Intelligent Solar Tracking System as a Prospect for Developing the Alternative Energetics in Ukraine

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Abstract

Now, alternative energetics and renewable energy sources are the main trends in the world. The development and use of alternative energy sources are important factors for strengthening the energy safety. But today, in Ukraine, alternative energy is still under development. Ukraine has significant resources for the development of renewable energy. Therefore, under favorable legislation, Ukraine has every chance to take a prominent place in alternative energy among the advanced countries. The main factors, through which the unfavorable investment climate in Ukraine don't allow investors and the state to fully develop alternative energy: political and foreign exchange market instability; weakly incentive state support in the development and use of alternative types of energy; inadequate funding for research in the energy sector; insufficiency informing and low awareness of the population in the efficiency of alternative energy sources; low competitiveness of domestic developments; the absence of industrial production of domestic analogues of facilities with non-traditional types of fuel. Given that "clean" and "green" energy from renewable sources is an important sustainable development goal for Ukraine, and the solar power plants have the highest growth rates, the urgent task is the correct positioning of solar panels and ensure maximum efficiency of their. The aim of this paper is to develop a system that would allow you to monitor the sun regardless of the clouds. The intelligent solar tracking system is developed in the paper. A mechanical design for positioning the solar battery in space, a light-sensitive photodetector for tracking the position of the Sun in two coordinates, a diagram of an intelligent solar tracking system were developed. The developed intelligent solar tracking system minimizes energy consumption for control and increases energy efficiency of electricity production. The use of such a system provides the significantly increase the amount of electricity produced by solar panels.

Keywords

Renewable energy sources (RES), alternative (renewable) energetics, scenarios for the development of alternative energy, intelligent solar tracking system

1. Introduction

At current rates of use of oil and gas, these resources will be sufficient to mankind for 50 years. In this regard, alternative energy and renewable energy sources (RES) are the main trends in the world. Therefore, EU countries are actively promoting the introduction of RES – by 2030 their share in the structure of electricity production should be up to 50% (Figure 1). By 2040, RES, in general, will account for 3/4 of the world's investment in electricity. Ukraine's plans are much more modest: the share of renewable sources in electricity generation in 2025 should be more than 13% [1, 2].

Alternative energetics, and more precisely, the production of energy from RES is still in the stage of development for almost ten years of implementation in Ukraine. Ukraine has significant potential of the main types of RES, but at the present time, they constitute a rather small share in the overall energy balance of the state [1, 2].

The total primary energy supply from 2012 to 2050 under different scenarios for the development of alternative energetics is presented on Figure 2 [2] (Conservative Scenario – the "freezing" of technologies at the current level, when the characteristics of most energy technologies remain unchanged by 2050 compared to 2012, i. e., only a very small part of the RES potential is used;

Liberal Scenario – the development of the energy sector under free and perfect competition in the national energy market; Revolutionary Scenario – rapid development of RES under the targeted renewable energy development policy). The structure of the predicted final energy consumption by 2050 according to Liberal and Revolutionary Scenarios are presented on Figures 3, 4 [2].

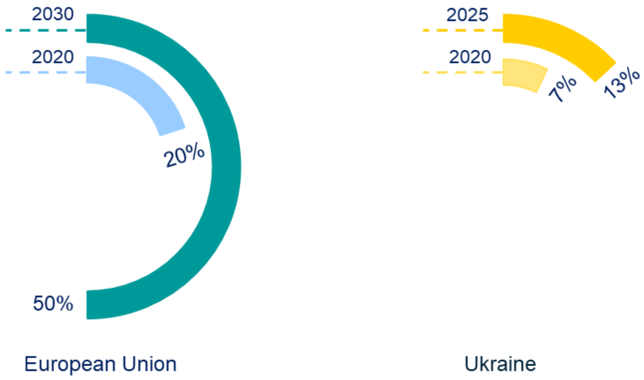

Figure 1: Share of RES in the structure of electricity production [1]

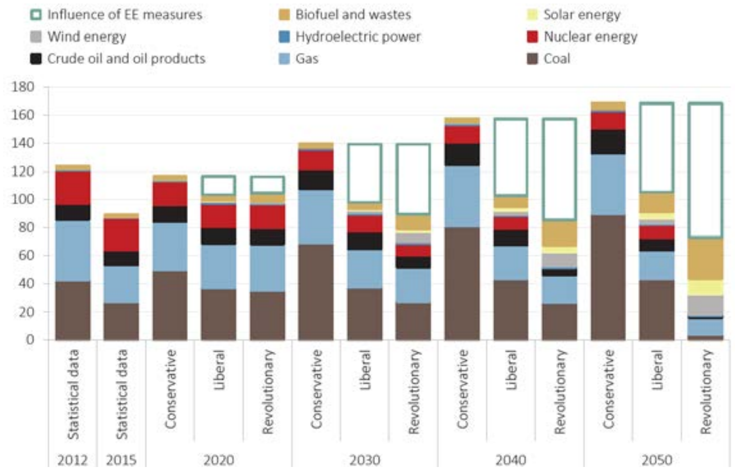

Figure 2: Total primary energy supply [2]

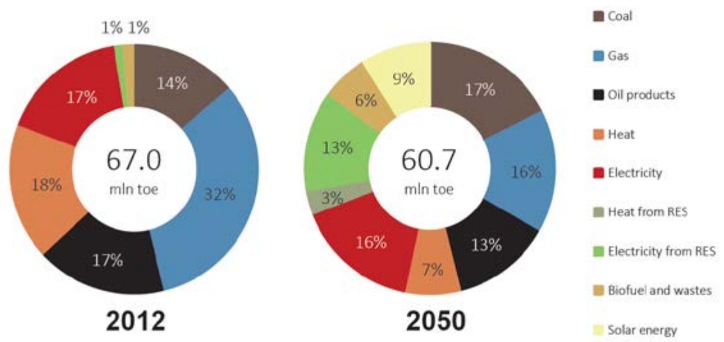

Figure 3: Structure of the final energy consumption under the Liberal Scenario [2]

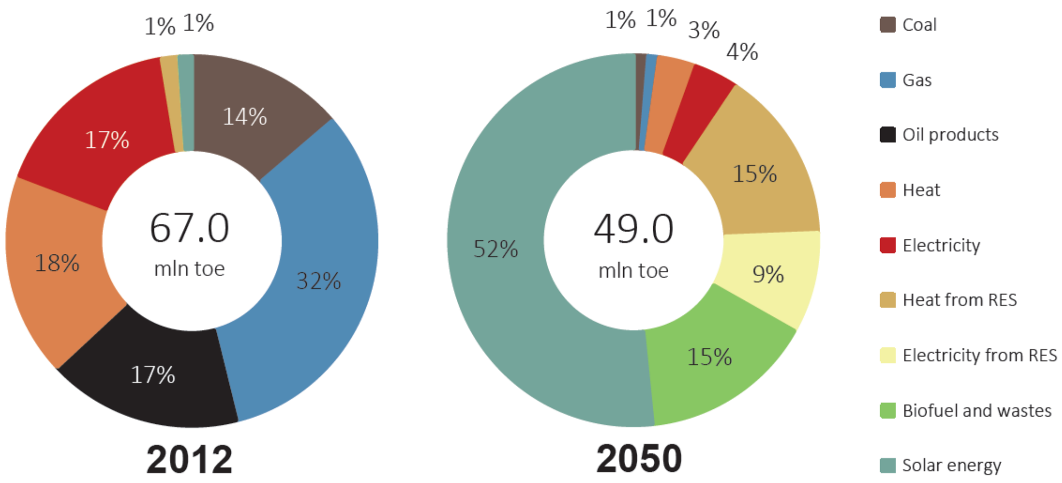

Figure 4: Structure of the final energy consumption under the Revolutionary Scenario [2]

It should be noted that in the world there are changes in the approaches to the formation of the energy policy of the states. It is the transition from the outdated model of the functioning of the energy sector (in which the large producers, fossil fuels, inefficient networks, imperfect competition in the markets of natural gas, electricity, coal were dominated) – to the new model (in which a more competitive environment is created, opportunities for development are equal, and the dominance of one type of energy production or sources and/or ways of supply ting fuel is minimized). At the same time, the preference is given to increasing the energy efficiency and use of energy from renewable and alternative sources. Ukraine uses various sources of energy for its own needs, such as oil, natural gas, coal, atomic and hydro energy, wind and sun energy, etc.

The use of alternative energy sources has features, in particular, due to natural conditions – due to dependence on atmospheric and other environmental conditions; due to availability of water resources of small rivers, which are necessary for the functioning the hydroelectric equipment; due to the presence of biomass, the quantity of which depends on the volumes of annual harvests; due to the presence of geothermal sources and wells, which are suitable for the production and use of geothermal energy; due to the presence of thermal emissions, the volumes of which depend on the functioning the industrial enterprises; due to the periodicity of natural cycles, resulting in an imbalance of energy production; due to the need to coordinate and balance the periodicity of the transfer of energy from alternative sources, in particular the transfer of electricity to the united power system of Ukraine.

Due to its size and diversity of natural landscapes, Ukraine has a significant natural potential for energy production from most RES - high levels of solar radiation, powerful wind power on the coasts and in the mountains, rivers with a powerful hydrological energy reserve, and large resources and large agricultural areas for biomass production [3]. Potential solar energy production in Ukraine is about 350 billion kWh per year. The potential for wind power generation varies from 50 to 67 billion kWh per year. Potential hydropower production ranges from 22 to 45 billion kWh per year. Renewable sources in Ukraine can potentially meet 78% of electricity generation needs [3, 4]. For example, in the territory of the Lviv region, there are 14 renewable energy facilities: 3 wind power plants with a total capacity of 33.9 MW, 9 solar power stations with a capacity of 29.0 MW, and 2 mini hydroelectric power stations with a capacity of 615 kW. More than € 34 million have been invested in the solar power industry of the Lviv region. Over € 57.6 million have been invested in the wind power industry of the Lviv region [5].

Affordable, "clean" and "green" energy from renewable sources is an *important sustainable development goal for Ukraine*, level of incorporation of which into policies is 80% [6].

Taking into account the importance and actuality of the alternative energy market in Ukraine, in the last 10 years, there has been the rapid development of scientific research in this field, in particular, the development of theoretical, methodological and practical issues of diversification of energy sources.

2. State-of-the-art

The authors of [7] determine the causes of the emergence of renewable energetics markets, make a comparative analysis of the attractiveness of Ukrainian and European renewable energetics markets, characterize changes in government policy in the RES market and prove the competitiveness of Ukrainian products in this area on the international market.

In [8] the importance of replacing the traditional types of fuels with alternative energy sources is considered, the particular attention being paid to the use of biofuels for Ukraine. On the basis of the analysis of the situation in the energy market, renewable energy is studied, which plays a compensatory role in the world energy consumption in the conditions of growing the depletion of non-renewable sources.

The authors of [9] prove that, according to the energy balance of Ukraine, the average annual gain of bioenergy is 45% for "biofuel and waste production" and 35% for "total consumption of primary energy from biofuels and wastes". It is also proved that, by 2050, the consumption of renewable energy sources will be about 13.8 Mtoe / year (of which biomass accounts for over 90%), and the corresponding replacement of natural gas will be about 17 billion cubic meters for the year. The authors of [9] argue that for a wider involvement of biomass in Ukraine's fuel and energy balance, it is necessary to ensure the legal framework and implementation of a number of important measures, in particular, creating the preconditions for increasing timber harvesting in Ukraine's forests, introducing the electronic system for trade in biofuels, etc.

In [10] the available methodological support was improved, the criteria for assessing the efficiency of energy consumption transformation based on RES was developed, and the system of criteria for assessing the efficiency of energy consumption transformation based on RES was proposed, which is based on economic, environmental and social efficiency.

The authors of [11] analyzed the use of the main types of fuel by the household sector in the regions of Ukraine. The example shows that the amount of fuel, which is consumed by the population, is non linearly dependent on the share of individual heating systems in the region. The authors of [11] prove that during the last decade, biofuel consumption for household needs in Ukraine has doubled, and it is increasingly displacing coal, thus having a positive impact on the environment.

The paper [12] evaluates the effectiveness of the use of RES in Ukraine. According to the statistical and correlation analysis, it has been proved that for Ukraine the most advantageous is the use of energy from biomass, while solar energy remains relatively expensive for our country. But the situation may change if the cost of solar panels will reduce. In any case, Ukraine needs increasing the implementation of RES – at present, RES in the energy balance of Ukraine is 2%, while in European countries – an average of 17%, and in some of them – more than 60%.

The authors of [13] propose the stimulating state mechanisms for the development of alternative energetics, such as: the establishment of advisory centers, the provision of long-term loans by the state for the construction of power plants, consideration of the inflation in the "green" tariff, the exemption from taxation of land used by power stations, the legislative establishment of the duration of "green" tariff that operates in accordance with the normative payback period from the moment of commissioning of the power plant. In addition, the authors of [13] conducted the determination of the economic feasibility of the construction of alternative energy objects as a form of family business.

The aim of the paper [14] is: consideration of the theoretical and applied bases for the use of alternative energy sources in Ukraine and in the world, studying the theoretical foundations and specifics of the use of existing alternative energy sources. Particular attention is paid to the analysis of energy efficiency of the regions of Ukraine.

The authors [15] highlight the factors that contribute to increasing the investment attractiveness of alternative energetics in Ukraine, in particular, the successful implementation of state development programs, the development of emission trading mechanisms, the increase of the share of equilibrium in the structure of resources, etc. The organizational and economic mechanism for alternative energetics, which evolves investment support at the present stage, as well as principles and ways of its realization, were proposed and grounded. The authors of [15] also consider the expected benefits from the introduction of alternative energy, in particular: diversification of the energy balance of Ukraine;

the increase of investment attractiveness of alternative energy, that can be achieved at the expense of legislative regulation of investment activity.

The purpose of the work [16] is to reveal the largest renewable energy facilities in Ukraine. This survey is based on an analysis of the natural potential, the legislative framework of the industry and active financial programs. The authors of [16] show that RES will increase Ukraine's energy safety and will reduce the negative impact of industry on the environment, will help to overcome global warming and adverse climate change. The survey showed that today the use of RES is a priority way to build a sustainable energy system in Ukraine. There are several state and regional financial initiatives that promote the development of RES. The main problem of renewable energetics development is the insufficiency of financing.

The authors of [17] conducted an analysis of existing types of non-traditional energetics with the purpose of determining the state of this industry in Ukraine, and showed the advantages of alternative energy sources and the need for their further development in Ukraine.

The purpose of the paper [18] is studying and determining the strategic priorities of investment in the development of alternative energetics. Strategic priorities for the development of alternative energy in Ukraine [18]: identification of those types of energetics that have the greatest potential and are economically attractive for the area and their involvement in fuel and energy balances of local fuels, secondary energy resources, alternative energy sources; development of economically grounded investment plans for the introduction of low carbon energetics, reduction of consumption of traditional fuel and reduction of harmful emissions; stimulating the business to achieve long-term strategic goals of strengthen its competitive position with increasing demand for environmentally friendly electricity generation and the expansion of the market for low-carbon technologies and equipment; promotion of private capital to the introduction of alternative energetics; the economic incentive for reducing the harmful emissions by the electricity producer; expansion of the scale of implementation of advanced foreign technologies; availability of information, information support for social recognition of economic long-term benefits of low carbon energy use.

The paper [19] outlines the existing rules, requirements and incentives for the development of "green" energy projects in Ukraine, and those that have recently become effective and will soon become effective and about of which the investor should know when planning a business strategy in this sector.

Authors of [20] offer a decision support system for calculating and evaluating the RES, which takes into account a number of the measures of the energy audit and real-time planning.

In the paper [21] the comprehensive analysis of strategic prospects for renewable energy development in Ukraine was conducted on the basis of PEST-analysis (P – political tools, E – economical tools, S – social-cultural tools, T – technological tools), and the set of strategic measures within the limits of the most influential environmental factors within the framework of PEST-analysis was proposed.

An important incentive for the development of the renewable energy of Ukraine, which are represented by solar, wind, hydropower and bioenergy, is the implementation of favorable tariff legislation - the feed-in tariff (guaranteed state obligation to procure the generated "green" energy) and the "green" tariff for electricity, which was produced from renewable sources [3, 4, 22].

The alternative energy market is attractive for investment, despite all the imperfections of the Ukrainian bureaucracy [23]. Favorable geographical conditions, legislative support, binding the tariffs to the euro, government guarantees to investors by 2030, high return on investment and very fast payback of projects (about 5-7 years) – all this prompts the development of new large-scale projects. In 2018-2020, the level of capacities of "green" energetics has increased almost fourfold. According to the State Agency on Energy Efficiency and Energy Saving of Ukraine (SAEE), the share of RES has increased from 3.9% to 5.8% in the last three years, from 7.4% to 7.8% in the electricity sector. One of the latest trends in Ukraine is the active development of technologies for the production of solar energy sources, so the highest growth rates are for solar power plants – over the past two years solar panels have been used twice as often [2, 4, 24]. Herewith, non-state and state institutions, even higher education institutions, are engaged in the production of solar power. So, Khmelnytskyi National University installed a 150-kilowatt solar power station in 2017 as a scientific-led initiative. In 2018 power of solar power station was expanded to 650-kilowatt (Figure 5). The cost of the Khmelnytskyi National University solar power station is 13000000 UAH (around €400000).

Figure 5: Rooftop solar power station of Khmelnytskyi National University

An important fact that significantly affects the performance of solar power plants is the orientation and angle of the solar panels. To date, the main direction of improving the efficiency of electricity generation by solar power plants is the creation and use of two-coordinate solar tracking system, which provides the increase of the energy efficiency by at least 30 - 50% compared to stationary power plants without a system to optimize the position of solar panels [25, 26].

For ensuring the maximum performance, solar panels should be placed perpendicular to the flow of solar radiation. The angle of incidence of sunlight depends on the time of day and season [25, 26]. Therefore, *the actual task* is the correct positioning of solar panels and ensuring their maximum efficiency.

Trackers can be implemented on the basis of different principles [25]: 1) control of motors by means of several photodetectors - such device has two or more photoresistors; with the movement of the Sun, the illumination of photoresistors becomes different; the device analyzes the illuminance and transmits control signals to the motors until the light flux on all photocells is the same, and the motor rotates the solar panel; 2) control of the movement of the tracker at azimuthal and zenith angles – for the correct positioning of solar panels need to compensate for two movements of the Earth [26]: the daily movement associated with the rotation of the Earth around its axis, and the annual movement associated with the Earth's rotation around the Sun.

The Sun moves differently in different parts of the planet, and such systems require unique settings. Solar trackers are beneficial primarily for small solar power plants that are not located in places with high storm activity [25, 27]. Solar tracking systems can be divided into two types: those that follow a program that prescribes zenith and azimuth angles for a specific area, and those that use light-sensitive sensors to directly track the sun. The latter, in turn, can be built both on analog elements and using programmable controllers, which increases their functionality.

Currently, a large number of different solar position sensors based on different principles of determining the position of the sun have been developed for solar tracking systems, including slit solar sensors, Sagnac effect sensors, heliotrackers of various designs, and other original devices and structures [28, 29]. The main disadvantages of slit sensors are the high cost and complexity of the design, the need to use a complex control and management system. The principle of operation of the optical gyroscope based on the Sagnac effect – along the optical path in a circle, due to the splitting of the beam, the light propagates in two opposite directions; if the plane of the solar battery is perpendicular to the sun's rays, both light rays propagate to meet the optical path of the same length, so when adding rays at the end of the path there is no phase shift; however, when the sun moves at an angular velocity, a phase difference occurs between light waves [28, 30]. The heliotracker can literally be translated as "sun way's tracker"; its task is to be constantly focused on the sun; one of the options for such a system is that it consists of a photodetector, controller and actuator in the form of two motors with gearboxes that rotate the solar battery and a photodetector mounted on it (a small board with four photodetectors mounted on it) [28, 31]. A team of developers from the University of Malaysia (UNIMAS) has developed a solar position sensor, the design of which is close to the above heliotracker, but the feature is the use of photoresistors as sensitive elements; when the sun illuminates the center of the system, the photoresistors receive the same amount of light and have the same resistance [28, 32, 33].

The conducted analysis shows that currently for use in solar tracking systems, a large number of different sensors of the position of the sun based on different principles of determining the position of the sun. However, all of them have a significant disadvantage, which is due to the fact that the time when the sun is covered by clouds is much longer than the time when the clouds do not cover it (in Ukraine the sun is more often covered by clouds, especially in autumn, winter and spring). Given that the clouds are moving, the system will constantly change its position, spending extra energy to power electric motors that change this position. This reduces the produced energy, which transmit for the consumer. Also a feature of some sensors is the complexity of the design and the ambiguity of the characteristics when the temperature changes, which leads to an increase in cost.

So *the aim of this paper* is the development of the system that would track the sun regardless of the clouds. The main factor for aiming at the sun in high clouds is the calculation of its position. For calculating the position of the sun, we use an online calculator that determines the zenith and azimuth in degrees [34].

3. Intelligent solar tracking system

The input data for the intelligent solar tracking system are the coordinates of the location of the solar tracking system and time. The presence of these data allows calculating with sufficient accuracy the coordinates of the position of the Sun, which will be transmitted to the system. In addition to the above problem, there is also the problem of changing the position of the solar panel under the influence of external factors. Under external factors we will understand the load that is carried out on the solar panel by gusts of wind. As a result of this load, the solar panel changes its position, which leads to a loss of the produced energy. An inertial measuring sensor is a device that can constantly monitor the position of the solar panel. This sensor must have a digital output, as the position of the solar panel can only be controlled by a microcontroller. However, the microcontroller cannot directly control the motors of the solar panel position. This can only be done using a driver to control two direct current motors that rotate the solar panel at the zenith and azimuth according to the coordinates transmitted by the inertial sensor.

The inertial measuring sensor MPU 6050 is selected to control the position of the solar panel. The inertial measuring sensor allows obtaining the orientation of the object in three-dimensional space, converting the position of the solar panel into digital values. The direct current motors control driver TB6612FNG is selected for motors control. The board Arduino UNO + Wi-Fi R3 from RobotDyn is selected for combining these components with each other, reading the data and performing the general control of the intelligent solar tracking system. The use of the inertial measuring sensor MPU6050 is only possible with the Arduino microcontroller, as the microcontroller must receive the initial data, process it and store it for future use.

Therefore, the following equipment was selected for the implementation of an intelligent solar tracking system:

1. Arduino UNO board with Wi-Fi module based on ESP 8266 microcontroller
2. MPU 6050 sensor
3. Driver TB6612FNG for control of two direct current motors.

The MPU 6050 sensor interacts with the Arduino board via the I2C protocol, its connection is made according to the scheme – Figure 6.

The wiring diagram of the TB6612FNG driver to the Arduino controller is shown on Figure 7. The diagram independently controls the two motors of the intelligent solar tracking system, that allows directing the solar panel to the sun. Outputs A01 and A02 are for controlling the motor that rotates in azimuth, and B01 and B02 are for controlling the moto that rotates at the zenith. Arduino controller receives data from the MPU 6050, processes it and controls the motors via the TB6612FNG driver, which rotates the solar panel.

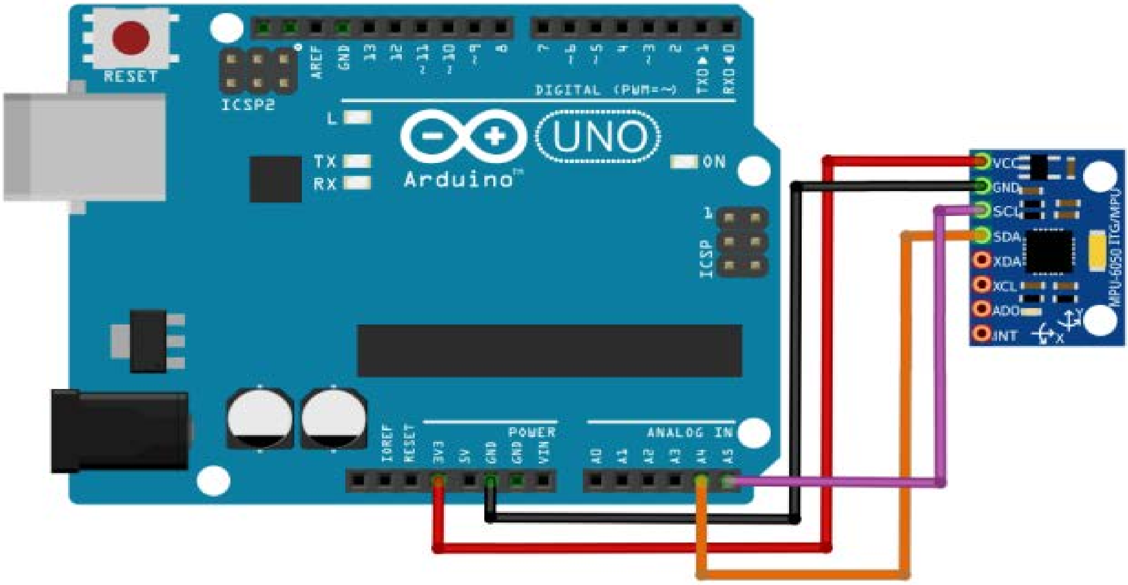

Figure 6: Wiring diagram of the inertial measuring sensor MPU 6050 to the Arduino microcontroller

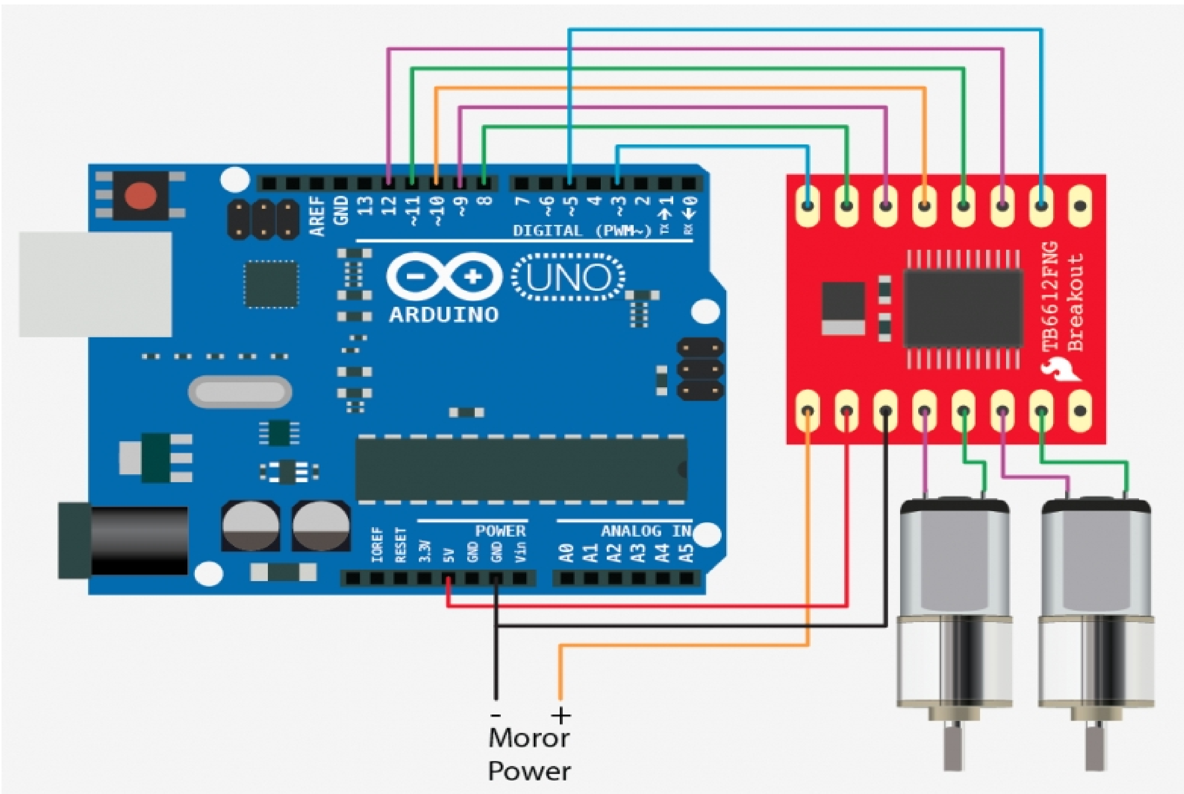

Figure 7: Wiring diagram of the TB6612FNG driver to the Arduino controller

The intelligence of the solar tracking system is that the system first determines its coordinates using GPS, and then calculates the coordinates of the zenith and azimuth of the sun and positions the surface of the solar panel at an angle of 90 degrees to the sun. The intelligent solar tracking system is mobile. It positions the surface of the solar panel at an angle of 90 degrees to the sun while changing its coordinates in space. The system also has sensors for wind direction and speed. If the wind speed exceeds the maximum allowable value, the system changes the position of the panel parallel to the wind direction. This is important for the reliability of such systems and to protect them from destruction at high wind speeds. The system also has strain gauges that record shocks on the surface of the panel in case of hail, which can damage the solar panel. If the hail sensor is activated, the system positions the solar panel vertically, which protects the panel from hail damage.

4. Results & discussion

The Arduino UNO controller and Wi-Fi module on the ESP8266 can work both together and completely independently. The mode of operation of both controllers is set by switches located on the board (Table 1). In the Table: CH340 – USB port control chip, ESP8266 – Wi-Fi module, ATMega328 – Arduino UNO controller. Using the Wi-Fi module, we can control the intelligent solar tracking system through a site that can be created in the memory of ESP8266. For this, the memory of ESP8266 is divided into two parts, one of which uses 1Mb for sketches (Wi-Fi management, file system messages, site implementation, etc.), and the other uses 7Mb for site files. The appearance of the Arduino UNO + Wi-Fi R3 board from RobotDyn is shown on Figure 8. As can be seen from Figure 8, the locations of the pins of the Arduino UNO board from Figures 6 and 7 completely match the pins of the Arduino UNO + Wi-Fi R3 board from RobotDyn. This simplifies the development of a general scheme for an intelligent solar tracking system that combines the above schemes (Figures 6 and 7).

Table 1

Operating mode of the Arduino UNO controller and Wi-Fi module on the ESP8266

Operating mode	1	2	3	4	5	6	7
CH340 is connected to ESP8266 (downloading the sketch)	Off	Off	Off	Off	On	On	On
CH340 is connected to ESP8266 (operation)	Off	Off	Off	Off	On	On	Off
CH340 is connected to ATMega328 (downloading the sketch)	Off	Off	On	On	Off	Off	Off
ATMega328+ESP8266	On	On	Off	Off	Off	Off	Off
Independent operation of ATMega328 and ESP8266	Off	Off	Off	Off	Off	Off	Off

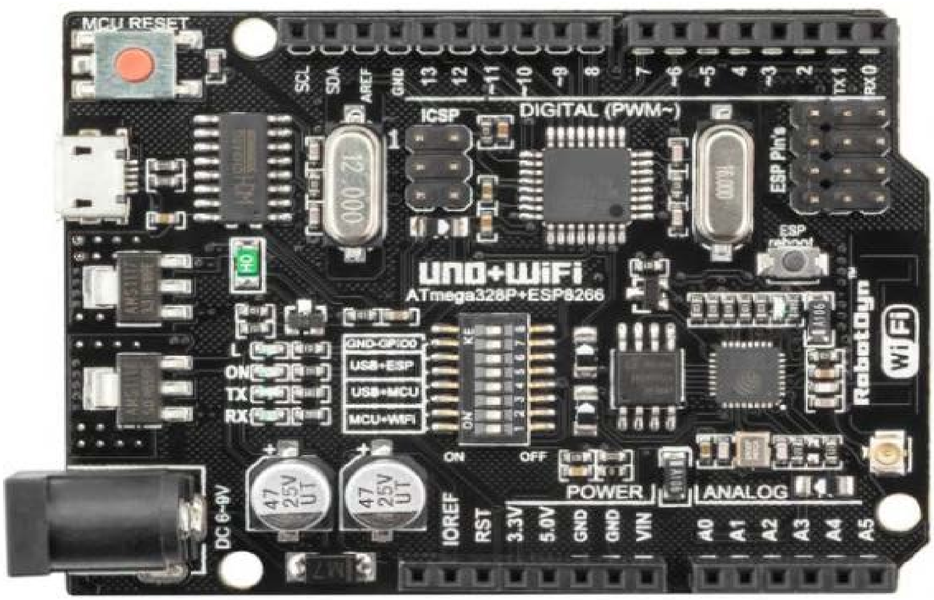

Figure 8: Appearance of the Arduino UNO + WiFi R3 board from RobotDyn

5. Conclusions

Ukraine has significant resources for the development of renewable energetics – the rivers with a power hydrological reserve, the mountains and seas for the installation of wind turbines, the long sunny period of the year, and significant agricultural areas for the cultivation of biofuel crops. All this combined with the favorable legislation and the "green" sentiments of society will enable Ukraine to take a prominent position in alternative energy among the advanced countries of the world.

The main factors, through of which the unfavorable investment climate in Ukraine don't allow investors and the state to fully develop alternative energy: political instability, instability of the foreign exchange market, budget deficits; weak stimulating state support in the development and use of alternative types of energy; inadequate funding for research and innovations in the energy sector; low awareness of people of the effectiveness of alternative energy sources; low competitiveness of domestic developments; the absence of industrial production of domestic analogues of plants that would use non-traditional fuels, etc.

Morally obsolete and physical wear and tear of the thermal power park of the fuel and energy complex of Ukraine, high energy dependence, environmental situation, high economic costs of heating testify to the need for effective steps in the legal regulation and legislative framework for the development of various types of alternative energetics and the stable attractive investment conditions for investors.

Consequently, Ukraine must develop, monitor and implement effective, environmentally friendly energy production technologies for the further sustainable development of the state. The importance of developing the alternative energetics is obvious, because it plays a crucial role in reducing the greenhouse gas emissions, in reducing the negative impact on the environment, in increasing the safety of energy supply and in reducing the dependence on energy imports. The development and use of alternative and renewable energy sources, and the adaptation of the legal regulation of alternative energetics to the needs of the present, are important factors for strengthening energy safety and reducing the negative technogenic impact on the environment.

The intelligent solar tracking system is developed in the paper. A mechanical design for positioning the solar battery in space, a light-sensitive photodetector for tracking the position of the Sun in two coordinates, a diagram of an intelligent solar tracking system were developed. The developed intelligent solar tracking system minimizes energy consumption for control and increases energy efficiency of electricity production. The use of such a system provides the significantly increase the amount of electricity produced by solar panels. All the above properties of the system, and control algorithms that ensure the performance of all these functions in automatic mode, determine the intelligence of the solar tracking system. This is currently the lowest level of intelligence that can be further developed by means of neural networks and ontological agents to control a large number of panels in automatic mode.

The authors plan to test alternative approaches to developing an intelligent solar tracking system - for example, using ontology-based intelligent agents implemented by the authors in [35-38], or using artificial neural networks studied by the authors in [39-41].

In addition, the authors plan to dedicate their further research to the implementation of the tree with solar panels and batteries that store solar energy as great innovation of using a renewable source of energy. Aim of this research will be providing the access to electricity and lighting and increasing the public's awareness of renewable energy. The concept is simple: there are leaf-like solar panels connected through metal branches using sunlight to make energy. The solar tree panels charge batteries during the day, and during the night, the tree automatically switches on LED lights, providing a safe and secure park. Plates with the solar panels should be movable and programmed to rotate in the direction of the sun's motion to store as much energy as possible during daylight hours. The basis of such a solar tree will be just the described principles of an intelligent solar traking system. The energy from the batteries of such a solar tree can be used to charge various gadgets, to create a workplace in the park, to power the information board, and so on. The installation of this solar tree will be done in the University Park where any student can have access to the trees without any cost.

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