AFD

# Terms of Reference

# Long-term model of the Uzbek power system with high penetration of intermittent renewable energy sources.

## 1. General information

Title: Long-term model of the Uzbek power system with high penetration of intermittent renewable energy sources.

Beneficiary: Joint-Stock Company National Electricity Grid of Uzbekistan (JSC NEGU)

Financing: Agence Française de Développement (AFD)

Consultant: To be determined by tender results (AFD procurement process)

Implementation Period: 6 months

## 2. Context

Uzbekistan is undergoing a significant transformation of its energy sector to meet growing domestic demand while aligning with global climate commitments. As part of its Nationally Determined Contributions (NDCs) under the Paris Agreement, the country has set a target to reduce specific greenhouse gas emissions per unit of GDP by 35% by 2030 compared to 2010 levels. The energy sector, which accounts for the largest share of emissions, is at the centre of this transition. To meet these targets, Uzbekistan is focusing on modernizing its energy infrastructure, improving energy efficiency, and integrating cleaner energy sources into its power mix. A key pillar of Uzbekistan's strategy is the accelerated deployment of variable renewable energy sources (VRES), particularly solar and wind. The government has set ambitious targets to install more than 20 GW of renewable energy capacity by 2030. To attract private investment, the country is leveraging international partnerships and implementing competitive procurement mechanisms such as public-private partnerships (PPPs) and tenders under the guidance of institutions like the IFC and ADB. These efforts are expected to significantly reduce the carbon intensity of power generation and diversify the energy mix, which is currently dominated by natural gas.

However, integrating a growing share of variable renewable energy into the national grid poses challenges for Uzbekistan's transmission system in terms of grid stability, power quality, and system inertia. The country's high-voltage grid is undergoing modernization to ensure reliability, flexibility, and regional interconnectivity.

## 3. Objectives

The overarching goal of this study is to enhance JSC NEGU's capacity to manage the integration of VRES into the national power grid through advanced power system modelling and scenario analysis.

Specific objectives:

- Identify global best practices for integrating VRES in power systems and assess their applicability to Uzbekistan.
- Build a dynamic simulation model of the Uzbek power grid using DigSilent PowerFactory.

- Analyze multiple VRES integration scenarios, assessing grid stability, frequency regulation, voltage control, and inertia implications.
- Analyze the application of advanced power system technologies and solutions for Modern Power Systems (GFM converters and so on).
- Assess the potential contribution of artificial intelligence (AI) and advanced data analytics to improve the operation, planning and stability management of power systems with high penetration of variable renewable energy sources.
- Formulate regulatory, operational, and investment recommendations.
- Train JSC NEGU engineers on the developed model and integration strategies.

## 4. Scope of Work

The consultant will implement the assignment through five main tasks:

**Task 1 – Review of International Best Practices**

- Conduct an in-depth global review of case studies, advanced power system technologies and methodologies for integrating high shares of variable renewable energy (VRES) into national grid.
- Review international experiences in the use of artificial intelligence and machine learning for power system planning, operation and maintenance in systems with high shares of VRES notably:
    - Forecasting of renewable generation (solar and wind production forecasting)
    - Electricity demand forecasting
    - AI-based dispatch and congestion management tools
    - Predictive maintenance of transmission assets
    - Automated alarm management and decision-support tools for system operators
    - AI applications for cybersecurity of critical energy infrastructure
    - Optimization of procedures for connecting new capacity (grid integration study)
    - Use of digital twins
- Analyze success factors and obstacles encountered in various countries (to be proposed by the consultant – 5 minimum).
- Assess how international practices relate to Uzbekistan's power system characteristics (e.g., grid topology, demand profile, climate).
- Summarize implications for frequency control, system inertia, voltage stability, and reliability of protection systems (RPA).
- Provide a synthesis of lessons learned and adaptation strategies relevant for JSC NEGU and the Central Asian regional context.

Deliverables:

- International benchmarking report with key lessons and applicability matrix for Uzbekistan.

**Task 2 – Development of Power System Models**

- Build digital models of Uzbekistan's transmission system using **PowerFactory DigSilent**, incorporating:
    - Current grid infrastructure and interconnections (national and regional via UES CA).
    - Operational characteristics of thermal power plants.
    - Existing and planned renewable energy power plants by 2050.

    - Effects of power electronics associated with renewable integration.
- Define and implement mathematical representations of renewable generators and power electronics.
- Document all modelling assumptions and provide a technical manual for model replication by JSC NEGU engineers.
- Identify opportunities to complement traditional power system modelling tools with data-driven & digital twin approaches and AI-based analytics, particularly for forecasting and system performance analysis.

Deliverables:

- Digital model files and accompanying model documentation.
- Technical report on assumptions, input data, and structure of the simulation environment.
- Synthesis roadmap for developing digital twin & AI-based analytics.

**Task 3 – Scenario Analysis and Grid Stability Assessment**

- Perform scenario-based simulations for different VRES penetration levels (e.g., 20%, 30%, 40%, 50%, 60% & 70% of total instantaneous production by 2030, 2040 and 2050).
- Evaluate the system's response in terms of:
    - Frequency and voltage stability.
    - Static and dynamic system inertia.
    - Protection system (RPA) performance under varying short-circuit current ranges.
- Include stress testing under climatic extremes (e.g., summer heat waves, winter demand peaks).
- Assess the operation of remote regions with high VRES share (e.g., Karakalpakstan).
- Identify system limitations and critical vulnerabilities under each scenario.

Deliverables:

- Scenario modelling report including simulation results and interpretation (visualizations of stability margins, frequency responses, inertia and voltage profiles notably).

**Task 4 – Policy, Technical and Operational Recommendations**

- Formulate recommendations in four categories:
    - **Regulatory**: updates to the Grid Code (if needed) and standards for VRES integration.
    - **Contractual**: power purchase agreements (PPA) between IPPs and the single buyer. This may include requirements for renewable generators to provide high-quality operational and meteorological data enabling advanced forecasting tools (including AI-based forecasting) and mechanisms to incentivize improved forecasting accuracy and system flexibility.
    - **Operational**: procedures for dispatch, asset management, congestion reserves, and coordination with power system stakeholders. This may include the potential use of artificial intelligence and advanced analytics to support system operation, such as renewable generation and demand forecasting, predictive maintenance of transmission assets, automated alarm management, anomaly detection in network behaviour, and decision-support tools for dispatch operators.
    - **Investment planning:** priorities for grid reinforcements, flexibility solutions (e.g. grid forming batteries, synchronous condensers, demand response, FACTS, etc.), control

systems, and digital infrastructure required to support advanced data analytics and AI applications. This may include investments in data platforms, monitoring systems, digital twins of the power system, enhanced sensor deployment, and cybersecurity systems necessary to enable future AI-supported grid operation.

- Propose a methodology for assessing (calculating) the sufficiency of inertia and statics of a power system
- Propose measures to address issues arising from reduced system inertia and static response.
- Suggest improvements to relay protection systems to maintain selectivity and reliability.
- Propose specific solutions for modernizing relay protection systems to maintain selectivity and reliability in the context of a significant increase in the share of renewable energy sources.
- Include cost and feasibility considerations to support implementation.

Deliverables:

- Detailed recommendation report with technical justifications.
- Draft policy briefs and technical memos for JSC NEGU, the Ministry of Energy, and the Energy market development and regulatory agency of the Republic of Uzbekistan (EMDRA).

**Task 5 – Capacity Building and Knowledge Transfer**

- Design and deliver a tailored training program for JSC NEGU engineers, including:
  - Theoretical modules on grid stability and VRES integration.
  - Advanced power system technologies, solutions for Modern Power Systems (GFM converters and so on).
  - Hands-on workshops using the developed PowerFactory model.
  - Case study analysis and interpretation of simulation results.
  - Introduction to artificial intelligence applications in modern power systems, including forecasting, predictive maintenance, decision-support tools and digital twins.
- Provide user manuals and simulation protocols to ensure autonomous model use post-project.

Deliverables:

- Training materials (slides, exercises, user manuals).
- Final training report (attendance, topics covered, feedback).
- Evaluation of knowledge transfer and capacity reinforcement.

## 5. Stakeholders and Institutional Arrangements

- Client: AFD (procurement & contractualization lead).
- Primary Beneficiary: JSC NEGU.
- Other Stakeholders: Ministry of Energy of Uzbekistan and EMDRA.

JSC NEGU will be responsible for overseeing the study and will be the main counterpart for each task of the assignment. The share of responsibilities between the various stakeholders may be clarified during the kick-off meeting if needed.

## 6. Planning & Deliverables

| Activity / Task | M1 | M2 | M3 | M4 | M5 | M6 | Deliverables / Milestones |
|---|---|---|---|---|---|---|---|
| Kick-off Meeting (on-site) & Finalization of Workplan | ■ | | | | | | Kick-off meeting report, finalized schedule & methodology |
| Task 1 – Review of International Best Practices | ■ | ■ | | | | | Benchmarking Report |
| Task 2 – Development of Power System Models | ■ | ■ | ■ | | | | Model files + Model documentation + AI roadmap |
| Task 3 – Scenario Analysis and Grid Stability Assessment | | ■ | ■ | ■ | | | Scenario Modelling Report |
| Task 4 – Policy, Technical and Operational Recommendations | | | ■ | ■ | ■ | | Draft & Final Recommendation Report |
| Task 5 – Capacity Building and Knowledge Transfer | | ■ | ■ | ■ | ■ | ■ | Training materials + Training report |
| Final Results Consolidation & Review with Stakeholders | | | | | ■ | ■ | Final report, stakeholder feedback |
| Final Presentation (on-site) / Restitution Workshop | | | | | | ■ | Restitution workshop presentation |

All deliverables must be submitted in English & Russian.

## 7. Consultant requirements

The selected consultant must demonstrate:

- Proven expertise in power system modelling using DigSilent PowerFactory.
- Expertise in electricity market regulation, policy planning, and institutional frameworks for renewable integration.
- Expertise in protection systems and automation under evolving grid conditions, with experience in short-circuit analysis and RPA adaptation to high-VRES environments.
- Knowledge in power electronics and regulation, familiar with grid codes, inverter behavior, and standards related to renewable energy connection.
- Knowledge of artificial intelligence applications in power systems (forecasting, predictive maintenance, decision-support tools) will be considered an asset.
- Demonstrated knowledge of Central Asian energy systems will be regarded as an asset.
- Proven expertise in capacity building and effective stakeholder engagement.

The consultant will propose a project manager who will be based in Tashkent and will be JSC NEGU's contact during the implementation of the activity.

## 8. Indicative list of experts and working-days

| Indicative list of experts | | Indicative working-days | | | | | |
|---|---|---|---|---|---|---|---|
| | | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 | TOTAL |
| 1 | Senior Electrical Systems Engineer (project manager based in Tashkent) | 15 | 30 | 25 | 15 | 10 | 95 |
| 2 | Renewable Energy Integration Expert | 10 | 20 | 15 | 10 | | 55 |
| 3 | Thermal Power Plants and Flexibility Expert | | 10 | 5 | | | 15 |
| 4 | Power Electronics and Stability Expert | | 15 | 10 | | | 25 |
| 5 | Training and Capacity Building Expert | | 15 | 5 | | 15 | 35 |
| 6 | Long-term planning and scenario analysis Expert | | 5 | 25 | 5 | | 35 |
| 7 | Grid Code and Operations Expert | | 5 | 5 | 10 | | 20 |
| | TOTAL | 25 | 100 | 90 | 40 | 25 | 280 |

## 9. Submission

Interested candidates are invited to submit a technical and financial offer in English including:

- A detailed curriculum vitae of experts;
- A technical proposal with the envisaged methodology;
- An estimated budget and work schedule;
- Relevant professional references.