Low power photovoltaic system implemented by means of flexible module

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Abstract: *Paper deals with low power photovoltaic system implemented by means of flexible module. Flexible modules powered by sunlight are really a very interesting and promising novelty, being one of the newer alternative energy sources. A selected technical solution with specific characteristics of the individual components is presented. Measurements with digital measuring equipment were performed and experimental results were presented. In conclusion, it is summarized that the tested flexible module gives good results.*
Keywords**:** *RENEWABLE ENERGY SOURCES, PHOTOVOLTAIC SYSTEM, ENERGY EFFICIENCY*

1. Introduction

Improving energy efficiency in public space was first discussed in the 1970s with the onset of the global oil crisis. In recent years, deepening price problems, fuel shortages and environmental pollution have become an increasingly frequent issue. In addition, public attention is focused on the no less important issue in terms of energy security - high growth rates of the world's population. In May 2021, it numbered nearly 7.8 billion people, and continues to grow rapidly. A number of governmental and non-governmental organizations are taking serious measures to increase the efficiency of energy use and are actively involved in financing projects in this direction. Bulgaria's position as an equal member of the European Union is clearly oriented towards active participation in international efforts to prevent climate change and increase energy efficiency. Bulgarian governments are increasingly accumulating measures and programs related to improving energy efficiency. For this purpose, the Energy Efficiency Act, the Renewable Energy Act, the National Long-Term and Periodic Short-Term Programs on this issue and a number of normative acts were adopted. A good idea in this direction is the Energy Efficiency Program (REECL) established in 2006, which is implemented with the assistance of the European Union and the Energy Efficiency Agency. It provides an opportunity for Bulgaria to reap the benefits of energy efficiency and receive targeted consumer credit and grants through the network of several commercial banks as individuals or legal entities.

The most recently developed direction in the work of research teams is the use of solar energy. Much of the effort is focused on the development and improvement of converters of solar radiation into electricity or heat. Converters of solar energy into electricity are called photovoltaics, and those that convert solar energy into heat are the widespread water and air solar collectors.

Recently, there has been a development in photovoltaic systems for own consumption. In this type of system, solar energy directly supplies the consumers of a household or enterprise, and when it is insufficient, it is added automatically from the electricity grid. This type of system is a great way to optimize costs and reduce electricity bills many times over. It is also possible to use completely autonomous systems not connected to the grid.

Based on the above, the paper focuses on the use of renewable energy sources (RES) and in particular the use of solar energy as the preferred technology for decentralized electricity generation. The aim of the authors is to study a photovoltaic system, which is undoubtedly estimated as a share of RES.

The research thesis defended in the present paper is formulated as follows: the use of RES and in particular solar energy as the preferred technology for decentralized electricity generation, directly correlates with issues of energy efficiency and environmental protection.

2. Some considerations

In November 2009, the Bulgarian government adopted a strategy aimed at turning Bulgaria into a "green paradise". Ecology, alternative energy, organic food, energy-saving technologies that lead to a significant reduction in energy costs, increase comfort and quality of life are the main highlights of the strategy.

With regard to alternative energy, it is assumed that in 1÷2 decades it will be cheap enough to compete with conventional energy. Then it is logical to wait 1 ÷ 2 decades and then invest in "green" energy. Why should we do it now and increase the price of electricity significantly? Proponents of green energy claim a fixed high electricity purchase price for the next 25 years. That is, all the RES power capacities that will be installed today, to redeem all the energy at a non-market price for the next 25 years. For such investors, this is promising - a guaranteed profit without any risk. But for taxpayers and electricity consumers, this is a guaranteed additional cost for the next 25 years. The cost of electricity from wind, solar and small hydropower plants is higher than from traditional power plants. This cost is calculated in the subscribers' accounts. Thus, in the areas where there are the most renewable power plants, people pay the most for electricity. This, of course, contradicts the Energy Act, which requires all citizens to bear the same weight from alternative energy sources.

In this context, the way in which the final price of electricity for consumers is formed is of interest. In general, the electricity market is divided into a regulated market and a free market. On a regulated market are household and business consumers of medium and low voltage. The final prices of electricity for the regulated market are formed along the production-transmission-distribution-supply chain. The formation of the price of electricity for end users is carried out as follows. Based on the prices of individual producers – thermal power plants, hydro power plants, nuclear power plants, alternative sources, which are paid by the National Electricity Company[1] and which are regulated by the Energy and Water Regulatory Commission[2], National Electricity Company prepares a single (united) price, also regulated by the Energy and Water Regulatory Commission. A transfer fee and an access fee are added to this price. For its part, the access fee is paid to the Electricity System Operator for maintaining a cold reserve of 1170 kW and for all other services it provides. The transmission fee is also paid to National Electricity Company for the 110 kV high voltge (HV) network, and for the 230 V low voltage (LV) network is paid by the electricity distribution companies. These fees are also regulated by the Energy and Water Regulatory Commission. 20% VAT is charged on the price thus obtained. In this way the accounts of the protected consumers are formed - household customers and small companies with employees up to 50 people and annual turnover up to BGN 20.5 million. Large consumers negotiate electricity at prices and volumes directly from producers and traders. These prices are free.

A novelty in Bulgaria is the opportunity for homeowners in neighboring facilities to be able to cooperate and apply for

[1] The main activity of National Electricity Company is the production and trade of electricity. The company occupies a central place in the Bulgarian electricity system, with an installed capacity of 2737 MW. The company is the largest producer of green electricity in Bulgaria, with production of 31 hydro power plants.

[2] The Energy and Water Regulatory Commission is an independent specialized state body of the Republic of Bulgaria, a regulator of two sectors: energy and water supply.

European funding for the installation of photovoltaic modules on the roofs. In this way, they will be able to produce electricity to use for their own consumption and reduce their bills. In addition, they will be able to sell electricity. By creating your own photovoltaic power plant, you can significantly reduce your dependence on corporations, as well as achieve protection against rising prices [1]. The idea is enshrined in the National Energy Strategy until 2030 with a horizon of 2050 and in the Green Pact. There are still no such energy cooperatives in Bulgaria for consumers who produce and sell electricity. An online training on 'The potential of Bulgarian municipalities and independent energy communities' is currently underway.

The idea of introducing preferential electricity prices from small photovoltaic plants is to encourage people to invest in those to cover their own consumption, with only the surplus to be sold to energy companies. On the other hand, energy companies warn that photovoltaics installed on abandoned buildings are pumping up the price of electricity that all consumers pay. These are photovoltaic modules, supposedly mounted on roofs for their own needs, but in reality they are placed on toilets, barracks and dilapidated buildings in depopulated settlements. In reality, the energy produced by them is not used for own needs, but is sold directly to the company that connected the installation. And the energy company is obliged to buy electricity at preferential prices from small power plants up to 30 kW. Currently, the purchase price for such power plants is BGN 160.11 per 1 MWh, and for power plants up to 5 kW - BGN 193.33. This is more than the base price set by the Energy and Water Regulatory Commission, which for the period from July 1, 2020 to June 30 2021 was BGN 90 / MWh, and for the period July 1, 2021 to June 30, 2022 was BGN 119 / MWh, which is an increase of 32% [2]. Consumers are loaded after the energy company enters as an expense the funds for the purchase of green energy from these photovoltaics in the price "Debt to society", which in turn affects that of electricity for households.

With the preservation of preferential prices and the mandatory purchase of electricity from power plants up to 30 kW in the last 2 years there is a mass construction of such. 1,300 'roof power plants' under 30 kW have been installed in the country and hundreds of other projects are waiting to be connected, commented the energy companies. Thus, in 2020, 226 photovoltaic power plants up to 30 kW are connected to the network of the electricity distribution company (EDC) in Northeastern Bulgaria 'EDC North', and their total number is currently 339. In Western Bulgaria on the territory of "CEZ Distribution Bulgaria" there are 550 units photovoltaic power plants up to 30 kW with a total installed capacity of 13439 kW. By the beginning of 2021, 405 such power plants have been put into operation in Southeastern Bulgaria on the territory of EVN operator. The total annual amount of electricity produced by these 405 plants is 15015000 kWh, while only 1.26% of this energy is consumed by the sites on whose territory the plants are located. An additional 293 are active (unfinished) procedures for joining EVN operator.

3. Technology and materials

Research and development in the field of photovoltaic conversion of solar energy is aimed mainly at reducing the cost of electricity generated by them. This can be achieved in three ways: by increasing the efficiency of photovoltaic cells; by lowering their price; or by seeking a compromise between these two approaches. In all cases, it is assumed that photovoltaic modules must operate reliably for 20÷30 years.

Currently, monocrystalline Si is the most common semiconductor material not only for the production of photovoltaic cells, but also in the entire electronics industry. Its technology continues to develop rapidly, mainly in the direction of obtaining high-quality pure material and lowering its price.

Higher efficiency is obtained from multi-transition photovoltaic cells made of amorphous Si alloys. In this type of photocells, materials reacting to waves in different regions of the solar spectrum are deposited one on top of the other, ie. of different lengths.

Polycrystalline photovoltaic cells based on CuInGaSe2 (CIGS) and CdTe have all the advantages of amorphous Si. They have a high absorption coefficient, use very little material and their production can be easily automated. In addition, they have some additional advantages - these materials do not degrade under lighting and are obtained through cheap and affordable technologies.

Flexible photovoltaic modules are also based on CIGS, which allow extremely high light absorption. The CIGS layer is only one micron, absorbing sunlight almost completely (99%). The total thickness of a solar cell is about 30 microns. This makes it thinner than human hair. Thanks to the flexibility factor, CIGS solar modules can be applied to various surfaces, such as curved structures. Flexible modules are unbreakable, much thinner and much lighter than conventional solar panels. An additional advantage of flexible panels over others is their ability to be less affected by high ambient temperatures [3].

The trend towards sustainable energy is observing a significant development in the different types of photovoltaic modules. The effective capture of each ray is on the agenda. The main disadvantages of conventional cells placed on flat roofs or occupying tens of acres of land are their staticity and the resulting low productivity.

Innovative flexible modules are lighter and take far less time to install than common technologies. The advantage is that they do not need to mount frames. With the photosensitive foil can be laminated not only the roofs, but also the dense parts of the facades of buildings. In this way, a lot of unused space can be used.

The products are already available on the market, and the range of applications is constantly being enriched. The characteristics of flexible photovoltaic modules allow them to be used in the automotive industry and in the development of solar-powered land, air and water vehicles. The current goal is to reduce the cost of flexible modules, although their price is competitive with existing standard installations [3].

The standard photovoltaic modules are heavy and hard, the front protective layer over the solar cells is 3-4 mm thick and is made of hardened ultra-light. This standard combination has been tested for more than 70 years and is undoubtedly the best option for the protection of cells from atmospheric influences and protection. The main disadvantage of the classic photovoltaic modules is their solid weight and massive body. They usually require constant constructive fixation and are best suited for domestic and commercial/industrial applications [4].

Flexible modules obviously cannot use glass for protection, and polymers are used instead. The most popular films have always been considered as substitutes for glass, they are lighter and more fragile, but even if it is a chemical choice, polymers cannot compare with glass in one longer period of time. It should be noted that flexible photovoltaic modules, as a whole, have a shorter operating life than traditional modules and many of the low-quality modules have a lifespan of up to 1-2 years [4].

One of the decisive factors in determining the lifespan of flexible photovoltaic modules is the coating material. The two more popular types are PET and ETFE. PET is a polyester plastic, and ETFE is based on fluorescent polymers. ETFE as a material has a very high ratio of sunlight absorption and reflection, thanks to which the module is highly efficient [5]. While PET-laminated flexible photovoltaic modules usually have a lifespan of up to 5 years, ETFE-laminated flexible photovoltaic modules have a lifespan of up to 10 years.

The main feature of flexible photovoltaic modules, in addition to significantly reduced weight (up to 80% lighter than conventional modules, ease allows installation in places where heavier modules are impossible to install), is the elasticity of the structure [3, 6]. They can usually be mounted without the use of heavy or constructive fixing elements - fastening with glue, bushings or zippers. They are easily transferable and can be transferred to other areas, which makes them great for home or a range of applications such as camping, trucks, buses, caravans, campers, boats and for charging different types, for example canopies of solar garages and vehicles [6]. The thin flexible structure allows their use in non-standard types of surfaces. One of the things that should be noted about flexible photovoltaic modules is that they cannot be torn or blown, but are very vulnerable to sharp objects and breakage [4].

4. Components of low power photovoltaic system with flexible module

Taking into account the market availability, as well as the economic dimensions, warranty conditions and available service network, an autonomous system was assembled. The implemented photovoltaic system, in addition to the flexible photovoltaic module, as a main component, includes several other basic components.

Photovoltaic flexible module ECOFLEX 100 Wp [7]

Specifications:

- Rated power: 100 Wp
- Cells: 36 pcs.
- Efficiency: 17.7 %
- Application: for solar systems with a voltage of 12 V
- Maximum current (Imp): 5.99 A
- Maximum voltage (Vmp): 16.7 V
- Open circuit voltage (Voc): 19.7 V
- Short circuit current (Isc): 6.51 A
- Dimensions: 515 x 1225 x 3 mm
- Weight: 3.5 kg

Fig. 1 *General view of a photovoltaic flexible module 100 Wp*

***Controller SOLSUM* 6.6X** [8]

High-performance charge controller with built-in protection against deep discharge and overvoltage, LED charge status display, temperature-compensated recharge protection via built-in sensor and battery charging according to the linear volt-ampere characteristic.

Specifications:

- modul current: 6 A
- consumption current: 6A
- voltage: 12/24 V

Fig. 2 *General view of the controller SOLSUM 6.6X*

Sinusoidal inverter MSP 352 [9]

Used if AC consumers are to be powered. The device generates from 12 V DC voltage of the battery 230 V AC voltage with a real sine wave as a local output, turning off at overvoltage or undervoltage. There are overload and short circuit protections. The voltage is precisely controlled by a microprocessor so that there are no sudden fluctuations in voltage and the shape of the curve is as close as possible to the ideal sine wave.

Specifications:

- Input voltage: 11-15 V DC
- Low voltage cut-off: 11 V
- Otput voltage: 230 V AC pure sine wave
- Idle current consumption 1.2 A
- Constant output power: 350 W
- Peak output power: 700 W

Rechargeable batteries Panasonic LC-RA1215P [10] – 2 pcs.

Specifications:

- Valve Regulated Lead-Acid (VRLA) Battery
- 12 V, 15 Ah
- Voltage regulation
- Cycle use: 14.5 V~14.9 V (25^{o}C)
- Initial current: less than 6.0 A
- Standby use: 13.6 V~13.8 V (25^{o}C)

5. Experimental results

The experimental setup thus created allows the measurement of technical characteristics, as well as the possibility of processing this data. The measurements have been done in front of Building 2A of the Technical University of Gabrovo, Bulgaria.

Measuring equipment used on June 10, 2021:

- UT-81B – digital multimeter with graphic display - for voltage measurements;
- PeakTech 3440 – graphical multimeter - for current consumed measurements;
- Voltcraft PL-110SM – for solar radiation measurements.

Below are the results of measuring DC consumers with a rated voltage of 12 V DC. The main goal is to obtain information about the current consumed in different cases, which is crucial for the normal operation of the low-power photovoltaic system. The slope of the PV module has been changed and the intensity of the solar radiation on its plane has been measured.

Table 1: *Measurement of DC consumer - submersible heater CARE 12 V DC/200 W* [11]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A
08:52	817	829	80^o	4.663
08:58	820	934	60^o	4.681
09:04	822	840	40^o	4.681
09:10	824	835	20^o	4.681
09:16	825	827	10^o	4.681

Table 2: *Measurement of oscillating (rotating) fan SAYOTA 12 V DC* [12]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A
09:22	826	840	80^o	0.225
09:28	828	845	60^o	0.223
09:34	832	851	40^o	0.222
09:40	836	847	20^o	0.221
09:46	839	842	10^o	0.225

Table 3: *Measurement of fan with heater UNITEC 12 V DC / 150 W* [12]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A	
				Without heater	With heater
10:02	840	852	80^o	0.120	4.682
10:08	842	857	60^o	0.119	4.683
10:14	845	861	40^o	0.119	4.683
10:20	847	858	20^o	0.118	4.682
10:26	850	853	10^o	0.117	4.681

Table 4: *Measurement of compressor RAIDER RD-AC08 12 V DC* [13]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A
10:46	851	865	80^o	3.922
10:52	853	869	60^o	3.906
10:58	857	873	40^o	3.913
11:04	859	870	20^o	3.926
11:10	862	865	10^o	3.937

Table 5: *Measurement of saving lamp SOLSUM ESL 12 V DC/7 W* [8]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A
11:20	863	887	80^o	0.502
11:26	865	891	60^o	0.504
11:34	868	894	40^o	0.505
11:40	872	883	20^o	0.507
11:46	873	878	10^o	0.508

Table 6: *Measurement of saving lamp SOLSUM ESL 12 V DC/11 W* [8]

Час	Global intensity of solar radiation, W/m^2	Intensity of solar radiation on the plane of the PV module, W/m^2	Incline of the PV module	Current through the load I, A
11:52	875	889	80^o	0.753
11:58	883	891	60^o	0.755
12:04	887	898	40^o	0.757
12:10	891	897	20^o	0.760
12:16	895	896	10^o	0.763

The intensity of solar radiation is a major factor in the production of electricity from photovoltaic modules. Different types of electrical consumers were tested - purely active, active-inductive and non-linear loads. It has been found that even at the highest current consumption of 4.682 A (in the case of a UNITEC fan with heater switched-on), the tested flexible photovoltaic module ECOFLEX 100 Wp (with a maximum current of 5.99 A) can ensure normal operation.

4. Conclusions

In recent years, the idea of using renewable energy sources is gaining popularity and for good reason! Undoubtedly, the energy development of our planet is associated with major challenges arising from population growth, improving living standards, requirements for reducing environmental pollution and reducing resources of organic fuels. To address these challenges in the global energy market, RES are gaining ground as the preferred technology for decentralized electricity generation.

In addition, the absorption of energy resources provided by renewable energy sources is a means to achieve sustainable energy development in a country. The economic pressure from rising liquid fuel prices requires the implementation of measures to develop local energy sources and especially those with negligible environmental impact. Encouraging energy production from renewable energy leads to a reduction in the energy dependence of the national economy. Their use and their integration into the energy system provide a key perspective for the development of the innovative economy of the future.

Taking into account the economic and financial conditions, as well as the opportunities for the absorption of the energy potential of RES, it is absolutely necessary to direct the efforts towards saving electricity produced from conventional energy resources and imported liquid fuels.

In this context, one of the most promising and controversial energy applications of solar resources, as a major representative of RES, in recent years are photovoltaic systems. It is a fact that the dynamic development and growth of the photovoltaic sector in Europe over the last decade has been largely supported by favorable regulations and incentives for RES. As a full member of the European Union, Bulgaria also prioritizes the need for environmentally friendly development and more mass introduction of renewable energy sources. Geographical location and solar radiation are suitable for the implementation of the photovoltaic system and this type of project attracts investor interest in view of the opportunities for free use of energy resources, modular implementation and a wide range of applications.

Currently, solar energy is in a phase of rapid development. New types of modules are being developed, their efficiency factor is being increased, production costs are being reduced. Even today, each of us can become a full participant in the energy market by buying and selling electricity. By creating your own photovoltaic power plant, you can significantly reduce your dependence on corporations, as well as protect yourself from rising prices.

The presented experimental setup in the development proves that photovoltaic systems are an important resource, the rational use of which can become the basis for increasing energy security and independence and energy efficiency. Cloudiness and shading have been shown to be important factors. Clear time is needed to accurately measure solar radiation. Only then is there a maximum approximation of the curve to the theoretical one. But for practical purposes it is necessary to measure in different atmospheric conditions. This gives a real idea of the possibility of using solar energy in a particular place - in this case Gabrovo, Bulgaria. The area has a value of solar radiation of 1291 kWh/m^2 on a horizontal surface or 1482 kWh/m^2 on an optimal incline.

The flexible photovoltaic modules, powered by sunlight, are really a very interesting and promising novelty. Big and small, wide and narrow, for more or less power - they all require money to buy. Most likely, such items will fill the market very soon, as there is a general decline in the prices of this product.

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