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Guaranteed versus real service life of PV panels in Romania

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Abstract. The paper briefly describes the degradation mechanisms of photovoltaic panels (PVs) in solar plants. After a short presentation of the nature and statistical distribution of defects, structured by type of defect, based on the data processed by TUV Rheinland globally, the paper presents in chapters 3 and 4 data collected and analysed from photovoltaic parks in Romania. This analysis is the starting point for a comprehensive study of the behaviour of photovoltaic parks between 2013-2016, which aims to present equipment nonconformities, design and execution flaws, their causes and effects on energy production and the return rate on investments. At the same time, solutions c*ould be also provided in order to troubleshoot and repower the equipment, as well as effective preventive maintenance solutions, with permanent monitoring of the photovoltaic parks status, including the power degradation rate of PV panels. Documentation elaborated by the ICPE-CA Photovoltaic Systems Laboratory (PV-LAB) team was used to prepare this paper, especially inspections reports and measurements performed in photovoltaic parks in the last two years as a result of a research project carried out in Romania. Also, well-documented papers, developed within the Task 13 - Performance and Reliability of Photovoltaic Systems of the IEA-PVPS Program of Photovoltaic Energy (IEA-PVPS) were used. The purpose of the paper is to raise awareness regarding the problems that can occur during the operation of a PV park before the point where the degradation becomes significant with very high repair costs.

Keywords: photovoltaic panels maintenance, repowering, photovoltaic park assessment, PV inspection.

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1. Definition of the defective PV panel

Lately there is a lot of interest and discussions regarding different opinions about the quality and performance of photovoltaic modules and their service lifetime. Thus, the reference definition of the defective PV panel was considered from Subtask *3.2: Review of Failures of Photovoltaic Modules* [1]*; IEA PVPS Task 13* [2],[3]. A PV panel is defective if its power has irreversibly degraded under normal operating conditions or creates a safety problem. A purely cosmetic problem that has no effect on the power or safety in operation is not considered a defect of the PV module [1].
A defect of the photovoltaic module is relevant to the warranty only when it occurs under normal operating conditions. Likewise, a problem that is caused by the misuse of the module or generated by the local environment in which the module operates, is not considered to be a defect. Here are some examples: dirt on the module or faults caused by lightning strikes. The dirt problem has to be treated by the operator, and lightning strike is considered a natural phenomenon which can occur if the solar park is not suitably protected and for which the module is not designed to withstand. However, defects due to heavy snow load are considered defects of the module, if stated in the technical specification that the product can operate under these conditions.
There may be a number of panel defects that come directly from production. If these faults do not affect the rated power stated on the label and do not cause a degradation acceleration of power or safety, they are not considered as major defects. For example, some defects in the structure of silicon crystal or striations on PV cells are not considered defects.
There are also phenomena that occur in production that leave visible traces and may appear as a defect. They are also not considered defective. For example, in Figure 1 there are brown spots at the edges of the solar cells (a) or lightly chipped cell in a PV module (2). These signs come from the solar cell support during the deposition of the anti-reflex layer (a) or the manipulation (b) and are not considered to be failures of the PV panel.

(*a*) (*b*)

Fig. 1. Brown color traces formed during cell processing (*a*) and chipped PV cell (*b*).

2. Defects of the silicon PV panels

Silicon photovoltaic panels account for more than 80% of the global photovoltaic modules installed and over 98% of those installed in photovoltaic power plants on the ground. Thus, it is justified to be the main study subject for most of those who have concerns in the field. TUV Rheinland is the undisputed leader in the global market for qualification, certification of photovoltaic power plants and solar product certification, has the most extensive expertise on the behaviour of PV modules over time (over 30 years of experience) on all continents (over 12GW of power plants inspected) [4]. In the report regarding the Quality Assurance and Risk Management of Photovoltaic Projects [4], based on the study of more than 100 PV plants (100 kWp - 30 MWp) located in different regions of Europe and divided into two periods (2012-2013/2014 - Q1.2015), TUV Rheinland makes a statistic of the particularly serious defects of photovoltaic power plants, for which immediate action is needed to prevent the power plants from being switched off (fig. 2).

First of all, it can be observed that the main problems are caused by the PV modules and secondly that the share of faulty modules has increased significantly during 2014-2015. This can lead to the conclusion that the experience of inverter manufacturers has increased, their reliability has improved, the experience of builders and installers has increased, while the reliability of the modules has remained the same or even dropped. The competition on the photovoltaic market, where Asian companies are ranked first (8 out of 10 are Chinese companies), has led module makers to boost productivity and dropping the costs so they can lower the sales price. Although productivity growth is also based on technology development, it has focused less on increasing the life of the products. The cost reduction went in two directions: increasing the efficiency of PV cells (prices are always expressed in currency / W) and cheaper raw materials production. However, none of these development policies also mean an increase in product quality, but on the contrary, increased productivity generates major challenges in quality assurance. All the world's top manufacturers boosted production capacities well above 1GW per year. A production rate of only 1 GW per year means a production of approximately 11500 PV modules per day. It is very difficult to ensure quality check procedures on the production line for such a large volume. Each module must have the I-V characteristic and power output determined at the factory as well as electroluminescent tests. Concerns about quality and longevity are considered by several companies and institutes in Europe such as Dupont and Fraunhofer.

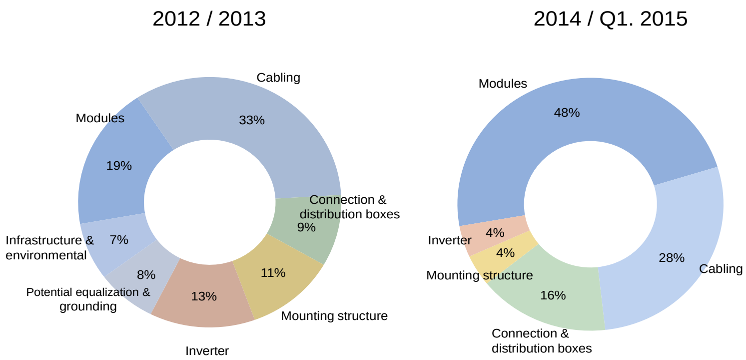


Fig. 2. Serious defects for which immediate corrective maintenance is required.

2.1. Classification of defects by the affected component

On their entire service life, photovoltaic modules are subjected to mechanical stresses, solar radiation, humidity, heat, snow, hail, salt fog, acid rains, dust, wind, abrasive particles, etc. All these external causes, when acting on PV modules made with incompatible materials, produce defects and / or accelerated degradation of their output power. It is absolutely normal that these causes affect all photovoltaic modules, but the degradation of power, for those manufactured with compliant materials, must be under 0.7% / year. The main phenomena that occur in photovoltaic modules and which lead to their failure and/or premature aging are listed below [5]:

- Power degradation;
- Corrosion of electrical contacts;
- Cells breaking;
- Interrupting cell connections;
- Delamination of encapsulation;
- Air bubbles formation inside the encapsulation;
- Changing the colour of the encapsulated foil and/or the backsheet;
- Snail trails (dark cell traces due to cell cracking);
- Backsheet deformation;
- Degradation of ribbon welding on the PV cell;
- Burning encapsulation and film due to electric arc or hot spot;
- Bypass diode failure;
- Breaking the glass;
- Degradation of the anti-reflex layer of the glass;
- Degradation of the adhesive that secures the connection box;
- Dismantling of the aluminium frames;

The aging and malfunctioning mechanisms observed over the last decades have been studied across a wide range of locations and sets of different materials. Defects may be due to material quality, defective product design, or due to quality control failure in the manufacturing line. The figure 3 below shows the aging mechanisms and malfunction defects of the module that occur in the three stages of service life: infant failure in the first 4-5 years, midlife failures of up to 10-12 years (the warranty) and the wear-out failure during the last stage of lifetime of the module.

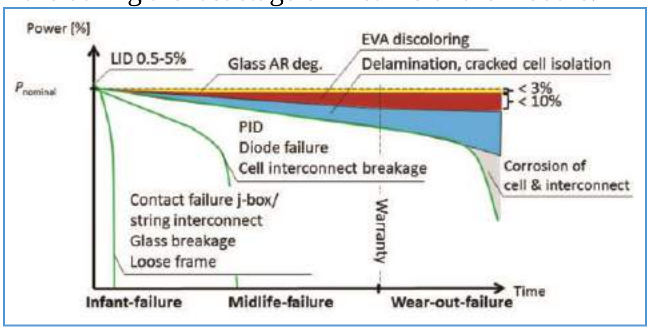


Fig. 3. Degradation of PV modules in time.

Early faults occur at the beginning of the PV module service life. The causes origins are usually: faulty construction, production defects and non-conforming materials. Interruption of the life cycle of up to 10-15 years of operation is called "mid-life failure", while at the end of the lifetime, wear effects of the PV module occur.

2.2. Classification of defects by the causes that produce them

PV module defects may have external causes or may be intrinsic due to nonconforming materials, non-compliant machining or deficient quality check on the production line. Usually, for PV modules, all these defects are hidden and become visible or measurable during three life cycles. Defects from external causes are due to the malfunctioning of electrical and / or mechanical installations, faulty assembly, including the transport of materials, or the lack of preventive maintenance.

External defects

• Defects of the gripping system: Figure 4 shows two images representing an example of mistakes in design and/or execution that generated defects.

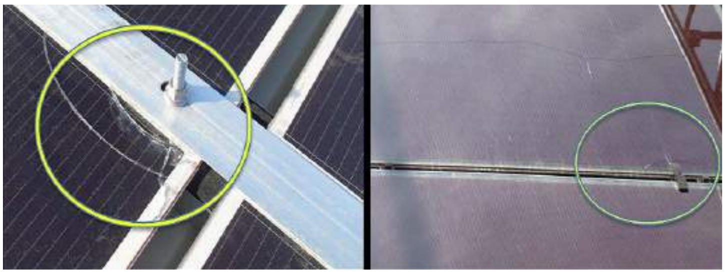


Fig. 4. Defects caused by the gripping system.

The figure on the left shows the glass breakage due to tight screws - faulty execution; the figure on the right shows a gripping system that broke the glass due to the faulty clamping design.

• Damage caused by transport or faulty handling during assembly. Sometimes, PV modules are put into operation with cracked cells during shipping or handling (often invisible) or with the scratched backsheet. The crack of the cell can evolve and break the string at a certain time, which affects the power of the module and the entire string connected.

• Interconnection defects of modules. The fast connectors which the modules are interconnected are usually not considered to be part of the PV modules. There are situations where the connections are tensed and the crimping of the cable in the connector fails or cases when the crimping is made improperly. In this case, the contact resistance leads to burning the cable or interrupting the module connection.

• Defects caused by plants shading the modules, bird droppings or snow that, until complete melting, create a hot spot. This type of defects is frequently encountered in most photovoltaic parks in Romania. Hot spots can cause burning of the encapsulation and backsheet, irreversible destruction of the crystalline structure of the PV cell and / or encapsulation.

Intrinsic defects

Intrinsic defects due to non-compliant materials or inappropriate manufacturing procedures are the most common and occur after commissioning in the first two stages of the module's life. Often, external causes and intrinsic causes act simultaneously.

3. Defects nature and their evolution in photovoltaic power plants in Romania

In Romania there are currently about 1400 MW installed in photovoltaic power plants, of which about 1100 MW were installed in 2013 and about 300 MW in 2014. We can assume that over 90% of the total capacity installed in the Romanian Photovoltaic Power Plants is in the transition from the infant to the middle stage of service life. Public information is available on the status of the dispatchable PV power plants on the Transelectrica S.A. website (power plants with a power of more than 5 MW). Thus, it was possible to extract the rated power for the PV plants that enters into production every year (listed quarterly) from the date of commissioning until the end of 2017. The power degradation in the first 5 years from commissioning is presented in Fig.5 for several PV power plants.

This diagram represents (with very few exceptions) the degradation rate of the power of photovoltaic power plants taken into consideration. Power degradation above the allowed limit of 0.7% per year - is relevant for 23 power plants out of a total of 27 commissioned in 2013. Figure 6 shows the duration, measured in years, when power degrades to 80 % of the rated power (blue curve) based on the annual degradation rate of the panels. The diagram present also the degradation curve for 90% (orange curve) and 95% (gray curve) [6].

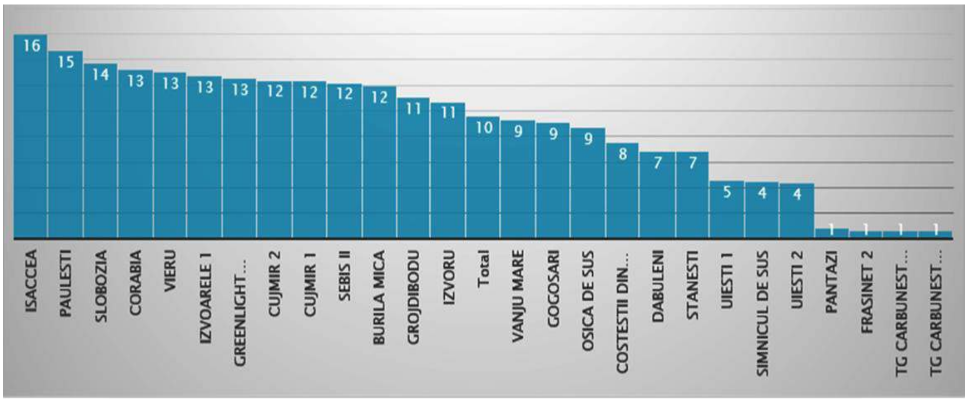


Fig. 5.The nominal power decrease rate (in percentages) for the PV power plants commissioned in 2013 in Romania.

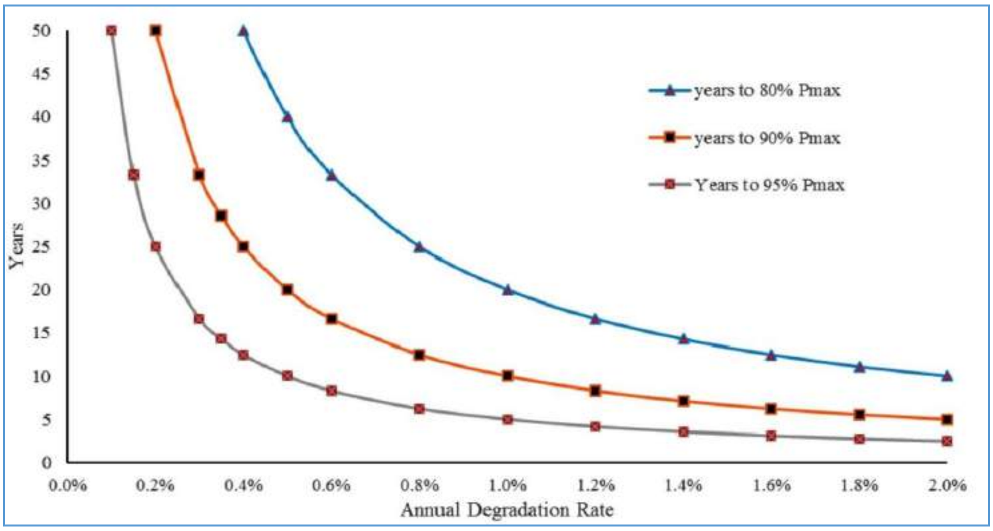


Fig. 6. Run time of a module up to the degradation limit of 80% of the rated power, 90% and 95%, depending on its annual rate of degradation.

If we choose from Fig.5 rates with a total degradation exceeding 10% divided by 5 (number of years of operation), it can be found that 14 power plants exceed the rate of 2%. Following this percentage on the blue line in Fig. 6 it can be observed that in order to reach 80% of the nominal power will be necessary only 10-12 years of operation. In other words, these panels will reach 80% of the nominal power in 5-7 years from now. On the other hand, manufacturers guarantee 80% of the rated power, stated on the label, for at least 25 years from commissioning. In this case, losses are very high and should worry investors. Despite this situation, with rare exceptions, they are not concern because the subsidy awarded cover the expenses, thus recovering the investment in the first 5 years.

The data collected refers exclusively to dispatchable PV power plants which add up to 600MW, meaning half of the total capacity installed in Romania. We do not have public data for plants under 5 MW, consisting in the other half, but the measurements and inspections made so far are worrying in terms of the power output.

4. Results of inspections and measurements carried out in PV power plants in Romania

In a national research program [7] or by expertise request, measurements and inspections have been made in PV power plants in **Teleorman** – PV power plant 1: 2,84 MW, **Covasna -** PV power plant 2: 2,025 MW, **Mureş -** PV power plant 3: 2,40MW, **Harghita -** PV power plant 4: 9MW, **Prahova -** PV power plant 5: 5,3MW, **Mehedinţi -** PV power plant 6: 0,6MW. The inspections and measurements carried out on site lasted for about 30 days, without taking into account the time spent in the PV-LAB laboratory where other measurements were made for modules extracted from power plants. Visual inspections were performed on PV panels using a precision IR camera (FLIR) and a portable microscopic camera. During the carried

out measurement, following components were investigated: inverters, electric panels, cables, and generally all electrical installations excluding high voltage equipment. Measurements of the current-voltage characteristic (IV) for panel strings and individual PV panels were made using HT IV 400 instrumentation, which determined the main parameters of the PV panels: no-load Voltage (Voc), short-circuit current (Isc), Voltage at maximum power (Vmp), current at maximum power (Imp), Maximum Power (Pm), fill factor (FF), Lighting and Temperature Conditions on site. The measurement instrument made all the neccesary corrections for Standard Measurement Conditions (STC) given the input data for each PV panel analysed.
The measurement of the I-V characteristic is relevant for determining the state of the photovoltaic panels (Fig. 7):

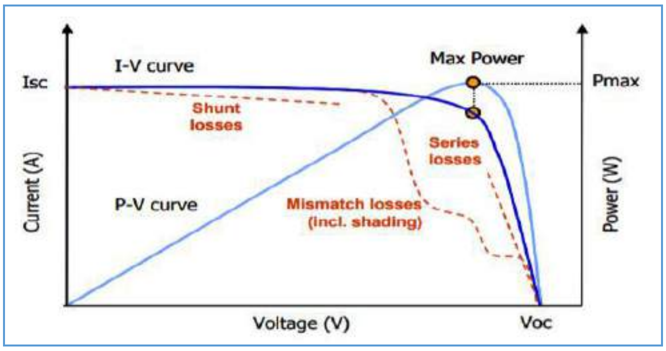


Fig. 7. I-V characteristic curve.

This type of diagram provides relevant information about the status of photovoltaic panels. A deviation of the dotted line can be caused by: one or more destroyed cells, a defective bypass diode or signs of Potential-induced degradation (PID). The shape of the current-voltage characteristic (IV), compared to the IV-rated or pre-delivered characteristics (flash-test), gives us information that mostly covers the entire range of defects appearing in silicon photovoltaic modules [7].

4.1. Maintenance deficiencies

Maintenance deficiencies are common in photovoltaic parks in Romania. The most common shortcomings are related to the growing vegetation in the immediate vicinity of the panels. The most common situations encountered is duet o the plants that grow under the panels and seeking the sunlinght, come out above the PV panels generating hot spots. The hot spot phenomenon produces not only a decrease in the string power of the shaded panel but also its irreversible degradation by changing the color of the EVA film and destroying the structure of the silicon crystal.

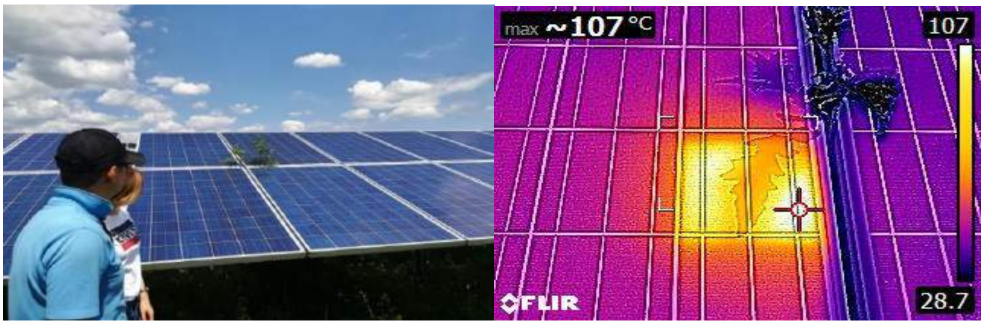
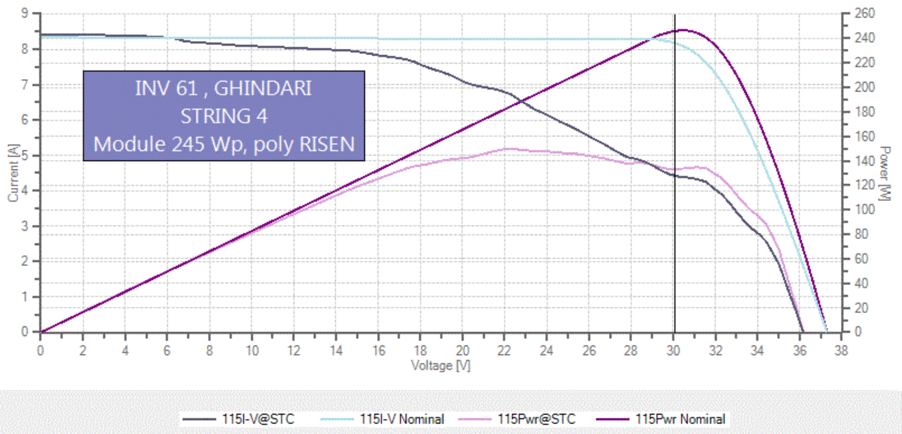


Fig. 8. Hot spot caused by partially shading in PV power plant no.2 - Covasna.

The hot spot generated by the plant that grew under the panel reached 107^{O}C and will destroy the PV cell eventually. During the inspections was discovered that, although corrective maintenance works were being carried out to mow the vegetation between the strings of panels, in all cases the operators did not give importance to the vegetation under the PV panels. This indicates the lack of training of the staff performing the work. The staff and the power plant manager were surprised to find out that a plant that partially shades a module can cause such damage. Thus, urgent measures are required to ensure the quality of preventive maintenance services. In figure 9 can be observed that the grey I-V curve as well as the pink power curve are strongly affected and have irregular shapes. The power of the PV panel decreased by 38.86% compared to the nominal value.



2 *	Nmod	Pmax	Voc	Vmpp	Impp	Isc	Irradiance	Module Temp.	FF	Temp
Meas. 115 - RISEN 245 05/31/2018 14:25		Not Ok (-38.86%)								
115 Measures@OPC	22	2463.38	719.10	415.20	5.93	7.43	874	55.0	46	MANU
115 Meas Avg@OPC	1	111.97	32.69	18.87	5.93	7.43	874	55.0	46	MANU
115 STC	1	149.79	36.17	22.29	6.72	8.39	1000	25.0	49	MANU
115 Nominal	1	245.00	37.30	30.30	8.09	8.34	1000	25.0	79	MANU

Fig. 9. I-V and power characteristic curve for a shaded PV panel from Mureş power plant no. 3.

Dust and bird droppings are also common problems for PV panels. Photovoltaic modules in Romania should be cleaned for dust twice a year, except for those located near farm roads or other sources of dust where the cleaning must be performed more often. Bird droppings should be cleaned when identified because a large dirty surface produce hot spot.

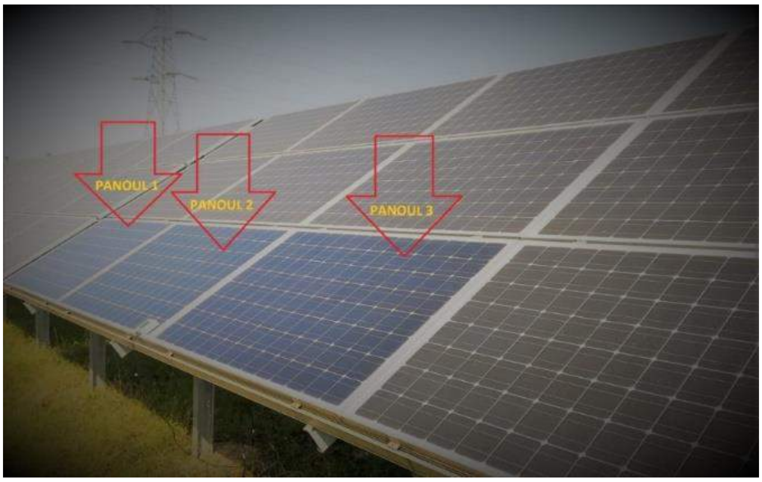


Fig. 10. PV panels comparison between dusty and cleaned panels in Teleorman power plant no. 1.

As can be observed from Figure 10, three panels were chosen from a randomly selected string and cleaned of dust. Measurements where then carried out to determine the current-voltage (I-V) and power-to-voltage (P-V) characteristics before dust removal and after to study the influence on energy production at from Teleorman power plant no.1

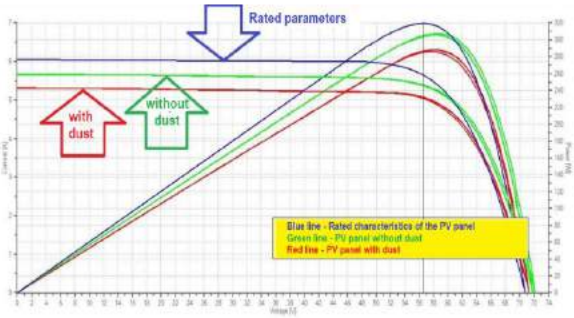


Fig. 11. I-V and power characteristic curve for one PV module with and without dust.

From figure 11 it can be observed that the average of the first measurements shows a degradation of 10% (red curves) and after cleaning the degradation decreases at 4,5% (green curves) falling within normal limits.

Three consecutive measurements for the dusty module (red values) and three measurements were made after the module was cleaned (green values). Power gain after the cleaning operation is about 6.5% as can be observed from figure 12.

2	Nmod	Pmax	Voc	Vmpp	Impp	Isc
Meas. 1 - AFP112-320W 9/11/2018 9:51 AM		Not Ok (-10.65%)				
1 STC	1	285.91	71.29	57.25	4.99	5.30
Meas. 2 - AFP112-320W 9/11/2018 9:52 AM		Not Ok (-10.04%)				
2 STC	1	287.88	71.21	57.68	4.99	5.30
Meas. 3 - AFP112-320W 9/11/2018 9:52 AM		Not Ok (-9.98%)				
3 STC	1	288.05	71.20	58.69	4.91	5.30
Meas. 19 - AFP112-320W 9/11/2018 10:20 AM						
19 STC	1	307.43	72.11	58.76	5.23	5.65
Meas. 20 - AFP112-320W 9/11/2018 10:22 AM						
20 STC	1	305.37	71.88	57.77	5.29	5.66
Meas. 21 - AFP112-320W 9/11/2018 10:23 AM						
21 STC	1	305.52	71.78	57.83	5.28	5.65

Fig. 12. Results of measurements before and after dust removal for the first PV panel.

Further, the effect of bird droppings on the PV panels is analysed by taking images with the infrared camera and by determining the IV characteristics in order to estimate the influence of the photovoltaic panels.

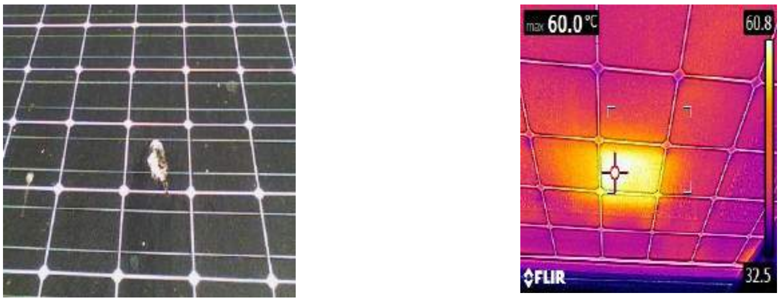


Fig. 13. Picture taken with infrared camera of a PV module with bird droppings.

The camera uses FLIR technology - Forward-Looking Infrared and detects the hot spot formed on the dirty cell. The overheating degrades the structure of the cell in an irreversible way. The faulty cell will cause a malfunction of the whole cells string and the entire PV panel.

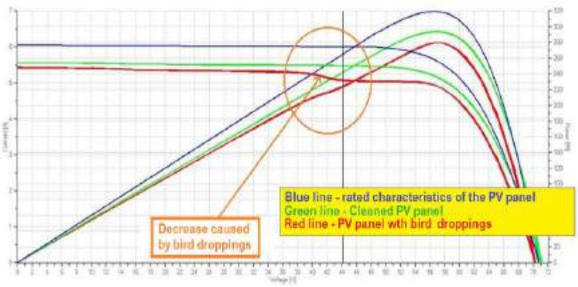


Fig. 14. I-V characteristic curve for one PV module with and without bird droppings.

The I-V characteristic curve determined is shown in Figure 14. The red line shows the decrease caused by bird droppings. After cleaning the panel, the characteristic curve is presented with green line.

The conclusions drawn from the measurements and inspection carried out in PV plant no.1 - Teleorman are as follows:

• Cleaning of the PV panels for dust and bird droppings generated an increase in production from the initial situation of over 7%, also taking into account mismatch losses caused by the unequal power loss on different panels.

• A non-negligible number of panels affected by hot spot due to bird droppings which in time leads to irreversible degradation of the panels.

• After cleaning, all modules fall within the manufacturer's power limits.

Another deficiency commonly found in PV power plants is the decrease in insulation resistance towards the ground caused by rodents. This defect can also be generated by poor execution (proper insulation and cable layout), non-conforming materials (cable insulation) or even design flaws. Rodent traces from power plant no.4 can be observed in Figure 15. Decreasing the insulation to the ground causes the inverters to enter in protection mode and therefore stop the production. This happens more often in the morning and right after the rain, when the ground is wet.

Fig. 15. Rodent traces found near the cable routes between the strings of PV panels.

Losses caused by reducing the insulation resistance below the protection threshold may be considerable, given that inverters are automatically shut down for a period of several hours (until the ground is dry, or the fault is corrected). In some cases, if the insulation has been destroyed on a larger surface the inverters are forced to shut down permanently.

4.2. Intrinsic deficiencies due to poor quality of photovoltaic panels

As expected from the statistical data presented above, the quality of the panels of the inspected power plants is extremely poor, with two exceptions: Altius Fotovoltaic panels (the Romanian producer from Giurgiu) mounted in PV plant no.1 in Teleorman and SUNTECH (China) panels found in PV power plant no.4. The SUNTECH panels with few exceptions, fall within the lowest annual degradation rate of 0.7%. Figure 16 below shows the I-V characteristic of a SUNTECH panel and corresponding parameters.

The same measurement for the Altius Photovoltaic Panel can be seen in the above diagrams where comparison for dusty panels was performed.

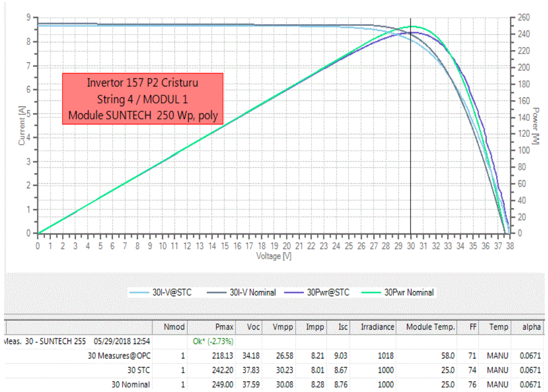


Fig. 16. I-V characteristic curve for one PV module from PV power plant no. 4.

During the 30 days spent in the mentioned PV power plants, about 500 measurements were carried out and over 300 pictures were taken with FLIR infrared camera and with microscopic camera. The results are interesting for researchers because they cover a wide variety of defects usually encountered. The identified deficiencies can be a strong alarm signal for investors.

In PV power plant no. 3 the situation is extremely alarming. RISEN panels used on this site are in an advanced degradation state. This causes a degradation of the EVA foil near the ribbon due to a defective manufacturing process (excess flow) or an alloy that degrades rapidly under UV action was used. In time, hot spot occurs that speeds up the damage process and leads to the final destruction of the module. In Figure 17, some defects caused by hot spot are presented. This kind of images are relevant for this type of defect encountered in several PV power plants in the world.

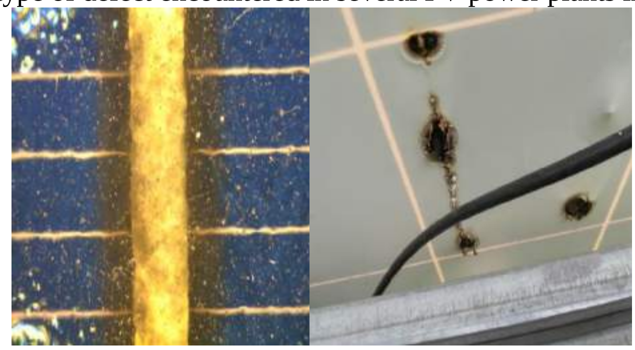


Fig. 17. Degradation of cell connections produces an electric arc or hotspot that causes burning of the back sheet and interrupting the modules string.

Delamination of the EVA (Ethylene-vinyl acetate) film during production process can be caused by:

- Operators not using gloves during manufacture leaving fingerprints on the encapsulated foil or ribbon (Fig.18).
- Insects that accidentally are caught between the EVA sheet and PV cells leads to delamination that can also be seen in Figure 18.

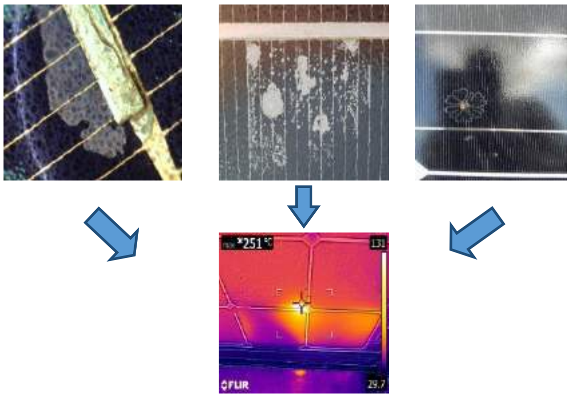


Fig. 18. Hot spot caused by delamination of EVA sheet.

Delamination of the EVA film can cause hot spot and ultimately the destruction of the module. Delamination to the left and centre of the image is due to fingerprints or dust deposited in the manufacturing process and the left one is due to an insect trapped in the encapsulated on the production line.

Another manufacturing defect found in PV plant no.5 is damage to cell surfaces and finger interruption (silver wires on the surface of PV cells). The defect is represented in Fig. 19.

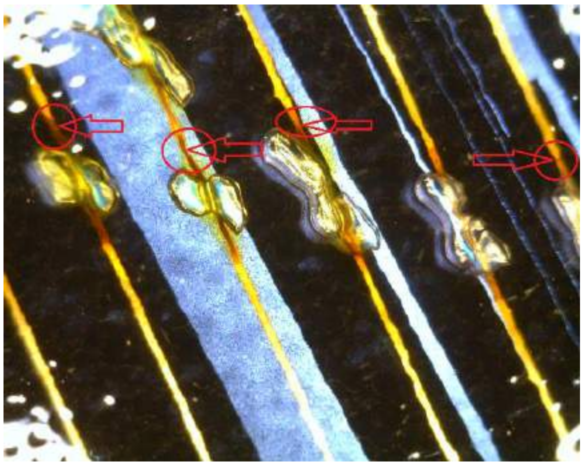


Fig. 19. Cell defect caused by excess of soldering flux (image taken with microscopic camera).

During the production process, due to malfunction of the cell straightening equipment, the ribbon remained disconnected by the buss-bar. In this situation, manual soldering of the cell strings was performed using soldering flux.

Excess flux has remained between the EVA sheets and the PV cells. In the lamination process, more precisely in the vacuuming step, the droplets have randomly migrated by flowing streams which have been sealed. It corroded the

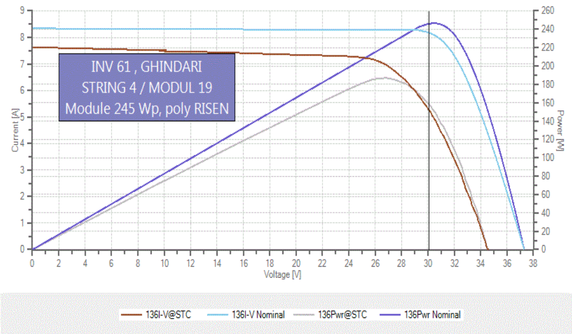
finger in time and slowly but surely the hot spot would occur. In the images above from Figure 19 the encapsulated flux droplets can be observed under microscope.
A junction box (JB) from PV power plant no.1 has caused the interruption of a string of modules (Figure 19). The degradation of the linkages inside the box was so advanced that the module had to be replaced.

Fig. 20. Damaged junction box by water penetration.

The initial deficiency was the lack of water-tightness that allowed water to infiltrate into the junction box and giving the high current throughput (5A in this case), an electrolysis phenomenon occurred that quickly corroded the metal as the electrodes until the circuit is interrupted. In the 0.6MW PV power plant no.6, the only one visited which has PV modules with thin-film technology (Thin Film) using CIGS (copper, indium, gallium, selenide), the situation is very serious and requires immediate action. After two years of operation, the degradation of the panels is well above the normal limit. Of the 9480 panels of the entire power plant, 444 panels are broken. The severe degradation is caused by numerous factors such as: panel non-compliance, lack of maintenance, poor design and deficient construction. The following images are relevant for the aspects mentioned above (Figure 21).

Fig. 21. Broken CIGS panels found at Oșorhei power plant no. 6.

The premature (accelerated) aging phenomenon was identified in 4 of the 6 inspected sites. Problems were identified also by direct request from the owners to measure the panels in the laboratory.
The most pronounced degradation, with the exception of PV power plant no.6, considered an isolated case, was found in PV power plant no.3 - Mureș. Figure 22 shows one of the 120 characteristics measured, typical for the status of the modules evaluated there.



2	*		Nmod	Pmax	Voc	Vmpp	Impp	Isc	Irradiance	Module Temp.	FF	Temp
		Meas. 136 - RISEN 245 05/31/2018 15:12		Not Ok (-23.74%)								
		136 Measures@OPC	1	163.25	31.52	23.58	6.92	7.59	986	54.0	68	MANU
		136 Meas Avg@OPC	1	163.25	31.52	23.58	6.92	7.59	986	54.0	68	MANU
		136 STC	1	186.84	34.62	26.86	6.96	7.54	1000	25.0	72	MANU
		136 Nominal	1	245.00	37.30	30.30	8.09	8.34	1000	25.0	79	MANU

Fig. 22. I-V characteristics measured for a Risen PV panel 245W in 31 may 2018, after 4 years from commissioning.

The I-V characteristic from Figure 22 shows the significant decrease in Voc voltage and short circuit current Isc. It is a consequence of the degradation of the solder alloy (yellowing in fig.17) which has led to the increase of the series resistance of the module, having a direct consequence on the decrease of Isc. The 3V drop of Voc can be attributed to the diffusion of metals (the solder alloy) in the cell structure due to degradation of the passivation layer or the deterioration of the bypass diode, PID or LID phenomenon.
Power losses in photovoltaic power plants are not proportional to the cumulative power losses of panels. Power Loss across power plant will always be greater due to additional loss caused by mismatch. If dispersion of modules with higher loss rates will be larger than the losses across the power plant will increase. This happens because each module is connected in series with another 21 modules and the loss of power affects the whole string.

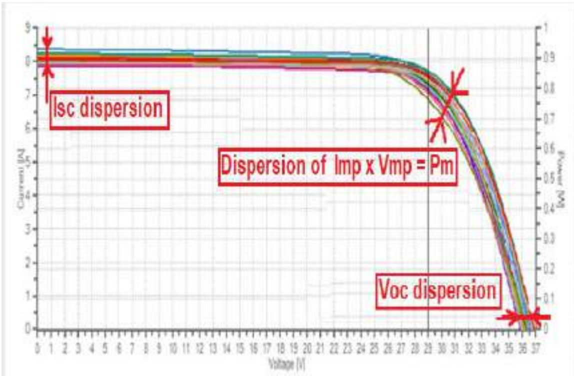


Fig.22. Relatively large dispersion of module parameters in a single string.

Fig.22 shows 22 overlapped I-V characteristics that measures power distribution and mismatch losses on modules in a single string in PV power plant no.3 – Mureș. The PV panels with weaker performances affects the whole string which supplies the inverter.

5. Conclusions

Tests, measurements and field inspections carried out at six PV power plants have highlighted major maintenance, design and execution deficiencies as external causes, but also a wide range of intrinsic deficiencies of the photovoltaic modules presented in the literature, listed in Subchapter 4.2. What makes the difference between PV power plants commissioned, for example in Germany, and those in Romania, is not the quality of the defects but their quantity. In just six power plants inspected, all possible defects were found in a considerably large number.

In addition to ensuring component quality, proper construction and installation, suitable maintenance must be ensured being critical to achieve good performance for a long life of the PV power plant. Therefore, quality assurance must be part of the EPC (Engineering, Procurement and Construction) and O&M (Operation and Maintenance) contracts. The EPC contract must provide detailed quality assurance measures such as product quality checks, commissioning procedures, including onsite inspections for commissioning.

The O&M contract should describe all activities (monitoring and off-line measurements), preventive maintenance at regular intervals, visual inspection, module cleaning, vegetation trimming, spare parts storage as well as information flow and clear responsibilities in the event of breakdowns or interruptions.

We recommend to all Romanian PV power plants urgent measures for O&M, which are well defined to maintain a suitable level of performance throughout their life. Without an adequate O&M strategy and measures, there is a very high risk of revenue loss. A new, improved, plant monitoring system is needed.

The results presented in this paper contributes to increase the knowledge in the field of PV plant operation with an emphasis on exploitation and evolution over time. The

investigated issues are particularly interesting and useful for both global research and for those interested in investing and developing energy production from renewable sources.
The purpose of the paper is to raise awareness regarding the problems that can occur during the operation of a PV park before the point where the degradation becomes significant with very high repair costs.

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