Improving the Reliability of the Central Asia Power System in the Context of the Energy Transition

Kh.A. Shamsiev[1,*], B.Kh.Shamsiev[1], and Sh.V. Khamidov[2]

[1] International Nongovernmental Noncommercial Organization "Coordination and power system control center "Energiya," Tashkent, Uzbekistan
[2] Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan

Abstract — **This paper provides an analysis of the issues concerning the improvement of the reliability of the Central Asia Power System in the contexts of its operation and the energy transition. The study considers the integration of renewable energy sources in the power system, given their prospective capacity additions to be made before 2030.**

Index Terms: **Power system, renewable energy, system failure, reliability, redundancy, stability.**

I. Main Objectives of the Central Asia Power System

The Integrated Power System (IPS) of Central Asia and South Kazakhstan (Central Asia Power System, CAPS) has been the backbone of the electric power industry of the four Central Asia republics and the adjacent regions of South Kazakhstan since 1960. The benefits of the interconnection of the power systems are known and related to the degree of their integration. Under the conditions that occurred in 1991, the strategically justified intent of independent states to achieve self-sufficiency in terms of energy balances led to the loss of the integration benefits and until recently, only power exchanges under intergovernmental agreements (IGAs) remained preserved. The new context has changed the principles for the joint operation of power systems in the CAPS, functions of coordinating bodies and the Joint Supervisory Control Office (JSCO). It was impossible to preserve all the advantages of parallel operation of power systems that had existed under rigid supervisory control, because each power system had its own criteria. The intention of each power sys-tem to maximize profits neglecting the interests of its partners results in the deterioration in terms of the criterion of the respective system [1].

The main objectives of the IPS remain to provide the redundancy of power systems under normal and emergency operating conditions, implement contractual cross-border exchanges of electric power under IGAs, and rationally consume energy resources. The power systems of individual states must meet the needs for baseload, peak, and reserve power; sources of reactive power, and develop expansion planning projects of the electric power industry with respect to the IPS as a whole. Such a plan should consider alternative options for the commissioning of generation capacity, the construction of new power plants with the efficient use of various energy resources, and promotion of renewable energy sources (RES) and energy-saving technologies.

II. Integration of RES into the CAPS

According to the Vision Statement of Energy Sector Development, Uzbekistan is planning to introduce RES with the total capacity of 4,000 MW (including photovoltaic power plants – 2 400 MW and wind farms – 1 600 MW) by 2024 and to increase RES capacity to 9 000 MW by 2030 [3].

To better understand this scale, it is worth noting that the installed capacity of the Uzbek power system is just over 16 GW. Whereas the impact of RES variability can be coped with by maintaining hot reserves at power units and with the help of storage units, the problem of intermittency inherent in PV plants has its features for Uzbekistan. Even such a gas-rich country as Uzbekistan cannot solve this problem by using mobile gas power plants, for example, gas turbines or gas-fired reciprocating engine plants. The problem with replacing the PV power that becomes increasingly unavailable as the sun goes down is not because of a lack of generation capacity in the power system but because the power ramp rate at gas-fired plants is limited due to existing constraints in the country's gas transmission system (GTS).

The ramp rate problem at the plants can be solved by [4–6]:

[*] Corresponding author.
E-mail: khshamsiev@gmail.com

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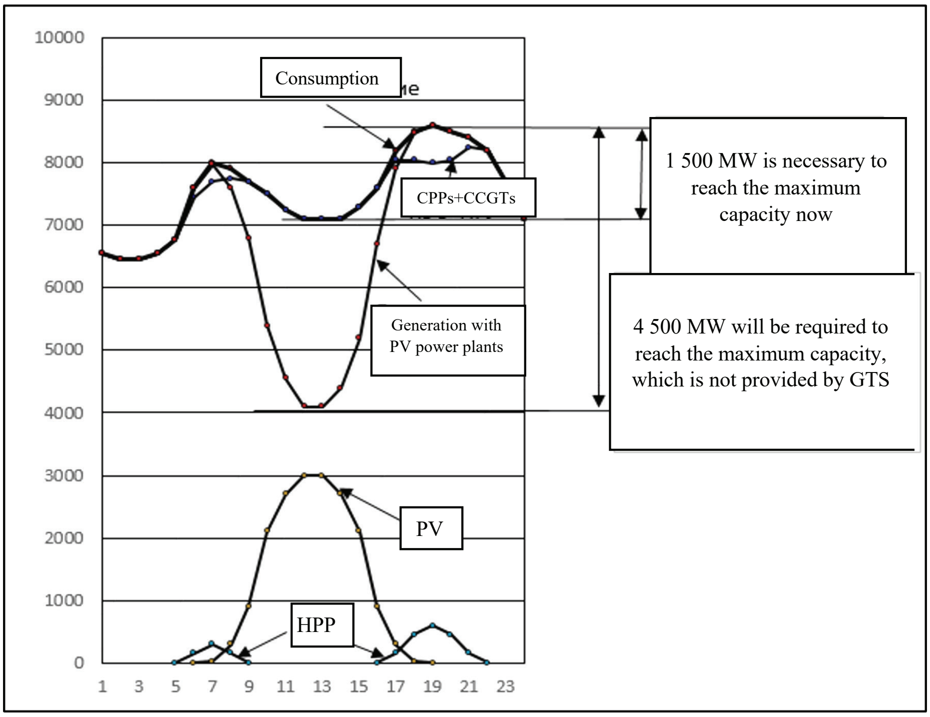

Fig. 1. Changes in daily generation from TPPs and HPPs in the Uzbek power system before and after commissioning the 3 000 MW PV power plants.

a) restructuring the operation of the gas transporters so that they operate according to a flexible daily load profile of power plants, rather than a practically flat load profile as is today, which is a very costly measure in terms of financial outlays and time;
b) installing, where possible, gas storage tanks at the plants to accumulate gas during off-peak hours and release it during peak hours (control over daily gas offtake at the plant itself). There has been no experience of this kind in the country yet;
c) switching to the daily combustion of fuel oil in the hours of evening peak load pickup, when there are restrictions on the load pickup due to a gas shortage. This would require maintaining the working condition of some of the existing conventional power units that can run on both gas and fuel oil. However, this is a very expensive measure: fuel oil is currently burned only under extreme circumstances in the wintertime and the transition to year-round daily burning of fuel oil is unlikely;
d) placing energy storage units at PV power plants and/or in the power system, which is also a costly measure, which countries adopting renewable energy on a large scale are forced to take.

If the above-mentioned problem is not solved, the situation with large uncompensated power surges on Kazakhstan's North-South transmission line, which is loaded to its limit, and, consequently, on the interface between the UPS of Kazakhstan and the UES of Russia will be created almost on a daily basis.

Currently, the permissible power surge is 500 MW in the direction of Russia, and 300 MW from Russia to the CAPS. Given the latter factor and the need to prevent stability loss in the power system of Uzbekistan, devices for automatic tripping of power units with a capacity of over 300 MW were introduced. For example, in case of shutdown of the 800 MW unit at the Talimarjan TPP, the special automatic load shedding system (SALSS) responds and sheds 800-300=500 MW, thereby monitoring the preceding power flow (PPFM), which determines the required size of load to be shed, depending on the load of the unit undergoing emergency shutdown.

As of today, there are not enough capacity reserves in the CAPS. For example, the Kyrgyz power system has reserves of about 150-200 MW, and after the connection of the Tajik power system, the reserves will reach about 700-1,000 MW. Mobile reserves can be increased through the joint construction of new HPPs by the countries of the region in water-abundant Tajikistan and Kyrgyzstan. With the view to creating peak capacity, compensating for the impact of RES, and taking into account the reduction in water resources, the focus should be on the use of pumped-storage power plants (PSPP) and the existing daily and weekly storage reservoirs [7, 8]. These measures will help reduce imbalances due to RES, but this is a very long-term process.

Note that the problem is not just a shortage of power reserves. The existing load surges in the direction of the UES of Russia are because of the currently operating centralized system of frequency control, which does not allow regulators in the national power systems of the CAPS to respond to disturbances earlier than the primary and secondary control units in Russia. Large imbalances leading to stability loss occur infrequently at present, mainly during emergency shutdowns, in which, compensating actions of the automatic emergency control system are inadequate for one reason or another. The introduction of RES, as will be shown below, will cause such imbalances in the CAPS to occur every day, which calls into question the possibility of fully ensuring the stability of parallel operation of power systems.

III. The Stability of the CAPS with the Introduction of RES

Given the high rate of RES penetration into the CAPS and the duration or costliness of measures to overcome the problems related, we should expect that power imbalances due to RES will take place daily and the probability of accidents in the CAPS will increase accordingly, as evidenced by system blackouts in the power systems of the CAPS in 2020–2022. In addition, the transfer capability of the North-South transmission line of the UPS of Kazakhstan is utilized to its maximum load capacity and, therefore, it will be necessary to daily disconnect consumers in the CAPS from the automatic emergency control system to maintain the stability of parallel operation.

Let us demonstrate this with the example of commissioning a power plant with a total capacity of 3 000 MW. Under the current operating conditions in the Uzbek power system, to cover the load during evening peak hours, the output at thermal power plants should be increased by about 1 500 MW, which the existing GTS can hardly cope with, especially in winter (Fig. 1).

With the commissioning of PV power plants in Uzbekistan, which will conclude take-or-pay contracts upon agreement between the parties, the power system will be forced to additionally unload up to 3 000 MW at TPPs during the day and, consequently, to increase output by already 4 500 MW in the evening, given the replacement of increasingly unavailable power at PV power plants. Since operating conditions of JSC Uztransgas do not allow changing gas consumption at thermal power plants by more than 250–300 thousand m3 per hour, which is equivalent to 1 000 MW/hour, it is clear that problems in the GTS will occur both during daytime unloading and during evening load pickups at thermal power plants, which will lead to power imbalances.

The danger of large uncompensated power imbalances was demonstrated by the events in the CAPS that took place on January 25, 2022 and resulted in the complete blackout of the power system interconnection.

The Commission of the CAPS under the leadership of the Coordination and Supervisory Control Center (CSCC) "Energia" conducted an investigation with the involvement of independent experts, including SO UES, identified the causes of the accident, and developed a set of measures to prevent similar accidents in the future.

The investigation of the accident revealed that at the Syrdarya TPP (STPP), there was prolonged arcing between fixed and mobile contacts of the incoming suspended-type disconnector of the 500 kV line L-502 (STPP - Tashkent SS), which, due to air ionization, turned into an inter-phase short circuit with L-502 tripping from fast-acting protections (phase-differential protection) on both ends with successful three-phase automatic reclosing.

At the same time, the second 500 kV bus bar at STPP was disconnected due to excessive action of the main and redundant sets of differential protection of the second 500 kV bus bar. Two minutes later, as a result of a repeated two-phase short circuit, L-502 again disconnected from the phase-differential protection on both ends. The short circuit occurred for the same reason. The first 500 kV bus bar at STPP was tripped due to excessive action of the main and redundant sets of differential protection of the first 500 kV bus bar.

A local accident with the outage of 500 kV bus bars at STPP, the loss of generation there, and separation of the power system resulted in an imbalance of more than 2 000 MW, which was seven times greater than the design value of imbalance and had to be offset by Kazakhstan's North-South transmission line, which caused a dynamic stability loss on that transmission line loaded almost to its limit.

The partition of the transmission line almost doubled the power imbalance in the CAPS, which led to the development of an emergency with a frequency drop to 47.1 Hz, the operation of under-frequency islanding system at some plants in South Kazakhstan, the shutdown of two CCGTs in the Uzbek power system and, eventually, a frequency avalanche.

The Commission has developed a set of measures to prevent the recurrence of such accidents and the cases of uncompensated power surges in the future. However, these measures seem to be insufficient to avoid such system-wide accidents in the event that the plans to build RES in the CAPS are implemented.

The accelerated introduction of RES in Uzbekistan and Kazakhstan can lead to:

- a dramatic exacerbation of the problem of controlling imbalances and the power reserves required for that during all hours of the day, not just during peak hours;
- the urgent need to solve the problem of surplus gas during daytime hours, when PV plants operate at full capacity and thermal power plants are at their minimum safe output;
- the ramp rate problem at thermal power plants.

Given the previously noted shortage of power reserves in the CAPS, we can conclude that with a large-scale introduction of RES, power surges will be inevitable for Kazakhstan's North-South transmission line, and daily stability loss on this transmission line will be the key problem, which may become the main obstacle to the RES integration. As experience shows, the increase in the transfer capability of Kazakhstan's North-South transmission line to maintain stability during power surges

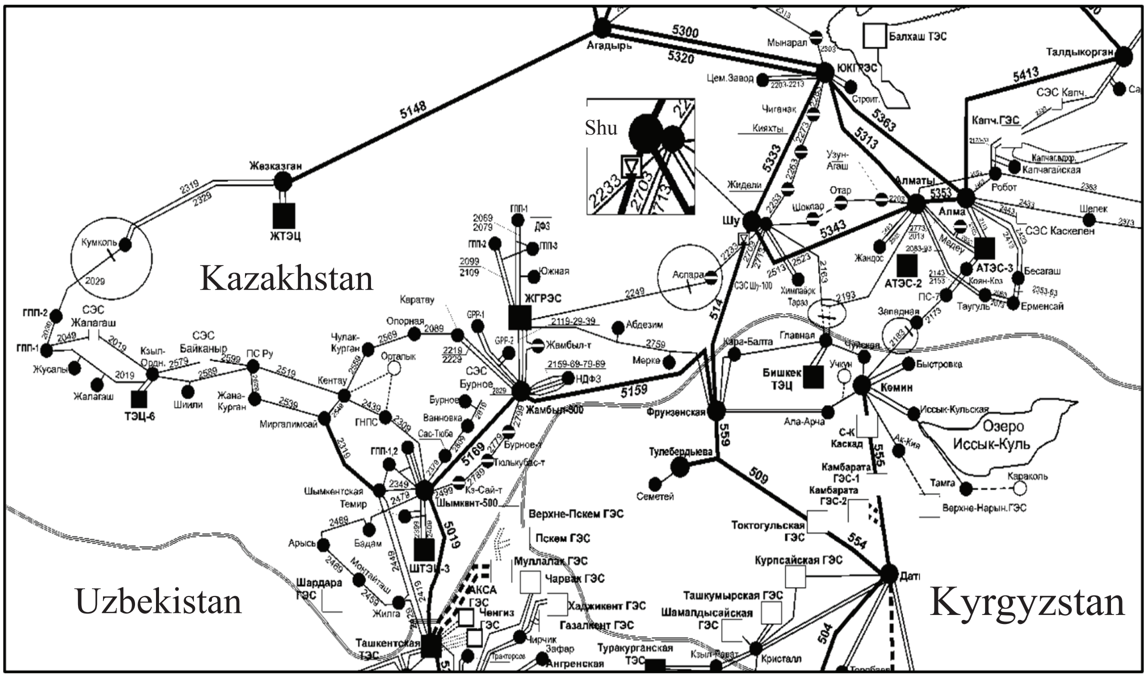

Fig. 2. Proposed DC link.

is an expensive and, at the same time, temporary measure, which reaches its limits quickly.

The idea of using a DC link in a problem area of the CAPS is proposed in [2] to ensure the stability of parallel operation of power systems of Central Asia with the UPS of Kazakhstan and the UES of Russia (Fig. 2).

As noted above, in the accident on January 25, 2022, the disconnection of Kazakhstan's North-South transmission line virtually doubled the power imbalance and the propagation of the accident.

If the injection of power supplied through this transmission line to the southern regions of Kazakhstan was maintained in the event of emergency, it would contribute to the operation of the CAPS with a smaller shortage and, accordingly, with lower costs for its normalization. We propose separating the CAPS and the southern regions of Kazakhstan from the UPS of Kazakhstan by installing a DC link in the L-514 (Shu - Frunze) break, and by switching the bypass 220 kV overhead lines to dead-end modes. The capacity of the DC link should be selected to be sufficient to supply Shymkent and Dzhambyl regions from the UPS of Kazakhstan, which is estimated at about 1 000 MW. The analysis shows that if such a link had been installed in the CAPS, then in the January 25th accident, after the bus bar outage at the Syrdarya TPP, the frequency would have been reduced only to 48.5 Hz and there would have been no development of the emergency followed by the operation of under-frequency islanding system at the plants and frequency avalanche in the power system. This approach will enable us to get rid of several current problems:

- with the frequency controlled in a centralized way by Russian plants, all power imbalances in the CAPS are offset by the cross-border tie lines directed to the UES of Russia and overload them, however, with the operation through the DC link, the imbalances will remain within the CAPS itself;

- with the power supplied through the DC link and the frequency effect of the load considered, the frequency control will be much easier than in the case of parallel operation with the UES of Russia and the UPS of Kazakhstan;

- the structure of the automatic load frequency control (ALFC), which is planned to be developed and implemented in the CAPS, will be simplified, because there will be no need to control deviations of the net power flows at the CAPS border with the UPS of Kazakhstan, and the ALFC will focus on the control of frequency and power flows within the power interconnection.

IV. Conclusion

1. Analysis of the January 25th accident in the CAPS highlights the power balancing problems when the stability of Kazakhstan's North-South transmission line is disturbed.
2. The large-scale introduction of variable and intermittent RES combined with existing and anticipated problems in Uzbekistan gas transmission system multiply the probability of uncompensated surges in Kazakhstan's North-South transmission line. The program for the introduction of RES should be linked to a large-scale redevelopment of the gas transmission system and the creation of interaction between the operators of electric and gas networks in the region to ensure the GTS operation aligned with the load profile of the power system.
3. In order to use water efficiently and create peak capacity

to compensate for the impact of RES, we propose intensifying the efforts in the region to jointly build HPPs and PSPPs, using the existing daily and weekly balancing storage reservoirs for this purpose.

4. The probability of the power imbalances due to RES in Kazakhstan's North-South transmission line increases several times. To prevent power surges and preserve this transmission line, we propose switching to the joint operation of the IPS of Central Asia and South Kazakhstan with the UPS of Kazakhstan and the UES of Russia through a DC link.

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