

Mathematical Modelling of Operating Modes of a Power Plant Based on Alternative Hybrid Energy Sources and Analysis of Power Distribution Optimization Problems

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ABSTRACT: The article presents a comprehensive review of the theoretical foundations of hybrid energy systems. In particular, the main characteristics of alternative energy sources (solar, wind, hydro, biomass and geothermal energy) are analyzed, and examples of types of hybrid energy systems and their application in various industries are given.

The methods for determining the indicators of power distribution and efficiency are described, formulas and calculation methods are given. In addition, factors affecting the efficiency of the system, waste issues and optimal distribution are considered.

The solutions presented in international standards (IEC, ISO) and scientific literature are analyzed, and the experience of Germany, China and India is given as examples.

Analysis of international standards and experiences has shown that hybrid systems are effectively used not only in isolated areas, but also in industrial and urban power supply.

In Uzbekistan, there is also an opportunity to provide agricultural facilities, island regions, and industrial enterprises with sustainable electricity through the introduction of hybrid energy systems.

KEY WORDS: Classification, Data Mining, Machine Learning, Predictive analysis, Social Networking Spam, Spam detection.

I.INTRODUCTION

In the current rapidly developing energy sector, the demand for electricity is increasing day by day. The limited reserves of traditional energy sources - oil, gas and coal, their high cost and negative impact on the environment are increasing interest in alternative energy sources. Therefore, the effective use of renewable energy sources - solar, wind, hydro and biomass - is gaining strategic importance.

However, these energy sources depend on natural factors and their reliability is not always high. For example, a wind turbine does not produce power when there is no wind movement, and solar panels only work when there is sunlight. Therefore, creating hybrid energy systems by combining different energy sources is an urgent task today.

Hybrid systems complement different sources, making electricity supply uninterrupted and reliable. At the same time, they can increase efficiency by properly organizing power distribution. This issue is not only economically important, but also environmentally and socially.

In recent years, global changes have been taking place in the energy sector. The depletion of traditional fuels such as oil, gas, and coal and their negative environmental impact have led to a demand for sustainable and renewable energy sources.

Alternative energy sources mainly include:

- solar energy – converted directly into electricity through photovoltaic panels;
- wind energy – electrical power is generated from mechanical movement using wind turbines;
- hydropower - the kinetic and potential energy of water flow is used through large hydroelectric power plants and micro-hydropower plants;
- biomass – allows you to obtain energy by processing waste and organic products;

Geothermal energy – uses heat from deep within the earth to produce electricity or heat.

Each of them can be effective depending on the climatic conditions, natural resources, and economic capabilities of a particular region.

characteristics of

Alternative energy sources (solar, wind, hydro, geothermal, biomass) are one of the main directions of sustainable development strategy in the 21st century. The main feature of these sources is that they are renewable, unlimited and environmentally friendly.

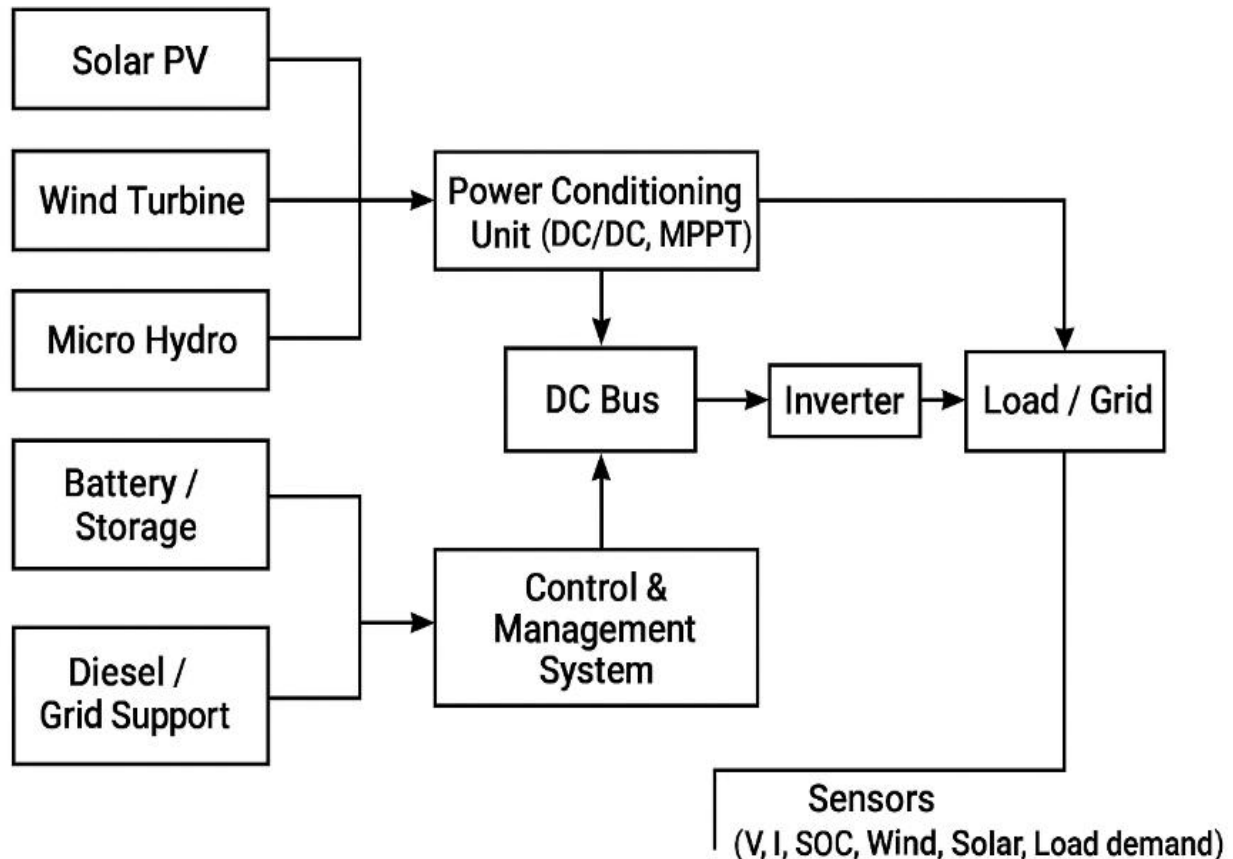


Figure 1. Hybrid system block diagram:

Solar energy is converted into electrical or thermal energy using solar panels. Its efficiency is around 15–22% in photovoltaic modules. Since solar radiation is not constant, integration with battery systems is necessary.

Wind energy – generates electricity through wind turbines. The efficiency of the turbine depends on the wind speed, operating in the range of 4–25 m/s.

Hydropower - allows you to generate electricity by using a river, canal, or special reservoir. Microhydropower is effective in small areas.

Biomass and biogas – generate electricity or heat energy by processing organic waste.

Geothermal energy is the use of underground temperature to generate heat and electricity.

The common feature of these sources is that their ability to generate energy depends on natural factors, and reliability is not always high. Therefore, their combined use in hybrid systems is relevant.

Alternative energy sources (solar, wind, hydro, geothermal, and biomass) are renewable and environmentally friendly energy sources. Each of them has different characteristics and uses.

One type of energy source often cannot provide stable production. For example, solar panels only work during the day, while wind turbines depend on the speed of the wind. Therefore, hybrid energy systems are created by combining different sources. Hybrid energy supply systems provide stable and efficient electricity by combining different sources. Hybrid systems integrate multiple sources to compensate for each other's shortcomings. They can be used in applications ranging from autonomous systems to large-scale integrated agricultural and industrial facilities.

Main types:

Solar-wind hybrid: The most common form, efficient due to the time-dependent complementarity of the two sources, and the sun and wind complement each other, creating a continuous source of energy.

Table 1
Characteristics of alternative energy sources:

Source	Nature of supply	Efficiency (adv.)	Main restrictions
Sun (PV)	Depends on the day, needs a battery for backup energy	15–22%	Radiation variability
Wind	Depends on air traffic	25–45% (depending on turbine)	Wind speed and stability
Microhydroelectric power plant	Depends on water capacity	50–90% (depending on the energy system)	Availability of water resources
Biomass/Biogas	A constant supply of organic matter	30–40%	Raw material continuity
Geothermal	Depends on the temperature of the earth	10–20%	Geological conditions

Solar-diesel or wind-diesel hybrid: used when renewable resources are insufficient and in autonomous regions, with a diesel generator acting as a backup.

Solar-wind-hydro hybrid: a multi-source system that provides high reliability throughout the year and is effective in areas where water resources are available.

Solar-wind-battery: solar panels collect energy during the day, provide nighttime operation through batteries, and provide consumers with uninterrupted power through an energy backup system.

Wind-battery system – the battery provides backup power when the wind turbines are not operating.

Hybrid systems have become widely used in agriculture, water pumping stations, isolated villages and settlements, as well as industrial facilities.

Application:

- for autonomous supply at work sites;
- in pumping stations and water supply systems;
- on campuses, schools, and hospitals;
- In order to save energy in industrial facilities.

II. SIGNIFICANCE OF THE SYSTEM

Power distribution and efficiency indicators. Power distribution in hybrid systems is a complex process, in which the following issues are addressed:

Power distribution principles: the available power, operating mode, and economic costs of each source are taken into account. For example, solar panels are used first because they are a cheap energy source, then wind, and finally a diesel generator is added.

Efficiency indicators:

- reliability (continuity of energy supply), (availability, loss of load probability);
- economic efficiency (cost of energy per kWh);
- environmental indicators (CO₂ emission reduction);
- stability of the energy balance (system efficiency).

The efficiency of a hybrid energy system largely depends on the power distribution algorithm. Optimal distribution is achieved based on the real-time operating status of the resources (e.g., solar radiation, wind speed, water consumption).

The main criteria for power distribution are:

- energy production;
- providing consumers with uninterrupted and stable supply;
- optimal use of reserve resources;
- It increases the efficiency of the system.

Mathematical modeling and optimization methods (linear and nonlinear programming, dynamic allocation algorithms, and robust heuristic methods) are widely used in this.

Power distribution of alternative hybrid energy sources (in percent)

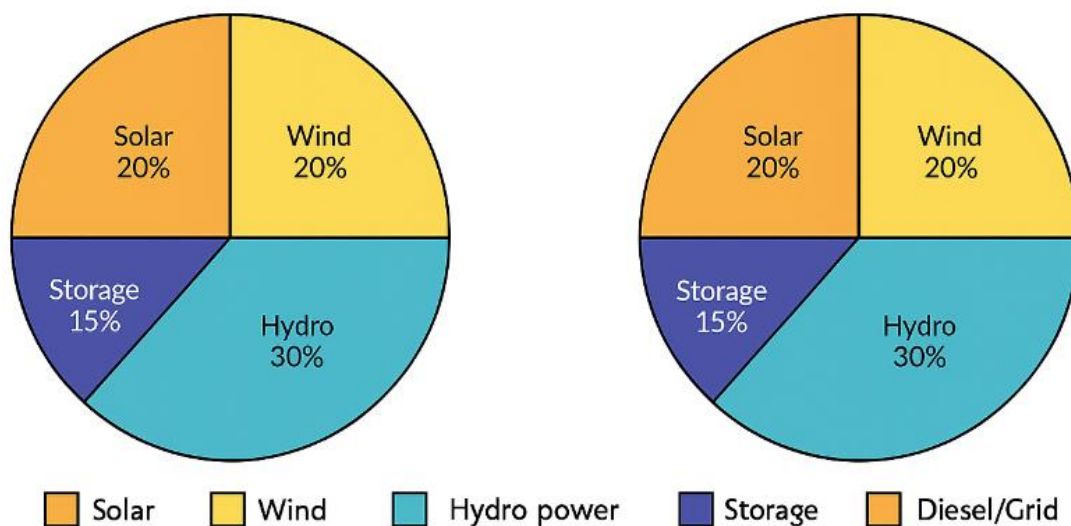


Figure 2. Power distribution of alternative hybrid energy sources (in percent).

As a formula, the overall operating efficiency of a hybrid system can be expressed as:

$$\eta_{tizm} = \frac{P_{yuklama}}{P_{quyosh} + P_{shamol} + P_{gidro} + P_{zaxira}}$$

where is $P_{yuklama}$ the consumer load, $P_{quyosh}, P_{shamol}, P_{gidro}, P_{zaxira}$ —source capacities.

Power distribution is still a system of rules that govern how power is distributed among energy sources and when it is used. Optimal distribution increases power efficiency and reduces costs.

Hybrid energy system components and their standards

1.5.1. International standards

To ensure the stable and reliable operation of hybrid energy systems, each of their components must comply with international standards. The main standards are as follows:

IEC 61215 is a standard for the design and reliability testing of photovoltaic (solar) panels.

IEC 61400 – is used to assess the safety, efficiency, and reliability of wind turbines.

IEC 62116 is a standard for "anti-rollback" (autonomous protection from failure) tests for inverters.

ISO 14001 – implementation of environmental management systems.

IEC 62933 – standards applicable to energy storage systems, especially batteries.

These standards guarantee the compatibility and technical safety of hybrid systems with the international market.

Table 2

Technical characteristics tables for photovoltaic panels

Parameter	Value (average)	Note
Rated power	250–500 Wp	Depends on panel type
Rated voltage	24–48 V	Depending on the system
Efficiency	15–22 %	High in monocrystalline panels

Table 3

Technical characteristics tables for wind turbines

Parameter	Value (average)	Note
Rated power	1–3 MW (large), 1–20 kW (small)	Depends on turbine size
Startup speed	3–4 m/s	Min. wind speed
Rated speed	12–15 m/s	Optimal operating mode
Stopping speed	25 m/s	For security reasons

Table 4
Technical characteristics tables for batteries

Parameter	Value (average)	Note
Talent	50–500 Ah	Depending on system power
Full discharge cycle	2000–6000 cycles	High in lithium-ion batteries
Efficiency	85–95%	Charge–discharge process

Real-world examples of application. Agriculture - solar-wind-battery hybrid systems are used to power water pumping stations.

Industrial and urban power supply - hybrid systems are integrated into the national power grid in areas with energy shortages.

Solar-wind hybrids are used to partially or completely replace diesel generators in isolated areas - islands and villages.

Technical formulas and calculation examples. Power balance equation:

$$P_{umumiy} = P_{quyosh} + P_{shamol} + P_{gidro} + P_{batareya} - P_{isrof}$$

where:

P_{quyosh} - photovoltaic panel power, P_{shamol} - wind turbine power, P_{gidro} - hydroelectric power, $P_{batareya}$ - battery power, P_{isrof} - waste.

Useful work coefficient :

$$\eta_{tizim} = \frac{P_{yuklama}}{P_{umumiy}} \cdot 100$$

III. LITERATURE SURVEY

Analysis of scientific literature. A number of scientific works have been carried out in global and local research on hybrid energy systems. In particular:

Many projects have been implemented in Europe and the USA to optimize solar-wind-diesel systems. Scientists from the USA, Germany and Japan have studied the economic and environmental efficiency of hybrid systems and proposed models based on MATLAB/Simulink. For example, software packages such as [Homer Pro] are used to optimize energy distribution.

Solar-wind-battery systems are being effectively used for rural areas in China and India.

Scientific work is being conducted in Uzbekistan on the integration of solar and wind energy. There is also research aimed at creating autonomous supply systems in rural areas. In Central Asia, including Uzbekistan, experiments are being conducted on the use of hybrid systems to power agricultural water pumps.

As can be seen from the literature review, hybrid energy systems are currently considered not only an environmentally friendly source of energy, but also an economically competitive solution. The efficiency of hybrid systems largely depends on the optimal management of power distribution. Therefore, this dissertation focuses on the issues of mathematical modeling and optimization. Therefore, increasing their efficiency, mathematical modeling and optimal distribution are current areas of scientific research.

An analysis of the scientific literature shows that there are various approaches to modeling hybrid systems: static optimization, dynamic simulation, heuristic and evolutionary algorithms. Each approach has its advantages and disadvantages and is chosen depending on the research task.

Platforms and programs such as HOMER Pro, MATLAB/Simulink, and OpenModelica are widely used in manual studies for residential and industrial facilities. PSO (Particle Swarm Optimization), GA (Genetic Algorithm), and MILP (Mixed-Integer Linear Programming) are also used for optimization.

Analysis of international experiences. Germany plans to increase the share of renewable energy in the national grid through hybrid solar-wind plants.

China is establishing a stable supply in isolated areas through the integration of micro-hydropower and solar panels.

India is working to power islands and rural areas using hybrid systems, reducing diesel consumption.

IV.CONCLUSION AND FUTURE WORK

The growing need for renewable energy sources, increasing demand for electricity, and sustainable development strategies make the implementation of hybrid energy systems a vital necessity. Therefore, the research topic is of great importance both scientifically and practically.

Thus, based on the theoretical analyses conducted in this article, the following general conclusions can be drawn:

Hybrid energy systems are an effective solution to overcome the problems of uncertainty and continuity in renewable energy sources.

The issue of power distribution is a crucial factor in improving system efficiency, and mathematical modeling and optimization methods play an important role in this process.

Analysis of international standards and experiences has shown that hybrid systems are effectively used not only in isolated areas, but also in industrial and urban power supply.

In Uzbekistan, there is also an opportunity to provide agricultural facilities, island regions, and industrial enterprises with sustainable electricity through the introduction of hybrid energy systems.

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