PHOTOMETRIC SIMULATION FOR PERFORMANCE IMPROVEMENT OF SOLAR ENERGY CONVERSION WITH FIXED PHOTOVOLTAIC PANELS AND REFLECTION MEMBRANE

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Abstract: For the transition to sustainable energies to happen in a relatively safe manner, there has to be as many improvements to actual capabilities that allows us to convert solar and wind energy into electric energy. For this reason, in this paper, we present a potential solution to rise the efficiency of solar irradiation conversion by using a cheap, highly reflective membrane under the already installed solar arrays. This solution can be used in order to maximize the radiation that falls on the photovoltaic cell, especially under the panel, by using bifacial photovoltaic panels.

Key words: renewables, photovoltaic, bifacial, efficiency, irradiance, simulation.

1. INTRODUCTION

Incidental solar radiation is the key factor that influences the performances of photovoltaic panels in order to produce electric energy. But all data from official sources are for horizontal surface. So, because PV panels are usually optimally inclined a prediction of solar radiation on inclined surfaces is necessary [1], [3], [6].

Empirical formulas were presented for prediction of the solar energy on the inclined surface and horizontal surface which mostly predicted the monthly and yearly solar irradiance [2], [7], [13].

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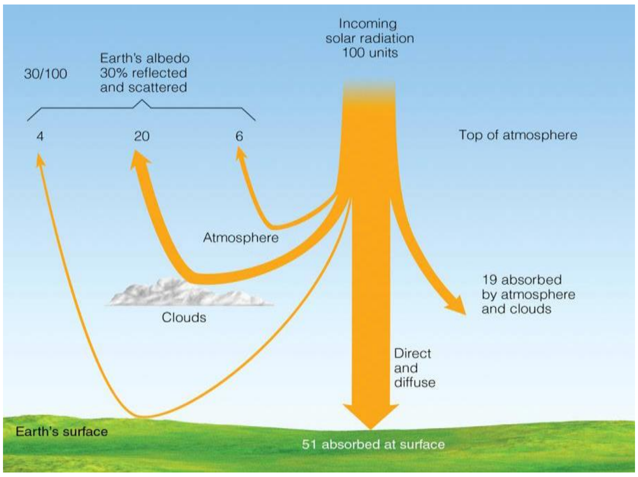


Fig.1. Total solar radiation on the Earth surface

2. GLOBAL IRRADIANCE

Direct radiation, diffuse irradiance and reflected irradiance are the components of global radiation on inclined surfaces.

$$R_{Tt} = R_{bt} + R_{dt} + R_{rt} \quad (1)$$

where
R_{Tt} is equivalent radiation,
R_{bt} is the direct beam,
R_{dt} is the diffuse irradiance
R_{rt} is the reflected irradiance

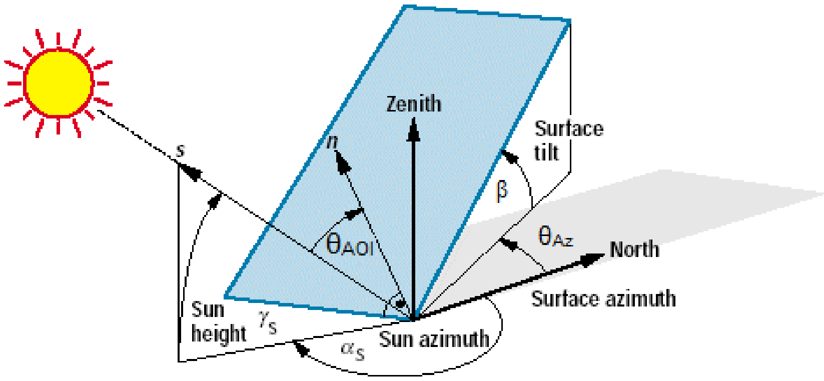


Fig.2. Solar Altitude angle

a) Direct Solar Irradiance (R_{bt})

Direct solar radiation on inclined plane is mathematically represented as follows:

$$R_{bt} = R_b cos\theta_{AOI} \quad (2)$$

Where R_b is the direct radiation on the horizontal surface and θ is the angle of incidence between the normal to the surface and the incoming solar direct beam.

Also the expression of R_b can be expressed:

$$R_b = Eexp\left(-\frac{k}{sin\gamma_s}\right) \quad (3)$$

b) Diffuse Solar Irradiance (R_{dt})

The model of the diffuse irradiance that arrives at a site on inclined solar systems with equal intensity from all direction as sky is considered as isotropic is expressed as:

$$R_{dt} = CR_b\left[\frac{1+cos\beta}{2}\right] \quad (4)$$

Where the sky diffuse factor C is approximated by the following expression as:

$$C = 0.095 + 0,04sin\left[360 * \frac{(N-100)}{365}\right] \quad (5)$$

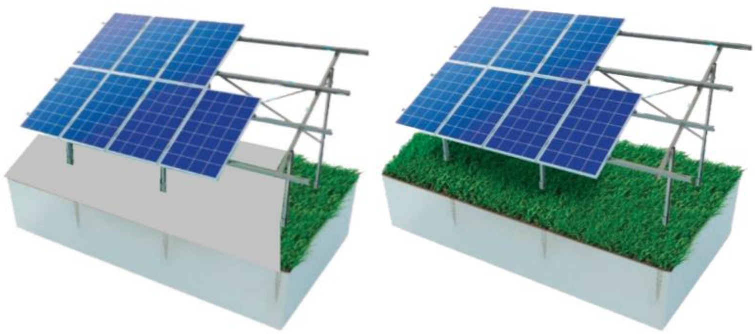
c) Reflected Solar Irradiance (R_{rt})

The reflected solar radiation is given by:

$$R_{rt} = \rho R_b(sin\gamma_s + C)\left[\frac{1-cos\beta}{2}\right] \quad (6)$$

ρ is the reflectance.

Equivalent solar radiation equation:



a) b)

Fig.3. a) Solar array over grass covered ground

b) Solar array with a white reflective membrane under the panels

In this comparison picture it is introduced a concept of increasing the solar radiation conversion performance by applying a reflexive white membrane under the photovoltaic panel. This membrane could be laid on very different support grounds like grass, gravel, roof bitumen isolation, etc. [5], [10], [17]

d) High Bifaciality

Bifaciality is the technology that uses two layers of glass on front and back side of the photovoltaic panel [4], [8], [11]. Performance will be affected by grid width of the back panel, bifaciality of the cell itself and test method which shall be analyzed through design and simulation in Dialux Evo [20].

HJT is considered one of the top cell technologies with highest bifaciality. Higher bifaciality allows more energy yield on the back [9], [14], [18].

Generally, this type of technology enables 5%-30% energy gain on the back, depending on the factors such as ground reflection, region type etc.

Fig.4. Solar panel array with bifacial technology

In these two images is presented a technical solution with the benefit of translucent backpanel that allows solar radiation to fall right underneath the solar array. This facilitates the reflection back to the panel, increasing overall solar conversion [12], [16], [19].

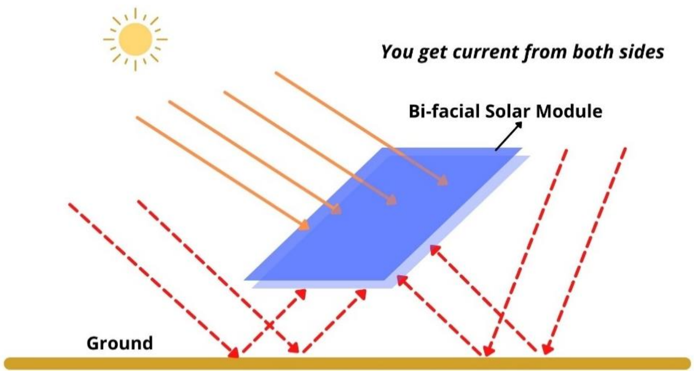


Fig.5. The directions of solar radiation: direct and indirect

Other radiation that is used by the bifacial solar panels is the indirect solar radiation that comes not directly from the Sun but reflected from the clouds, atmosphere and nearby objects.

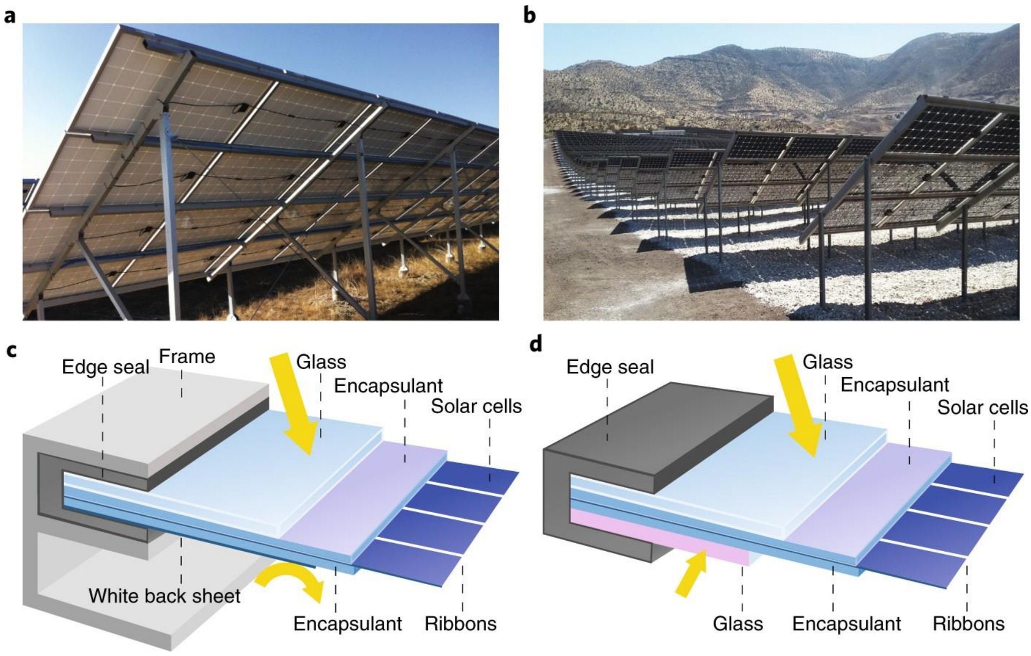


Fig.6. Difference between two types of technology, a) solar panel with a white opaque back panel, b) solar panels with glass technology c)-d) structure

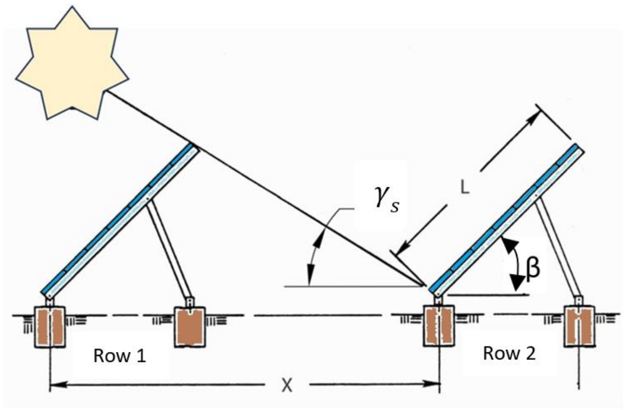


Fig.7. The solar array spacing variables

In order to know how to arrange the solar array, simple mathematical calculus is needed. The number of approaches for that matter is not low, but for this example one solution is to use Sun elevation, the angle of the solar panel to the ground and the location’s latitude.

The system may be built with two or more rows of PV panel, so in this case the necessary preparations should be previously made to ensure that none of them cast a shadow onto the one behind it.

For this determination the image above is used.

There is no perfect solution because the solar trace on the sky and the elevation starts at zero in the morning and ends at zero when it sets. The irradiation on an array has three components, direct irradiation, diffuse (from blue sky and overcast), and reflected from the ground. Here it is considered only the direct irradiation that is subject to shadowing by the row in front or any other object that is placed there.

The elevation of the sun at noon at the winter solstice in December in the Northern Hemisphere is:

$$\gamma_s = 90° - 23.45° - t \qquad (7)$$

where:
γ_s – the solar elevation
t - it the latitude of the construction site.

In most cases 90% of the unobstructed solar irradiation on the panel array occurs when the solar elevation is above half of the maximum winter elevation.

The elevation correction is therefore 50%. This may be excessive for rows that are less than about 4 times the height of the panel [15].

To solve for the minimum distance between the rows to fulfill the condition on nonshadowing, the following equation is used:

$$X = L\left\{cos(\beta) + [sin(\beta) \cdot tan[t + 23.5 + \tfrac{1}{2}\gamma_s]]\right\} \qquad (8)$$

where:
L - solar panel length
β = panel tilt angle
t= geographic latitude of the solar array system

Calculated values are:
Winter minimum noon solar elevation = 90-23.45-latitude
90% of unobstructed elevation = 50% of Winter minimum solar elevation

3. PHOTOMETRIC SIMULATION

For this simulation we used Dialux Evo, a software tool that is used for photometric simulations of high accuracy. In the simulation we chose a powerful 1kW luminaire that was arranged in a rectangular array of 30p per 20p. So the total amount of luminaires is 600p on a surfaces of 15 by 10 meters, to simulate the parallel sunrays.

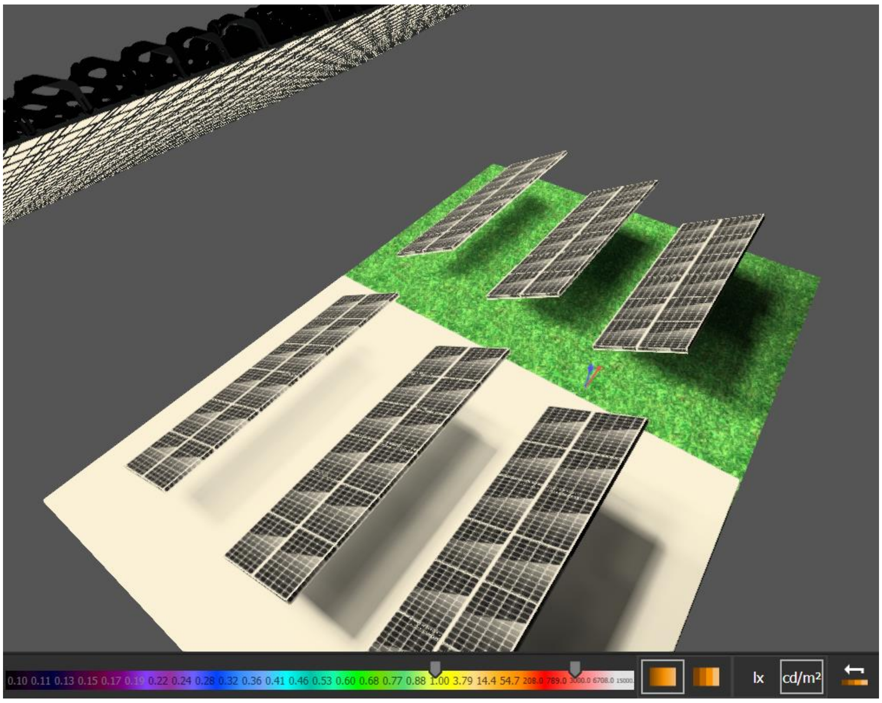


Fig.8. The comparison image with grass and white reflective membrane underneath the solar panels

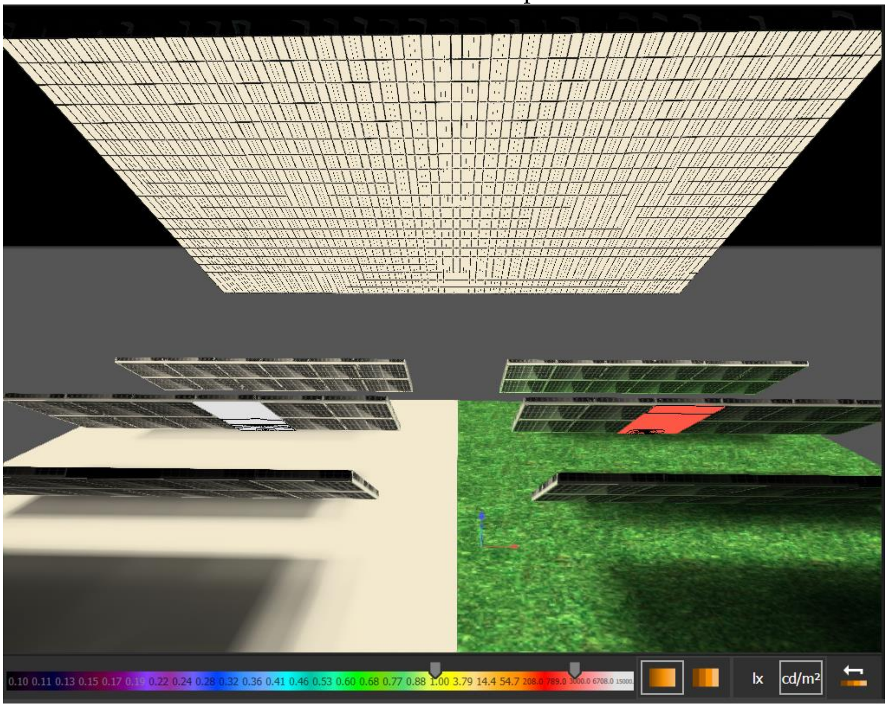


Fig.9. The two calculation surfaces selected in the middle of the solar panel arrays for accurate comparison

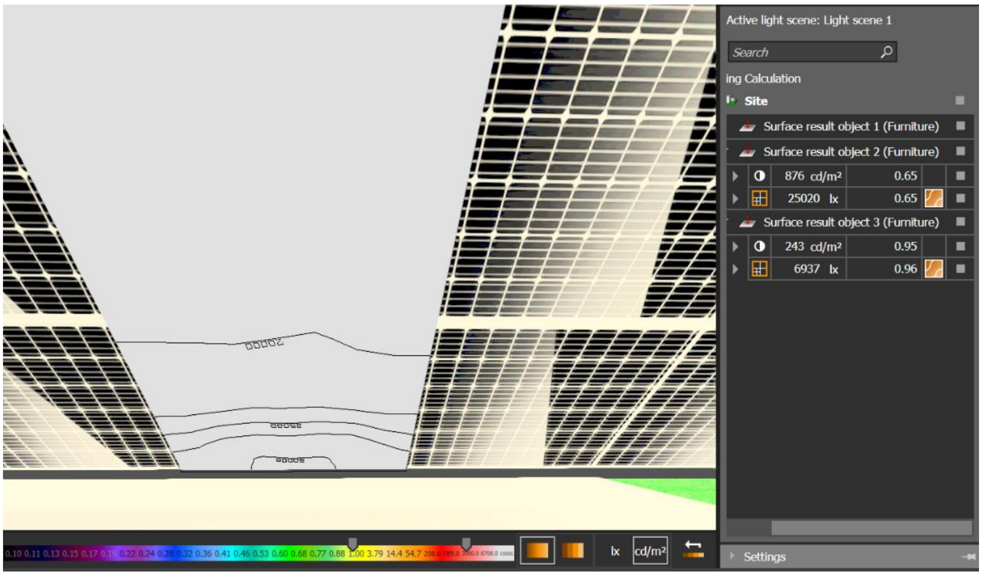


Fig.10. Calculation surface on the solar panel with the white membrane

By placing a calculation surface on the back side of the bifacial solar panel, the software is able to calculate the amount of light that is reflected from the ground under the panels. In the first control group of solar panels, the usual grass has a reflection factor of 14% while the tested reflective membrane which is white, has a 87% reflection factor.

This difference represents a good amount of solar energy, indirect energy that can be converted into electrical energy by the bifacial solar cells in the modules.

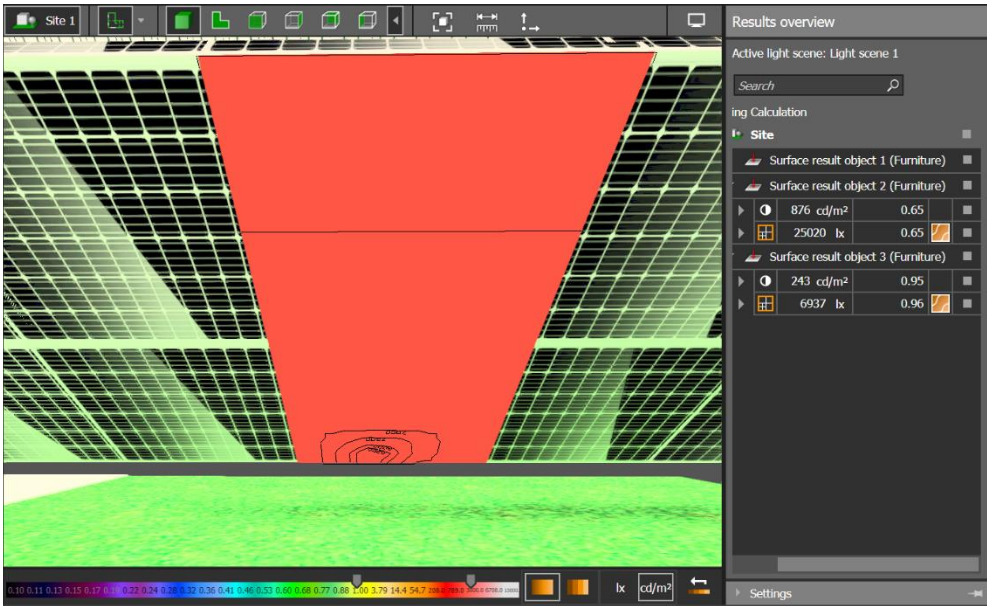


Fig.11. Calculation surface on the solar panel with grass covered soil

Given the comparison between the grass covered soil and the white reflective membrane, only the percentage of extra light is needed, so the simulated radiation level must not be an accurately determined due to the fact that the Sun gives a gradient radiation during a day.

Table 1. ***Surface results***

Ground type	Luminance	Performance	Illumination	Performance
Surface results (grass)	243 cd/m^2	100%	6937 lux	100%
Surface results (white reflective membrane)	876 cd/m^2	360%	25020 lux	360%

On a clear day, if the Sun is directly overhead, the intensity of the radiation hitting the ground **directly from the Sun** is around 1,050 W/m^2, on top of this a further 70 W/m^2 comes from the bright blue sky, giving a total of 1,120 W/m^2. If is it's cloudy the amount will be lower. This means that only about 6.2% of the radiation can be used by the solar cells, and adding the reflection factor of the white membrane the usable light is even lower, to 5.4%.

Another source of indirect radiation are the other solar modules or even walls, objects that are close to the panel rows.

4. CONCLUSIONS

Continued advancements in solar cell technologies, materials, and manufacturing processes may lead to more efficient and cost-effective bifacial solar panels. Improvements in the design and construction of these panels could enhance their performance and make them more competitive in the market.

Ongoing research and development in the solar industry may lead to breakthroughs in materials and design, further boosting the efficiency of bifacial solar panels. Research efforts may also focus on optimizing the panels for specific environments and applications.

Bifacial solar panels could be integrated with other emerging technologies, such as energy storage systems and smart grid solutions, to create more resilient and efficient solar energy systems. The percentage gain in energy production from using a white membrane under a solar array can vary based on several factors, including the local climate, the tilt and orientation of the solar panels, and the specific characteristics of the reflective surface. The reflectivity or albedo of the surface, which is a measure of its ability to reflect light, plays a crucial role in determining the impact on energy production.

REFERENCES

[1]. Antohe S., *Organic Materials and Electronic Devices,* Publishing house University of Bucharest, Bucharest, 1996.

[2]. Green M.A., *High Efficiency Silicon Solar Cells*, Trans Tech Publications, Switzerland, 1987.

[3]. Handra A.D., Popescu F.G., Păsculescu D., *Utilizarea energiei electrice - lucrări de laborator*, Editura Universitas, Petroşani, 167 pag., 2020.

[4]. Lazăr T., Marcu M.D., Uțu I., Popescu F.G., Păsculescu D., *Mașini electrice - culegere de probleme*, Editura UNIVERSITAS, Petroșani, pp.197, 2023.

[5]. Marcu M.D., Popescu F.G., Pana L., *Modeling and simulation of power active filter for reducing harmonic pollution using the instantaneous reactive power theory*. Environmental Engineering and Management Journal, June, Vol.13, No. 6, Pages: 1377-1382, DOI:10.30638/eemj.2014.148, 2014.

[6]. Marcu M.D., Popescu F.G., Pana L., Slusariuc R., *Modeling and simulation of solar radiation. Applied Mechanics and Materials*, Vol. 710, pp. 113-118, Trans Tech Publication, Switzerland, 2015.

[7]. Maric Dj.M., Meier P.F., S.K. Estreicher, *Materials Science Forum*, Vol. 83-87, p. 119-124, 1992.

[8]. Markvart T., Castaner L., *Technical Handbook of Photovoltaics,Fundamentals and Applications*, Elsevier, Ltd, 2003.

[9]. Niculescu T., Arad V., Marcu M., Arad S., Popescu F.G., *Safety barrier of electrical equipment for environments with a potential explosion in underground coal mines*. MINING OF MINERAL DEPOSITS. Volume: 14 Issue: 3 Pages: 78-86, DOI: 10.33271/mining14.03.078, 2020.

[10]. Niculescu T., Pasculescu D., Pana L., *Study of the operating states of intrinsic safety barriers of the electrical equipment intended for use in atmospheres with explosion hazard*, WSEAS Transactions on Circuits and Systems, Volume 9, pp.430-439, 2010.

[11]. Niculescu T., Păsculescu D., *Use of numerical simulation to study capacitive loads which is connecting to an AC power source,* 15th SGEM GeoConference on Informatics, Geoinformatics and Remote Sensing, SGEM2015 Conference Proceedings, Albena, Bulgaria, June 18-24, Vol. 1, pp. 391-398, 2015.

[12]. Pasculescu D., Dobra R., Ahmad M.A., *Dosimetric Quantity System for Electromagnetic Fields Bio-effects*, International Journal of Scientific Research (IJSR) 5, no. 2, pp. 28-32, 2016.

[13]. Pasculescu D., Romanescu A., Pasculescu V., Tatar A., Fotau I., Vajai Ghe., *Presentation and simulation of a modern distance protection from national energy system*, Proceedings of the 10 th International Conference on Environment and Electrical Engineering – EEEIC 2011, Rome, Italy, pp. 646-650, 2011.

[14]. Pasculescu D., Slusariuc R., Popescu F.G., Fîță N.D., Tatar A., Lazar T., *Modeling and simulation of lighting of a road with 2 strips per direction to en 13201: 2015 Standard*, Annals of the University of Petrosani, Electrical Engineering, Vol.24, pp.67-76, Petrosani, 2022.

[15]. Popescu F.G., Pasculescu D., Marcu M., Niculescu T., Handra A.D., *The technical and economic advantages of power factor correction*, Annals of University of Petrosani, Electrical Engineering, Vol. 21, pp.35-42, Petrosani, 2019.

[16]. Popescu F.G., Pasculescu D., Marcu M., Pasculescu V.M., Fîță N.D., Tatar A., Lazar T., *Principles of effective energy management and power control system*, Annals of the University of Petrosani, Electrical Engineering, Vol.24, pp.111-118, Petrosani, 2022.

[17]. Popescu F.G., Pasculescu D., Marcu M., Slusariuc R., Buica G., Lazar T., *Analysis of filtering and correction of the power factor in distorted balance*, Annals of University of Petrosani, Electrical Engineering, Vol. 23, pp. 77-82, Petroşani, 2021.

[18]. Popescu F.G., Păsculescu D., Păsculescu V.M., *Modern methods for analysis and reduction of current and voltage harmonics*, LAP LAMBERT Academic Publishing, ISBN 978-620-0-56941-7, pp. 233, 2020.

[19]. Tatar A, Pasculescu D., Marcu M., Lazar T., Popescu F.G, *Electric power production and national energy security considerations*, Annals of the University of Petrosani, Electrical Engineering, Vol.24, pp.5-16, Petrosani, 2022.

[20]. Zekai S., *Solar Energy Fundamentals and Modeling Techniques*, Springer, 2008.