

**DEVELOPMENT OF A COMBINED SOLAR–WIND ENERGY
SYSTEM ADAPTED TO THE CLIMATIC CONDITIONS OF
BUKHARA REGION**

Rustamov Nurmurod

Bukhara State Technical University

200100, 15 Q. Murtazoyev Street

Bukhara city, Uzbekistan

rustamovnurmurod40@gmail.com

Abstract. This thesis examines the development of a combined energy system designed to utilize solar and wind energy simultaneously, taking into account the natural and climatic conditions of the Bukhara Region. The high level of solar radiation and the availability of wind energy resources in the region create favorable conditions for the efficient utilization of renewable energy sources. The proposed system is intended to improve the stability of electricity generation by integrating photovoltaic solar panels and a wind turbine into a single energy system. The adaptation of the system's structural parameters, energy performance characteristics, and operating efficiency to the climatic conditions of the Bukhara Region is identified as the main research direction.

Keywords: solar energy, wind energy, combined energy system, photovoltaic panel, wind turbine, renewable energy, Bukhara Region, energy efficiency.

Introduction

Today, the growing demand for electricity and environmental problems associated with the use of conventional fuel resources necessitate the efficient utilization of renewable energy sources. Solar and wind energy are considered

environmentally friendly, renewable energy sources that can be utilized over a long period. Among the regions of Uzbekistan, the Bukhara Region has favorable natural conditions for the utilization of solar energy. At the same time, the region has the potential to utilize wind resources during certain seasons and periods of the day. Considering the temporal variability of solar and wind power generation, combining these two energy sources within a single system can improve the continuity and stability of electricity generation.

Main Part

Over the past decades, the growth of the renewable energy sector has accelerated at an unprecedented rate. According to data from the International Energy Agency (IEA), renewable energy capacity increased fourfold between 2010 and 2024. In 2023, more than 500 GW of new renewable energy capacity was commissioned worldwide, with the majority coming from solar and wind power projects [1].

In accordance with Resolution No. PQ-4422 of the President of the Republic of Uzbekistan dated August 22, 2019, entitled *“On Accelerated Measures to Improve Energy Efficiency of the Economy and Social Sectors, Introduce Energy-Saving Technologies, and Develop Renewable Energy Sources,”* long-term target parameters for the development of renewable energy sources and an action plan for further development of renewable energy sources were adopted. According to this resolution, it was planned to increase the share of electricity generated from renewable energy sources to at least 25% by 2030. To achieve these objectives, the construction of approximately 10 GW of renewable energy capacity was planned, including 5 GW of solar power capacity (excluding individual household installations), 3 GW of wind power capacity, and 1.9 GW of hydropower capacity.

Today, the utilization of wind energy is considered one of the most promising areas among renewable energy sources. The wind energy resources

of Uzbekistan have been assessed, and according to the results of conducted studies, the gross (theoretical) wind energy potential of the Republic over an area of 17,000 [unit/image value unclear in the source] at a height of 80 m was estimated at 520 GW, while the technical potential was determined to be 10 GW. Scientific research aimed at improving the energy efficiency of wind energy systems under variable wind-flow conditions, particularly through the development and practical implementation of vertical-axis wind energy systems, is currently of significant importance [2].

Combined solar–wind energy systems are hybrid systems developed for the efficient utilization of renewable energy sources. They are designed to simultaneously convert solar radiation and wind-flow energy into electrical energy. The main concept of such systems is to utilize the complementary characteristics of natural energy sources in order to ensure continuity and stability in the energy generation process. Another important advantage of combined systems is their adaptability to different climatic conditions. In particular, Uzbekistan has an average of approximately 300 sunny days per year and high levels of solar radiation. In addition, the presence of wind corridors and persistent low-speed wind flows in certain areas, particularly deserts and open plains, makes the implementation of such systems appropriate.

In July 2025, the total electricity generation from solar, wind, and hydropower plants in Uzbekistan reached 2.089 billion kWh, accounting for 27% of the country's monthly electricity generation. This amount of renewable electricity generation saved 633 million cubic meters of natural gas and prevented the emission of 1.88 million tons of harmful gases into the atmosphere [3].

In combined solar–wind energy systems, the photovoltaic subsystem provides electricity generation during daylight hours and can partially compensate for the reduction in the output of the wind energy system during

periods of low wind speed. The combined utilization of solar and wind energy makes it possible to improve the reliability of autonomous power supply systems and enhance the overall energy balance of the system [4].

These systems can be widely used, particularly in the following areas:

- decentralized (off-grid) power supply systems;
- agricultural facilities, including irrigation pumps and greenhouses;
- settlements located in remote and mountainous areas;
- small-scale industrial and residential applications.

In addition, combined energy systems are environmentally friendly, do not emit harmful gases into the atmosphere during electricity generation, and reduce dependence on conventional fuel resources. This is an important factor in mitigating the impacts of global climate change.

The solar energy subsystem of the proposed system consists of photovoltaic panels. Photovoltaic panels convert solar radiation into electrical energy. The wind energy subsystem consists of a wind turbine that converts the kinetic energy of the wind flow into mechanical energy and subsequently into electrical energy. To provide autonomous consumers with a continuous supply of electricity, the wind energy system can be used in combination with solar panels (4) (Figure 1).

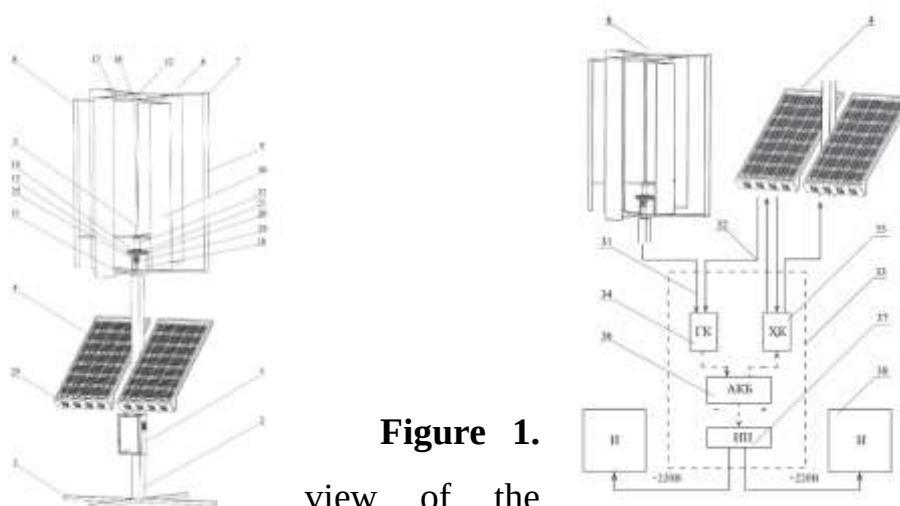


Figure 1.
view of the

General
combined

solar–wind energy system (a) and schematic diagram of the control system of the combined solar–wind energy system (b).

Brief Description of the Device: The vertical-axis wind energy system operates as follows. The wind blades (9), installed at an optimal angle β relative to the tangent to the circumference of the outer wind rotor (8), are rigidly connected through metal profiles (10) to the rotating tube (11). The rotating tube (11) is mounted on the stationary shaft (3) by means of tapered bearings (12). The metal profiles (10) are connected to the armature (14) of the electric generator (13) by means of a metal sleeve (15). Under the action of the wind flow, this system begins to rotate in the clockwise direction. The blades (17) of the inner wind rotor (16) are rigidly connected through metal profiles (18) to the rotating tube (19). The rotating tube (19) is mounted on the stationary shaft (3) by means of tapered bearings (20). The inductors (21, 22) of the electric generator (13) are connected by a flange joint (23). Under the action of the wind flow, this system begins to rotate in the counterclockwise direction. As a result, the wind energy system (28) converts the kinetic energy of the wind flow into electrical energy. The armature (14) and inductors (21, 22) of the electric generator (13) begin to rotate in opposite directions relative to each other. In this process, the brush (26), connected to the armature (14) through the metal sleeve (15), transmits the three-phase

alternating voltage to the collector (27) mounted on the stationary shaft (3). Thus, electrical energy is generated depending on variations in the wind flow and is transmitted through the cable (29) to the hybrid charge and discharge controller (32) of the control system (31). The hybrid charge and discharge controller (32) supplies the generated electrical energy as direct current, which is stored in the battery bank (34). The electrical energy stored in the batteries (34) is then converted by the inverter (35) into single-phase alternating voltage, thereby providing autonomous consumers (36) with a continuous supply of electricity. The wind energy system converts the kinetic energy of the wind flow into mechanical rotational energy. In small-scale systems, vertical-axis turbines, such as Darrieus and Savonius types, are often used because they can operate under low-wind-speed conditions and have relatively simple designs. In the proposed system, a 1 kW wind energy system is employed, consisting of a combination of an H-type Darrieus turbine and a Savonius turbine [5]. This hybrid turbine configuration was selected to ensure reliable starting under low-wind conditions and high operating efficiency.

The total installed capacity of the proposed combined energy system is determined as follows:

- Solar panels: 1.15 kW
- Wind turbine: 1 kW
- Total capacity: ≈ 2 kW

The operating principle of the system is as follows:

- Under sunny weather conditions, the primary energy source is the photovoltaic panels;
- Under windy conditions, the wind turbine serves as the primary energy source;

- When both energy sources operate simultaneously, the system can generate its maximum combined power;
- The generated electrical energy is stored in the battery bank and subsequently supplied to the consumer.

The power output of the wind turbine can generally be determined using the following expression:

$$P_v = 0,5 \cdot \rho \cdot A \cdot v^3 \cdot C_p \cdot \eta \quad (1)$$

P_v — electrical power output of the wind energy system, W;

ρ — air density, kg/m³;

A — swept area of the wind turbine, m²;

v — wind speed, m/s;

C_p — power coefficient of the wind turbine;

η — overall efficiency of the generator and other system components.

The electrical energy generated by the solar photovoltaic system depends on solar irradiance, the panel area, the efficiency of the photovoltaic panel, and the losses within the system:

$$P_s = G \cdot S \cdot \eta_s \cdot \eta_t \quad (2)$$

where:

P_s — output power of the photovoltaic panel;

G — solar irradiance intensity, W/m²;

S — photovoltaic panel area, m²;

η_s — efficiency of the photovoltaic panel;

η_t — overall system efficiency coefficient.

The total electrical power of the combined energy system is:

$$P_{\Sigma} = P_s + P_v \quad (3)$$

is expressed in the following form:

Conclusion

Experimental studies were conducted at the Green Energy Scientific and Innovation Center under Bukhara State Technical University. Under the climatic conditions of the Bukhara Region, a hybrid energy system consisting of a 1 kW photovoltaic panel and a 1 kW wind generator produces an average of 8210 kWh of electricity per year, demonstrating the potential for efficient utilization of renewable energy sources.

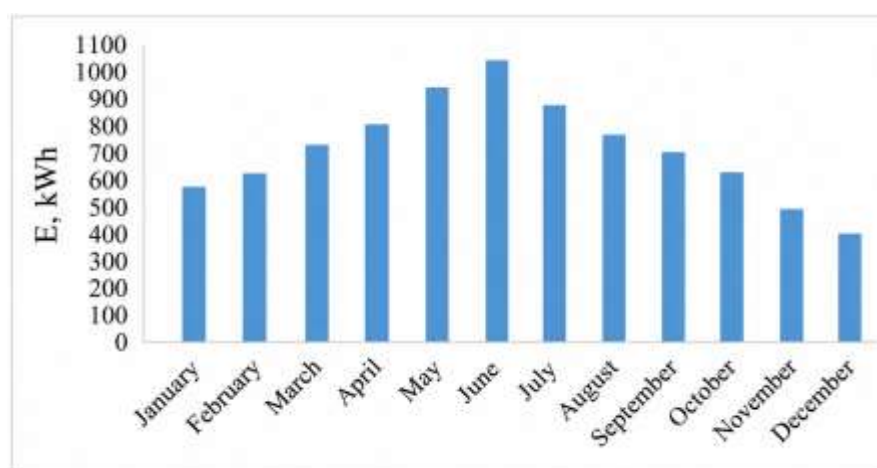


Figure 2. Monthly Electricity Generation Dynamics of the Combined Solar–Wind Energy System

The natural and climatic conditions of the Bukhara Region provide favorable opportunities for the integrated utilization of solar and wind energy. By combining photovoltaic solar panels and a wind turbine into a single energy system, it becomes possible to utilize two different renewable energy sources simultaneously.

Designing the combined energy system based on the actual solar irradiance, wind speed, temperature, and other meteorological parameters of the region can contribute to improving its energy efficiency. In the future, it is advisable to develop an experimental prototype of the system and conduct

tests under both laboratory and real-world conditions to determine its electrical power output, amount of generated energy, and overall efficiency.

References

1. International Energy Agency IEA, 2024.
2. R.A. Zakhidov., M.V. Kremkov. The wind power potential of Uzbekistan. Applied Solar Energy. volume 51, pp. 336–337(2015).
- 3.https://www.uzdaily.uz/en/solar-and-wind-power-plants-supplied-17-ofuzbekis-tans-electricity-in-july/?utm_source
4. Masters G.M. Renewable and Efficient Electric Power Systems. 3rd Edition. Hoboken: John Wiley & Sons, 2021, 676 p
5. G.N.Uzakov, R.A. Zaxidov, A.B.Safarov, X.A.Davlonov —SHAMOL ENERGETIKASI 2023 y. 33-43 b.