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MICROSPRAY IRRIGATION SYSTEM INTEGRATED WITH PHOTOVOLTAIC PANELS

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Abstract: *Global food security is endangered by rapid population growth and consequently increasing demand. Only an optimal combination of energy and water resources used for irrigation, mineral fertilization and organic soil of the Republic of Moldova will ensure a continued growth in agricultural production and food security. The microspray irrigation systems integrated with PV, a method of PV pump system calculation for small irrigation are presented. The numerical example contains pump flow rates, pumped water volumes (daily, monthly and for all irrigation period)*

Keywords*: Microspray photovoltaic installation, solar radiation, solar pump*

1. Introduction

Global food security is endangered by rapid population growth and consequently increasing demand. As result, world market food prices are continuously increasing. Climate change is manifested by increased severity and climate variability and this phenomenon is not a regional, but rather global. It is clear that sustainable agriculture development is closely related to irrigation and fertilization of the agricultural land. Only an optimal combination of energy and water resources used for irrigation, mineral fertilization and organic soil of the Republic of Moldova will ensure a continued growth in agricultural production and food security. Also, this will help to decrease soil degradation and climatic vagaries dependence of agricultural production.

The climatic conditions of the Republic of Moldova impose that the optimal water amount needed during the active growing season for most crops consists of 300-700 mm. According to long-term weather observations for the above-mentioned period, the average amount of rainfall is from 235 mm in the south up to 330 mm in the northern region. Natural moisture is insufficient to achieve the expected amount for fruits, or especially for vegetables, even in years with above average climatic characteristics. Often, the Republic of Moldova, Romania and Ukraine are subjects to long-term droughts.

After 1991, there were implemented the key agriculture reforms characterized primarily by restructuring large agricultural units, decentralization of agricultural production, land privatization, formation of new economic relations based on market economy. The changes that took place in agriculture and power supply sector influenced negatively in particular the existing irrigation systems [1]. The main causes that contributed to the aggravation of irrigation systems status are:

- sudden increase in electricity and fuel prices;
- reduced water demand from new landowners;
- parcellation of the land made impossible the efficient use of pumping stations, water supply systems and irrigation facilities, designed, developed and built to irrigate large areas;
- small or even negative economic efficiency of irrigation systems placed at great heights with respect to water sources;
- bad management of involved companies and local authorities led to disassembly of watering plants, removing and selling non-ferrous metal pipes;
- technical obsolescence of irrigation equipment and facilities. In the last 10 years there were not purchased any new equipment;
- lack of state subsidies for the electricity purchase.

Considering the above, the Government of RM adopted Decision no. 256 of 17 April 2001 „*On the rehabilitation of irrigation systems”* According to this decision it is expected to achieve the following objectives: rehabilitation of large irrigation on 124 300 ha (40% of the irrigable area), 1991 irrigation systems will be equipped with mobile irrigation equipment with high productivity, low energy and water consumption; small irrigation implemented on 36,000 ha (small irrigation is executed on areas from 1 ha to 100 ha). As water supply sources there will be used 3000 water reservoirs, of which the most important are 411 lakes, Dniester Prut and Raut rivers. Also, small irrigation will be done with mobile units, preferences given to modern and efficient methods including drip, sprinkler and aerosols irrigations, with the use of renewable energy as power supply. In order to minimize the negative effects on both humans and environment there will be developed and implemented the irrigation schedule techniques based on soil, crop and weather conditions monetarization. The existing technologies and methods range from water balance or control registers up to sophisticated sensor-based systems. There is a need for an automated from the point of view of quality for watering (e.g. Dropwise) co-cultivation and fertilization (for a drip irrigation fertilizer is brought to the root of the plant).

2. Prerequisites and solutions

The issue of global food security is amplified by the rapid growth of the number of population and, consequently, by the increased demand for food. As a result, food prices on the world market are rising. Climate change is manifested by the amplification of climate severity and variability. This phenomenon is not a regional one, but a global one (*Figure 1*).

It is obvious that the sustainable development of agriculture in the Republic of Moldova is indispensable for irrigation and fertilization of agricultural lands. Only an optimal combination of water and energy resources for irrigation, mineral and organic fertilizers with Moldovan soils will guarantee a continuous increase of agricultural production, food security, and will provide the processing industry with raw materials. It will also contribute to reducing soil degradation and the dependence of agricultural production on climate conditions.

In the climatic conditions of the Republic of Moldova, the optimal water requirement during the active vegetation period is an amount between 300 and 700 mm for most agricultural crops.

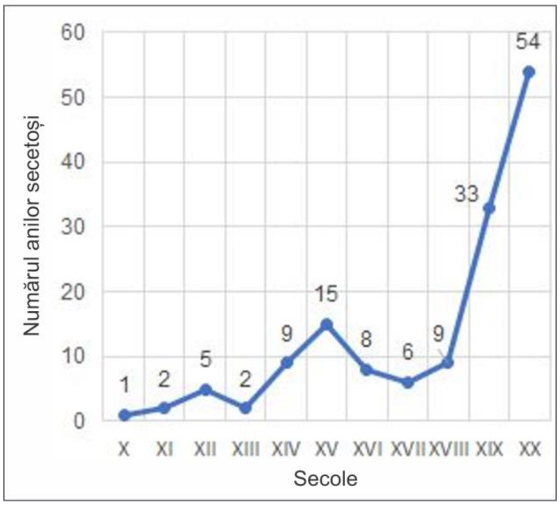


Fig. 1. Number of dry years during the second millennium.

After 1991, there were essential reforms in the agrarian sector, characterized first by the restructuring of large agricultural units, decentralization of agricultural production, privatization of agricultural land, formation of new economic relations, based on the laws of the market economy. The increase in the price of electricity and fuel has caused the price increase of one cubic meter of pumped water, which has led to a drastic decrease in the demand for irrigation water from the new agricultural producers. The share of electricity cost often exceeded 50% of total irrigation costs. After 1994 there was a decrease of about 16 times of the irrigated areas and a sudden increase of the share of energy cost in the total cost. In order to redress the situation, the Development Strategy for Agriculture was elaborated in Moldova, which provides for a series of priorities and measures to achieve the proposed objective and to analyze the agrifood sector.

Solar energy potential

The amount of solar energy received by the Earth's surface depends on a number of factors, primarily the duration of the Sun's sunshine and the Sun's height above the horizon. In the Republic of Moldova, the possible (theoretical) sunshine duration is 4445-4452 h/year. Actual time is 47-52% or 2100-2300 hours of the possible one [2]. The variation of about 5% is due to the difference in latitude between the northern and southern areas, which is about 2,50. A considerable part of the sunshine hours are in the months from April to September and is about

1500 - 1650 hours. The global radiation (sum of the direct and diffuse radiation) on a horizontal surface, under medium nebulous conditions, is 1280 kWh/m^2/year in the northern area and 1370 kWh/m^2/year in the southern area (*Figure 2*). More than 75% of this radiation lasts from April to September. Global radiation in the northern area is 3,5% lower than in the central area, and in the southern area – 2,6% higher.

The irradiation values present the results of the systematic measurements carried out by the State *Hydro meteorological Service* between 1954 and 1980, in conditions of clear sky and medium nebulosity, at 6^{30}, 9^{30}, 12^{30}, 15^{30} and 18^{30}. With this data irradiation (exposure) can be defined over a concrete duration in kWh/m^2 or MJ/m^2, taking the irradiation integral over that time interval.

Fig. 2. Solar energy potential map of the Republic of Moldova.

3. Elaboration of microspray irrigation system integrated with photovoltaic panels [3,4]

To reduce costs, it was decided not to use battery packs. In this case irrigation will occur if the values of the solar radiation or the wind speed exceeds the minimum values necessary for the operation of the pump.

The functional scheme is shown in Figure 3, and the technological scheme of the autonomous irrigation system are shown in Figure 4.

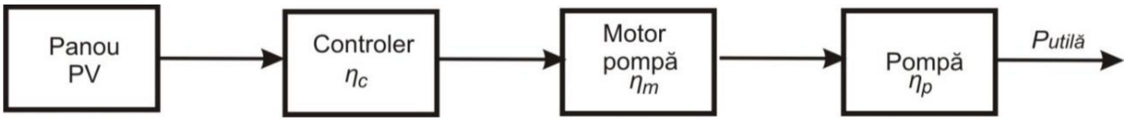


Fig. 3. The functional scheme of the irrigation system.

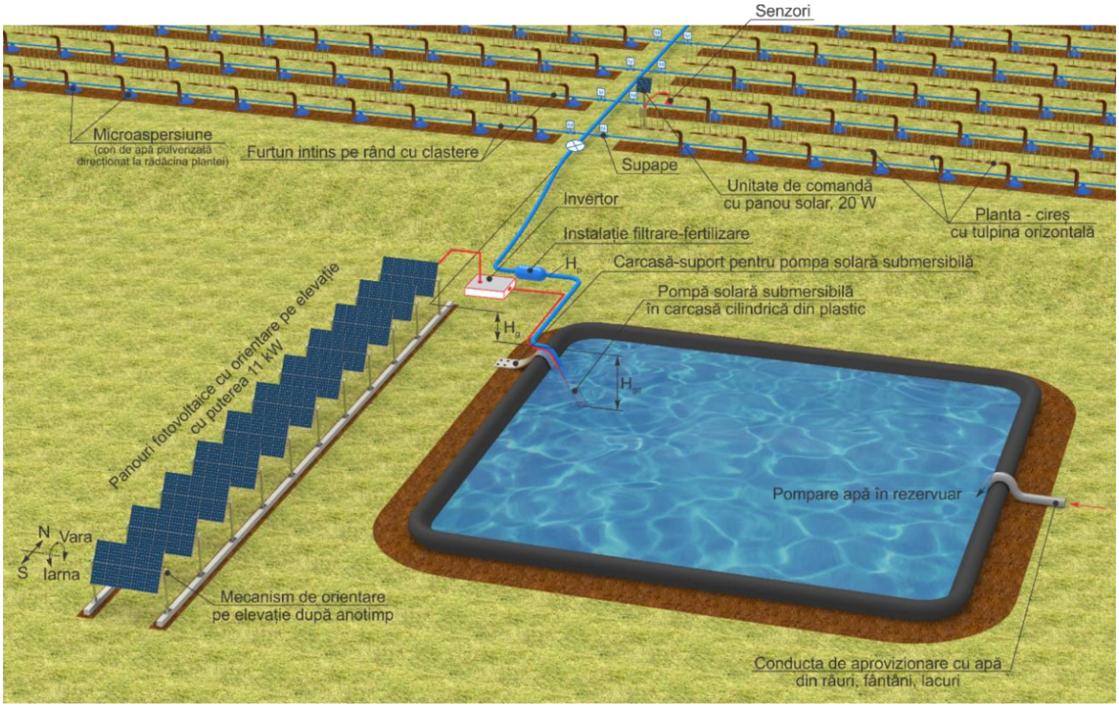


Fig. 4. The technological scheme of the autonomous irrigation system.

3.1. Microspray irrigation system integrated with photovoltaic installations (PV) developed for agricultural enterprise „*TriDenal*”, Criuleni

- Irrigated surface, S=7,0 ha or 2 land plots of 3,5 ha of cherry orchard comprising 22 rows (figure 5). Is located 10 km away from the Dniester River, with coordinates:
  - wide. 47^{o}12'04,00 N";
  - longitude 29^{o}07'36,33" E.

The land has no obvious inclinations, the altitude of the 4 corners: 97, 99, 105,103 m. A water tank is built for the storage of 9000 m^3 of water, being pumped from the Nistru River.

- Irrigation technology - Micro Sprinkler. Micro Sprinkler Type - SuperNet UD. Pressure and water flow of a Sprinkler: P_{SPmax} = 4,0 Bar and Q_{SPmax} = 0,058 m^3/h, P_{SPmin} = 1,5 Bar and Q_{SPmin} = 0,03 m^3/h.

Fig. 5. Sectors with cherry orchard.

- Period of irrigation season: April – September or T=183 days.
- The number of operating pump hours in the event that the number of operating hours per day is equal to N_{day} = 7 h, N_h= N_{day}.

T= 7·183=1281 h.

- Irrigation norm, N_I = 5000 m^3/ha.
- Watering rate, N_U = 300 m^3/ha.
- Length of row in a sector, A= 170 m.
- Watering rates per season, $NR_{UD} = N_I / N_U$ = 5000/300= 16,7, accepting N_U =16.
- Width of sector, B=99 m.
- Row width, L_R = 4,5 m.

Necessary water volume

$V_{nec.}=S\cdot N_I$ = 7·5000 = 35000 m^3.

Pump sizing

To ensure the necessary volume of pumped water we select a surface solar pump PS7k2 CS-F20-5, nominal flow, $Q_n=27m^3$, $H=40m$ [10]:

- Minimal pressure – P_{Pmax} = 4,0 Bar;
- Maximum pressure – P_{Pmax} = 7,0 Bar;
- Maximum flow rate - Q_{Pmax} = 12 m^3/h;

Pump Controller Type: PS4000:

- Maximum power – P_{Cmax} = 4,0 kW; Maximum input voltage – U_{Cmax} = 375 V c.c.;
- Optimum input voltage - $U_{Copt.}$ > 238 V c.c.; Maximum motor current – I_{Mmot} = 15 A;
- Maximum efficiency – η_{Cmax} = 98 %;

Motor type ECDRIVE 4000 CS-F, brushless, d.c.:

- Rated power – P_{Mnom} = 3,5 kW; Maximum efficiency – η_{Mmax} = 92 %;
- Rotation speed – n=900=3300 tur/min.

Determining the solar radiation for your location

- Appropriate data should be used to determine the amount of solar radiation available at the site. These data are available in the archive of the State Hydro Meteorological Service (SHMS) or in [5]. With them, the global solar radiation, G_β in W/m^2, on tilted surface or PV pane can be calculated l. The used formula is the following [6]:

$$G_\beta = R_b B + \frac{1}{2}\left(1+Cos\beta\right)D + \frac{1}{2}\left(1-Cos\beta\right)\rho G\,, \tag{1}$$

- where R_β is the ratio of total radiation on the tilted surface at angle β to that on the horizontal surface; B – direct or beam radiation; D - diffuse radiation; G – global radiation on the horizontal surface; ρ – reflectance coefficient. The B, D and G values can be found in [5]. All data are for a horizontal surface as a possessing result of SHMS measurements for the period of 1954-1980.

- In [6] are presented numerical values of the ratio R_b for the difference of latitude ϕ and inclination angle β (every 5^0) and the latitude of the place (every 5^0). Based on these data the values of the report R_b for Moldova were interpolated. The territory was divided into three areas - south (latitude 46^0), center - (47^0 latitude) and north - (latitude 48^0). Linear interpolation was used, the difference ϕ-β ranges from 0 to ± 20^0 with a step of 5^0. Numerical data of R_b can be found in [7].
- Using (1) we can calculate the daily global solar radiation, G_β for a different month for each 3 hour: 6^{30}, 9^{30}, 12^{30}, 15^{30} and 18^{30}. In this case we should use data about *B, D* and *G* published in [6]. EU countries have developed a free online software for calculation of diurnal and monthly solar radiation. The diurnal radiation is calculated every 15 minutes. For the calculation a new database Climate-SAF PVGIS [8] is used. These data are based on satellite images performed by CM-SAF (Geostationary Meteosat and Polar EUMetSat). The database represents a total of 12 years of data. From the first generation of Meteosat satellites, known as MFG, there are data from 1998 to 2005 and from the second-generation Meteosat satellites, known as MSG, there are data from June 2006 to May 2010. The coverage extends from 0° N (equator) to 58° N and from 15° W to 35° E. These data are more representative of the last climate years, and show often higher irradiations than the classic PVGIS data.
- Using this software [8], we calculated the diurnal radiation at Chisinau meteorological station on horizontal surface and compared them with the ones from the 1954-1980 period.
- We note the following:

  - The average error from April to September in the period 9^{30} - 15^{30} does not exceed + 3,0%.

  - Early in the morning (6^{30}) and evening (18^{30}) the errors are high and may exceed 100 %. But this does not affect the calculations because at the respective hours the PV pump does not work.

  - The calculated diurnal radiation values based on the new Climate-SAF PVGIS database are higher compared to those from 1954 -1980. In our view, these are the consequences of global climate change.
- We used the new Climate-SAF PVGIS database and free online software for calculation of diurnal radiation [8].

3.2. Design and manufacturing of the photovoltaic installation with orientation to the sun in the axis of evolution [9]

Figure 6 illustrates the June setting: the selected point coordinate Latitude: *47,200768*, Longitude: *29,128662*, the optimal tilted angle is *130*, the panel is facing the south – Orientation: 00. The results are displayed every 15 minutes. In the same way, we did for all 6 months of the irrigation period. Diurnal radiation over each hour is shown in fig. 7.

According to the calculations, an 11 kW PV power plant is required for the supply with electricity of the micro-sprinkler irrigation system (*see p. 3.1*) necessary for the *TriDenal* Enterprise, Criuleni, with a 7,0 ha irrigated area which requires an 11 kW PV plant.

For the solar radiation exposed on the target agricultural land, also taking into account the uncertainty meteorological factors and the deviation from the perpendicular direction of the surfaces of the PV panels towards solar rays, etc., the projected power P = 11 kW can be converted by 250W 44 panels each.

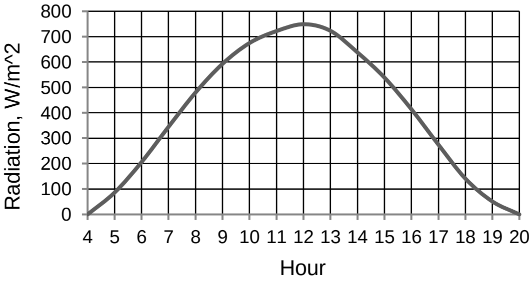
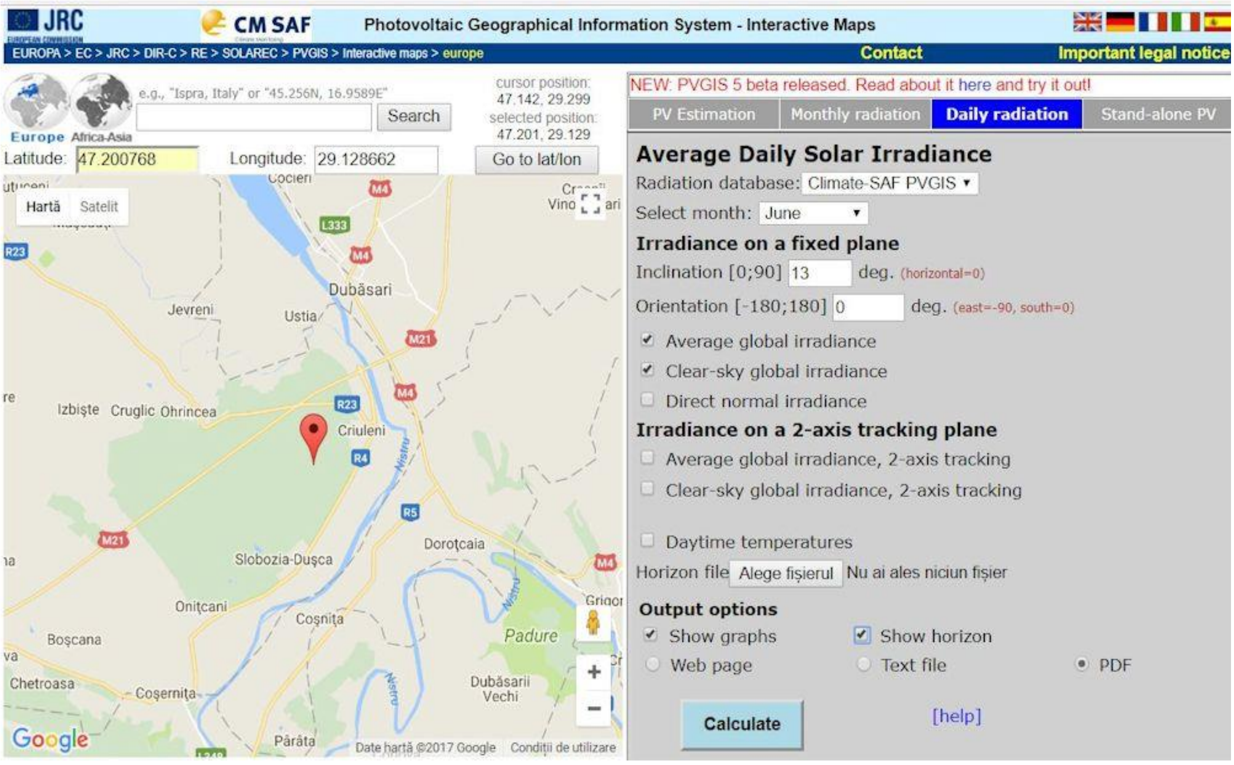


Fig. 7. Hourly radiation, September month.

In the calculation of the photovoltaic installation presented in *Figures 8, 9* it was taken into consideration the proximal perpendicularity of the photovoltaic panels to the solar rays in the seasons when the Sun has relatively different *„heights”* in relation to the Earth (at latitude 47°).

Proximal perpendicularity of the surface of the photovoltaic panels at the elevation is ensured by the PV mounting panel structures (*figure 9*), which include: a body with the ability of rotating around its axis, installed at the end in sleeves 2 and 3 with the game ≈ 1 mm; perpendicular to the body 1, five wings 4 made of 1 mm thickness sheet fixed by welding, stiffened by the applied form



Photovoltaic Geographical Information System - Interactive Maps

EUROPA > EC > JRC > DIR-C > RE > SOLAREC > PVGIS > Interactive maps > europe

cursor position: 47.142, 29.299
selected position: 47.201, 29.129

Latitude: 47.200768
Longitude: 29.128662

NEW: PVGIS 5 beta released. Read about it here and try it out!

Average Daily Solar Irradiance

Radiation database: Climate-SAF PVGIS

Select month: June

Irradiance on a fixed plane

Inclination [0;90] 13 deg. (horizontal=0)

Orientation [-180;180] 0 deg. (east=-90, south=0)

☑ Average global irradiance
☑ Clear-sky global irradiance
☐ Direct normal irradiance

Irradiance on a 2-axis tracking plane

☐ Average global irradiance, 2-axis tracking
☐ Clear-sky global irradiance, 2-axis tracking

☐ Daytime temperatures

Horizon file Alege fișierul Nu ai ales niciun fișier

Output options

☑ Show graphs ☑ Show horizon
○ Web page ○ Text file ● PDF

Fig. 6. PVGIS setting for June month.

in which the mounting holes of the PV panels 5 are made. From the constructive considerations, four photovoltaic panels 5 are installed on the wings 4 of each body 1. The housing is provided at one end with a perforated welded disc 8 on which the PV panels 5 are installed. The housing is mounted on the roof of the house or the ground by means of two legs 6 and 7, being fixed thereto by the nuts 10. The half-disc 8 with a series of holes is installed on one of the ends of the housing 1. Depending on the season and the need for the most perpendicular exposure of the PV surfaces to the sun's rays, the rotation of the body 1 with the photovoltaic panels 5 is done in such a way as to ensure the most efficient exposure of the panels to the sun. Subsequently, the axially aligned holes of the half-disc 8 are rigidly assembled with the fastening bolt 9 by the leg 6.

Photovoltaic panels have been installed on the roof. This would allow the optimization of photovoltaic panel's orientation to the sun only in azimuthal plane. For this it was elaborated the steel structure design of photovoltaic panels installed on the roof (fig.7).

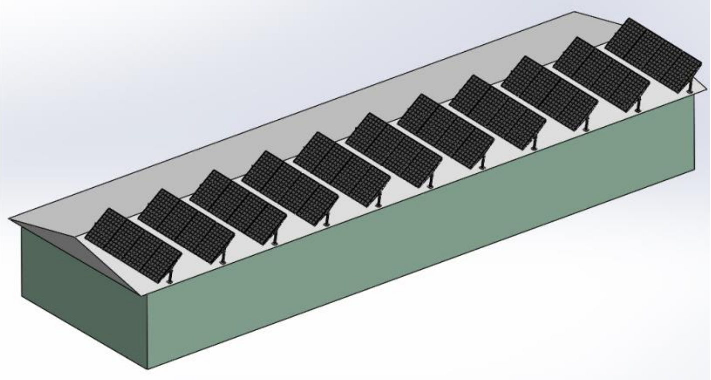


Fig. 8. *Photovoltaic panels installation scheme on the roof.*

Below we present brief technical characteristic of selected standardized components.

PV module (fig. 10):

1. Module type AFP-255 ALTIUS, Romania;
2. Rated power - P_{PVmax} = 255 W;
3. Cell efficiency, η_C = 17,9-18,1 %;
4. Module efficiency, η_M = 15,7 - 16,0 %;
5. Open circuit voltage, U_0 = 37,1 V;

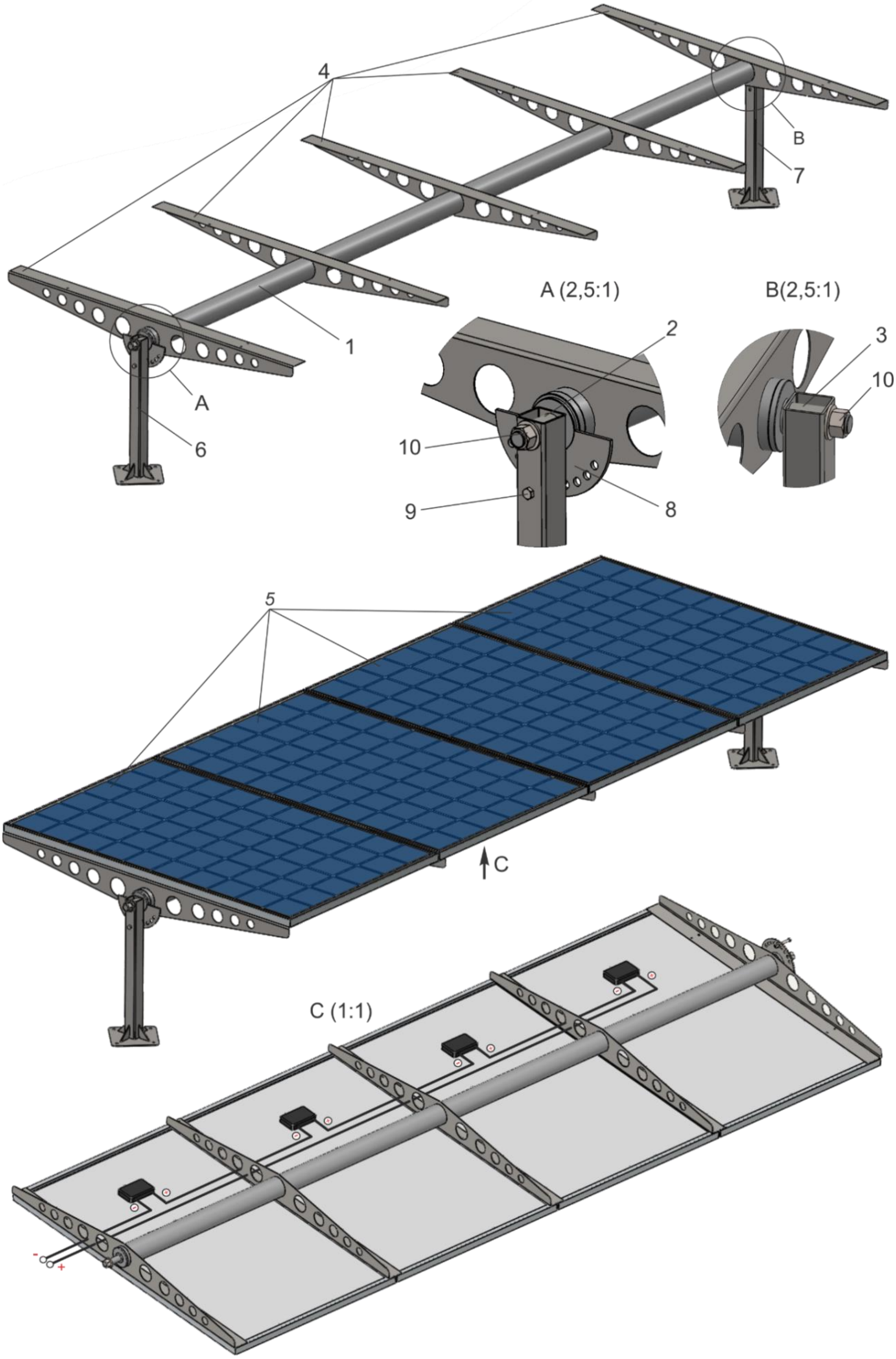


Fig. 9. Design of the PV photovoltaic system with rotary spindle discrete on seasons with 8 angular positions.

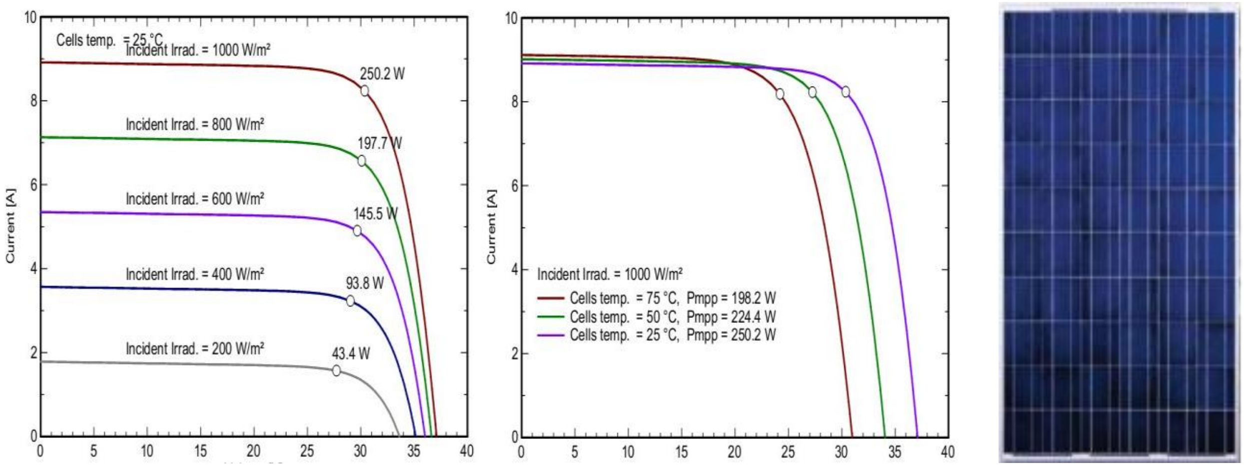


Fig. 10. PV module technical data.

6. Short circuit current, I_{sc} = 9,0 A;
7. Maximum power point voltage, U_M = 30,3 V;
8. Maximum power point, I_M = 8,43 A.
9. External dimensions 1640x992x40 mm.
10. Weigh 19 kg.

The total number of modules - 44, maximal photovoltaic panel power is equal to 11 kW. The PV module technical data is shown in Figure 10.

Solar Surface Pump System [10]

System Overview:

Head max. 40 m;
Flow rate max. 33 m^3/h.

Controller PS7k2

- Control inputs for dry running protection, remote control etc.;
- Protected against overload and overtemperature;
- Integrated MPPT (Maximum Power Point Tracking).

Power - max. 11,0 kW
Input voltage - max. 850 V
Optimum - V_{mp} > 575 V
Motor current - max. 13 A
Efficiency - max. 98 %
Ambient temp. - 30...50 °C
Enclosure class - IP54

Motor AC DRIVE CS-F 5.5kW

- Highly efficient 3-phase AC motor;
- Frequency: 25...50 Hz;

Motor speed - 1.400...2.850 rpm;
Power factor - 0,84;
Insulation class – F;
Enclosure class - IPX4.

Pump End PE CS-F20-5 (figure 11)

- Premium materials
- Optional: dry running protection
- Centrifugal pump

Fig. 11. Pump system PS7 k2 CS-F20-5.

Standards: 2006/42/EC, 2004/108/EC, 2006/95/EC, IEC/EN 61702:1995, IEC/EN 62253 Ed.1.
Figure 12 show the photovoltaic installation oriented to elevation integrated in the microspray

irrigation system, designed for the „*TriDenal”* Agricultural Enterprise, Criuleni (PV panels installed on the roof).

Fig. 12. Components of the photovoltaic plant with installed power P = 11 kW: *(a) - Mounting of PV panels in housings with ability of rotating around the central axis; (b) – the pumping station hall; (c) – the central water supply pipeline of the irrigation system.*

4. Conclusion

- The feeding of irrigation system has been optimized with renewable electricity. The most suitable for irrigation process is solar energy, the variation of which during the day coincides with the need for water consumption;
- It was designed, realized and implemented the microspray irrigation system integrated with photovoltaic installations (PV) developed for agricultural enterprise „*TriDenal”*, Criuleni.

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