Yashil energetikaga o‘tish davrida O‘zbekiston elektr energetika tizimining ishonchliligini oshirish

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Dolzarbligi: Markaziy Osiyoning Birlashgan energetika tizimiga (BET) qayta tiklanuvchi energiya manbalarini (QTM) keng ko‘lamda integratsiya qilish rejalari doirasida elektr energiyasi ishlab chiqarish va iste’mol o‘rtasidagi muvozanatni saqlash masalasiga alohida e’tibor qaratish zarur. Qayta tiklanuvchi energiya manbalari (QTM) asosida ishlab chiqariladigan elektr energiyasining uzluksiz bo‘lmagan tabiati energetika tizimining ishlash barqarorligiga sezilarli ta’sir ko‘rsatishi mumkin. Ushbu tadqiqot elektr energiyasi ishlab chiqarish va iste’mol o‘rtasidagi qoplanmagan nomutanosiblik ehtimolini kamaytirish va iste’molchilarga elektr energiyasi yetkazib berish ishonchliligini oshirishga qaratilgan zamonaviy energiya saqlash tizimlarini o‘rganadi. Tahlil natijasida O‘zbekistonda joriy etish uchun eng mos energiya saqlash tizimlari turlari aniqlanadi hamda qayta tiklanuvchi energiya manbalari (QTM) integratsiyasi orqali energiya tanqisligini qoplash imkoniyatlari baholanadi.

Maqsad: yashil energetikaga o‘tish jarayonida O‘zbekistonning elektr energetika tizimining moslashuvchanligi va ishonchliligini oshirish imkoniyatlarini o‘rganish, qayta tiklanuvchi energiya manbalarining keng joriy etilishi sharoitida tizimda yuzaga kelishi mumkin bo‘lgan muvozanatsizlik va barqarorlik muammolarini aniqlash hamda ularni bartaraf etish bo‘yicha zamonaviy texnologik yechimlar, jumladan energiya saqlash tizimlari va boshqa qo‘llab-quvvatlovchi vositalarning samaradorligini baholash.

Usullari: SCADA/EMS, SMART GRID va virtual elektr stansiyalar(VES) kabi ilg‘or boshqaruv tizimlarining joriy etilishi va ularning real vaqtda tizimga ta’siri baholandi. Ularning yordamida qayta tiklanuvchi energiya manbalarining tizimga moslashtirilgan boshqaruvi o‘rganildi.

Natijalar: qayta tiklanuvchi energiya manbalarining (QTM) tezkor va keng ko‘lamli integratsiyasi O‘zbekiston elektr energetika tizimi uchun yangi muammolarni yuzaga keltirmoqda. Xususan, ishlab chiqarish va iste’mol o‘rtasidagi muvozanatning saqlanmasligi, chastota tebranishlari va kuchlanishdagi beqarorliklar tizim barqarorligini pasaytiradi.

Kalit so'zlar: Elektr energetika tizimi, moslashuvchanlik,ishonchlilik, qayta tiklanuvchi energiya manbalari (QTM), energiya saqlash tizimlari (EST), aqlli tarmoq (Smart Grid),birlashgan energetika tizimi(BET), virtual elektr stansiyalar(VES), Lityum-ion batareyalar(Li-ion).

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Повышение надежности энергосистемы Узбекистана в условиях «зеленого» перехода

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Актуальность: в связи с масштабными планами по интеграции возобновляемых источников энергии (ВИЭ) в Единую энергетическую систему (ЕЭС) Центральной Азии, необходимо решить проблему поддержания баланса между выработкой и потреблением электроэнергии. Переменный характер выработки электроэнергии на основе ВИЭ может значительно повлиять на устойчивость работы энергетической системы. В данном исследовании рассматриваются современные системы накопления энергии, направленные на снижение вероятности некомпенсированных энергетических дисбалансов и повышение надежности электроснабжения потребителей. Анализ определяет типы систем накопления энергии, наиболее подходящие для внедрения в Узбекистане, и оценивает потенциал покрытия энергетических дефицитов за счёт интеграции ВИЭ.

Цель: изучение возможностей повышения гибкости и надежности электроэнергетической системы Узбекистана в процессе перехода к «зеленой» энергетике, выявление возможных проблем дисбаланса и устойчивости в системе при широком внедрении ВИЭ, а также оценка эффективности современных технологических решений для их устранения, включая системы накопления энергии и другие поддерживающие средства.

Методы: были оценены передовые системы управления, такие как SCADA/EMS, SMART GRID и виртуальные электростанции, а также их влияние на систему в режиме реального времени. С их помощью изучалось адаптированное управление возобновляемыми источниками энергии в системе.

Результаты: быстрая и масштабная интеграция возобновляемых источников энергии (ВИЭ) создает новые проблемы для энергосистемы Узбекистана. В частности, нарушение баланса между производством и потреблением энергии, колебания частоты и нестабильность напряжения снижают устойчивость системы.
Ключевые слова: Электроэнергетическая система, гибкость, надёжность, возобновляемые источники энергии (ВИЭ), системы накопления энергии (СНЭ), интеллектуальная сеть (Smart Grid), объединённая энергосистема (ОЭС), виртуальные электростанции (ВЭС), литий-ионные аккумуляторы (Li-ion).

Improving the reliability of the energy system Uzbekistan under the conditions of “green” transition

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Relevance: Considering the large-scale integration plans for renewable energy sources (RES) into the Unified Power System (UPS) of Central Asia, it is essential to address the issue of maintaining the balance between electricity generation and consumption. The intermittent nature of RES-based electricity generation can significantly affect the operational stability of the power interconnection. This study examines modern energy storage systems aimed at reducing the likelihood of uncompensated power imbalances and enhancing the reliability of power supply to consumers. The analysis identifies the types of energy storage systems most suitable for implementation in Uzbekistan and evaluates the potential for covering energy deficits through RES integration.
Aim: study of the possibilities for enhancing the flexibility and reliability of Uzbekistan's power system during the transition to green energy, identification of potential imbalance and stability issues in the system amid large-scale integration of renewable energy sources, as well as evaluation of the effectiveness of modern technological solutions to address them, including energy storage systems and other supporting tools.
Methods: the implementation of advanced control systems such as SCADA/EMS, Smart Grid, and Virtual Power Plants (VPPs) was assessed, along with their real-time impact on the power system. These technologies were used to study the adaptive management of renewable energy sources within the system.
Results: the rapid and large-scale integration of renewable energy sources (RES) is creating new challenges for Uzbekistan's power system. In particular, imbalances between generation and consumption, frequency fluctuations, and voltage instability reduce the system's overall stability.
Keywords: Power system, flexibility, reliability, renewable energy sources (RES), energy storage systems (ESS), smart grid, unified energy system (UES), virtual power plants (VPP), lithium-ion batteries (Li-ion).

1. Introduction

While the environmental benefits of renewable energy sources (RES) are well known, their potential to enhance energy security remains less publicized. Nevertheless, renewable energy technologies can significantly improve energy security both in electricity generation and in heating and transportation systems. In countries where the increasing reliance on imported natural gas undermines energy security, the deployment of renewable energy technologies offers a viable and sustainable alternative for electricity generation. The deployment of renewable technologies typically increases the diversity of electricity sources and, through localized generation, enhances system flexibility and resilience. However, discussions in this area have often been overly focused on the issue of variability in renewable electricity production. While this concern is mostly associated with wind energy, its actual impact depends on several factors, including the market penetration level of renewables, the overall energy balance, system interconnectivity, and demand-side flexibility.

Variability is rarely a fundamental barrier to scaling up renewable energy use. Nevertheless, at high penetration levels, it requires thorough planning and system management, and may entail additional costs for backup capacity or system modifications. Notably, renewable energy shares ranging from 20% to over 50% have already been successfully integrated into several European power systems.

In Uzbekistan, approximately 85% of electricity generation is based on natural gas. Given the rapid growth in electricity demand and the corresponding need for fossil fuel resources, the large-scale deployment of renewable energy sources (RES) has become a strategic priority. According to the “Uzbekistan–2030” strategy, electricity production is planned to reach 120 billion kWh per year, with the share of RES increasing to 40% [1, 2].

To ensure the stable operation of the power system, measures have been planned to modernize the existing grid infrastructure, construct new substations and transmission lines, implement automated protection systems, and deploy digital control technologies (SCADA/EMS). Additionally, increasing the share of reserve capacity and energy storage systems (ESS) is a key component of the strategy.

The growing energy demand and accelerated integration of RES require improved approaches to power system management. The integration of distributed generation — particularly from solar and wind sources — poses challenges to system stability, power quality, and controllability. Effective integration of distributed energy resources (DER) is essential for ensuring energy system stability. Inadequate management of DER can lead to voltage fluctuations, frequency deviations, and degradation of power quality. Addressing these challenges necessitates the implementation of intelligent control systems and advanced energy storage technologies [2].

After 1991, the pursuit of energy independence by Central Asian countries, without conducting comprehensive feasibility studies, resulted in the loss of the advantages offered by the United Power System (UPS). The efficiency of parallel operation declined due to limited mutual power exchanges and changes in coordination mechanisms and institutional roles. Diverging national strategies and a focus on self-interest have further undermined the long-term sustainability of the regional power systems.

The key objectives of regional energy integration include ensuring redundancy of power supply under both normal and emergency operating conditions, fulfilling cross-border electricity exchanges under intergovernmental agreements (IGAs), and promoting the rational use of energy resources. National power systems should be capable of meeting base, peak, and reserve capacity demands while jointly developing projects to advance the regional UPS. These initiatives must consider alternative generation technologies, the construction of resource-efficient power plants, and the integration of RES alongside energy-saving technologies.

Currently, Uzbekistan's energy system is addressing a persistent power and energy deficit driven by several key factors:

1.High population growth — In recent years, the annual population growth rate in Uzbekistan has exceeded 2%. By 2030, the population is projected to reach 41 million, with the economy expected to grow by 1.5 times;

2.Rising electricity demand and insufficient new capacity — The rapid development of the national economy necessitates substantial increases in installed capacity. By 2035, electricity demand is forecast to reach 135 billion kWh, which is 1.7 times higher than current levels. To reduce generation costs (currently 5–6 cents/kWh for thermal power plants and 3 cents/kWh for renewables), the share of RES is planned to exceed 50%;

3.Infrastructure constraints and limited investment — The absence of new base-load generation and limited investments due to regulatory risks hinder generation expansion. Aging transmission infrastructure contributes to technical losses and constrains energy delivery to end-users, even in areas with sufficient generation potential;

4.Challenges related to RES integration and system stability — The installed capacity of RES in Uzbekistan is growing rapidly. However, the variable nature of solar and wind generation necessitates the presence of reliable base-load and flexible generation, as well as energy storage systems. The lack of such balancing capacities has led to shortages of stable power supply. Addressing this issue requires investments in infrastructure modernization, construction of new power plants, and deployment of energy storage technologies;

5.Insufficient flexible and base-load generation — Daily fluctuations in demand require rapid response from generation assets. However, the existing generation fleet lacks sufficient flexibility, contributing to system imbalances and energy shortages.

2. Methods and materials

Hydropower plants (HPPs) and gas turbine power plants (GTPPs), which provide maneuverable capacity, play a crucial role in balancing the power system during peak demand hours and periods of unstable renewable energy (RES) generation. However, their current capacities are insufficient. As a result, the imbalance between the rapid expansion of RES and the limited availability of flexible generation capacity has intensified. In addition, there is a notable shortage of base-load capacity, which is essential for ensuring the stable supply of minimum demand levels, particularly during peak load periods.

The shortage of both flexible and base-load generation is primarily driven by insufficient natural gas production and extraction, as well as the underdevelopment of base and maneuverable power generation infrastructure. This imbalance has contributed to a series of systemic failures in recent years, affecting the entire United Power Systems of Central Asia (UPS CA), due to overloading of major power plants and several interconnection transmission lines. The energy deficit can potentially be addressed through increased imports of electricity and natural gas, as well as through the large-scale integration of RES. In both cases, the deployment of energy storage systems (ESS) is of strategic importance. Notably, since 2023, natural gas has been supplied in reverse flow through the Bukhara–Urals pipeline [2,3].

Ensuring Additional Reserve Capacity in the UPS CA

The reserve capacities required to maintain frequency stability in the UPS CA remain inadequate — frequency regulation is currently performed by the United Power Systems of the Russian Federation (UPS RF). The reserve capacity at regulating power plants in the UPS CA should be sufficient to compensate for imbalances, provided that deviations do not exceed 200–250 MW. Each national power system within the UPS CA is expected to independently meet its own peak demand. If the available capacity is insufficient, the system must procure the necessary power from neighboring energy systems. However, there may be no surplus capacity available in those systems.

A significant challenge has been the integration of large-scale solar PV and wind farms into the grid, which must be accompanied by adequate tertiary reserves to compensate for generation losses when RES output drops. A regional market mechanism is needed to incentivize the deployment of energy storage systems (ESS) and mobile reserve power plants that can support the integration of large-scale variable RES into the power grid.

The accelerated integration of renewable energy sources into the Central Asian Energy System has led to daily imbalances, increasing the risk of large-scale outages — as demonstrated by system disturbances observed between 2020 and 2022. The transmission capacity between the Russian UPS, Kazakhstan, and the Central Asian interconnected power grid is already approaching its technical limits, which may necessitate scheduled consumer disconnections to preserve overall system stability [4].

Potential Consequences of RES Integration into the United Power Systems of Central Asia (UPS CA)

The integration of renewable energy sources (RES) into the UPS CA can lead to the following consequences:

1.Increased frequency and scale of power imbalances — The variable and unpredictable generation from photovoltaic (PV) and wind power plants significantly increases the load on interstate transmission lines, particularly in the absence of adequate energy storage systems and flexible generation assets;

2.Higher risk of system instability — As evidenced by the major blackout on January 25, 2022, significant imbalances can rapidly destabilize key transit corridors (e.g., North–East–South Kazakhstan), increasing the likelihood of cascading outages across the region;

3.Insufficient cross-border reserve capacity — The current reserve margin of 700–1000 MW is not adequate to offset emerging imbalances, especially during peak demand periods when the generation from RES does not correspond to the load;

4.Greater demands for flexibility and fast-response control systems — The integration of advanced control technologies becomes increasingly important. These include intelligent automated control systems, flexible alternating current transmission systems (FACTS), and energy storage systems (ESS);

5.Declining reliability of parallel system operation — Without coordinated planning, forecasting, and dispatch, RES integration may become a destabilizing factor for the entire interconnected power system in Central Asia.

To ensure high-quality and uninterrupted electricity supply, it is critical to provide both backup generation to meet peak demand and the ability to reduce output during low-load periods, while maintaining acceptable system response times.

Electricity consumption varies significantly throughout the day, requiring continuous frequency regulation to maintain the balance between generation and demand. Power plants must operate in real-time to match supply and demand of active power. This leads to increased wear and tear on equipment, higher fuel consumption, and operational limitations in bringing additional generators online quickly. A lack of sufficient power reserves may result in load shedding and economic losses for the power system.

The large-scale integration of RES — particularly wind and solar — in the Central Asian Energy System (CAES) raises critical challenges due to their intermittent and non-dispatchable nature. Addressing these challenges requires advanced forecasting of RES output and studying its impact on the operational efficiency of power systems.

According to the International Renewable Energy Agency (IRENA), the total installed capacity of RES globally reached **4,448 GW by the end of 2024**, representing a **15.1% increase compared to 2023**. Key indicators for global RES growth in 2024 include:

-Solar PV: +452 GW (77.3% of total new RES capacity);

-Wind Power: +113 GW (19.3% of total new RES capacity);

-Total RES Addition: 585 GW — a record-high annual increase.

These figures confirm the consistent global trend toward accelerating renewable energy deployment to maintain power system balance within the UPS, energy storage systems are essential. These systems store excess energy during low-demand periods and release it during peak demand.

Rapid growth in ESS deployment is expected particularly in developing countries and remote or off-grid areas. In such regions, a combination of solar/wind farms, storage systems, and diesel backup often proves more cost-effective than building new transmission infrastructure or relying on traditional fossil-fueled power plants.

According to forecasts by Wood Mackenzie, the global energy storage market will grow **13-fold by 2024**, with total installed storage capacity increasing from **12 GWh to 158 GWh** [5].

3. Results and discussion

In brief, we present an overview of the main types of energy storage systems (ESS) [6–10]:

1.Pumped Hydro Storage (PHS) — According to statistics, up to 98% of global energy storage capacity is provided by hydroelectric energy storage systems. According to IEA data, the global installed capacity of storage systems is around 200–210 GW, with over 90% attributed to pumped hydro storage (PHS), which remains the most efficient technology. Initially developed to compensate for the inflexibility of nuclear power plants, PHS now plays a critical role in stabilizing power systems with high penetration of renewables. However, the limited availability of suitable water resources and topography in Uzbekistan hinders the construction of PHS at the necessary scale.

2.Superconducting Magnetic Energy Storage (SMES) — These systems use both high-temperature and low-temperature superconductors and are characterized by high specific power, ultra-fast response times, virtually unlimited charge-discharge cycles, and efficiency exceeding 95%.

3.Cryogenic Energy Storage (CES) — The British company Highview Power commissioned the world's first 5 MW / 15 MWh air-based cryogenic storage system. The company claims its solution costs approximately $140 per MWh, compared to $200–300 per MWh for lithium-ion batteries, making the substitution of peak gas turbines with a combination of PV, CSP, and LNG economically viable.

4.Gravity-Based Storage Systems — These operate by raising and lowering heavy masses (e.g., concrete blocks) to store and release energy. These systems can reach full power output in 3 seconds, offer around 90% efficiency, and a lifespan of 40 years at half the cost of conventional storage technologies.

5.Electrochemical Batteries — A wide range of electrolytes is used in batteries applied to power systems, though their typical service life is under 10 years. Lithium-ion batteries (Li-ion) are gaining popularity due to their high energy density, deep discharge cycles (up to 80%), low self-discharge, and absence of the memory effect. Despite high specific cost and limited cycle life, declining prices are improving their competitiveness. BloombergNEF (BNEF) projects a 52% cost reduction for Li-ion batteries by 2030.

6.Supercapacitors — Offering high power density, long lifecycle, and low internal resistance, supercapacitors can rapidly discharge stored energy. However, they are limited by relatively low energy storage capacity.

7.Hydrogen Storage — Hydrogen technologies store electrical energy through electrolysis, converting it into hydrogen gas, which can later be used as fuel to regenerate electricity. This is a promising form of chemical energy storage.

The application of ESS is especially important in virtual power plants (VPPs) — digital platforms that coordinate distributed energy resources (DERs), such as RES, ESS, and controllable loads in real time. VPPs enhance flexibility, reliability, and cost efficiency of energy systems by optimizing supply and demand.

Energy storage technologies also play a key role in smart grids — actively adaptive systems that allow for dynamic interaction between supply and demand. In this context, ESS can operate both as active participants in grid management (providing energy injection or load reduction) and as uninterruptible power supplies (UPS) during external power failures.

A positive example of successful ESS integration is South Australia. In 2017, Elon Musk pledged to install a 100 MW / 129 MWh lithium-ion battery system within 100 days for $50 million. After installation, the battery responded immediately to a major grid disturbance — stabilizing frequency and saving nearly $40 million in its first year of operation. This case demonstrated the ability of ESS to provide extremely fast and effective compensation for fluctuations — up to six times faster than conventional thermal generation systems.

A negative example involves the large-scale blackout that occurred on April 28, 2025, affecting Spain, Portugal, Andorra, and parts of France and Morocco. At the time, Spain's energy system experienced a significant generation surplus, with up to 70% of output from solar and wind sources. The resulting power imbalance led to grid collapse. A sufficient volume of ESS would likely have prevented this large-scale system failure.

In recent years, several projects for the construction of solar, wind, and hydroelectric power plants have been approved in the Central Asian countries that are members of the Economic Cooperation

Organization (ECO). In **Uzbekistan alone**, installed capacity increased from **17,048 MW in 2022 to 24,182 MW in 2024** (a 41% increase), while the number of power plants grew from 73 to 100 (a 37% increase). By the end of 2025, installed capacity is expected to reach **29,479 MW**, representing a **73% increase** compared to 2022 (see Figure 1). Renewable energy projects in the CIS countries up to 2030 are shown in Fig.2.

By 2026, the total capacity of solar and wind power plants in Uzbekistan is expected to reach 8,000 MW, increasing the share of renewable energy sources in the country's energy balance to 25%. The first two solar power plants, each with a capacity of 100 MW, were constructed without energy storage systems. It is well known that at an integration level of 3–4% of the total installed capacity, the impact of renewable generation on the system's dynamic stability and controllability remains negligible. However, as the share of RES increases, the need for additional stability-enhancing measures grows as well, including the deployment of ESS, fast-response regulators, FACTS devices, and adaptive automation technologies.

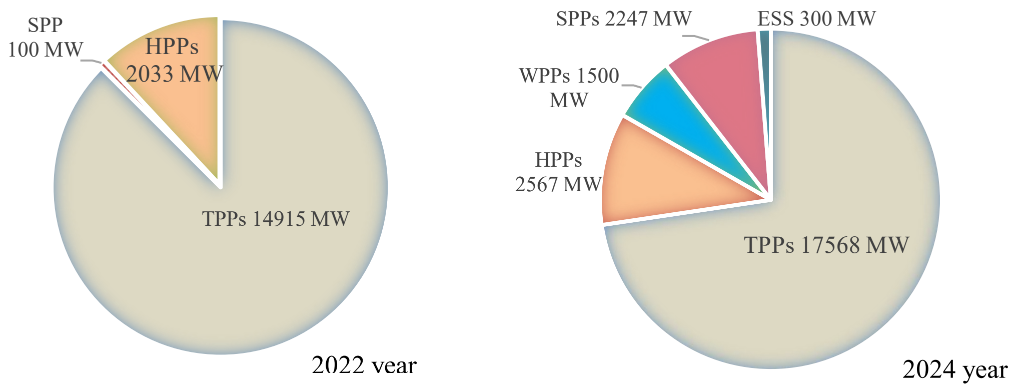

Fig.1. The structure of generating power in Uzbekistan

The charts show the distribution of installed capacity of Uzbekistan's power plants in 2022 and 2024. Key changes for these years:

Indicator	2022 Year	2024 Year	Growth
TPPs	14 915 MВт	17 568 MВт	+2 653 MВт
HPPs	2 033 MВт	2 567 MВт	+534 MВт
SPPs	100 MВт	2 247 MВт	+2 147 MВт
WPPs	—	1 500 MВт	+1 500 MВт
ESS	—	300 MВт	+300 MВт

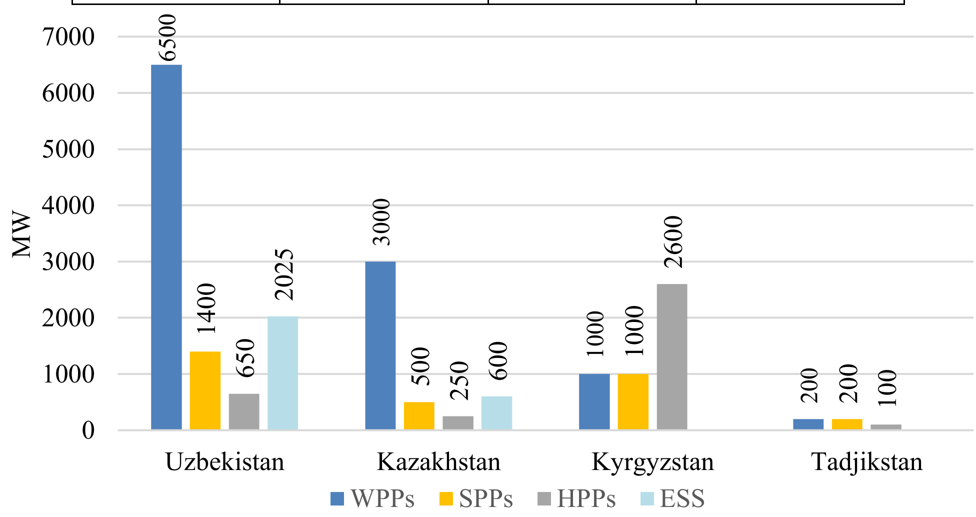

Fig.2. Projects in Renewable Energy in the ECO Member States by 2030

The diagram (Fig.2**)** shows a comparison of the installed capacity of different types of renewable energy sources and energy storage systems (ESS) in Central Asian. Analysis:

- Uzbekistan leads in terms of installed capacity of wind power plants (WPPs) and energy storage systems (ESS);
- Kazakhstan is actively developing wind generation and also has well-represented ESS;
- Kyrgyzstan emphasizes hydropower (HPPs), the highest among all countries.

It is worth noting that in European Union countries such as Germany and Denmark, the share of RES exceeds 50%, enabled by substantial investment in energy storage technologies, digitalization, advanced infrastructure, and cross-border energy balancing mechanisms.

The rapid growth of electricity generation, especially from RES, requires a corresponding enhancement in dispatch and operational control. Considering the significant increase in the share of RES in the power mix across Central Asia, the locations for energy storage systems were determined based on power flow and stability studies. As a result, 17 energy storage projects with a total capacity exceeding 2 GW have been approved for implementation (see Fig.2).

These studies evaluated potential generation-consumption imbalances, as well as the inertia and flexibility of existing thermal power plants (TPPs), and assessed reserve requirements and frequency regulation needs. For the year 2030, daily power balance schedules were developed for each energy system, considering planned generation additions and withdrawals, along with projected load growth.

Uzbekistan – Regional Leader in the Deployment of Energy Storage Systems (ESS)

According to current project plans, the total capacity of battery energy storage systems (BESS) proposed in Uzbekistan exceeds 4 GWh, positioning the country as one of the leaders in Central Asia in the deployment of advanced storage technologies. The largest projects are being implemented with the participation of international financial institutions (IFIs) and private investors.

Major BESS Projects Under Development in Uzbekistan

No	Project	Power Generation	BESS Capacity
1	"Nur Bukhara" (Masdar)	250 MW (Solar PV)	63 MW / 126 MWh
2	Agreement with ACWA Power	—	2,000 MWh
3	"Sazagan-2" (ACWA + Sumitomo)	500 MW (Solar PV)	500 MWh
4	ACWA Power Project	400 MW (Solar PV)	400 MW
5	Samarkand Region Project	1,000 MW (Solar PV)	400 MW
6	Bukhara Region BESS Project	—	400 MW
7	"Artemisia" (Voltalia)	126 MW (Solar) + 300 MW (Wind)	100 MW / 200 MWh
8	Karakalpakstan Project	200 MW (Wind)	100

-Total generation capacity across these projects exceeds 3,200 MW (solar and wind);

-Combined storage capacity is over 4,000 MWh, underscoring Uzbekistan's commitment to grid flexibility;

-Strong involvement of companies such as Masdar, ACWA Power, Sumitomo, and Voltalia reflects high international investor confidence.

Investments in BESS projects allow Uzbekistan to:

-Mitigate the variability of renewable energy sources;

-Improve power supply reliability;

-Accelerate energy sector decarbonization;

-Enhance energy independence amid rising demand.

4. Conclusion

1.In order to assess the impact of renewable energy sources on the daily production and consumption balance in the coming periods, the system's specialists applied the method of modeling the quasi-dynamic regime to each energy system within the Unified Power Systems of Central Asia, thereby determining the volume of regulatory imbalances.

2.The analysis results show that energy storage systems are an effective solution for integrating renewable energy sources into an interconnected energy system.

3.The main condition for reliable and efficient operation of the energy system is the application of appropriately selected energy storage technologies. At the current stage of rapid growth of renewable energy sources in Uzbekistan, battery energy storage systems (BESS) are considered the most promising option.Looking ahead, the effectiveness of the energy system can be further enhanced through the deployment of **hybrid solutions**, which combine BESS with pumped storage hydropower plants (PSH) at existing reservoirs, intelligent load management systems, and automation. This integrated approach would enable the advantages of different technologies to be leveraged, thereby ensuring the long-term, sustainable development of Uzbekistan's power sector.

4.The efficiency of the energy system can be further enhanced by implementing hybrid solutions in existing reservoirs, comprising a combination of Battery Energy Storage Systems (BESS) and pumped-storage hydroelectric power plants (PSHPPs), along with smart load management systems and automation methods. This comprehensive approach allows for leveraging the advantages of various technologies, thereby ensuring the long-term and sustainable development of Uzbekistan's energy sector.

5.Investments in energy storage projects will allow Uzbekistan to mitigate the impact of renewable energy variability, increase the reliability of electricity supply, contribute to the decarbonization of the energy sector, and enhance energy independence against the backdrop of growing demand.

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