POSSIBILITIES OF USING SOLAR ENERGY IN LAND IMPROVEMENTS

PhD thesis - Summary

to obtain the scientific title of Doctor at

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in the doctoral field of Ingeneering Sciences / Civil Engineering _

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Chapter 1. INTRODUCTION AND GENERAL PROBLEMS OF LAND IMPROVEMENT (WITH SPECIAL REFERENCE TO IRIGATIONS)

1.1. Land Improvements Facilities in Romania

1.1.1 General problems

The land improvements (Fig.1) represented for Romania's agriculture a real shield, given that of the 14.8 million ha of agricultural land, 9.3 million ha of arable land, of which the irrigable potential is 7.5 million ha according to some authors, namely 5.5 million ha after others. Long-term droughts over time have led to the irrigation arrangement of some 3.1 million hectares of irrigation at the level of 1989.

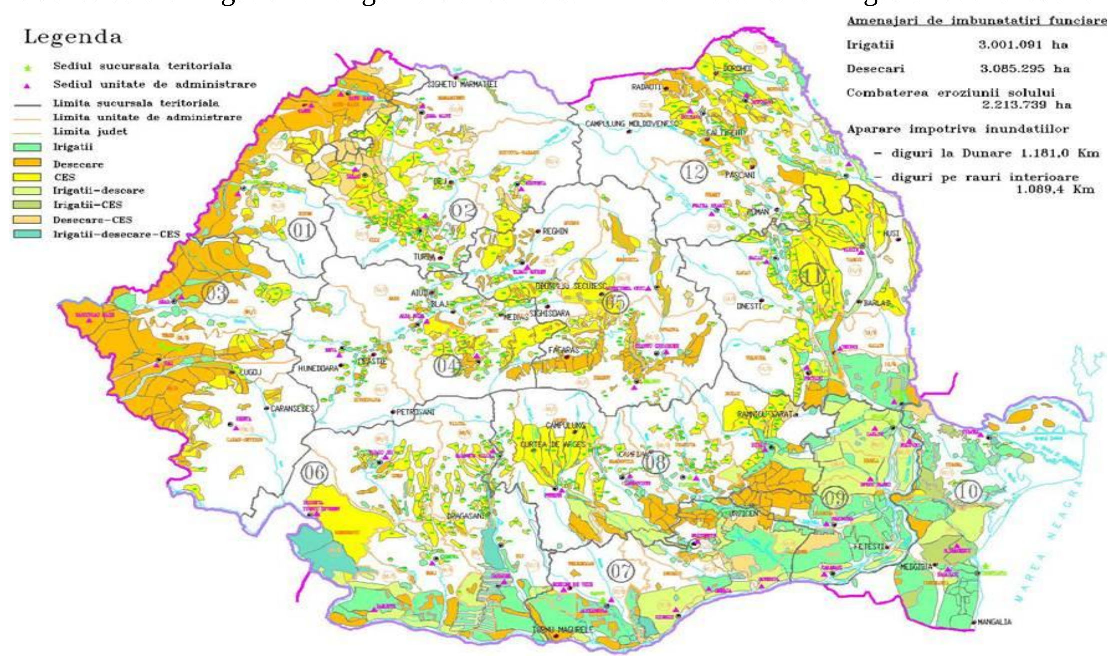

Fig.1 Location of land improvements in Romania and the 12 territorial branches of ANIF Bucharest [190]

Irrigation has a strategic importance for Romanian agriculture, being a factor for ensuring safe and high-yielding agricultural produce in the conditions of global warming, combating depopulation and environmental degradation, and at the same time supporting and developing rural areas. Irrigation facilities in Romania were mostly carried out between 1970 and 1989.

Until 1989 Romania had:

- 3.1 million ha for irrigation
- 3.1 million hectares with draining-drainage facilities
- 2.2 million hectares with soil erosion control

• 1180 km of defense dams at the Danube
• 1089.4 km to the inner rivers

All these facilities ensured Romanian agriculture a safe and stable production irrespective of the evolution of climatic conditions in that period.

The largest irrigated areas of the world in 2000 were in India (54 800 thousand ha), China (5402 thousand ha), USA (22 400 thousand ha) and Pakistan (18 090 thousand ha), Iran (7 500 thousand ha) ha), Mexico (7 500 thousand ha).

In Banat (Western plain, Timis County) in recent years, the following local irrigation facilities with private investments were designed / partially realized:

1. Arrangement of central pivots irrigation in the Mureşan drainage system, Sânnicolau Mare (490.94 ha)
2. Arrangement of irrigation in the North Lanca Birda drainage unit, Birda village irrigation system facilities in the drainage system of Răuţi - Sânmihaiul German, Cenei village, (1031.00 ha)
3. Arrangement of irrigation in the drainage system of Răuţi - Sânmihaiul German, Cenei village, Timiş County (290,00 ha)
4. Arrangement of irrigation in the Teba-Timişaţ drainage system, Otelec village (900 ha)
5. Arrangements for irrigation in the drainage systems of Rudna - Giulvăz and Ţeba – Timişat, Foeni and Giulvăz villages(471.60 ha)
6. Arrangement of irrigation in the Teba-Timisat drainage system, Otelec and Giulvăz villages(400 ha)
7. Arrangement of irrigation in the drainage system of Răuţi - Sânmihaiul German, Uivar village (923.84 ha).

In the thesis were presented: possibilities of financing land improvement works in Romania; specific legislation to Land Improvement Works in Romania; water requirements in irrigation and drainage installations - global drainage and one calendar year; pumping stations in Land Improvement arrangements and installed power; National Program for Rehabilitation of the Main Irrigation Infrastructure in Romania, according to Law no.269 / 2016 and SWOT Analysis of irrigation facilities in Romania (paragraphs: 1.1.3 - 1.1.8).

For small beneficiaries / farmers with areas up to 1 to 10 ha located in areas without electricity, it is opportune and necessary to use the financing possibilities for the purchase of mobile watering equipment (drip or sprinkle) and for the provision of electricity for the insurance water pumps to use photovoltaic panels. The main goal of the PhD thesis is the implementation of the future use of photovoltaic energy produced by the use of photovoltaic systems in order to pump water for irrigation to small, local plantations for vineyards, hazelnuts, blueberries, fruit trees and crops especially vegetables grown in the field or in protected areas (greenhouses and solariums).

In this context experimental researches were carried out on: estimation of the energy production of a photovoltaic system, experimental study of a directly coupled water pumping photovoltaic system (photovoltaic panels, solar cells, solar cell efficiency, solar panels, setting of electricity possibly obtained by photovoltaic conversion, graph of solar radiation evolution, solar radiation, orientation, angle of inclination, etc.).

1.1.2 The current situation of land improvements in Romania

Land improvements are complex and pedo construction works that aim to promote the integral and sustainable development of agriculture and rural areas, for which reason the protection of rural and agricultural areas against floods becomes a priority for the National Land Improvement Agency.

In its activity, the ANIF Administration has the obligation to exploit, maintain and repair the land improvements declared by the public utility; to make investments regarding the rehabilitation of existing land improvements and the construction of new developments; to realize and ensure the functioning of the national surveillance system, evaluation, forecasting and warning system regarding the economic and ecological effects of land improvement activities.

The use of solar energy in various applications has become increasingly large, the irrigation sector is one of its most appropriate uses, and more and more agricultural producers are turning to this solution, attracted by the fact that they no longer have any further costs related to energy or fuel, and the maximum amount of water is delivered just at times when it is most needed.

In addition during the cold season, after the irrigation interruption, the electrical energy obtained from the photovoltaic panels can still be used for powering the location that serves the farm, or even heating it.

Romania has one of the largest agricultural potential in Europe. Beyond the fact that the pollution of some agricultural land is still low, having a major advantage for organic farming, we also have a high hydrological potential. Unfortunately, due to the destruction of the old irrigation system and in the absence of coherence, or viable solution, much of the agricultural area has been deserted.

Also, the National Energy System (NPS) is the one that embraces all networks and power stations in the country, and even if it may seem expanded it is actually quite limited, especially when it comes to agriculture. In the same way, connecting costs and implicit bureaucracy often discourage farmers from making such connections, deprive them from the electricity required to put the water extraction pumps into operation.

1.1.3. Possibilities to finance land improvement works in Romania

The external pre-accession financing granted to ANIF was made through the SAPARD Program - Special Accession Program for Agriculture and Rural Development

The main external post-accession funding is included in the programs:

- ERDF - European Regional Development Fund
- EAFRD - European Fund for Agriculture and Rural Development
- ESF - European Social Fund

Within the framework of the EAFRD - European Fund for Agriculture and Development

1.2. Objectives of the PhD thesis

The objectives of the doctoral thesis proposed within this PhD thesis are the following:

- Making a complex, current and perspective bibliographic synthesis in the field of land improvements (historical, capacities, current organization, national strategy, sources of financing, specific legislation in the field of water improvements, irrigation needs, etc.)
- Making a bibliographic synthesis in the field of solar energy
- Presentation of the theoretical bases of the conversion of solar energy into electrical energy
- Evaluation of solar resources in the western region in order to use solar energy in water pumping for irrigation
- Implementation of experimental research by realizing an experimental stand for the study of the efficiency of water pumping using the direct coupling photovoltaic - pump
- Numerical modeling of solar energy resources
- Modeling the direct coupling pump - photovoltaic mode
- The graph of the evolution of solar radiation
- Determining the amount of electricity that can be obtained by photovoltaic conversion

- Achieving a database of achievements in the world and in our country to use solar energy to pump irrigation water

- Inventory of the main photovoltaic panels and some world-made facilities

- Designing new research directions on the use of solar energy in land improvements.

Chapter 2. RENEWABLE ENERGY SOURCES

2.1. Hydropower

Hydropower is represented by hydraulic energy, thermal energy of the seas and oceans, and hydrogen energy.

2.1.1. Hydraulic energy

Hydraulic energy was the first form that man converted into other forms of energy, including electricity. The hydraulic power of the rivers has become a conventional form of energy, and the other forms (of waves, tides, and sea currents) have begun to be of interest only with the onset of the energy crisis in 1972, although concerns are older.

Hydraulic energy can take several forms:

- The wave energy
- Hydra tidal energy
- The hydraulic energy of the sea currents

2.1.2. Thermal energy of seas and oceans

On the surface of the seas and oceans, in tropical areas the water temperature reaches 30-350C, and at depths of 500m it decreases to 60C and at 1000M to 40C. The temperature difference between the surface and 100 m is enough to put into operation a thermal engine. For this, fluids are used which boil at the temperature of the surface water and condense at the temperature of the deep water, such as: freon, ammonia, propane, etc.

2.1.3. Energy from hydrogen

As hydrogen is currently produced only from the water, we included this resource throughout the hydropower.

In the eco-economy, it is estimated that hydrogen will be the fuel of the future that will replace petroleum, just as petroleum replaced coal, as coal replaced wood. However, for the time being, the use of hydrogen as an energy resource still has many economically, technically and technologically unsolved problems. Problems also arise in hydrogen production, storage, transport and, of course, its final use.

2.2. Solar energy

The solar radiation flow reaching the terrestrial surface has an energy potential corresponding to the impressive sum of 172 billion GW, which means about 20,000 times more than the energy consumption in 2000.

This energy source could permanently ensure the need for ever-increasing consumption. However, viewed from the practical point of view and from the real volume that can be used, this becomes a particularly complex problem, complexity that resides in three directions:

- uneven distribution across the globe and dependence on geographical location, including climate;
- alternating days with nights creating discontinuities;
- Low density of energy flow (up to 1400 W / m2), which requires the use of large catchment areas, which means land removal, including agricultural use, as well as high costs.

Solar energy interests sectors like: home heating, agricultural irrigation and greenhouse heating, and the heating industry.

2.3 Wind power

There are four reasons why wind energy deserves special attention: it is found abundantly, it is cheap, it is unusable and it is clean.

Wind power is used through the windmills, which has been built since the Middle Ages in the Iberian Peninsula and the North Sea coastline. In the last century, the first "huge windmills" were built to produce electricity; their maximum efficiency being about 60%, but the average is 35%. Wind generators should be located in areas with strong winds (minimum 5m / s).

The installed global capacity increased rapidly from 10 MW in 1980 to 6000 MW in 1997 and over 40 000 MW in 2004.

2.4 Geothermal energy

Geothermal energy is generated by the radioactive decomposition of some substructure elements and can be used in geothermal power plants and heating.

Warm or hot baths have been used for thousands of years, the most experienced in this field proved to be Romanians, through the famous therme. Today, geothermal is a variety of uses, ranging from electricity to heating to dwellings, public, commercial and tourist spaces.

2.5.Energy from biomass

The biological conversion of solar radiation through photosynthesis annually provides biomass energy reserves at 3 x 1021 j / year.

Currently, biomass provides 6-13% of the world's energy requirement, equivalent to approx. 8.5 million barrels of petroleum per day.

The main biofuels are ethanol and biodiesel, as well as liquid fuels and biogas. Ethanol is made from sugar cane, corn, wheat, barley, sugar beet, prairie grass and poplar, and biodiesel is produced from rape, soy and palm oil.

In the field of electricity, recent research has demonstrated the viability and efficiency of small scale generators, including those with unconventional energy, which are closer to consumers as a power and distance.

Innovations in electronics, information technology, as well as energy storage solutions allow the formation of dispersed energy systems based on unconventional sources such as the ones below.

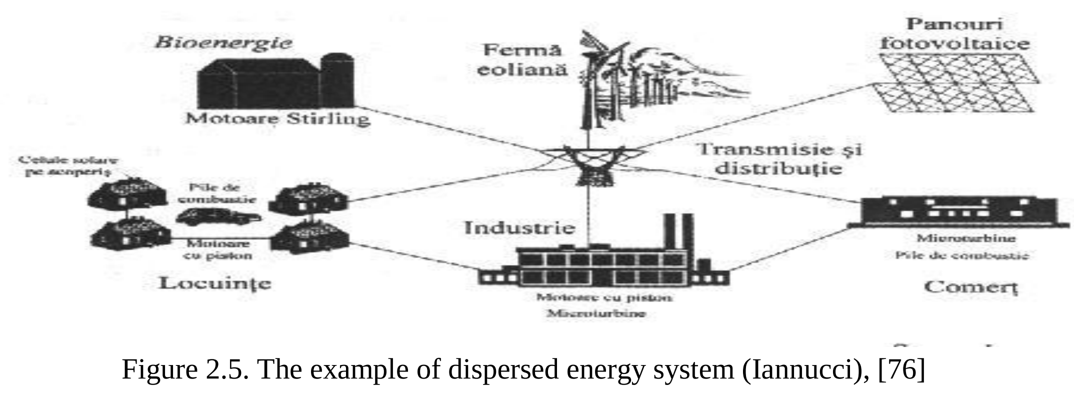

Figure 2.5. The example of dispersed energy system (Iannucci), [76]

The high costs, specific random and intermittently of one of these energy sources make some of them a far-off alternative or, in other words, when there is no alternative, and the technologies of capitalization will be more advanced than current ones, and , of course, cheaper. However, the prospect of capitalizing on other forms of energy (unconventional energies) is very close, as they are also the energy hope of mankind.

Chapter 3. Worldwide developments (producing companies, photovoltaic panels - features, accumulators, water pumps, irrigation, etc.). Examples.

3.1. Photovoltaic panels, photovoltaic panels - features

The world's leading photovoltaic cell manufacturers are Chinese and Taiwanese companies. The No. 1 in the Top 10 is Suntech Power, a Chinese company that was in second place in 2009, with its production capacity doubling from one year to the next, according to “La Tribune” daily.

At local level, the company "Eetim" Timisoara offers photovoltaic systems, electrical panels and automation equipment from Schneider Electric, and solutions for the use of solar energy for water pumping for irrigation.

3.2. Examples of local irrigation systems using solar energy

3.2.1 Irrigation system with solar pumps

The principle of running such an irrigation system is simple. Solar panels feed the pump that pulls water out of the underground or from a nearby source on the surface. In (Fig.4.5) we have presented two systems for pumping water from drillings, rivers, lakes, etc., intended for water supply of farms, irrigation systems, fishes or any applications that require pumping water in areas where there is no electricity grid.

Fig.4 Photovoltaic panel view and irrigation network to a plantation of fruit trees [203, 204]

Fig. 5 Photovoltaic panel view and electric generator to provide the pump irrigation water to a vine plantation [203, 204]

3.2.2. Drip irrigation or irrigation channels

Modern irrigation systems use the pressure to bring water and distribute it through pipelines directly to the crop root. The combination of photovoltaic systems with submersible pumps is used in isolated areas without connection to the power grid. Water is distributed directly from the pump or from a gravitational retention basin. For irrigation channels we need a high flow and low pressure pump.

3.3. Applications for Irrigation Systems - examples

These irrigation systems are used for: plant cultivation (cereals, vegetables, mushrooms, fruits, grapes / vine, fruit trees and shrubs, technical plants, fodder plants, herbs, forestry, gardening, planting material;

3.4. Solar water pumps in agriculture

Solar water pumps represent a reliable solution to the farmer's problems face in order to ensure the flow of water irrigation and they can also be used in animal husbandry, fish farming or other fields.

Solar water pumps can be submersible or surface.

The main types of solar water pumps are:

1. Submersible Solar water pumps
2. Solar water -mixed pumps
3. Surface solar water pumps

3.5. Results of studies on photovoltaic solar water-pumping systems.

3.5.1. The performance of photovoltaic solar water-pumping systems

In a similar work, a pumping system using an induction motor pump that is capable of delivering a daily average of 50 m^3 at a height of 37 m was developed by Daud and Mahmoud, which was installed in a desert pit in Jordan where the average solar radiation available is 5,5 kW h/m^3/ day. Long-term field testing of the system has shown that the system is safe and has a general efficiency of more than 3%, a result comparable to other studies reported with the highest efficiency for photovoltaic solar water-pumping systems.

3.5.3. Types of engines and pumps

Worldwide there are several types of DC motors (eg brush and permanent brushless magnet, variable resistance switch) and AC motors (synchronous and asynchronous) are available for solar water-pumping solar systems [Short TD, Oldach R.2003]. Engine selection depends on size, efficiency, price, reliability and availability. DC motors are attractive because they can connect directly to photovoltaic arrays. DC motors are not suitable for high power applications (over 7 kW), if an AC induction motor is required with a DC-AC inverter using an inverter will result in extra costs and energy loss.

Chapter 4. SOLAR ENERGY PHOTOVOLTAIC ENERGY SOURCE FOR IRRIGATION WATER SUPPLY

4.1. Solar energy

Solar radiation is an electromagnetic radiation emitted by the Sun, placed in the spectral range between the X-ray and the radio waves. The terrestrial applications of energy obtained using solar radiation are based on radiation called generic "optical radiation" with a spectral range between 0.3 and 4 μm.

Integrating the wavelength of the extraterrestrial solar spectrum (from 0 to ∞) is known as the solar constant or AM0 spectrum.

Since solar flux is not constant but slightly vary over short (daily) or long (years) (Frölich, 1998), in the last years, a much better name was introduced for the solar constant, namely Total Solar Irradiance-TSI. Since 1978, TSI variations have been monitored from space with broadband radiometers. The precision of these instruments is at least one order of magnitude greater than that of instruments used to measure the spectral distribution of extraterrestrial solar radiation.

The science that deals with the measurement of electromagnetic radiation from the Sun is called radiometry.

Radiometers consist of: the radiation detector and electronic circuits assembled in the so-called body of the instrument. For instruments whose primary purpose is to measure short wavelength radiation, the detectors are of three types: thermopiles, perfect absorbent materials, and semiconductor materials. Detectors have a spectral response known to the incident radiation.

The total incident radiation incident on a horizontal surface resulting from the sum of diffuse and direct radiation is called global radiation. The global term comes from the fact that the incident radiation on a horizontal surface comes from the entire vault, from a solid angle equal to 2π. The difference between global radiation at ground level and radiation at the upper limit of the atmosphere lies in the amounts absorbed and reflected by the atmosphere. On average, Earth reflects back into space, about 29% of the incident solar radiation.

The spectral distribution of extraterrestrial solar irradiation graphically represented in Figure 3.1 is modified and separated into a variety of components when passing through the different layers of Earth's atmosphere.

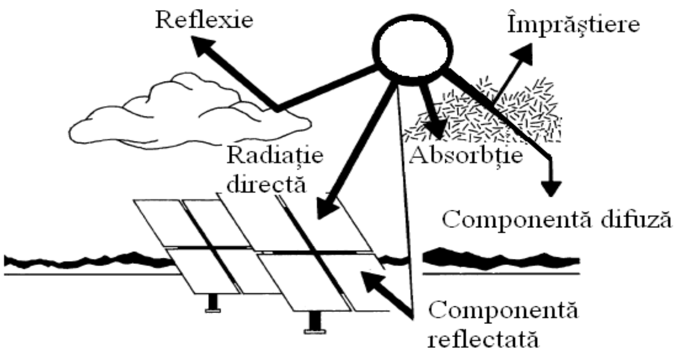

Figure 4.1. Separation of solar radiation in interaction with atmosphere and soil

Total solar radiation incident to a non-horizontal surface is the sum of the direct, diffuse radiation and the radiation reflected by the soil.

In solar power, at ground level, the major solar radiation-specifics are defined as:

- G [W / m2]- Global solar radiation represents the total incident solar energy in one second on a unitary, horizontal surface.
- G_d [W / m2] - Direct-normal solar radiation represents the solar energy coming from the solid angle below which the solar disk is seen, incidence in the unit of time on a normal unitary surface at the direction of the sun.
- G_d [W / m2] - Diffuse solar radiation is the solar energy transmitted by the entire visible surface of the sky, received at ground level on a horizontal, unitary surface, in the unit of time.

4.2. 1.Measurement of solar radiation

Since solar radiation monitoring databases are used to improve solar radiation models, the essential aspects of solar radiation, solar radiation components in the earth's atmosphere, and the devices used to measure these components will be discussed. The accuracy of these measurements depends on how well the instruments are performing, the calibration techniques and their periodic checking.

Measuring the sun's shining duration in the sky is to determine the time when the density of the direct solar flux is superior to a certain value, unique, established by international convention. The constant accepted today internationally was set in 1982 by the World Meteorological Organization at 120 W / m2 (WMO, 1983).

Devices measuring the effective sun's shining duration are called heliographs. There are two common parts of all the heliographs: the transducer that senses the threshold of direct radiation at 120W / m2 and the time recording system.

Pyranometers are instruments that measure the density of global solar flux.

4.2.2 Solar energy resources in the Banat area

Solar radiation falling on the soil varies with daytime, but may vary considerably depending on location, especially in mountain areas. Solar irradiation varies between 1000KWh / m2 per year in northern European countries and 2000-2500 KWh / m2 per year in dessert areas. These variations between locations are given by latitude differences and weather conditions.

An imperative condition for the correct dimensioning of photovoltaic solar systems, including water pumping, is the knowledge of the amount of collectable solar energy [122] (Paulescu et al., 2013). A complete knowledge of the available solar energy in a location not only means its characterization by its total value, but also the knowledge of the temporal distribution and its nature (direct or diffuse). Most countries have created solar radiation measurement networks, but investment and maintenance costs for each radiometric station are not negligible.

The uncertainty present in the radiometric data available for the Banat Plain is further analyzed. Twelve monthly average values of global solar irradiation are the most accessible information available, and are widely available and in the coming years the situation may not change.

• To know the amount of solar energy, data from different sources for the Banat plain region is taken. For this, the monthly average values of global solar irradiation provided by five international databases for Timisoara are evaluated and compared:

• 1.World Radiation Data Center (WRDC) (http://wrdc.mgo.rssi.ru/). WRDC collects data from the largest solar radiation monitoring network developed within the World Meteorological Organization

2. Photovoltaic Geographic Information System (PV-GIS): http://re.jrc.ec.europa.eu/pvgis/ PV-GIS is a research tool for the evaluation of solar resources in Europe.

• 3. Solar Database (SODA): http://www.soda-is.com/ SODA is a service provided by MINES ParisTech - ARMINES. SODA is the result of an effort to connect different satellite databases to a unique web server that provides data on solar radiation and other relevant information.

• 4. NASA Surface Meteorology and Solar Energy (SSE): http://eosweb.larc.nasa.gov/sse/ SSE is a large data base with over 200 meteorological and radiometric parameters derived from satellite observations

• 5. The SolarRadiation Monitoring Station (SRMS): http://solar.physics.uvt.ro/srms

• SRMS is part of the Solar Platform from the West University of Timisoara.

The solar energy available in the Banat Plain. Using data available online (those that are practically accessible to any engineer involved in solar projects), we calculated monthly averages of daily global solar irradiation provided by each of the five databases. The results are presented in Figure 3.10. The analysis of the figure shows significant differences between the values provided by the five bases. As a result, we can conclude that the assessment of the solar resource is an important source of uncertainty in the design of water pumping systems. The results in figure 3.10

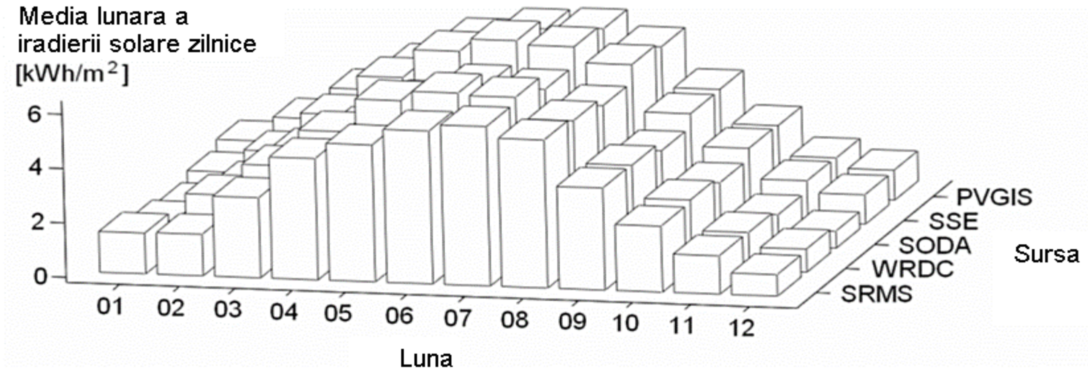

Figure 4.10. the monthly average of daily global irradiation in Timisoara. For the same location, Timişoara, different data bases provide different values of solar irradiation [152] (after Turi et al., 2015)

4.4. Solar water pumping systems

4.4.1 The Principle of Operation of PV Pumping Systems

The photovoltaic water pumping systems (SPVP) consist of a series of photovoltaic panels, an engine and a pump (Figure 3.20). Depending on the design, the system contains or does not contain electrical energy storage batteries and charging regulator. The engine is chosen according to the power required and the nature of the electrical current supplied by the system. If the motor uses alternating current, an inverter needs to be installed. SPVP without energy storage is more economical, requires less maintenance compared to battery systems. Adding a water storage tank to SPVP is a more economical method of storing energy than using a battery. The use of photovoltaic solar energy is considered to be an important resource for the western region of Romania where direct solar radiation can reach up to 1000 W / m2.

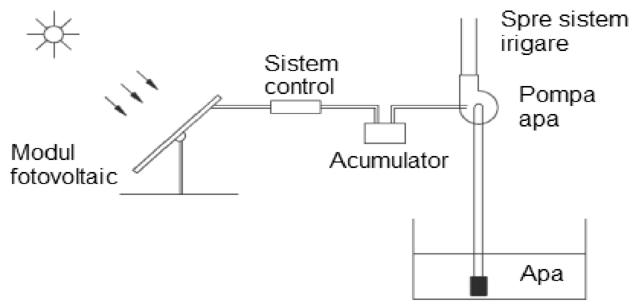

Figure 4.20. Sketch of a photovoltaic water pumping system

Chapter 5. EXPERIMENTAL RESEARCH ON PUMPS COVERED DIRECTLY WITH THE PHOTOVOLTAIC GENERATOR

In this part of the thesis are presented the main results obtained during the research conducted in the doctoral program. Both, the experimental results and those obtained in the numerical modeling of the physical phenomena involved in the water pumping process are analyzed and discussed. These results were reported in four scientific papers as follows.

The paper Balaj et al. (2015.a) [15] deals with the study of the correlation between solar radiation and energy production of an autonomous photovoltaic system, energy intended to supply water pumping systems. Research has been geared to two directions: the estimation of global solar irradiation at ground level as a prerequisite for the design of a photovoltaic system and the determination of the conversion efficiency of a photovoltaic module under real operating conditions. Using data measured on the Solar

Platform, semi-empirical procedures have been established and validated for estimating monthly solar energy and the conversion efficiency of a photovoltaic module. Based on the analysis of the results, it can be concluded that the proposed procedures can be feasible solutions for sizing the photovoltaic generator for powering the water pumping systems. Since the location of Timişoara was arbitrarily chosen, it can be estimated that the proposed procedures can be successfully applied to the dimensioning of solar irrigation systems in the Banat Plain. The results obtained are presented in section 4.1 of the thesis.

5.1. Estimation of the energy production of a photovoltaic system

Figure 4.1 illustrates the scheme of a powering water pumping system. There are two major difficulties facing an engineer engaged in a design project for such a system. First of all, the question arises: how accurate does the model reproduce the actual value and timing distribution of solar energy collected? Second, under real weather conditions, solar irradiation and ambient temperature vary continuously. As a result, the current-voltage characteristics of photovoltaic modules under conditions also change continuously. However, the current-voltage characteristics of photovoltaic modules are provided by manufacturers only under standard operating conditions (STC). In spite of the abundance of models adapting catalog parameters of photovoltaic modules measured at STC to actual external weather conditions (an example is given in Section 3.3.3 of the thesis), the engineer faces the dilemma of choosing the appropriate translation model, able to operate with accuracy in the geographic area of interest.

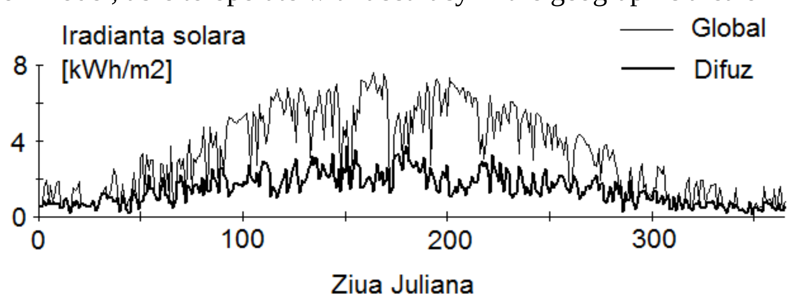

Figure 5.1. Daily, global and diffuse solar irradiation, measured on the Solar Platform, in 2009

In the work Balaj et al. (2015a) [15] results are reported in assessing the availability and quality of measured radiometric data and the influence of meteorological parameters on the operation of a photovoltaic module. Procedures are also established for the estimation of collectible solar energy and for the assessment of the photovoltaic conversion efficiency. The results can be considered as a useful tool for designing and evaluating the performance of an autonomous photovoltaic system installed in the Banat Plain to supply a water pumping system.

Availability of solar energy. Measurement of solar radiation involves local or global radar stations. Like most countries, Romania has set up a national global solar radiation monitoring network on horizontal surfaces that provides data to the Global Radiation Data Center (described in section 3.2.2 of the thesis). These data are measured in the national meteorological network, which includes more than 150 weather stations. Of these, only 35 are equipped to monitor global solar irradiation and only 8 of them have a long-term data base for global solar irradiation.

In this study, measured data were measured at the Solarium Solar Monitoring Station of the Western University of Timişoara (http://solar.physics.uvt.ro/srms), also described in Section 3.2 .2 of the thesis. The measurements were carried out over the entire day at an equal interval of 15 seconds.

Figure 5.2 illustrates the global (Hg) and diffuse (Hd) solar irradiation measured over 2009 on the Solar Platform. Table 4.1 summarizes the daily monthly average of global and diffuse solar irradiation calculated from the daily data series. In 2009, the annual average of global radiation in Timisoara was 3.34 kWh / m2.

Table 5.1. The monthly average of global and diffuse solar irradiation, calculated from what measured in 2009 on the Solar Platform

Month	01	02	03	04	05	06	07	08	09	10	11	12
$\bar{H}_g$ [kWh/m2]	0.92	1.63	2.72	5.01	5.43	5.35	6.13	5.07	3.85	2.01	1.19	0.64
$\bar{H}_d$ [kWh/m2]	0.62	0.94	1.52	1.84	2.31	2.30	1.94	1.96	1.64	1.13	0.64	0.44

Operation of PV modules in real conditions. The results of solar panel monitoring of a 90 W commercial photovoltaic module have shown a net difference between the efficiency measured under real weather conditions and that measured under standard test conditions. This means that when a photovoltaic module is sized using the catalog sheet yield, it can overestimate energy production by up to 30%.

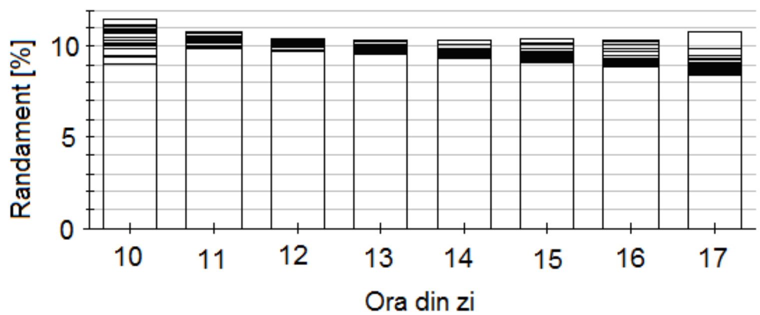

Figure 5.2 Effective photovoltaic module estimated each hour between 10am and 17pm during April 2011

Such an error in design would lead to a water pumping system with a lower flow and volume than required in the application

The results below are intended to solve the presented problem. The results are based on experimental data acquired in April of 2011 on Solar Platfom. The experimental assembly consists of a photovoltaic module FVG90M (FVG 2009), which was directly connected to an active load. Voltage, current and temperature system were monitored continuously. At the same time, total solar irradiation was measured in the direction of the module, on a plane inclined 45 degrees southwards relative to the horizontal surface. The data were recorded with four samples per minute, with each channel recording 84400 measurements.

Figure 5.2 shows the efficiency of the photovoltaic module under real operating conditions, based on the hourly data recorded between 10 AM and 17 PM every April. It is noted that the efficiency of the module is varied from one day to the next day, but also suffers from hourly variations within a day. The efficiency of the photovoltaic module calculated hour by hour based on the direct recordings of the supplied current and voltage and the solar irradiation ranges from 9% to 11.5%, far from the efficiency obtained under standard test conditions of 14.05%.

The experiment reveals the importance of accurately estimating the parameters of a photovoltaic module operating under real weather conditions. But in Romania, the equipments for testing photovoltaic modules operating under real weather conditions are very rare. Thus, numerical methods have become a practical alternative, especially due to much lower costs than laboratory testing.

5.2. The experimental study of a directly coupled water pumping photovoltaic system

The work Balaj et al. (2015b) [16] presents the results of the experimental study of a water pumping system coupled directly to a photovoltaic module. The direct connection of the photovoltaic module to the water pumping system is the cheapest commercial solution. Generally, the system consists of a photovoltaic module directly connected to a DC motor of a centrifugal pump. Due to its simplicity (not including batteries and control system) such a system is simple and reliable.

The experimental stand was built on the Solar Platform of the West University of Timisoara and is briefly described in the next section. The pump was monitored during five months, during the spring and summer months, during which the crops were irrigated in the Banat plain. The system has been evaluated from two different perspectives: (1) the volume of pumped water and its distribution in time; and (2) the influence of the solar radiation regime on the performance of the system. The first perspective is essential in dimensioning the mode (or the series of modules) directly coupled to the water pumping system to ensure its optimal operation in the Banat plain. The second perspective provides an overview of the case study with the aim of generalizing the obtained results.

5.2.1 Experimental stand

The experiments were carried out at the Solar Platform of the West University of Timisoara (http://solar.physics.uvt.ro/srms). The Solar Platform includes a Solar Radiation Monitoring Station (SRMS) and three experimental stands dedicated to PV module testing. The Solar Radiation Monitoring Station is equipped with first-class DeltaOHM pyranometers in accordance with ISO 9060. The platform monitors global, diffuse, reflected, and total solar irradiation. Measurement of all parameters (electrical, meteorological, radiometric) is performed simultaneously at equal intervals of 15 seconds, 24 hours per day.

Figure 5.3 shows the experimental installation used to test the photovoltaic system directly coupled to the water pumping system. Figure 3.6 shows two pictures illustrating the main components of the system: PV module and water pump. The experimental assembly consists of a SHURflo 2088-403-144 photovoltaic pump powered to a PV module FVG90M. The main characteristics of the photovoltaic pump and of the PV module are presented in Table 5.2 and Table 5.3.

Pyranometer G in Figure 5.3 measures solar irradiation on the surface of the photovoltaic module. T is a thermal sensor for measuring ambient temperature. The R-resistor has the role of limiting the current, which is used to protect the module when the sun shines loudly. The water is pumped from a reservoir to another tank located at a 4.5 meter level difference from the first tank. From the second tank the water flows to the first tank under the action of gravity. Thus, the water circuit is a closed circuit. The volume of pumped water is measured through the flowmeter D. All sensors are integrated into a NI PXI data acquisition system located in the PV lab. The transmission of information between the Solar Platform and the data acquisition system is performed in the current 4-20mA.

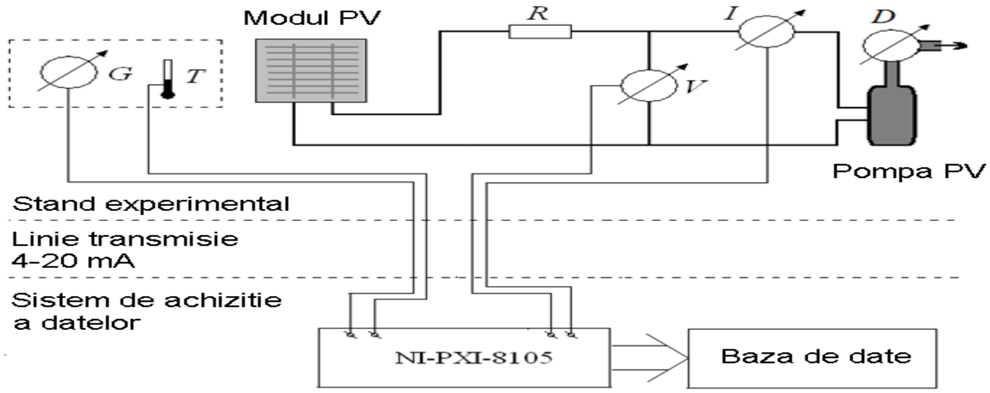

Figure 5.3. Schematic of the experimental installation for studying the directly coupled water pumping photovoltaic system: G - is a pyranometer for measuring solar irradiation on the surface of the PV module; T - is a thermal sensor for measuring ambient temperature; D - is a standard flowmeter.

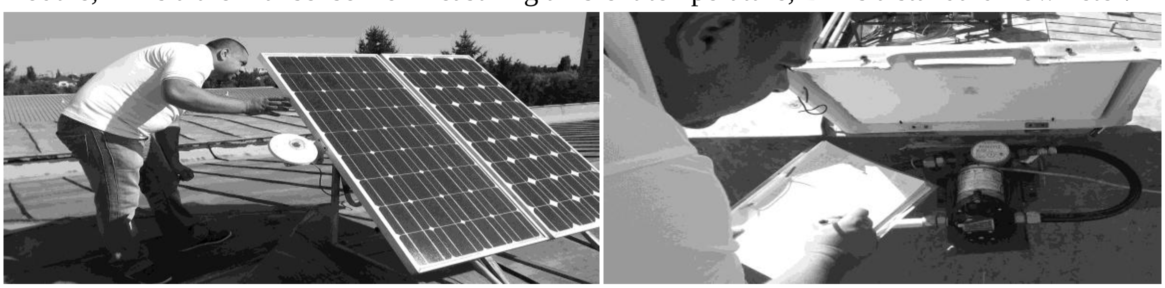

Figure 5.6. Photographs of the experimental installation used to study a photovoltaic system coupled directly to a water pump: (a) the PV FVG90M (on the right) PVPYRA 02 module and the LPPYRA 02 pyranometer for measuring solar irradiation on the module surface; (B) water pump SHURflo 2088-403-144.

Table 5.2. The main features of the SHURflo 2088-403-144 pump

Type	Positive displacement 3 chamber diaphragm pump
Operation	One way operation, check valve
Voltage	12V DC nominal
Pressure switch	3.1 bar Shout-Off, Turn On 1.7±0.35 bar
Motor	Permanent magnet
Performance	Open/10.6/3.1
(pressure [bar]/debit [l/min]/current [A])	0.7/7.8/3.7; 1.4/6.2/4.2; 2.1/4.7/4.5; 3.5/2.2/4.5

Table 4.3. The main features of the PV FVG 90M module

Nominal power	90W
Open circuit voltage	22.3 V
Short-circuit current	5.37 A
Tension in MPP	18.5 V
Current in MPP	4.86 A
Thermal coefficient of voltage	- 0.0034 $°C^{-1}$
In open circuit	0.0005 $°C^{-1}$
Noctua	45 ± 2 °C
Module surface	0.596 m^2

5.2.3. Experimental results

Experimental assembly has been monitored for five months from April 25, 2013 to September 30, 2013. This period covers the required irrigation period in the western part of Romania. Meteorological and radiometric measurements were automatically recorded while the flow meter was read in the morning before the pump started. This study looked at the behavior of the pumping system from two perspectives: the volume of pumped water and the dependence of this amount of water on the solar radiation regime.

Figure 5.7 shows the cumulated volume of pumped water during test period according to the Julian day. It can be seen that the cumulated water volume varies approximately linearly according to the Julian day.

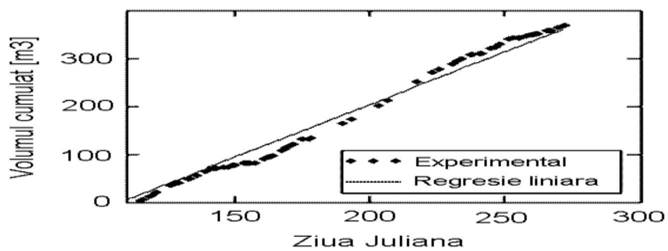

Figure 5.7 Cumulative volume of water pumped during the test period.

The daily variation of the pumped water volume is approximated by linear regression:

$$V = 2.2 \cdot j - 235 \qquad (5.16)$$

where V is the pumped volume, and j> 120 is the Julian day. During the test period, the total volume of pumped water was 369.2 m3, which is a daily average of 2.33 m3 / day. Table 5.4 shows the data on the volume of pumped water month by month and the daily value average. The maximum volume of 91.3 m3 was reached in July, which is a daily average of 2.94 m3. This is due to the fact that in July most days were completely sunny (□ m = 0.762). The highest value of the daily average of solar irradiance Hm = 458.2 Wm2 was reached in July. In May and June, the volume of pumped water was about 2/3 compared to the one pumped in July.

The volume of pumped water can not be directly associated with relative sunlight. On the other hand, since solar irradiation depends heavily on the season, even if every day of January is sunny, the volume of pumped water will be lower than in July.

The data presented in Table 5.4 demonstrates that the monthly volume of pumped water depends in a complex manner on the monthly average of solar irradiation, relative sunshine and the number of hours of the day.

We continue to focus on the daily variation in the volume of pumped water. In an experiment on April 25, 2013, we set a threshold value (at which the pump starts / stops)of total solar irradiation on the surface of the photovoltaic module of HS = 450 W / m2. This means that when the total solar irradiance is less than 450 W / m2 the pump does not work, it starts at 450W / m2 and the water flow increases with the increase in solar irradiation.

Table 5.4 Different monthly values of the measured physical quantities: the volume of pumped water (V); the daily average of the volume of pumped water (Vm); the daily mean of relative sunshine; day average of total solar irradiation (Hm).

Month	May	Jun	Jul	Aug	Sept
V [m^3]	58.5	60.4	91.3	88.4	48.4
V_m [m^3/day]	1.88	1.94	2.94	2.85	1.61
Hours of day [hours]	14.9	15.6	15.3	14.1	12.5
σ_m	0.494	0.504	0.762	0.704*	0.465
H_m[W/m^2]	382.5	351.7	458.2	440.1*	364.3

The performance of the water pumping system coupled directly to the photovoltaic module depends on the relative position of the sun and clouds. As defined in equation (5.14), SSN is a suitable parameter to describe the relationship between pump performance and the state of the sky. The dependence of the volume of water pumped daily according to the solar radiation regime is illustrated in Figure 4.8. The minimum volume of water was pumped on June 12 V = 0.30 m3, a cloudy day ($\overline{SSN} = 0.014$), with a short period of time in which the sun shone. The maximum volume of water was pumped on June 20, V = 3.49 m3, an almost serene day ($\overline{SSN} = 0.930$). The days of 11 June and 13 June were characterized by the same degree of sky coverage ($\overline{SSN} = 0.763$ and $\overline{SSN} = 0.749$). However, the volumes of water pumped these days were different: V = 1.66 m3 on June 11 and V = 3.05 m3 on June 13. As shown in the corresponding graphs in Figure 4.8, the difference is made by the stability of the solar radiation regime.

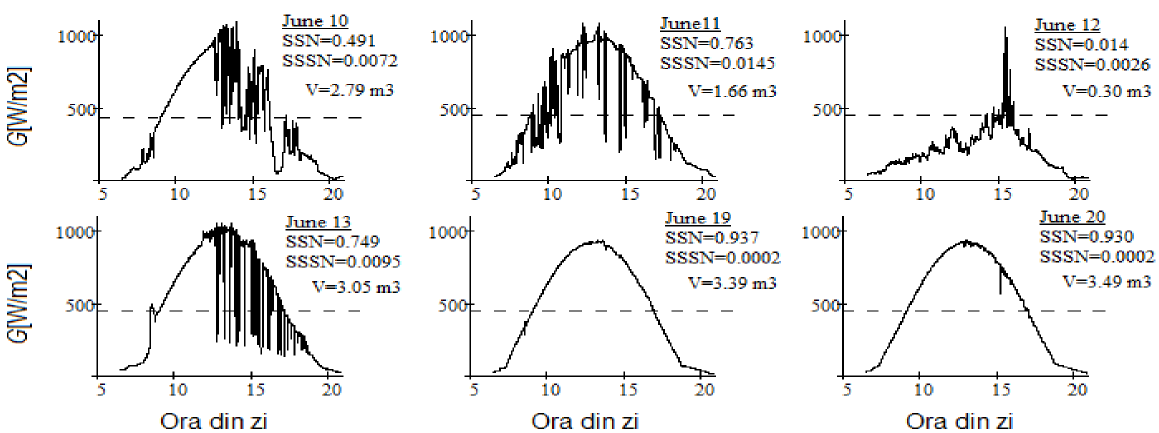

Figure 5.8. Total solar irradiance measured on the surface of the PV module over time in six days of June 2013. The Daily Sunrise Indicator (SSN) daily average sunshine stability (SSSN) value and the volume of pumped water are shown on the graphs . The dotted line indicates the threshold value of solar irradiation from which the pump starts.

Thus, 11 June was characterized by high instability ($\overline{SSSN} = 0.0145$) while June 13 was characterized by moderate instability($\overline{SSSN} = 0.0095$). Even though June 10 was a less stable day than June 11, the volume of water pumped on July 10 was significantly higher than on June 11.

In conclusion, the case study presented in Balaj et al. (2015.b) [16] illustrates the performance of a water pumping system coupled directly to a photovoltaic module. The experimental results highlight the amount of water that can be pumped with this system and the dependence of this volume on the characteristics of the local solar radiation regime.

5.3.3. Modeling the operation of a directly coupled water pumping photovoltaic system

In the work Balaj et al. (2016) [17], the experimental data collected in the experiment described in Section 4.2 of the thesis are analyzed from a different perspective, namely the estimation of the water flow according to the total solar irradiance measured in the photovoltaic plan. The empirical model developed and the procedure for obtaining it are novelties and are described below. Tests on model performance revealed excellent accuracy when estimating the volume of water pumped daily.

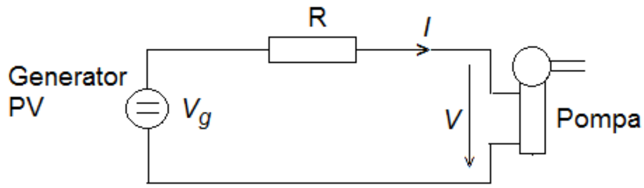

Figure 5.9. Simplified electrical circuit of the pumping system

Figure 5.9 shows the simplified circuit diagram of the photovoltaic generator - pump system (shown in detail in Figure 5.5). Resistance R = 2Ω has the role to limit the current through the pump, ensuring them protection when the sun shines and is strong in a direction close to the normal to the surface of the photovoltaic module. We write down with *I* the current through the circuit, with the V_g voltage at the photovoltaic module terminals and with the V voltage at the pump terminals. Obviously, the three sizes are correlated with Ohm's law:

$$V_g = V + IR \qquad (5.17)$$

In relation (5.17) the current *I* and the power of the photovoltaic generator $V_g I$ are solar irradiation functions.

5.3.4 Water flow

This dependence was determined in a separate laboratory-assisted experiment. Instead of the photovoltaic generator, an adjustable voltage source has been used which has allowed successive variations in the absorbed power by the pump. Otherwise the pumping conditions (the difference in level) were kept the same as those in the experiment monitored under external conditions. Experiment points and curves are represented in Figure 4.12. There is a much smoother variation in the pumped water flow depending on the absorbed power by the pump than on the current.

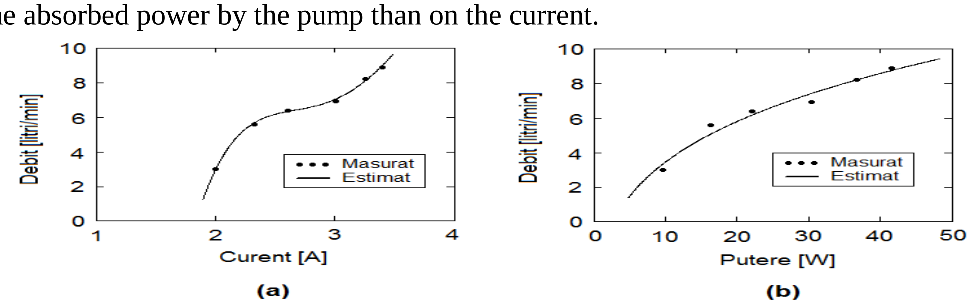

Figure 5.12. Water flow according to (a) pump current and (b) power absorbed by the pump

The equation of the water flow curve according to the pump current is (r2 = 0.998):

$$D(I) = -288.3694 + 391.6104I - 193.137I^2 + 41.6497I^3 - 3.2806I^4 \quad (5.18)$$

and the equation of the water flow curve according to the power absorbed by the pump is (r2 = 0.966):

$$D(P) = -8.8921 + 6.9521P^{0.25} \quad (5.19)$$

Since in photovoltaic mode, in terms of total solar irradiation, the generated power suffers a lower dispersion than the current, equation (3.19) was used in the model.

5.4. Calculation of the need for photovoltaic panels for different crops and irrigated surfaces (for design)

5.4.1.The elements of the irrigation regime

In order to calculate the need for photovoltaic panels for different crops and sprinkled and dripping / perforated ramps, it is necessary to calculate the elements of the irrigation regime: irrigation standard, watering pattern, watering scheme and watering hydromodul.

The following are the computing relations of the irrigation regime:

1. Irrigation Norm (N) - is the total quantity of water to be administered per hectare of crop in the form of watering during and outside vegetation period (watering supply or watering washing)

N = m + a + S; (m3/ha)

where: m - watering standard (m3 / ha);

a - supply standard (m3 / ha);

S - Washing standard (m3 / ha).

The irrigation standard during the crop growing period is the amount of water, expressed in m3, used for irrigation during the vegetation of one hectare of land with a given crop. This is equal to the sum of the watering norms applied to the crop during the vegetation period. The annual irrigation rate can be determined according to the climatic conditions of the area of the Irrigation Map of Romania [93] (Figure IV.6), in which the territory of Romania was divided into 64 districts. [93]. For each district it is possible to obtain, according to the main crops, the irrigation rule for dry and medium year [93].

Example: On the map of irrigable areas in Romania, Oradea is located in the 60th district. For this rayon in Table IV.5 [93] are specified the average year and the dry one for the main agricultural crops (tab.5.5) :

Table 5.5. Watering standard N (m3 / ha) for the main agricultural crops in district 60 [93]

The kind		Maize	Wheat	Lucerne II	Lucerne I	Beet	Sunflower	Beans	Potatoes
Irrigation Norm (N)	Dry year	2000	900	3500	2500	1500	1500	1200	1500
	Medium year	1500	600	2800	2500	1500	500	600	100

From the above table we can see that the irrigation standard for maize for a dry year is N = 2,000 m3 / ha and for an average year 1500 m3 / ha.

2. Watering scheme

The watering scheme is a 6-digit combination that indicates the number of waterings that apply in each of the 6 months of the growing season of a crop. For Oradea, located in district 60 from the map of irrigable areas in Romania, the watering scheme is presented for the main crop plants in Table 4.6.

Table 5.6. Watering scheme for the main agricultural crops in district 60 [93]

The kind		The main agricultural crops							
		Maize	Wheat	Lucerne II	Lucerne I	Beet	Sunflower	Beans	Potatoes
Irrigation Norm (N)	An secetos	000220	120000	001211	002221	002210	001200	002200	000210
	An mediu	000210	110000	001111	001220	000210	000100	001100	000200

For grown maize in district 60, in a dry year the annual irrigation standard of 2000 m3 / ha (see Table IV.4 [93]) the watering scheme is 000220, which shows that this quantity of water is administered during July and August of the vegetation period, namely that in April (IV), May (V), June (VI) and September, the water consumption of corn is covered by precipitation, so irrigation is not necessary. Monthly irrigation standard for maize is: Nl = N/n = 2000/2 = 1000 m3/ha, administered in two waterings per month.

Under these conditions, the watering standard m is: m = m = Nl/n = 1000/2 = 500 m3/ha;

t - daily watering duration; t = 20 hours.

5.4.2. How to calculate the need for photovoltaic panels for different crops and surfaces with sprinkler and drip irrigation / perforated ramps

In the thesis were calculated, based on the proposed algorithm and the calculation of the elements of the irrigation regime, the necessity of photovoltaic panels (surface and number of photovoltaic modules) for surfaces with sprinkler irrigation for vegetable crops, sweet corn for cooking, lucerne year 1, lucerne year 2, Maize, Wheat, Sunflower, Potatoes (as an example for vegetable crops and sweet corn for boiling in this abstract), and for drip irrigated surfaces / perforated ramps for crops of vegetables, cattle, vines, blueberries, fruit trees on trellis, peanuts, roses, flowers, sweet corn (as an example, vegetable and cattle crops in this summary), see Tables 5.7 and 5.8.

Table 5.7. The need for photovoltaic panels (surface and number of photovoltaic modules) for crops of vegetables and sweet corn for boiling and irrigated surfaces by sprinkling (for example, only for crops of vegetables, sweet corn for boiling, lucerne year 1, lucerne year 2, Corn, Wheat, Sunflower, Potatoes)

Nr. Crt	Crop	Year	Watering scheme	Irrigation standard (mc / ha)	Watering module (qi) (l / sha)	Wet area (ha)	Water flow rate at a watering (l / s)	Electricity consumption per 1000 m3 of pumped water (kWh / 1000 mc)	Power consumption at a watering (kWh)	Photovoltaic energy production per m2 PFV (kWh / mp) in 14 days	Required area PFV (m2)	Surface PVF (mp)	Nr. PFV (pcs)
1	Vegetables	as	002200	1200	0.556	1	0.556	20	6	11.5	0.521	1.46	1
						5	2.778		30		2.608		2
						10	5.556		60		5.210		4
		am	001100	600	0.278	1	0.278		6		0.521		1
						5	1.389		30		2.608		2
						10	2.778		60		5.210		4
2	Sweet	as	001100	100	0.463	1	0.463	20	10	11.5	0.869	1.46	1

	corn for boiling			0		5	2.315		50		4.347		4
						10	4.630		100		8.692		6
		am	000100	500	0.231	1	0.231		10		0.869		1
						5	1.157		50		4.347		4
						10	2.315		100		8.692		6

Table 5.8. The need for photovoltaic panels (surface and number of photovoltaic modules) for drip irrigated surfaces / perforated ramps for crops of vegetables, cattle, vines, blueberries, fruit trees on trellis, peanuts, roses, flowers, sweet corn (as an example crops of vegetables and cattle in this summary)

Nr.Crt	Crop	Year	Watering scheme	Irrigation standard (mc / ha)	Watering module (qi) (l / sha)	Wet area (ha)	Water flow rate at a watering (l / s)	Electricity consumption per 1000 m3 of pumped water (kWh / 1000 mc)	Power consumption at a watering (kWh)	Photovoltaic energy production per m2 PFV (kWh / mp) in 14 days	Required area PFV (m2)	Surface PVF (mp)	Nr. PFV (pcs)
8	Vegetables	as	122331	1200	0.556	1	0.556	20	2	11.5	0.173	1.46	1
						5	2.778		10		0.865		1
						10	5.556		20		1.73		2
		am	122221	600	0.278	1	0.278		1.2		0.104		1
						5	1.389		6		0.626		1
						10	2.778		12		1.04		1
9	Seabuckthorn	as	122331	1500	0.694	1	0.694	20	2.5	11.5	0.217	1.46	1
						5	3.472		12.5		1.085		1
						10	6.944		25		2.17		2
		am	122221	1000	0.463	1	0.463		2		0.173		1
						5	2.315		10		0.865		1
						10	4.630		20		1.73		2

Notifications:

1. The calculation was made for the TAMESOL 235W polycrystalline PV module with the catalog sheet here:

http://calculationsolar.com/pdfs/Calculationsolar_module_TASMESOL_TM660250W344.pdf

2. Energy production per square meter is the average energy produced in two weeks between April and September. I chose two weeks as an average time between two waterings.

3. The required area is obtained by dividing the energy required for watering at the energy produced by the module in two weeks.

4. The number of modules is obtained by dividing the required surface at the surface of a module, and increasing to the whole. If we need more than one module, then their number must be even number, so they can combine the correct series-parallel.

From the analysis of the calculated data in Tables 5.7 and 5.8, the following conclusions are drawn:

- In sprinkler irrigation the water demand is higher than in drip irrigation, the number of photovoltaic panels (PFV) is higher;

- The number of PFV panels needed differs from crop to crop depending on water demand / electricity consumption for pumping water;

- For the type of panel considered, it can be seen that a 235-watt panel produces electricity to pump irrigation water for 1ha of irrigated land.

- For the use of other types of PFV, knowing the energy production, irrigation water requirements and the electric power consumption per 1000 m3 of pumped water (kWh / 1000 m3) the number of PFVs required for each crop is calculated.

According to the algorithm presented in paragraph 5.4.2 for the four photovoltaic modules available on the market (China, the Netherlands, Spain, USA, Tab.5.9), the surface and the number of photovoltaic modules needed to produce photovoltaic energy needed for sprinkler irrigation Table 5.10) and drip irrigation(Table 5.11) of several representative agricultural crops cultivated on surfaces of 1, 5 and 10 hectares.

Table 5.9. Synthetic for 4 types of polycrystalline and monocrystalline photovoltaic modules

Indicative	Commercial name	Producer	The kind	Surface [m2]	Power [W]	Yield [%]
PV1	KD-P100	ZHEJIANG KINGDOM SOLAR ENERGY TECHNIC CO.,LTD, CHINA	Polycrystalline	0.67	100	14.5
PV2	SPM031301200	VICTRON ENERGY, OLANDA	Monocrystalline	0.99	130	13.0
PV3	TMP660235	TAMESOL, SPANIA	Polycrystalline	1.46	235	14.4
PV4	SPR-X21-345	SUN POWER, USA	Monocrystalline	1.62	345	21.5

Table 5.10. Calculation of photovoltaic panels (surface and number of photovoltaic modules) for different crops and surfaces sprinkler irrigated for 4 types of photovoltaic modules produced in China, the Netherlands, Spain and the USA.

Nr. Crt	Crop	Year	Wet area (ha)	Power Consumption at Watering (kWh)	Photovoltaic energy production per m2 PFV (kWh / mp) in 14 days				Required area PFV (m2)				Surface of PVF (M2)				Nr. PFV (pcs)			
					PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4
1	Vegetables	as	1	6	11.2	9.60	11.5	16.1	0.535	0.625	0.521	0.372	0.67	0.99	1.46	1.62	1	1	1	1
			5	30					2.678	3.125	2.608	1.863					4	4	2	2
			10	60					5.357	6.250	5.210	3.726					8	6	4	3
		am	1	6					0.535	0.625	0.521	0.372					1	1	1	1
			5	30					2.678	3.125	2.608	1.863					4	4	2	2
			10	60					5.357	6.250	5.210	3.726					8	6	4	3
2	Sweet corn for boiling	as	1	10	11.2	9.60	11.5	16.1	0.892	1.041	0.869	0.621	0.67	0.99	1.46	1.62	2	1	1	1
			5	50					4.464	5.208	4.347	3.105					8	6	4	2
			10	100					8.928	10.41	8.692	6.210					16	12	6	4
		am	1	10					0.892	1.041	0.869	0.621					2	1	1	1
			5	50					4.464	5.208	4.347	3.105					8	6	4	2
			10	100					8.928	10.41	8.692	6.210					16	12	6	4

Table 5.11 Calculation of photovoltaic panels (surface and number of photovoltaic modules) for different crops and irrigated surfaces: drip / perforated ramps for 4 types of photovoltaic modules produced in China, the Netherlands, Spain and the USA.

Nr. Crt	Crop	Year	Wet area (ha)	Power Consumption at Watering (kWh)	Photovoltaic energy production per m2 PFV (kWh / mp) in 14 days				Required area PFV (m2)				Surface of PVF (M2)				Nr. PFV (pcs)			
					PV 1	PV 2	PV 3	PV 4	PV 1	PV 2	PV 3	PV 4	PV 1	PV 2	PV 3	PV 4	PV 1	PV 2	PV 3	PV 4
8	Vegetables	as	1	2	11.2	9.60	11.5	16.1	0.178	0.208	0.173	0.124	0.67	0.99	1.46	1.62	1	1	1	1
			5	10					0.892	1.041	0.869	0.621					2	1	1	1
			10	20					1.784	2.082	1.73	1.242					4	2	2	1
		am	1	1.2					0.107	0.125	0.104	0.074					1	1	1	1
			5	6					0.535	0.625	0.521	0.372					1	1	1	1
			10	12					1.071	1.250	1.04	0.745					2	2	1	1
9	Seabuckthorn	as	1	2.5	11.2	9.60	11.5	16.1	0.223	0.260	0.217	0.155	0.67	0.99	1.46	1.62	1	1	1	1
			5	12.5					1.115	1.302	1.085	0.776					2	2	1	1
			10	25					2.230	2.604	2.17	1.552					4	4	2	1
		am	1	2					0.178	0.208	0.173	0.124					1	1	1	1
			5	10					0.892	1.041	0.869	0.621					2	1	1	1
			10	20					1.784	2.082	1.73	1.242					4	2	2	1

Chapter 6. General conclusions and personal contributions

6.1. General Conclusions

In the PhD thesis, studies and researches have been carried out regarding the determination of the possibilities of using solar energy in the land improvements, especially for local landscaping, on small surfaces especially in areas where there exist solar radiation and there is no power supply with the electric current of the pumps.

In the first chapter of the thesis there is presented a synthesis on the current state of the irrigation facilities in our country highlighting the history, the arranged capacities, the current organization, the national strategy, sources of financing, the specific legislation in the field of water improvement, the water needs, irrigation, National Program for rehabilitation of the main irrigation infrastructure in Romania, according to the Law no. 269/2016 and approved by Government Decision no. 793/2016, as well as a SWOT analysis of irrigation facilities in Romania, both for large irrigation facilities and for small beneficiaries / farmers with areas up to 1 - 10 ha. For those who have the land / properties located in areas without power grid, use financing opportunities to purchase mobile drip irrigation equipment (drip or sprinkle) and use photovoltaic panels to provide electricity to ensure water flow.

The main goal of the PhD thesis was to implement the future use of photovoltaic energy produced by the use of photovoltaic systems in order to pump water for irrigation to small, local plantations for

vineyards, hazelnuts, blueberries, fruit trees and at agricultural crops, especially vegetables grown in the field or in protected areas (greenhouses and solaria).
In this context experimental researches were carried out on: estimation of the energy production of a photovoltaic system, experimental study of a directly coupled water pumping photovoltaic system (photovoltaic panels, solar cells, solar cell efficiency, solar panels, determination of the amount of electricity possibly obtained by photovoltaic conversion, graph of solar radiation evolution, solar radiation, orientation, angle of inclination, etc.).

In the second part of the thesis succinct sources of renewable energies were presented: hydropower, hydraulic energy, hydraulic energy of the waves, hydraulic energy of the tides, the hydraulic energy of the sea currents, the thermal energy of the seas and oceans, the energy from hydrogen, solar energy, wind energy, geothermal energy, biomass energy, focusing on solar energy as an inexhaustible and usable energy for the aviator, and pumping water into small irrigation facilities.

In Cap. 3 were presented the achievements in the world (producing companies, photovoltaic panels - characteristics, accumulators, water pumps, irrigation etc.), Examples of realization of local irrigation systems using solar energy: Irrigation system with solar pumps, irrigation by drip or irrigation channels (sizing of drip systems, irrigation systems (flooding), results of studies on photovoltaic solar water pumping systems, working principle of photovoltaic solar water pumping systems, performance of photovoltaic water pumping systems, types of engines and pumps, types of engines, water pumps used in the pumping system.

In Chapter 4. we presented the theoretical aspects of solar energy as a source of photovoltaic energy for irrigation water pumping, presenting: components of solar radiation in the atmosphere, solar radiation measurement, solar energy resources in Banat area, photovoltaic solar energy conversion, Dember effect, photovoltaic effect at the junction p-n. semiconductor solar cells, the operation of photovoltaic systems in real-time conditions, solar water pumping systems, the defrosting principle of PV water pumping systems, engine types, water pumps used in SPVP, solar panel cooling, optimal dimensioning of SPVP, SPVP control, environmental and economic aspects of SPVP, SPVP limitations, directly coupled water photovoltaic systems, elements needed to know the issue of photovoltaic energy.

In Chapter 5 are presented the results of the performance evaluation of a photovoltaic module under real operating conditions. The numerical results have demonstrated that the proposed procedure has an acceptable level of accuracy for practical purposes. The procedure is general that can be applied at any location, for any photovoltaic module, the only condition is to know the catalog data of the studied module.

The set of results demonstrates the importance of transposing the I-V characteristic of a PV module under standard test conditions to the real conditions in the dimensioning of a photovoltaic module used for water pumping, which was done in paragraph 5.4.

In this chapter, on the basis of own experiments conducted at West University of Timisoara, the Department of Physics presents the results of a case study on a water pumping system coupled directly to a PV module. The system consisted of a 90W photovoltaic module that directly powered a small water pump. Over a five-month period, the system pumped a remarkable 369.2 m3 of water at a 4.5 meter difference. Taking into account the market price for the components, the cost of the system is less than 180 euros.

The volume of daily pumped water is clearly dependent on total solar irradiation on the surface of the module. Taking into account only the clear sky days, the volume of pumped water can be easily estimated simply by knowing the output power of the photovoltaic module. The analysis shows that both the sunlight and the sunshine indicator are the appropriate parameters for modeling the volume of pumped water under real weather conditions. The results can easily be extrapolated to larger systems operating in the Banat plain.

The obtained results are presented graphically in Figure 5.4. It is noted that the estimated photovoltaic module efficiency drops from 14.5% in the early morning to 10.5% in the middle of the day. Module efficiency is close to the efficiency calculated under standard test conditions only during the winter.

In mid-April, the estimated photovoltaic efficiency is 11.5%, about one percent above the measured values. It follows that the proposed model accurately estimates the efficiency of a photovoltaic module operating under real weather conditions.

Also in Cap. 5 shows an algorithm calculation on which based it was established in table 5.7. the need for photovoltaic panels for different crops and sprinkled irrigation surfaces, respectively in Table 5.8. the need for photovoltaic panels for different crops and drip irrigation / perforated ramps.

According to this algorithm and knowing the energy production for the respective area based on the knowledge of the solar radiation, the exploitation of these irrigation arrangements can be established for each month of the vegetation period (April to September), knowing the scheme and the watering norm required for the respective crop, the need for electricity and if available photovoltaic energy exists, otherwise it is proposed to increase the surface with photovoltaic panels to ensure sufficient electricity production to ensure the flow of irrigation water.

In the case study of Tables 7 and 8, the TAMESOL 235W polycrystalline PV module was used with the catalog sheet on the link:
http://calculationsolar.com/pdfs/Calculationsolar_module_TASMESOL_TM660250W344.pdf

Energy output per square meter is average energy produced over two weeks between April and September. It was chosen as the average time interval between two watering two weeks (which depending on the requirements of different cultures may differ).

The required panel surface was obtained by dividing the energy required for watering the energy produced by the module in two weeks.

The number of modules is obtained by dividing the required surface at the surface of a module, and increasing to the whole. If we need more than one module, then their number must always be the even number, so they can combine the correct series-parallel.

The calculated data analysis in Tables 5.7 and 5.8 highlights some practical conclusions:

- In sprinkler irrigation the water demand is higher than in drip irrigation, the number of photovoltaic panels (PFV) is higher;

- The number of PFV panels needed differs from crop to crop depending on water demand / electricity consumption for pumping water;

- For the type of panel considered, it can be seen that a 235-watt panel produces electricity to pump irrigation water for 1ha of irrigated land.

- For the use of other types of PFV, knowing the energy production, irrigation water requirements and the electric power consumption per 1000 m3 of pumped water (kWh / 1000 m3) the number of PFVs required for each crop is calculated.

6.2. Personal contributions

As a result of bibliographic documentation, both from the country and the world (276 bibliographic titles), many of which are very current, of the study and research program carried out within this doctoral thesis, of its own experimental program, of the automated calculation programs designed for this work, and following case studies undertaken, resulted in the following personal contributions:

- Making a complex, current and perspective bibliographic synthesis in the field of Land Improvement arrangements (historical, capacities, current organization, national strategy, sources of financing, specific legislation in the field of water improvement, water supply, local irrigation arrangements, etc.)

- Making a bibliographic synthesis on solar energy

- Presentation of the theoretical bases of the conversion of solar energy into electrical energy

- Evaluating solar resources in the western region, in order to use solar energy in pumping water for irrigation

- Elaboration of experimental research by realizing an experimental stand for studying the efficiency of water pumping using the direct photovoltaic coupling - the pump

- Numerical modeling of solar energy resources

- Direct pump coupling modeling - photovoltaic mode

- The Solar Radiation Chart

- Determining the amount of electricity possible to obtain by photovoltaic conversion

- Achievements in the world and in our country to use solar energy to pump irrigation water

- Inventory of the main photovoltaic manufacturing company

- Propose new research directions on the use of solar energy in land improvements.

- In tab. 7 and 8 of Chapter 4 presents the calculation of the need for photovoltaic panels for different crops and irrigated surfaces (for design) according to an algorithm proposed by the doctoral student.

6.3 Proposal for new research directions on the use of solar energy in land improvements.

- Numerical modeling of water pumping systems

- Development of water pumping systems equipped with photovoltaic storage devices

- Elaboration of prototypes of photovoltaic irrigation systems for various surfaces cultivated by small farmers

- Efficiency / optimization of photovoltaic systems related to irrigation methods and watering equipment.

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