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EV off-grid solar charging station for emergency

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Abstract. Current climate change and its aftermath lead to critical situations. The power grid is often affected/damaged and consumers can remain several days without electricity supply. The response of the authorities has been delayed for more or less justified reasons. In the paper it is proposed to use EVs for freight transports, evacuation of people etc that use off-grid solar charging stations instead of fossil fuel refuelling stations for ICE vehicles, if power is not restored or is no longer available. The solar station features bi-facial steerable solar panels, buried energy storage system and energy optimization/limiting software.

Keywords: solar charging stations, adjustable solar panels, electrical energy storage system.

1. Introduction

Whenever natural disasters (hurricanes, floods, earthquakes, etc.) strike populated areas or even entire countries, the situation becomes critical because practically all the facilities that accompany normal life are affected. Of paramount importance in these difficult times is when power and connectivity are lost, people have no electricity for utilities, cannot recharge cell phones or have no way to get around. Such situations also arise in the case of military attacks when cybersecurity, which protects both power grids and computer systems and the users of these systems, is primarily affected. In some borderline situations, it is impossible to restore power and communications in the short term and the damage is irreparable. Transportation is needed for rescuing the sick/wounded, transporting food, evacuating entire families, etc. But fossil fuel stations are no longer operational, leaving only electric

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vehicles that can be recharged from the only indestructible energy resource, which in such cases is solar energy. If an off-grid solar charging station does not exist, an ad-hoc one can be set up from standard components, which do not require tall buildings, and parts of it (energy storage batteries and control systems) mounted underground except for the solar panels. In the paper such a maximum efficiency solar charging station is proposed which has bi-facial solar panels, dual-axis steerable tracker, energy storage system and software for optimization/maximization and limitation of EV battery charge level. The station will be the first of its kind realized in the distributed structure (charging point without a canopy remote from the tracker and underground layout of the storage battery, inverters and control circuits.

2. Energy generated by a solar source

Powering isolated equipment from solar sources requires the need to evaluate the energy generated by solar panels according to the day of the year and the cloudiness of the sky.
The PPV power generated by a solar panel is determined by the relation (1) established on the basis of its equivalent schematic (fig.1) [1].

$$P_{PV} = U \cdot I = U_T \cdot I \cdot \ln\left(\frac{I_{pv} - I + I_0}{I_0}\right) - I^2 \cdot R_s, \tag{1}$$

where U is the voltage at the output terminals of the panel, I – the load electric current, I_{pv} – the theoretical electric current of the cell, I_d – the electric current taking into account the recombination processes in the cell, I_{pv} is the theoretical electric current of the cell, I_d – the electric current taking into account the recombination processes in the cell, I_0 – the saturation electric current, R_s – the equivalent electric resistance of the load at the terminals of the panel.

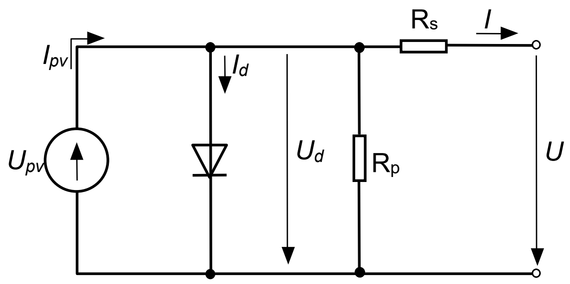

Fig. 1 Equivalent diagram of a photoelectric cell.

In real computations, the use of relation (1) is not practical, and relations that provide the information needed for concrete applications are preferred.
The energy produced by a solar panel on a clear day has the form shown in Fig. 2 for two representative days of the year.

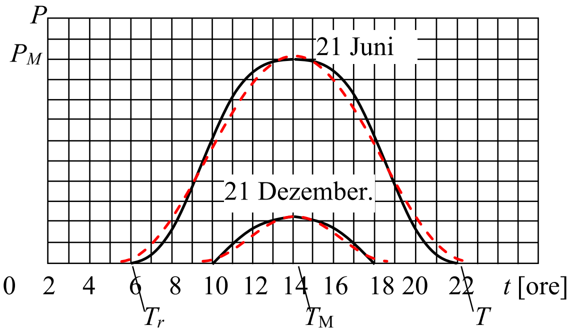

Fig. 2 The power generated on two significant days of the year (clear sky). Approximate curves are also indicated (in red).

The experimentally determined power production curves (shown in black in Fig. 1) can be approximated sufficiently well by a sinusoidal curve of the form $P_{PV} = \frac{P_M}{2} \cdot \left[1 + \sin\left(\frac{-T_r - \frac{T}{4} + t}{T} \cdot 2 \cdot \pi\right)\right]$, (2)

where P_M is the maximum power generated on the analyzed day, T is the duration of the sun's presence in the sky between the time T_r of sunrise and sunset.

The values of the magnitudes T_r and T can be determined from the solar activity tables. For Romania, data from https://www.astro-urseanu.ro/rasarit_soare_blank.html can be used.

The energy generated during one day can be determined from the relation

$$E_{zi} = \int_{T_r}^{T-T_r} P_{PV} \cdot dt = \frac{P_M}{2} \cdot T\,. \tag{3}$$

From a practical point of view it is necessary to know the P_M value in order to plot the production curve and determine the daily energy generated. For the solar panels used, the power generated P is measured at a given time t [h] on the day under consideration and the relations (1) and (2) give the PM value and then the energy generated on the day under consideration, in the case of a clear sky.

In the case of a cloudy sky, the electric current and thus the power generated by the solar panels depend on the irradiance according to a law of proportionality (Fig. 3). Thus, if the irradiance level is measured, the power output can be evaluated by multiplying relation (1) by a proportionality factor calculated as the ratio between the measured irradiance G and the reference irradiance G_0 (1000 V/m^2).

Since there may be time intervals with different irradiance values during the course of a day, the calculations should be carried out on time intervals with quasi-stationary conditions.

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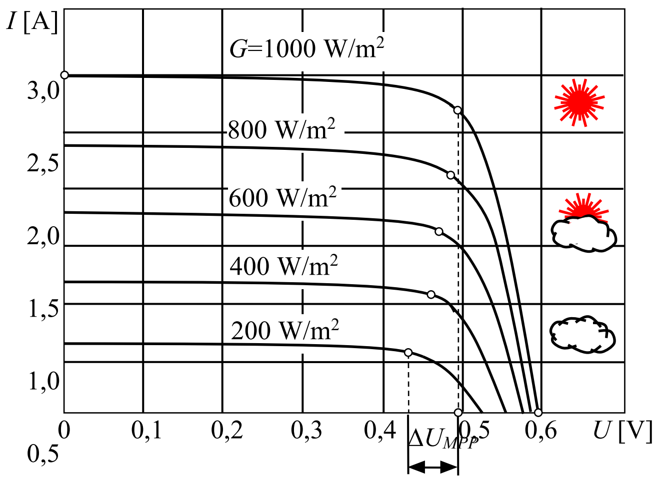

Fig. 3 Influence of global irradiance G on the current-voltage characteristic of a photoelectric cell.

The usable P_{PV} power at a given site must also take into account the plant's η_{PV} efficiency, which depends on the local irradiance and cell temperature.

$$P_{PV} = \frac{P}{G_0} \cdot G \cdot \eta_{PV}, \tag{4}$$

where G is the on-site irradiance, G_0 - the reference irradiance and η_{PV} - the plant efficiency, dependent on the irradiance G and the actual cell temperature T_c, with values between 0.8 and 0.9.

3. Influencing factors

During operation, a solar installation is subject to external factors that lead to a reduction in the theoretical energy generated. Figure 4 shows the main influencing factors and the weight of their influence on the module performance. The example in Fig. 4 refers to a solar panel with an installed power of 1 kWp and the balance is realized for one year [2].

The balance analysis in figure 4 shows that dust deposits, shielding (shading), losses in the electrical and electronic circuits reduce the energy generated, so that the energy yield of a panel for one year can be as high as 76%.

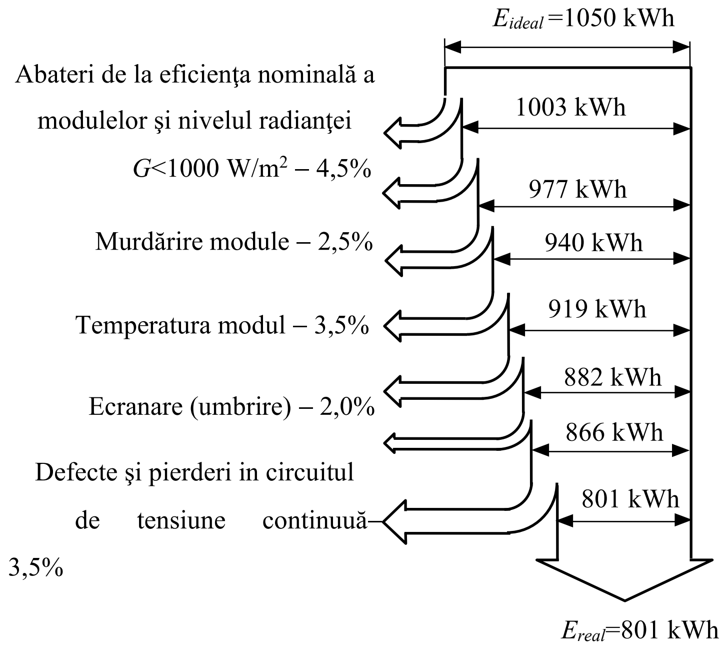

Fig. 4 Energy balance of a photoelectric power source 1 kWp.

The energy generated by a photoelectric installation is strongly influenced by solar radiation and therefore by the season. For this reason, the annual energy generated by a solar installation is calculated over representative time intervals, typically three intervals: spring and fall, summer, winter, taking into account the mid-April, July, January.

The degree of sky cover determines the change in the production curve of a solar installation (Fig. 5). In this way, the electricity production for one year can be determined from the approximate relationship

$$E_{anual} = \eta_{\mathrm{panou}} \cdot \left(2 \cdot \eta_{\mathrm{ap}} \cdot E_p + \eta_{\mathrm{av}} \cdot E_v + \eta_{\mathrm{ai}} \cdot E_i\right), \qquad (5)$$

where η_{ap}, η_{av}, η_{ai} represent the reduction in panel performance due to sky cover in spring (fall), summer and winter respectively, E_p , E_v and E_i the energy theoretically generated in the spring, summer and winter months, η_{panou} – the panel efficiency.

The energy generated in the representative time intervals can be roughly determined based on relation (3) in which the number of days over the 3 time intervals considered is taken into account.

In the case of fixed solar systems, the angle between the solar panel and the ground shall be chosen in such a way that the maximization of the generated energy is

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ensured at the level of one year. The maximum output is achieved when the sun's rays are perpendicular to the panel surface.

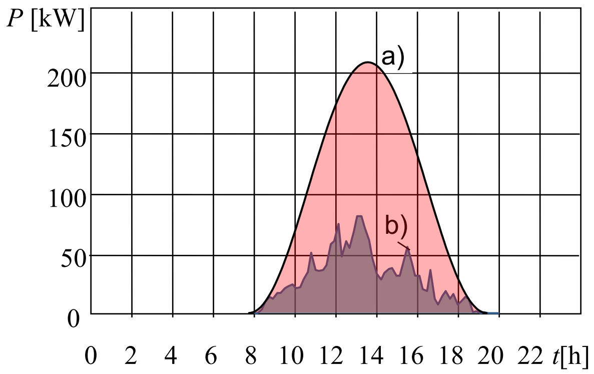

Fig.5 Power generated on a winter day by a plant with an installed capacity of 300 kW:
(a) clear sky; (b) overcast sky

4. Solar installations using ***tracking system***

Fixed solar installations are designed to face south and at a certain angle to the ground, chosen so that the maximum possible energy yield is obtained in a given year. Due to the fact that the sun's rays do not fall normally on the panel surface at all times, the performance of the panel is affected by the angle between the normal on the panel surface and the sun's rays. To make more efficient use of solar radiation, *tracker* systems have been developed that follow on one or two axes the path of the sun on the sky and ensure that the solar radiation received by the PV panel is maximized. In this way, in two-axis tracker systems the solar radiation is permanently normal to the panel surface and a superior solar system performance can be achieved (Fig. 6) [3].
The use of a single-axis tracker system can result in an increase of 25-30% of the energy harvested compared to a fixed installation with the same number of panels, while a two-axis tracker system can increase the energy harvested by up to 40% [4].

The realization of tracker systems implies the use of motors to drive the assembly and the existence of a system to track the position of the sun in the sky, which provides the signals for the drive motors. In general, the tracking system and drive motors use no more than 5% of the power generated by the solar installation.

Given the increased output of the tracker system and the reduced power generated by powering the tracking system and the drive system, the annual yearly energy Yearly energy generated by the tracker system can be determined from the relation

$$E_{tanual} = k_t \cdot k_{ua} \cdot \eta_{\text{panou}} \cdot \left(2 \cdot \eta_{\text{ap}} \cdot E_p + \eta_{\text{av}} \cdot E_v + \eta_{\text{ai}} \cdot E_i\right), \qquad (6)$$

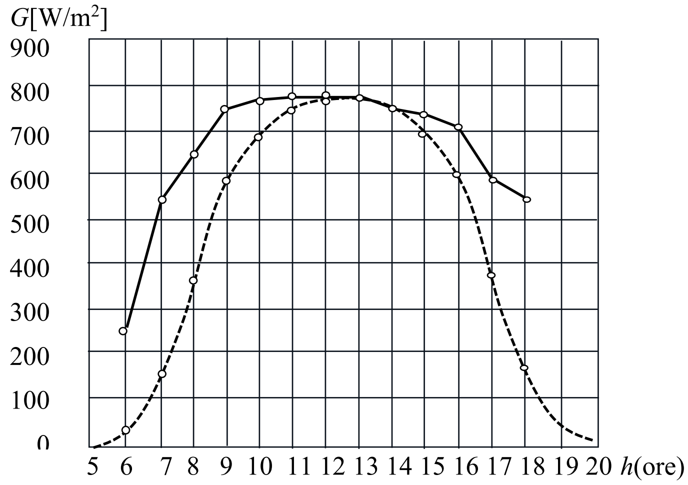

Fig. 6 Data measured in a dual-axis tracker installation (—) and theoretical values (---).

where k_t is a factor that takes into account the increase in power generated due to the *tracker* system (k_t =1,25···1,4) and k_{ua} – takes into account the reduction in power generated by the solar plant due to the tracker and drive system ($k_{ua} \cong 0.95$).

5. Use of indirect light

Solar radiation contributing to energy conversion has three components

- direct radiation measured on a surface perpendicular to the light beam, which accounts for more than 85% of the energy generated by solar panels;
- the indirect (diffuse) radiation from clouds in the sky or the atmodosphere in the early morning or evening hours, which accounts for up to 12% of the energy generated by the panels;
- reflected radiation from the ground or from neighboring objects contributes less than 3% of the electricity production.

The presence of clouds in the sky reduces direct radiation and increases the contribution of indirect radiation.

Current technological advances aim to improve the efficiency of solar panels under indirect light conditions. The main solutions in this respect are the development of film cells (a few nm thick) which are more efficient in indirect light. Concentrated-light solar systems using a lens system have also been developed. Bifacial panels also provide higher efficiency in low light by being able to absorb light from both sides, which allows the capture of reflected and diffuse light, important in cloudy skies or areas with indirect light.

Bifacial solar panels provide superior performance when installed above a highly reflective surface (water pools, sandy beaches, snowy areas or light-colored earth).

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The right choice of installation site allows up to 30% more energy to be generated by the bifacial panel.

6. Storing energy generated by solar panels

The storage system is intended to provide power to some customers even when the solar installation is inactive (no sun or during the night). Typically, storage installations of this type are made with storage batteries. The batteries are charged during the excess output of the solar source or when consumption is low.
The sizing of the accumulator battery requires knowledge of the energy required by the powered receivers, the possible power output, the battery's DoD (depth of discharge), the battery's efficiency, the battery's nominal voltage, the mode of supply to the users (direct or alternating voltage). The correct choice of battery ensures the required performance, reliability and lifetime.
Battery capacity can be determined from the relation

$$C_{bat} = \frac{E}{U_{bat} \cdot DoD \cdot \eta_{bat}} \text{ [Ah]}, \quad (7)$$

where E is the energy required to power the users, U – the voltage at the battery terminals, DoD - the permissible depth of discharge of the battery, η_{bat} – the efficiency of the battery.
The use of the storage battery requires a correlation between the energy available at the terminals of the storage system and the solar source.
The available energy during a day can be determined from the approximate relation (3) in which the maximum power PM and the day length (dependent on the time of analysis and the degree of cloud cover) must be known.
The P_M values in relation (3) must take into account whether the power generation system is realized with tracker or bifacial panels.
The DoD and η_{bat} values are chosen from the chosen battery leaflet.

7. Block diagram of off-grid charging station

Fig. 7 shows the simplified structure of the station consisting of the PV panel placed on a tracker rotatable on two axes (x,y), a first DC-DC inverter for matching to the battery energy storage system (BESS) voltage, a second DC-DC inverter for off-board DC charging of EV type A according to Level 3 standard, a third DC-AC inverter for direct AC charging of EV type B through the on-board converter (OBC) according to Level 2 standard, the last two inverters operating alternately. The µC micro-controller ensures, through embedded software, optimal control of all station blocks.

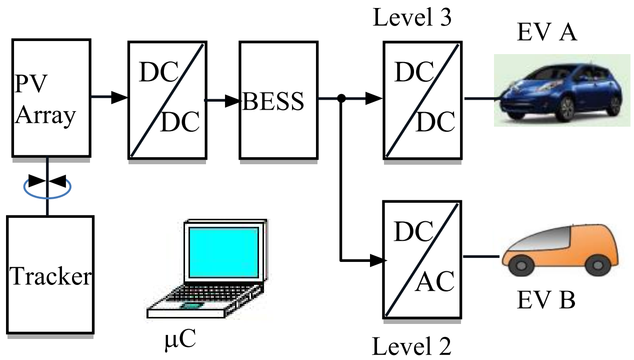

Fig. 7 Block diagram of off-grid charging station

The PV panel mounted on the tracker (fig.8) is composed of 12 monocrystalline silicon modules of 435 Wp with a surface area of 1.5 m^2. In total the PV panel has 18 m^2 and **5.22** kWp which can be extended on the existing tracker (as shown in the picture) to 16 modules with a total surface area of 24 m^2 and total power of 6.96 kWp.si puterea totală de **6,96** kWp.
The electrical characteristics of the 435 Wp modules in the above 108-cell solar panel are as follows:

- open circuit voltage (V_{oc}): 38.8 V;
- electric short-circuit current (I_{sc}): 3.9 A;
- voltage at maximum power (V_{mpp}): 32.4 V;
- peak power current (I_{mpp}): 13.3 A;
- Efficiency: 22 %.

The BESS block in Figure 7 contains a standard Li-Ion battery with C_{bat} = 200 Ah with nominal voltage of 420 V sized based on relation (6) with capacity of E = 80 kWh such that its tinc charging time (SoC = 100%) is:

$$t_{inc} = \frac{E}{P_{PV}} = 16 \text{ ore.} \tag{8}$$

With this storage battery it is possible to provide partial recharging of some EVs that are common for the circulation in the locality. The multiplication of such stations eliminates the need for grid electricity in emergency situations/
Currently, the realization of an efficient solar capture installation is based on data provided by the EU which together with the World Bank [5] has provided financial support to Solargis [6] to produce solar irradiance and PV power distribution maps for each country. Figure 9 shows the situation in Romania [7]

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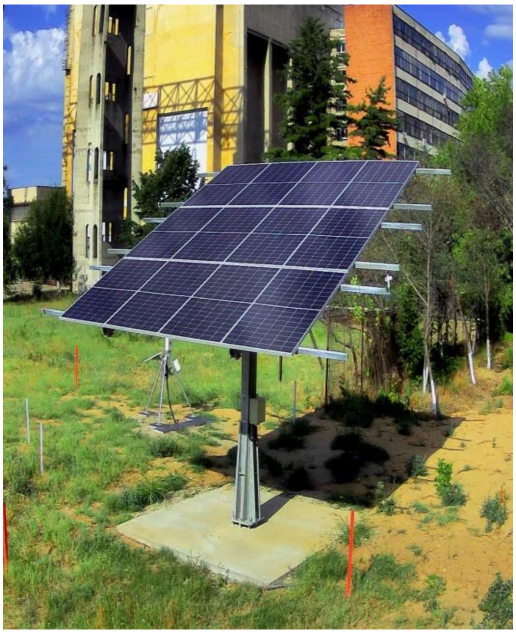
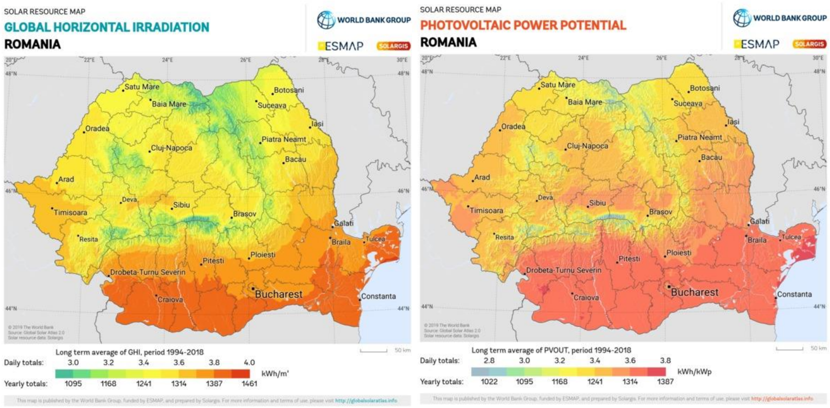


Fig. 8 Bidirectional tracker with 18 m^2 PV panel extendable up to 24 m^2 located in the outdoor field of the INCD ICMET HV Laboratory (in the background the weather station tripod can be seen).

Shown in Figure 9 a) are the global horizontal irradiance (GHI), defining the terrestrial irradiance falling on a surface horizontal to the Earth's surface, and in Figure 9 b), the potential PV power in kWh/kWp. GHI is measured with a pyranometer [8] which has a 180° viewing angle and gives the result directly in kWh/m^2.



a) b)

Fig. 9 Irradiance map in Romania a) and PV power map in Romania b)

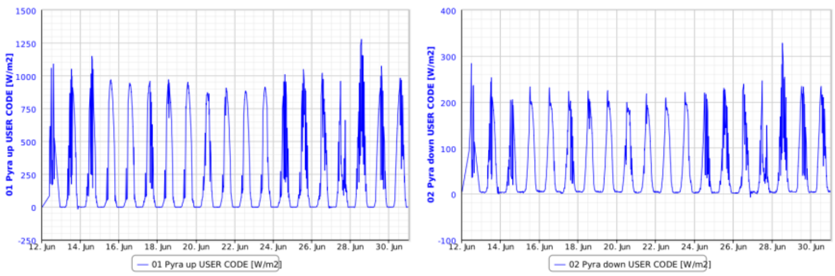
The main purpose of a tracker as a solar photovoltaic tracking system is to expose the solar panel to maximum radiation at any time of the day, so that the efficiency of electricity production increases by up to 50% compared to situations where the panel is mounted in a fixed position.

The orientation of the tracker is realized automatically by µC in real time in two directions based on the information received from the weather station. The two orientation directions are:

-orientation by azimuth of the PV panel which is the angle of the projected position of the sun in the horizontal plane as the sun moves across the sky from east to west during the day calculated as an angle to true south. The correct orientation of the solar panel varies with latitude and time of year.

-the orientation by altitude (zenith) of the PV panel which is defined as the angle of the sun in the vertical plane with 0° degrees at sunrise and sunset and 90° degrees at noon when the sun is directly overhead. This also varies. However, the height of the sun at midday is different between the summer solstice and the winter solstice, representing the longest and shortest days of the year.

The weather station is essential for determining the optimal operating conditions of the tracker both for locating it on the map and for providing real-time parameters (global solar incident irradiance, solar indirect (reflected) radiation, ground temperature at one meter depth, wind speed and direction, humidity, etc). Through a datalogger the above information is transmitted to the µC system. The station contains an essential apparatus, the albedometer [ISO9060/2018] which measures the solar irradiance using the two pyranometers [9] in Fig. 10 mounted back to back so that one measures the global solar irradiance and the other measures the solar irradiance reflected by the ground as ratio:



a) b)

Fig. 10 Incident solar irradiance a); reflected solar irradiance b) (measured with the ICMET station albedometer).

$$\text{Albedo} = \text{Iradianţa globală reflectată}/\text{Iradianţa globală incidentă} \qquad (9)$$

This measurement is essential to obtain the information needed when using bi-facial PV panels to be mounted on the actual PV panel (Fig.11)

Fig.11 Albedometer for measuring solar irradiance

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The albedo is of order 25% in the range of characteristic values of the bi-facial PV panels to be purchased in order to increase the PV efficiency accordingly.

8. Conclusions

Off-grid electric vehicle charging stations can play an important role in overcoming emergency situations in case of critical situations. The loss of supply from the public power grid in case of natural disasters causes all rescue actions to be affected in the absence of vehicle transportation.

This paper proposes a solution based on energy stored in batteries powered from an off-grid solar source. The appropriate sizing of the installation provides the necessary electrical energy to power the electric vehicles involved in emergency actions, independent of the state of the power system.

The microcontroller that controls the operation of each equipment of the station also controls the charging process of the vehicles and the level of energy in the batteries to provide the possibility of rational use of the stored energy.

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