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Problems of integration of the photovoltaic power stations with the grid systems

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Abstract. The analysis of the factors of renewable energy sources (mainly solar ones) integration with the central grid was conducted in the paper. Various problems arising during integration, solved in Uzbekistan through the development and adoption of a modern legislative and regulatory framework were described. Various aspects of solving the problem were considered, including research work intensification in this direction.

1. Introduction

Renewable energy is developing all over the world at a rapid pace due to many reasons: limited conventional fossil resources, environmental requirements, consumer demand, etc. In 2010 - 2019 the global capacity of installed renewable energy sources (RES) has increased more than 4 times - from 414 GW to 1650 GW, and the volume of investments in new RES capacities creation has become three times greater than the corresponding index in conventional power engineering [1, 2].

The factors determining the development of renewable energy technologies are: long-term forecasting of power consumption; changes in power consumption structure, (in developed countries directed towards the decentralized systems); low carbon energy; automation and intellectualization of metering systems, monitoring and control systems in the energy sector; development of energy accumulation and storage systems; environmental pollution and others.

According to the forecasts of the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), by 2050, from 50 to 70% of the world's energy will be produced from renewable energy sources, mainly, based on solar plants [3].

In accordance with the state program "Strategy for the innovative development of Uzbekistan", by 2025, the share of renewable energy sources in the total energy balance of the country should be 20% [4].

There are necessary prerequisites for this task:

- the technical potential of renewable energy sources is several times greater than the republic's need for energy resources;

- the presence in the country of world-class scientific schools and highly qualified teaching staff for training personnel in the field of renewable energy.
- a certain experience has been accumulated in the design, organization of serial production of solar collectors, photovoltaic modules and their components.

However, there are a number of factors hindering the development of renewable energy sources in Uzbekistan, which require solution. They can be conditionally divided into three groups (Table 1).

Table 1. The factors hindering RES development in Uzbekistan

Regulatory	Economic	Technical
1. Adoption of a long-term strategy for the RES development	1. Introduction of government measures and investments support in RES development	1. Solution of technical aspects of design, construction and connection of RES facilities to the grid
2. Development and harmonization of national standards	2. Granting benefits and preferences to manufacturers of renewable energy equipment	2. Modernization and development of electrical networks
3. Determination of the mechanism of land allocation for RES	3. Implementation of the mechanisms of "green" tariffs	3. Development of energy storage systems

At present, renewable energy sources cannot compete with conventional energy resources in the cost of generated electricity. In this regard, there is a need to develop legal frameworks and regulations that contribute to the development of RES use and to adopt a long-term strategy for their development until 2050. It is necessary to develop national legal documents, norms and standards to ensure the commissioning and subsequent operation of power plants based on renewable energy [5, 6.7].

In addition, it is necessary to harmonize national standards with international ones in order to increase the energy efficiency of RES use and reduce their prime cost when commissioning the facilities. It is also necessary to develop regulatory and legal norms related to the allocation of land sites for the construction of renewable energy facilities.

The next limiting factor is the need to stimulate the accelerated development of RES by introducing a special system of "green" tariffs. Introduce mandatory purchase of electricity by grid companies from RES suppliers at established “green” tariffs.

Attracting investment flows to renewable energy is one of the conditions, the implementation of which will allow in the future implementing the program of transferring generating capacities to a renewable resource base and, thereby, preserving hydrocarbon reserves and the environment.

2. Methods

Technical aspects of inclusion of photovoltaic power plants (FVP) into electric power system of Uzbekistan. Today, most of the renewable energy-based power plants installed in Uzbekistan are autonomous (GRID-OFF), the capacity of which does not exceed 50 kW. The exception is a 1.2 MW FVP plant in the Navoi region and several small plants.

The decree of the President of the Republic of Uzbekistan "On accelerated measures to improve the energy efficiency of economic and social sectors, to introduce energy-saving technologies and to develop renewable energy sources" approved the target parameters for further development of renewable energy sources, construction of large solar and wind power plants, bringing their share by 2030 to at least 25 % of the total volume of electricity generation [8].

At present, the task of installation, i.e. construction and connection to the grid (GRID-ON) of RES-based power plants in the republic is not solved, since the existing requirements and the corresponding technical regulations for the connection to the grid are very strict and complex. Therefore, today only a few such power plants operate in the republic [9].

It is necessary that power plants operating based on renewable energy sources meet the requirements for power generating facilities, namely:

- power plants based on renewable energy sources must have sufficient capacity and maneuverability;
- electric power systems (EPS) with renewable energy sources must be able to maintain a stable frequency and voltage within the permissible range;
- EPS should have sufficient flexibility to solve the problem of irregular power generation from renewable energy sources and uncertainty of its demand;
- the quality of electricity generated by RES-based power plants must meet the requirements of Uzstandart;
- electricity generation and transmission network capacity must be sufficient to meet the maximum demand for electricity [10].

To stimulate the development of renewable energy sources, these requirements must be met based on various arrangements.

3. Results and Discussion

In the summertime, due to the import of electricity from Tajikistan and Kyrgyzstan, the reserve capacities of the Uzbek power plant are further reduced due to the shutdown and repair of some generators of thermal power plants (TPPs), which in turn leads to a decrease in the maximum possible value of capacities that can be generated by FVP integrated into the Power Grid System.

Thus, a high depreciation of fixed-capital assets (45-65%), a lack of reserve funds and a restricted limit for the acceptance of balancing power from neighboring power systems create certain difficulties for the development of photovoltaic power plants [4, 12].

The most expedient way of developing renewable energy sources and solving problems associated with the energy system balancing of Uzbekistan while integrating large FV plants with the grid system is the mandatory construction of energy storage systems (ESS) of sufficient capacity.

Large and local ESS can be used in EPS branching points, power plants, and power transmission lines, substations and in the areas of consumer responsibility. Considering variable nature of renewable energy sources and an increase in their share in the future, the requirements for the ESS speed will increase to ensure the reliability of FVP in the modes of a sharp decrease in generation and prompt inclusion of reserve capacities. It should be noted that the integration of RES has changed the mode of ESS operation; while earlier they worked with a maximum of one or two cycles per day, nowadays, the number of on-off cycles is an order of magnitude greater.

Modern high-speed systems allow accumulating energy in case of its surplus and returning it in case of deficit, controlling (without inertia) the active power balance to maintain the frequency in the system. The most promising power system modes for the operational control are ESS on lithium-ion batteries and supercapacitors; in terms of economic indices - pumped storage power plants, gravitational and hydrogen installations. By 2030, the total installed capacity of electric energy storage systems in the world will amount to 125 GW [13, 14].

Another negative aspect of solar power plants integration into the energy power system of Uzbekistan is the increase in the deficit of reactive power at the connection branching points. Inverters and electronic control units for RES-based power plants are the consumers of reactive power and contribute to voltage reduction [15].

Parallel to solar power plants, the connection of high-speed devices of controlled flexible alternating current transmission systems (FACTS) - series synchronous static compensator (SSSC), thyristor-controlled series compensator (TCSC), static compensator (STATCOM) compensates for the shortage of reactive power and helps to increase the dynamic and static stability of the power grid system [16].

When developing integration schemes for power plants based on renewable energy sources, it is necessary to take into account that inverters are the sources of higher harmonic components.

At present, no manufacturer in the world produces an inverter that converts direct current from solar panels to alternating current in the form of an ideal sinusoid. The presence of slight deviations in the output current waveform is the source of higher harmonics.

The main forms of negative impact of higher harmonics on the power system are:

- an increase in the currents and voltages of higher harmonics due to resonance;
- a decrease in efficiency of the processes of generation, transmission and research of electric energy;
- aging of electric equipment insulation and reduction of its service life;
- false alarms of relay protection and automation systems.

To damp higher harmonics, it is necessary to provide for the installation of line filters at the design stage of power plants [17].

Modern ESS based on supercapacitors and FACTS equipment allow solving this problem. The FVP control system with regulation of power capacity supplied to the grid, contributes to the increase in EEP operation reliability. The operator has the ability to choose a generation source depending on the cost of tariffs and economic feasibility.

The most serious problem requiring large investments is the modernization of existing and the construction of new power transmission lines (PTL) and substations, taking into account the change in power flows (the interchange) after the commissioning of solar and wind power plants. The most preferred regions for the wind and solar plants construction are the Republic of Karakalpakstan and the southern regions of the republic. There appears a necessity to wheel electricity generated by renewable energy sources over long distances to the main consumers in the center [18-20].

As an example, consider the possibilities of installing large power plants based on renewable energy sources and their integration to the North-Western part of the energy grid system of Uzbekistan.

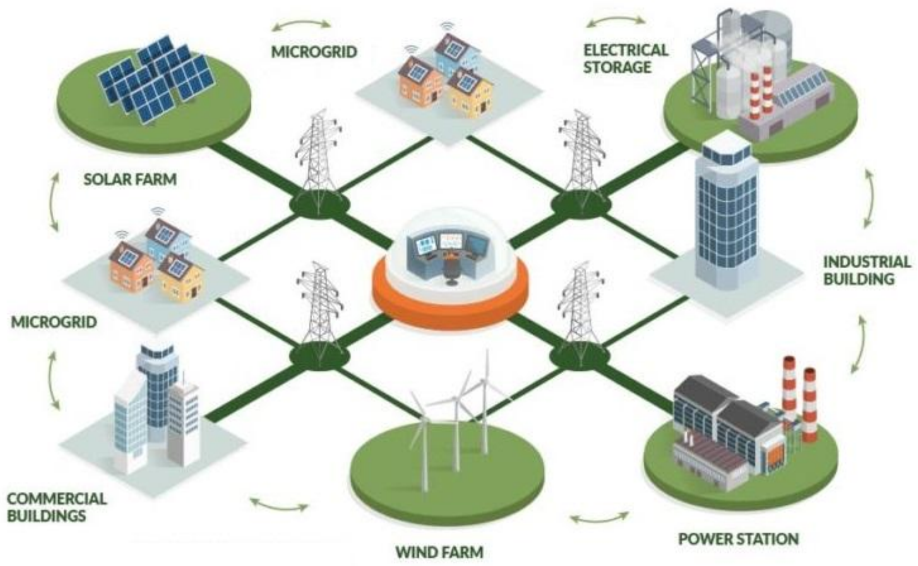

Figure 1. Scheme of the grid section used in calculations

Figure 2 and Table 2 show the grid diagram and the results of its mode calculations, taking into account the generation by large photovoltaic power plants planned for commissioning in 2030. Calculations conducted using the DIG Silent POWER FACTORY software package show that at a relatively small RES power, additional generation practically does not affect the parameters of EEP mode, and the lines LV-1-V-2, LV-2-V-3, L- PCH or 220-PCFES can withstand additional power flow. However, a further increase in FVP power leads to certain problems in power flows, in ensuring the stability of the power system and electricity quality indices. These calculations show that under existing conditions, without modernizing the grid, the maximum possible power of FVP for integration into the grid of the Western part of the Uzbekistan energy system should not exceed 200 MW (excluding local consumption).

The main disadvantage of FVP is intermittent (IRES) and variable (VRES) generation, time-of-day and time-of-year dependent, fluctuations due to weather conditions, clouds that affect the global horizontal insolation (GHI). As an illustrative example, we present the results obtained by measuring the key parameters of an experimental FVP with a capacity of 9.2 kW, installed on the territory of the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIIAME).

Figure 2 shows that electricity generation from grid-connected solar panels was interrupted from 19-30 to 07-30, and varied during daylight hours.

Table 2. Calculation mode taking into account the FVP generation

FES 200 MW						
Name	Type	Length, km	Parallel lines	Max. load, %	Full capacitive losses, MVAr	Rated current, kA
L-1-X	AC_240	147.6	1	72.29639	19.24635	0.61
L-1V-X-2(197.8)	AC 400-51(220)	186.8	1	103.2059	21.9675	0.80
L-30-X-1	AC_150	59.4	1	12.80114	2.215134	0.45
L-30-X-2	AC_150	59.4	1	12.80114	2.215134	0.45
L-B-X	AC 300-39(220)	53.2	1	26.88856	6.365598	0.71
L-V-1-V-2	AC 300-39(220)	51.5	1	78.95493	4.986886	0.71
L-V-1-X	AC 240-32(220)	149.6	1	97.32098	15.7975	0.61
L-V-2-V-3	AC 300-39(220)	59.8	1	76.32047	5.836573	0.71
L-XAZARASP-1	AC_70	32	1	22.63878	1.09939	0.265
L-XAZARASP-2	AC_120	32	1	19.03982	1.148564	0.39
L-Z-V3	AC 300-39(220)	103.482	1	70.55436	10.72085	0.71
L-ΠC_ Xor220-ΠC_FVP	AC 240-32(220)	10	1	85.02938	1.158456	0.61

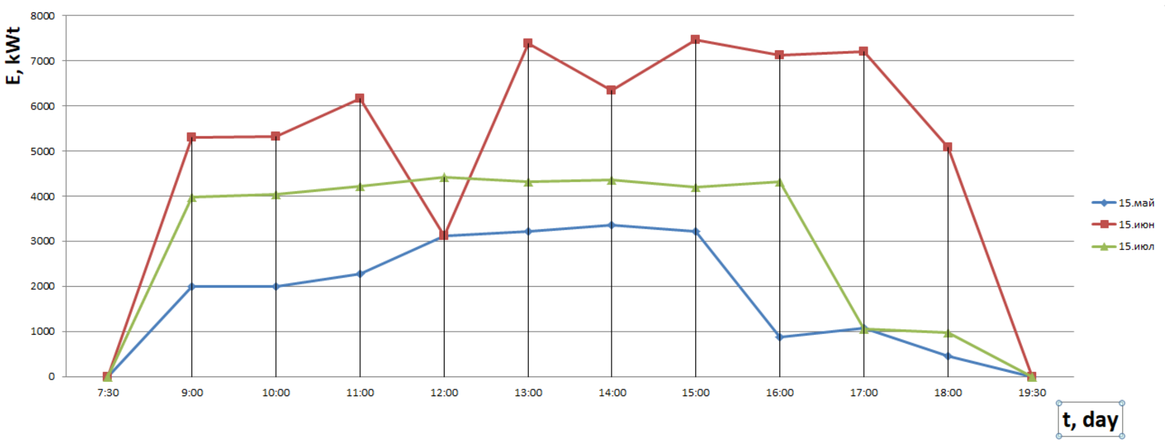

Figure 2. Graphs of changes in electricity generation throughout the day: 1 - on May 14, 2020, 2 - on May 22, 2020, 3 - on June 15, 2020

Figure 3 shows the variable nature of current intensity and FVP voltage for one hour. As seen from the graphs, the FVP voltage, current and power vary in a wide range depending on the season and climatic conditions. For example, on a rainy day (05/14/2020), the electricity generation began only after 9:30 am and its average value was almost three times less compared to a sunny day (05/22/2020).

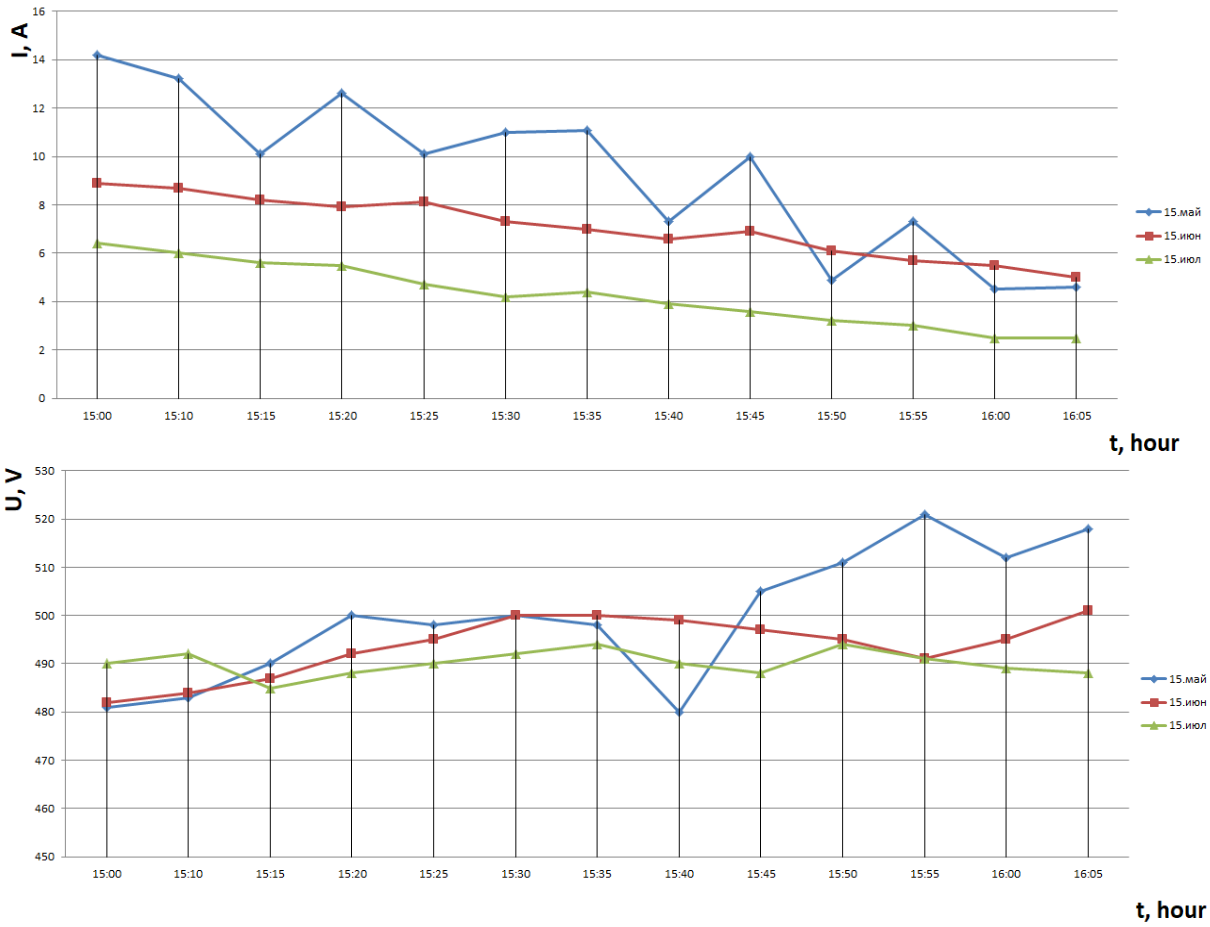

Figure 3. Graphs of change in current strength (upper image) and FVP voltage (lower image): 1 - on May 14, 2020, 2 - on May 22, 2020, 3 - on June 15, 2020

However, this disadvantage should not affect the reliability of power supply to consumers. The balance of the system must be maintained constantly, regardless of any changes in the level of FVP power generation and load consumption. These changes must be balanced by the system at the expense of capacities or energy accumulated in storage.

As is well known, reserve capacities serve to stabilize the grid frequency and are conventionally divided into three components:

- operational (primary, secondary and tertiary) reserve;
- replacement reserve (cold reserve);
- emergency reserve.

The amount of reserves is determined by technical-economic calculations, taking into account the statistics of the plant accident rate, risks and uncertainty in load predictions [11].

The variability of FVP generation mainly affects the size of the replacement reserve. It should be noted that due to the large number of obsolete stations, the Uzbek EPP is not self-sufficient in terms of real time balancing service, and the introduction of large renewable energy capacities only aggravates the situation. Due to the fact, that Uzbekistan joined the synchronized zone, it became possible to balance the system at the expense of the service capacities regulated from Russia. It should be noted that these services are not cheap, have a certain limit due to restrictions on power capacities wheeled through Kazakhstan.

At present, MISE, Tashkent State Technical University, TIIAME and "MIR SOLAR" LLC continue joint research on the development and implementation of proposals for solving problems associated with the integration of renewable energy sources into the central electric grid.

4. Conclusions

Thus, the construction of large power plants based on renewable energy sources and their integration into central grid system requires a large amount of research work to analyze the joint modes and stability of the Uzbekistan power system, modernize grid equipment, and introduce modern energy storage systems and reactive power compensation.

Due to the shortage of reserve capacities, the limits and high cost of service regulation during large FV plants construction, it is necessary to provide for the mandatory commissioning of energy storage systems of appropriate capacity. To reduce the costs during integration with the grid and to modernize the grid equipment, to lower the power losses during current flows, to increase the performance ratio (PR) and stability, it is recommended to build medium and low-power FVPs (along with large ones) in close proximity to the load consumption and linked with FACTS devices.

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