max\,(new)}$ and $P_{\max\,(old)}$ represent the measured maximum output power of the new and old solar panel, respectively.

Due to the production tolerance, and the discrepancy between the maximum power value of the new and old solar panels – 185.94 Wp for the new panel and 183.33 Wp for the old one (based on the available solar panels) – we observe a lack of equality in the maximum power output

The calculation was done to correct the values of practical % *D.R* accurately by multiplying the maximum power results of the old solar panel by a factor equal: 185.94 / 183.33 = 1.014. A correction was made for the results of the performance degradation values of the old solar panel, which should be accurate to a very high degree. The process of correcting values of % *D.R* is shown in Fig. 6.

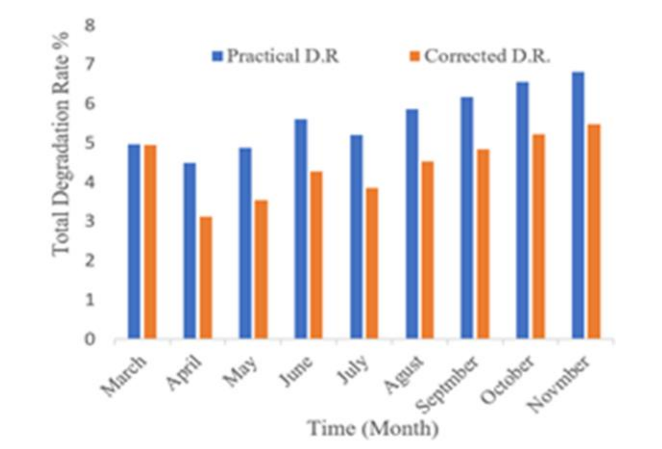

Fig. 6. The total degradation rate.

Figure 6 illustrates the annual performance degradation rate of the old solar panel (2015) over eight years of its operational life in the PV system compared to the performance of the new solar panel (2023). The obtained value of % *D.R* / year during the operation months ranged from 0.441–0.850% / year and the average of these values equal to 0.788%. The % *D.R* per year values, after undergoing a correction process to align with the maximum power values of the selected solar panels for real evaluation, ranged from 0.391% to 0.684% per year, with an average value of 0.621% per year.

The average value of the % *D.R* per year, after correction (*0.621% per year), for the aged solar panel used under the operational climatic conditions in the evaluation area (Baghdad, Iraq) closely aligns with the performance degradation rate of all PV system solar panels, which was 0.593% per year. These values were deemed logical and consistent with the natural rates of performance degradation for panels of this type, specifically manufactured using monocrystalline technology, as indicated by previous research mentioned in the theoretical framework of this study.

In general, the annual performance degradation rate % *D.R* / year of PV solar panels varies depending on the classification of the solar cell preparation technology, the guarantee, the brand of solar panel you purchase, environmental factors and climatic conditions that are exposed to it. These factors pose a major challenge to the generated electrical energy by PV solar panels. Finally, solar panel with low degradation rates will produce more energy and will be considered as the better one before purchasing and using it in PV solar systems. Proper maintenance of your solar panel system can result in a decrease in the annual rate of solar panel degradation and prolong their life (25–30 years), which includes regularly inspecting your solar panels, and exposed wires checking, and keeping your solar panels clean, free of dirt and debris, and away from the shade of trees.

4. Conclusions

In this research, the evaluation of PV solar panels performance 2 kWp connected to the electrical grid. The performance degradation rate (% *D.R*) of all PV system modules (2 kWp) over eight years of operation, from 2015 to 2023, was calculated for a previous performance evaluation conducted in August 2015. It is equal to % *D.R* = 4.74%, or 0.593% per year. The calculated values of % *D.R* per year for the old solar panel during the operational months ranged from 0.441% to 0.850% per year for each month, with an average of 0.788% per year, While the obtained values of % *D.R*/year – corrected after a correction process ranged from 0.391–0.684%/year with the average value equal to *0.621%/ year. The corrected average value of % *D.R*/year for the used old solar panel is very close to the value of %*D.R*/year of all PV system modules (0.593% / year) under the operational climatic conditions in the evaluation area (Baghdad, Iraq).

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