TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 61, Issue IV, November, 2018

DUST DEPOSITION CALCULATION FOR PANNELS ROBOTIZED CLEANING AND MAINTENANCE

Lorand KACSO-VIDREAN, Raluca-Dorina BAIDOC, Daniela Corina JUCAN, Adrian PÎSLĂ

Abstract: *Nowadays, the processes digitization is of top priority. Time is increasingly as enemy and by the evolutionary effect must find solutions to gain it. How is possible? By digitizing the manufacturing and logistic process. Regarding the photovoltaic green, renewable energy there is also a need for digitization to push the limits of the generation capacity and to reduce the energy losses in the electricity generation chain. In the photovoltaic system, energy losses may have multiple causes. The paper addresses the photovoltaic energy losses caused by the dust deposition congruential with the type of soil in the location environment. In order to ease the operator's work with data transmission in real time, the process is digitized and user graphical interfaces are developed. In this way, the user will know when and where to act for the photovoltaic maintenance and interventions, to maximize the power output of photovoltaic work over the system lifecycle.*

Keywords: *Photovoltaic panels, Dust, Solar energy, Robots, Management Interface.*

1. INTRODUCTION

Within the industrial design the human–computer interaction occurs in what is named User Interface (UI), the interaction space between humans and machines allowing the effective monitoring, operation and control. Beside the technical considerations (sensors, motors, actuation drivers, etc.) the design considerations are related with ergonomics and psychological aspects, with the goal to produce an self-explanatory and efficient user interface, with real time access to the process parameters.
With the increased use of personal computers and the relative decline in societal awareness of heavy machinery, the term user interface is assumed as a graphical user interface, while industrial panel and machinery control design commonly refer to human-machine interfaces.

2. PHOTOVOLTAIC SYSTEMS

Solar photovoltaic energy is produced by solar photovoltaic cells (PV) that convert sunlight directly into electricity with the participation of the subatomic particles, and the electron-guided flux. Photovoltaic cells are made of semiconductor materials similar to those used in electronics for integrated chips. The performance of a photovoltaic cell is measured by the intensity of the produced electrical current. The actual technology offers less than 15% efficiency and therefore large power demands requires large number of panels with high costs. The current and future goal of solar industry is to improve the PV efficiency.

2.1 Photovoltaic panels

The knowledge of the designers and the way of operation of the photovoltaic panels is defining the maintenance activity. In order to provide the energy required by a consumer, solar panels can be used separately or in packages (in series, in parallel or mixed), solar batteries, for supplying independent consumers or generating electricity into the public distribution network.
Basically, a solar panel is characterized by:

- electrical parameters;
- mechanical parameters;
- operating conditions.

The basic electrical parameters are:

- maximum working voltage;
- maximum working current;
- maximum specific energy/ surface unit.
- total yield.

Mechanically, the solar panels are using various materials for cells with different characteristics: radiation transparency, weatherproofing, holding capacity, rigidity, shock and vibration protection, moisture protection, resistance and compensation to thermal expansion, robust electrical connections, easy handling and installation.

2.2 Types of photovoltaic panels

There are different possibilities to classify the PV. One of the most common considers the photovoltaic cells material and there are four groups: the PV monocrystalline, the PV polycrystalline, the PV amorphous and the PV Thin Film.

Monocrystalline panels

Monocrystalline PV have a uniform appearance, they are made up uniform single crystalline structure of silicon atoms with a high degree of chemical purity, with good efficiency even under weak sun or cloudy sky.

Monocrystalline photovoltaic panels offer the highest efficiency in converting solar light into electricity, the best option in a limited space. The installed capacity is higher by 3%-4% than with the use of polycrystalline photovoltaic panels and by 10% higher than with the use of amorphous photovoltaic panels.

Polycrystalline panels

Polycrystalline PV has a non-uniform surface and color, are made of not uniformly oriented silicon atoms that form crystals in many directions. Due to a lower price and fairly performance, polycrystalline photovoltaic panels are the most widely used, if there are no space limitations,

The manufacturing technology of polycrystalline photovoltaic panels has been continuously improved; the polycrystalline photovoltaic panels are considered the best value-for-money, for all types of applications with performance close to the monocrystalline panels (13%), but at a lower cost. A power of 80% of the initial value is guaranteed for at least 25 years, but needs more panels resulting a larger structure and more maintenance activity.

Amorphous photovoltaic panels

"Amorphous" literally means: "no form", the silicon is not structured or crystallized at the molecular level.

Amorphous silica is the non-crystalline form of silicon, best developed in thin film technology being on the market for more than 15 years, as one or more layers of photovoltaic material is deposited on a substrate.

Some types of amorphous solar cells have huge potential, the technology is expected to grow, in 2011, amorphous silicon solar cells accounted for 3% of the market.

Under laboratory conditions, scientists pushed efficiency rates to 12.5%, but the efficiency of amorphous solar cells varies between 6-9% (2009) to 10% (2017).

What are the amorphous panels made of?

Amorphous silicon panels are made of silicone material – (about 1 µm) on a substrate of material such as glass or metal. Amorphous silicon can work at low temperature (about -75°C) having the following advantages:

- Requires only 1% of the material (a tape);
- Substrates can be made of glass, stainless steel or plastic;
- The cell is flexible, allowing to be creative when it comes to applications, being possible to be positioned on curved spaces. Resistance and flexibility depend on the surfaces or substrates that amorphous solar cells are attached to.
- Amorphous solar cells function relatively well in poor light conditions and are not affected by the shadow;
- Because the manufacturing process is much simpler, they often have fewer defects. Even the very advanced methods in manufacturing solar chips involve a lot of details regarding welding, with many warranty issues, unlike thin films.

The disadvantages of these types of photovoltaic panels:

- Amorphous solar cells have a lower efficiency, but is a new technology;
- Amorphous solar panels tend to degrade faster and do not keep as much as monocrystalline and polycrystalline solar panels

• Heat retention. As the amorphous solar panels are applied directly to a surface, they can retain more heat. Traditional panels are generally installed with a support, meaning that there is space between the panel and the surface on which it is located, allowing the air to cool the panels. Amorphous solar panels can retain more heat, creating a balance between it and its benefits - better performance at high temperatures.

Amorphous – Thin Film photovoltaic panels

The "Thin Film" technology, removes silica from equation, using a semiconductor material such as copper, gallium and selenium. PV Thin Film are much lighter and more flexible, unlike those containing silicon, being specially designed to deal with adverse weather conditions.

Amorphous cells of these types provide a better response to the light spectrum, being more efficient also in cloudy conditions, becoming a part of the new generation. The cell production process involves the deposition of successive layers of semiconductor material with nanomaterial thickness that reduces the amount of material and implicitly the cost of cells with about 30%.

The yield of amorphous photovoltaic panels is still lower than from crystalline silicon: 7% (amorphous silicon panels) and 13% (CIS/CIGS cell panels), but the PV - Thin film has a major development potential, because silicon solutions have reached a maximum technological threshold. PV thin films have the following features:

• CIS/CIGS cell industrial panels have a yield equal to the 13% polycrystalline silicon variant, some studies have shown that yields of over 17% (2016) can be achieved;

• The laboratory version achieves the efficiency of the monocrystalline silicon panels at 15%;

• the panel mass, for the same surface is much smaller;

• the cost for the same surface (power) is lower;

• Material flexibility allows molding on different surfaces;

• They are effective even at low luminous intensity (including cloudy sky), due to the sensitivity for a wider spectrum of frequencies.

The downside is related to the actual reduced production capacities, the process of technological development is not completed, relatively low advertising, traders' orientation towards classical solutions.

Hybrid photovoltaic panels

Hybrid solar systems use not only the effect of radiation but also the thermal effect for obtaining electricity. Although apparently it looks like a conventional panel, it is made of copper tubes, coated in aluminum and aluminum oxide and partially filled with catalytic nanoparticles. Vacuum tubes circulate a mixture of water and methanol, which can reach temperatures above 200°C. The structure allows absorption of up to 95% of solar energy. Once the temperature of 200°C has been reached, the evaporated liquids are mixed with small amounts of catalyst, resulting in H2 hydrogen, which is immediately redirected to the storage cells to produce instantaneous electricity (hydrogen cells) or stored for later use.

The major advantage of these panels is the efficiency of over 18%, disadvantage: very high cost.

2.3 Coupling solar panels

In order to have practical utility solar cells they must be connected in modules. Typically, each module includes a 36-cell set if it is intended to charge 12V or 60 cells when the destination is residential applications. For large commercial applications, the modules will typically have 72 solar cells. Increasing the number of cells per module is accompanied by increased voltage and power generated.

To maximize the amount of incident light on photovoltaic cells, manufacturers use the most diverse techniques. The surface of the cell can be textured in the form of pyramids with the tip down that the light radiation reaches the surface of the cell walls and is not reflected back into the environment.

For the same purpose a fine anti-reflective coating with a thickness of about 0.3 mm is applied to the cell surface. The antireflection layer can reduce the amount of radiation reflected in the medium with about 10%. In maintenance activity, mechanical or chemical

interactions should lead to the protection and maintenance of these layers.
In some situations, lenses or mirrors are used to concentrate a larger amount of solar radiation on cells, more complex and expensive, but more efficient, achieving yields of over 44% (valid only for direct exposure to solar radiation and 0 % under cloudy sky).
Principally, there are two radiation concentration technologies: Low (LCPV) and High Level (HCPV). LCPV technology can concentrate light on any photoelectric effect while HCPV technology is applied to triple-junctional silicon solar cells. Most concentrated technologies require automatic solar panel guidance systems, the focused incident light falls directly onto photovoltaic material.

3. MODELING FACTORS IN ACTIVITY OF ENERGY PRODUCTION THROUGH PV

For maximizing the power generation efficiency, technical details are the basic elements, influenced by components such as: the average annual temperature, orientation of the land, direction and speed of wind and the type of soil.

3.1 Location details

The location is influenced by both the over-positioning of the panels and the supporting structure, conditional solarization, precipitation levels, temperature and wind variations as well as the amount and type of particulates in the atmosphere. In the study, is considered a surface near an urban area specific to the common profile of the Cluj County 6 cities. The area has a moderate continental climate, during the winter prevails sea-polar or maritime-Carpatic air penetrations (N-V), and summer predominates the warm air of S-V. Annual precipitation values are low, aridity indexes 30-31 places the area within the semiarid areas.
The relief of the location is hilly, with valley portions near lower rivers, but creating color airflow. From the hydrographic point of view, sources of salt water and low or medium surface lakes can be found frequently.

3.2 The technical characteristics of the area

Urban irregular area, with 119 inflection points, a total useful area of 394,146.25 m^2. The area of the photovoltaic park has a perimeter P = 1000 m and the study area the photovoltaic park occupies an area A = 62.003 m^2.
Coordinates established for the photovoltaic park, represented in the 1970 Stereogram system and in the Black Sea 1975 system.

3.3 Technical characteristics of photovoltaic components

In the realization of the photovoltaic park was considered the use of 9690 photovoltaic panels, which can generate a maximum energy quantity of 3.3 MWh.
The mechanical characteristics of the photovoltaic panels considered for modeling are presented in Table 1.

Table 1: Mechanical data of the PV used

Mechanical data	
Cell type	Polycrystalline
Number of cells	72 (6x12)
Dimensions	1960x 992x 40mm

4. FACTORS OF INFLUENCE OVER THE PRODUCTION OF SOLAR ENERGY

The factors that influence the energy output of solar panels are: annual average temperature, land orientation, wind direction and speed, and the type of ground on which the park is located. An important factor was considered the dust deposition; estimation of the amount of dust deposited on PV panels is based on a self-developed model.

4.1 Type of soil and its characteristics

The "Romanian Soil Taxonomy System" is structured into three higher taxonomic units (A): class, type and subtype and four taxonomic units of lower level (B): variety, family, species, variant.
Soil structure means how to group the elementary particles into aggregates of different

shapes and sizes (which easily break out if the soil is subjected to a mechanical action). It refers to two components:

- spatial layout of elemental soil particles
- the nature and intensity of the links between them

The main types of structure are identified by the shape and arrangement of the structural elements; the following types of soil are distinguished:

- Glomerular Structure - Disperses roughly spherical, porous aggregate particles with curved surfaces (concavities and convexities). It is characteristic of soils with the "Am" horizon rich in humus of calciferous type and with intense activity of mesofauna (chernozem, etc.)
- The angular polyhedral structure with aggregates with approximately equal dimensions on the axes, with irregular faces delimited by obvious edges, placed in the middle, which gives a rounded appearance. It occurs in the "Bt" horizons of the argilo-brick soils.
- The sub angular polyhedral structure - similar to the angular polyhedral, but the structural elements have more obtuse, erased edges and irregular surfaces. This is where the "Bv" horizons of brown eumezobasic soils and cambrian chernozems
- Prismatic structure - made up of elongated, orientistic aggregates, with flat faces and sharp edges, ends of the ribbed prisms. They are characteristic of the "Bt" horizons of bruneluvice soils, whitish luvisols
- The columnoid - prismatic structure - similar to the prismatic one, but the edges are rounded
- The columnar structure - similar to the prismatic, but the ends of the structural aggregates are rounded. It is characteristic of the horizon "Btna", the genetic horizon of the solonts
- Foil, shale or lamellar structure - made up of sub-plate aggregates or lamellas, horizontally oriented fragments. It is specific to the soiled soils and the horizons "El" and "It" characteristic of luvic soils
- Grass structure - the structural elements are approximately spherical, with no joints between them; are relatively non-porous.

By size, the structural elements are:

- Very small with a diameter of less than 1 mm
- small with a diameter of 1-2 mm
- Medium diameter 2-5 mm
- Large with a diameter of 5-10 mm
- Very large with a diameter of over 10 mm

By overlaying the location of the photovoltaic park over the distribution in Figure 1, within the developed model, the photovoltaic park is located on a soil type called Chernozem, characterized morphogenetically by the presence of a dark "Am" horizon.

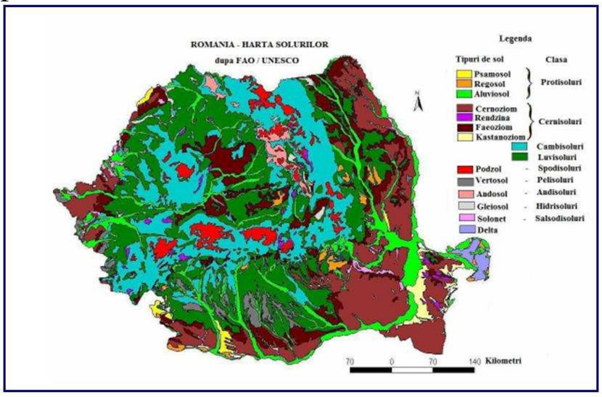

Fig.1: Romania's pedological map.

Typical chernozem have a profile with Am - AC - C or Cca well - expressed horizons. The "Am" horizon is darker (dark brown or blackish), over 50 cm thick, AC is 20-30 cm thick, darker, and A/C appears at depths greater than 70 cm . The profile has many biogenic neoformations, and the $CaCO_3$ ones start from only at the base of "Am" or "A/C".

The texture is undifferentiated, medium (sometimes fine or coarse, depending on parent material), glomerular structure, porosity and good aerohydricity. The humus content is higher (3-6%) and top quality (calcified). The degree of saturation with bases (V%) is around 90%, pH between 7-7.6, increased microbiological activity and supply of nutrients favorable to plant growth. Figure 2 Soil-agrochemical characteristics of chernozem.

4.2 Estimating the amount of dust deposited

The yield of photovoltaic (PV) solar modules is essentially influenced by the amount of dust deposited, an important chapter within the electricity production activity.

Indicatorul determinat / Orizontul/Adâncimea (cm)		Amp 0-25	Am 30-40	AC 50-60	C_1 85-95	C_2 150-150
• Propietăți fizico-chimice						
pH_{H2O}		7,40	7,50	7,86	7,90	7,85
$CaCO_3$%		0,4	0,6	3,0	10,4	14,9
Humus (%)		7,10	5,45	2,20	1,13	-
P – AL(ppm)		13,0	3,1	10,0	3,0	6,1
K – AL(ppm)		330,3	180,1	131,1	93,0	117,8
Da(g/cm^3)		1,04	1,15	1,31	1,42	1,48
Analiza granulometrică%	Nisip grosier (2,0-0,2mm)	8,9	10,8	15,5	0,5	0,7
	Nisip fin (0,2-0,0,mm)	28,9	25,5	27,4	17,7	14,4
	Praf (0,0-0,002mm)	16,9	12,5	17,8	36,0	38,9
	Argilă (<0,002mm)	45,3	45,2	39,3	45,8	46,0

Fig.2: Pedro-agrochemical soil characteristics of Chernozem (SRTS - 2003).

Studies on the effect of dust on PV system performance are rare.The influence of dust on the PV system performance is investigated. The results are extrapolated to indicate the instantaneous power and the resulting financial losses. Reduction of glass transmittance is indissolubly dependent on: amount of dust, inclination angle, orientation in the dominant wind, the exposure period and the climatic conditions of the site. One of the first studies regarding the effect of dust on performance was made by Sayigh, but maintenance and cleaning plans are recommended by all the studies. The magnitude of the dust effect on the I-U (intensity-tension) photovoltaic output characteristics, depends on the dust density, composition and particle distribution. Asl-Soleimami specified that the power production of a solar module was reduced by 60% and recommended a 30-degree tilt angle to be optimal for the network-connected applications. For the PV model with the dust deposited amount on the surface, the wind erosion equation of the soil was determined, The loss of material through erosion can be evaluated using Wishmeier's universal equation:

$$E = R \times K \times L \times S \times P \qquad (1)$$

Where:

E is the average annual value of ground mass loss (mass/area)

R - erosive index of rain (depending on the intensity and duration of rain, mass, diameter and speed of rain drops), in Romania has values of 0.08 - 0.16

K - is the erodibility index of the earth, in Romania it has values of 0.6-1.2

L - factor that takes into account the length of the slope

S - factor that takes into account the slope angle

P - location conditions factor (usually equal to 1, unless the site is in terraces)

By replacing the equation becomes:

$$E = 0.098 \times 0.65 \times 1 \times 1 \times 1 = 0.0637 \qquad (2)$$

In order to obtain the average annual loss of ground mass in t/km^2, the right part of the equation must be multiplied by 330.3 (See Figure 2 - K-AL value (ppm) for the upper erosion layer Amp 0 -25 cm).

E becomes:

$$E = 0.0637 \times 330.3 = 21.04011 \ t/km^2 \text{ per year} \qquad (3)$$

Determination of the rain erosion index for the studied site (R)

The soil erosion produced by the rain depends on: the rain characteristics, the physic mechanical properties of the soil, the morphometric parameters of the soil and the degree of vegetation coverage.

The impact of rain drops is particularly strong. Rain drops that reach the ground have a kinetic energy of 1000 times the amount that leaks out on the ground.

Most erosive torrential rains have droplets with diameters between 1 mm and 4 mm. The drop sizes change during the fall. Drops up to 2.9 mm in diameter have spherical shape, those with larger diameter have the characteristic shape of drop. Drops with a diameter of more than 6 mm break through the fall due to air resistance. The cut-off speeds of drops of rain drops in a calm atmosphere are shown in Table 2.

Table 2: Drops speed

Drop diameter [mm]	0.5	1.0	2.0	3.0	4.0	5.0	6.0
Speed limit [m/s]	2.1	4.0	6.5	8.1	8.8	9.1	9.2

The falling speed changes in wind conditions, especially when it is in burst. In the case of large droplets, their kinetic energy increases by up to 30%.

For the mass of drops from a heavy rain the impact force of all drops is:

$$F = \sum_l^n v_i\, d_i^2 \quad (4)$$

Where v_i is the drop velocity and d_i is the diameter of the drop.
To infer the mean rainfall diameter, the cumulative weighted average rainfall over the year will be used as follows:

- In 62.7 days out of 365, the diameter of a drop of rain is 3.05 mm, i.e. 50.12% of precipitation;
- In 34.2 days of 365, the diameter of a drop of plaice is 8.13 mm, i.e. 27.34% of precipitation,
- In 28.2 days of 365, the diameter of a drop of plaice is 9.21 mm, i.e. 22.54% of precipitation;
- In the remaining 239.9 days of 365, there was drought or snow, with no precipitation in liquid form that could have affected soil erosion.

The weighted average rainfall dimension is:

$$di = \frac{3{,}05\cdot 50{,}12 + 8{,}13\cdot 27{,}34 + 9{,}21\cdot 22{,}54}{100} = 5{,}83\ mm \quad (5)$$

Given that the rain drop diameter is 5.83 mm, then the drop velocity (v_i) will be 1.79 m/s (data collected from Table 2). From these data the equation follows:

$$F = \sum_l^n v_i\, d_i^2 = 60.84\ \text{N} \quad (6)$$

The erosive index of the rainfall for the studied site is:

$$R = \frac{1}{2}\sum_l^n F\, v_i^2 10^{-3} = 0{,}098 \quad (7)$$

For the studied site, the determination of the erodibility index of the soil (K)

Applying the formula proposed by Stănescu P., the erodibility values of the common chernozems were calculated based on the parameters of the properties that influence the erosion, using the clay humus content and the apparent soil density (see Figure 2)

$$K = \frac{(100 - A)}{(A + n * h)Da} \quad (8)$$

Where:
A - clay content (%) - 45.3% according to Fig.2
h - humus content (%) - 7.1% according to Fig.2
Da - apparent density (g/cm^3) - 1.04 according to Fig. 2

$$K = \frac{(100 - A)}{(A + n * h)Da} = 0.65 \quad (9)$$

Determining the length factor (L)

Considering that the elevation is virtually null at the location of the photovoltaic park (zero gradient), the slope length factor (L) will be equal to 1.

Determining the slope angle factor (S)

Considering that there are no significant quota differences on the photovoltaic park location the factor considering the slope angle (S) is 1.

Determination of site-condition factor (P)

According to the descriptions, the factor that takes into account the conditions of the site (P) is equal to 1, because there is no terraces on the site of the solar farm.
To determine the amount of dust deposited on panels in the photovoltaic park, the factors previously calculated, but given for the studied area, will be taken into account. Considering that the surface of the photovoltaic park is 62003 m^2, it results that out of a total quantity of 21,04011 t/km^2 per year, the amount of eroded dust in the photovoltaic park is 1304549,94033 g (1.30454994033 tones) within one year.

21040.11 kg … … … … … 1 000 000 m^2 (10)

0.02104011 kg … … … … 1.000 000 m^2 (11)

The total amount of eroded and high-dust dust in the photovoltaic park is:

21.04011 g · 62003 m^2= 1304549,94033g in one year (12)

Considering the fact that the surface of the photovoltaic panels represents 30.39% of the total area of the park, the real quantity deposited at their level is:

- Determining the surface of photovoltaic panels:

9690 · 1.960· 0.992 = 18840.4608 m^2 (13)

- Determining the amount of dust from photovoltaic vessels:

21.04011 g · 18840.4608 m^2 = 396405.3677 g (14)

Since the apparent chernozem density is 1.04 cm^3 (See Figure 2 for Amp 0-25 layer), determine the amount (in cm^3) of total dust deposited on photovoltaic panels:

$$V_{praf} = \frac{396405{,}3677}{1{,}04} = 381159{,}0074\ cm^3 \quad (15)$$

Determining the amount of dust from a single panel:

$$\frac{381159,0074}{9690} = \mathbf{3933,53\ cm^3} \qquad (16)$$

From previous equation, the dust thickness, in a single year on a single photovoltaic panel is 2,023 mm.

$$\frac{3933,53}{196 \cdot 99,2} = \mathbf{0,2023\ cm} \qquad (17)$$

5. SENSORS, ROBOTS AND INTERFACE

Dust deposits are inevitable and depend on the wind and the type of ground in the photovoltaic park. Due to the dust deposition, photovoltaic panels have a lower efficiency. By implementing opacity sensors, real-time dusting state data are collected and the operator decide over the performing of the cleaning operation.
The automatic dust-cleaning and dust removal from the photovoltaic panels can be carried out by service robots.

5.1 The service robot

Within the maintenance activity there are many specific functions that can be performed with service robots. There are some applications, at international level, representing the results from research topics from prestigious institutes.
In Fig.3, is presented one of this solutions, where a service robot is directly programmed by the operator to perform robotic cleaning of photovoltaic panels, depending on the data that the opacity sensor transmits and the values of the pre-set parameters.

Fig.3: Service Robot.

Among recent achievements, photovoltaic systems maintenance can be done with a service robot for solar photovoltaic parks in desert areas where dust accumulation presents a permanent problem, reducing energy production by up to 30%.
Dust storms can reduce production, up to 60%, which makes it extremely important to clean the photovoltaic panels. The advantages of the automatic cleaning system for photovoltaic panels are:

- Dry type (no water) cleaning system, does not require the installation of water pipes, water tanks, electrical cables to start / charge the robot; works independently, does not consume outside energy;
- Daily cleaning improves the production of solar photovoltaic power plants to 20-25% by eliminating over 98% of the dust on the panels;
- The most cost-effective way to have clean photovoltaic solar panels compared to manual cleaning;
- There is no need for permanent staff;
- Higher revenue through higher production;
- Compatible with over 99% of existing products in the profile market such as the dimensions, configuration and inclination of solar panels as well as with multiple mounting structures;
- It is modular, scalable, and adaptable to the specific configuration of photovoltaic solar panels;
- It is simple, powerful, reliable, using high quality components and equipment;
- The cleaning robot can be personalized and starts from a manually operated system to a completely independent and controlled SCADA or mobile web interface
- Depending on the particularities of the panels, it is easy to customize to work with minimal or no changes in the support structure of the photovoltaic solar panels and the panels themselves;
- The system can be equipped with meteorological sensors in order to determine the optimal conditions for cleaning (wind, humidity, solar radiation, temperature, etc.);
- The possibility to program the operating parameters is based on customer demand

(start time, speed, direction of travel, conditions, weather conditions, etc.);
- Do not use chemical cleaning agents or other products that could harm the environment or photovoltaic panel;
- Does not require human intervention during cleaning;
- For large photovoltaic parks, a fleet of cleaning robots is working, synchronized, connected to a local SCADA and controlled locally or remotely.

The technical details of the robot are:
- Dry cleaning system with modular rotating brushes that do not affect the surface of photovoltaic panels;
- Uses brushless motors;
- Operating at high temperatures;
- All processes are controlled by a dedicated PLC;
- Power supply system - hybrid - solar battery;
- HMI or push buttons for local operation;
- Increased reliability and high quality components
- Manual control /SCADA control / remote monitoring (depending on the configuration request)
- Approximate speed: 8-10m / min
- Cleaning surface / hour (on two photovoltaic panels with standard portrait configuration): approximately 120-150 kWh / hour
- Increased travel distance of up to 700m at night and unlimited in daytime (the distance is increased by using the solar photovoltaic panel in combination with the battery)

In selecting and implementing a service robot a set of parameters is considered:
- the cost of implementation;
- the number of robots required;
- energy loss due to lack of maintenance and dust on the panels;
- the cost of energy losses;
- energy consumption of the robot;
- The cost of annual manual cleaning of photovoltaic panels.

6. CONCLUSIONS

This article addressed a less well-researched issue and taken into account in the photovoltaic area. Dust deposits are a real problem because they directly affect the photovoltaic power production capacity of the photovoltaic panel.
The calculations can be adapted to any type of soil and any climate, so the layer of dust deposited on photovoltaic panels will vary from one area to another or from one climate to another.
As we have seen, the digitization and robotization of photovoltaic panel cleaning (maintenance) is a necessity, because in this way we can obtain real-time data and act on the factors that negatively influence the production capacity of solar renewable energy.
By robotizing processes we will get lower costs and higher production, product quality control, accurate and real-time responses.
The type of soil on which the photovoltaic farm was located is part of the soft soils category, so the deposition of dust on the glass of the panels was not a major one. In the case of a solar farm located in a desert area, the deposited dust layer will increase predominantly with the higher content of small and very small particles in the soil composite.

7. REFERENCES

[1] L. Freris and D. Infield, “Renewable Energy in Power Systems”, Wiley, 2008, p. 300

[2] D. Yogi Goswami, F. Kreith and J. Kreider, “Principles of Solar Engineering”, Second Edition, Taylor and Francis, 2000, p. 694

[3] B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher, B. Canada, D. Narang, D. Shugar, H. Wenger, A. Kimber, L. Mitchell, G. Rich and T. Townsend, "Performance Parameters for Grid-Connected PV Systems", in 31st IEEE Photovoltaics Specialists Conference, Lake Buena Vista, Florida, 2005.

[4] M. Mihalache, „Pedologie-geneza, proprietăţile şi taxonomia solurilor", Edit. Ceres, Bucureşti, 2006.

[5] Gh. Blaga, I. Rusu, S. Udrescu, D. Vasile, „Pedologie", Editura Didactică şi Pedagogică RA, Bucureşti, 1996.

[6] AAM Sayigh, „Effect of dust on the flat-plate collectors", in Proceedings of the intelligent solar energy society congress, New Delhi, India, 1978

[7] V. Băloi, V. Ionescu, "Apărarea terenurilor agricole împotriva eroziunii alunecărilor şi inundaţiilor", Editura Ceres, Bucureşti, 1986.

[8] R. Siddiqui, U. Bajpai, „Correlation between thicknesses of dust collected on photovoltaic module and difference in efficiencies in composite climate" Iny. Journal of Energy and Environmental Engineering, Dec. 2012

[9] M. Monto, P. Rohit: Impact of dust on solar photovoltaic (PV) performance: research status, challenges and recommendations", in Renew Sustain Energy Rev, 2010

[10] D. Cueto JA, "Comparison of energy production and performance from flat plate photovoltaic module technologies deployed at fixed tilt", Proceedings of the 29th IEEE Photovoltaic Specialists Conference, Piscataway, 2002.

[11] A. Shaharin, Sulaiman SA, Hussain HH: Nik Leh, NSH, Mohd SI, R, "Effects of dust on the performance of PV panels", in World Academy of Science, Engineering and Technology, 2011.

Calcularea depozitelor de praf pentru panouri curățate și întreținute robotizat

Rezumat: În zilele noastre, digitizarea proceselor este prioritară. Timpul este din ce în ce mai mult inamic și prin efectul evolutiv trebuie să găsească soluții pentru a-l câștiga. Cum este posibil? Prin digitizarea procesului de fabricație și logistică. În ceea ce privește energia regenerabilă fotovoltaică, există și necesitatea digitizării pentru a împinge limitele capacității de producție și pentru a reduce pierderile de energie din lanțul de producție a energiei electrice. În sistemul fotovoltaic, pierderile de energie pot avea mai multe cauze. Hârtia abordează pierderile de energie fotovoltaice cauzate de depunerea de praf congruențială cu tipul de sol din mediul de localizare. Pentru a ușura munca operatorului cu transmisia de date în timp real, procesul este digitizat și sunt create interfețe grafice ale utilizatorilor. În acest fel, utilizatorul va ști când și când să acționeze pentru întreținerea și intervențiile fotovoltaice, pentru a maximiza puterea de ieșire a energiei fotovoltaice pe durata ciclului de viață al sistemului.

Lorand KACSO-VIDREAN, Department of Design Engineering and Robotics, Technical University of Cluj-Napoca, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Romania, kvlorand89@gmail.com.

Raluca-Dorina BAIDOC, Department of Design Engineering and Robotics, Technical University of Cluj-Napoca, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Romania, baidoc_raluca@yahoo.com.

Daniela Corina JUCAN, Department of Management and Economics Engineering, Technical University of Cluj-Napoca, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Romania, corina_jucan@yahoo.com.

Adrian PÎSLĂ, Department of Design Engineering and Robotics, Technical University of Cluj-Napoca, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Romania, adrian.pisla@muri.utcluj.ro.