Renewable Energy Integration and Regional Deficit Mitigation in Kazakhstan's Electricity Market

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Introduction

Kazakhstan's electricity market is undergoing a complex transformation shaped by rising demand, regional imbalance of generation and consumption, aging infrastructure, and the need to integrate a larger share of renewable energy sources. Although the country remains one of the largest electricity producers in Central Asia, its power system continues to face structural challenges that limit reliability, flexibility, and long-term sustainability. A key feature of the national electricity market is the uneven spatial distribution of energy resources: the northern regions concentrate the largest share of coal-based generation, while the southern regions, including Almaty and surrounding areas, experience persistent electricity deficits and depend on long-distance power transfers and imports to meet demand. At the same time, the western part of the country remains partly isolated from the Unified Power System, which further complicates national balancing and market integration.

Wind power plant integration to the power grid

The primary objective of power system operation is to maintain a continuous balance between electricity generation and demand [3]. In the classical sense, power system instability is generally understood as the loss of synchronism following a disturbance. Figure 1 presents the IEEE classification of power system stability problems.).

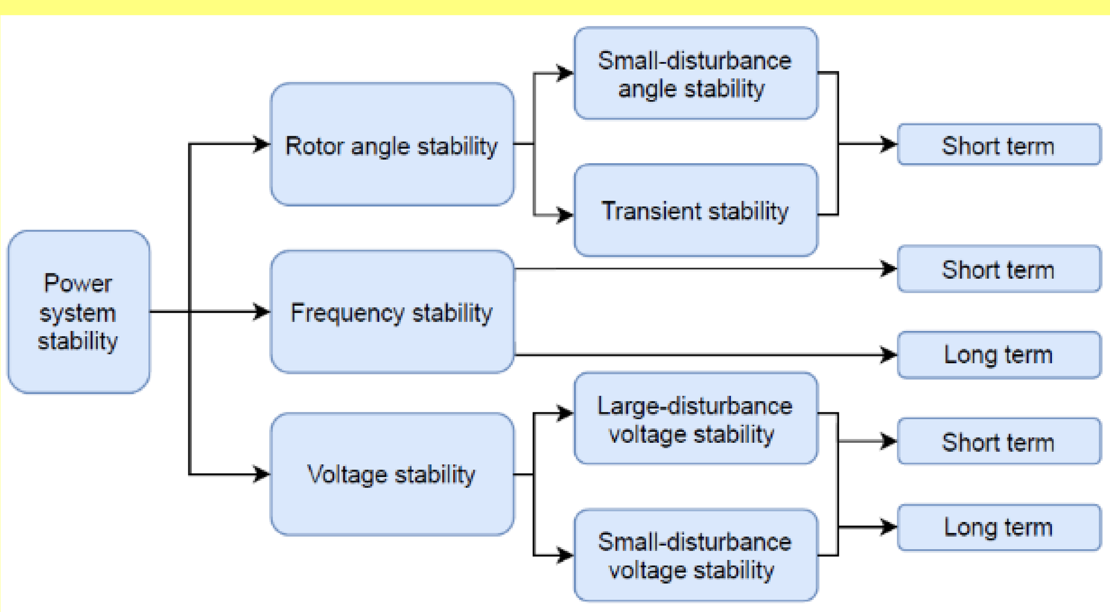

Fig. 1. IEEE Classification of power system stability .

GRID CODE FOR WIND POWER INTEGRATION

To connect to high-voltage networks of 110 kV and higher, WPPs must meet certain grid requirements, which may vary depending on the country. These requirements are usually reflected in the grid code in the form of ranges and limits exceeding these limits, deviation of specific parameters can lead to disconnection from the grid and require specific measures to reconnect to the network. For this study, the results of transient simulation modelling will be evaluated in accordance with the Kazakhstan network code issued for the integration of renewable energy facilities into the national energy system.

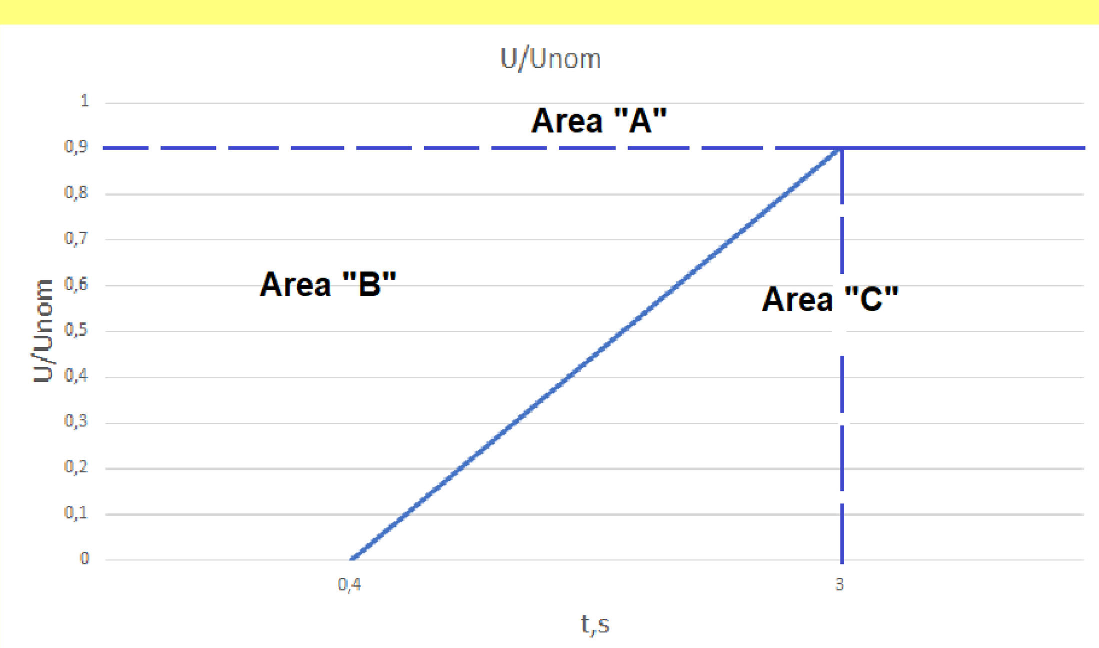

Fig. 2. Grid code requirements on voltage stability for RES facilities in Kazakhstan .

Results

A. Study case

RES system integration simulations and calculations were performed using the DIgSILENT PowerFactory software package. Figure 3 shows the single-line diagram of the studied power system. The model is based on real data from the Shelek area in the Almaty region of Kazakhstan, located at 43°53′41″ N, 78°22′09″ E.

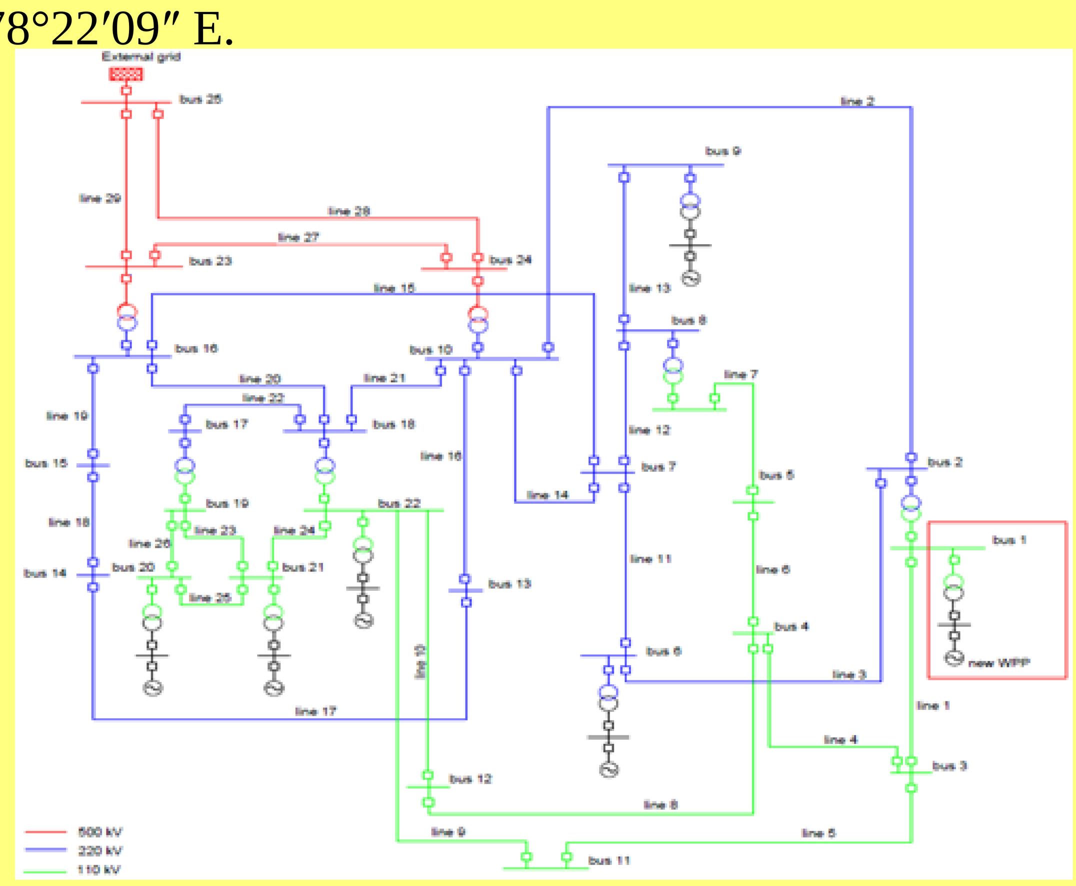

Fig. 3. Single line diagram of the considered grid

B.Rotor angle stability. Transient Stability

Frequency and voltage response of the system during a short circuit on Line 1. At the fault moment, the frequency experiences a sharp transient deviation, followed by damped oscillations around the nominal value of 50 Hz. After fault clearing, the frequency gradually returns to a stable condition. The voltage response shows a sudden voltage drop during the short circuit, especially at the affected buses. After the fault is cleared, the voltage quickly recovers with minor oscillations and stabilizes close to its initial level.

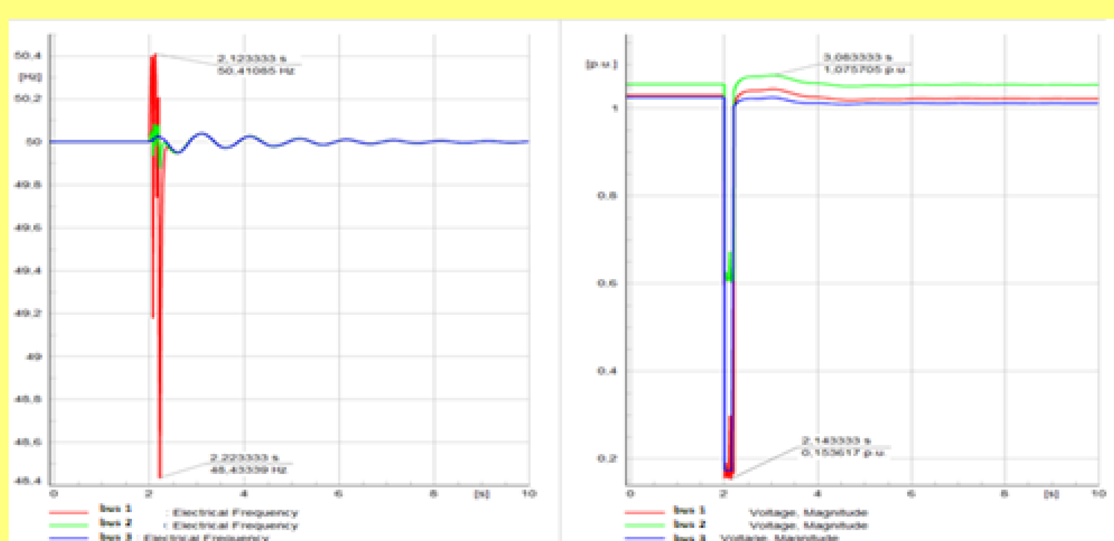

Fig. 4. Frequency and voltage response to short circuit at the line 1.

C. Impact of PSS and WPP on the Small Signal Stability

After the disturbance, the rotor speed exhibits oscillations around the nominal value of 1.0 p.u. In the case without PSS and WPP, the oscillations are more pronounced and take longer to decay. When PSS is introduced, the damping improves and the oscillation amplitude decreases. The combined use of PSS and WPP provides the best damping performance, as the rotor speed stabilizes more smoothly and approaches the steady-state value faster.

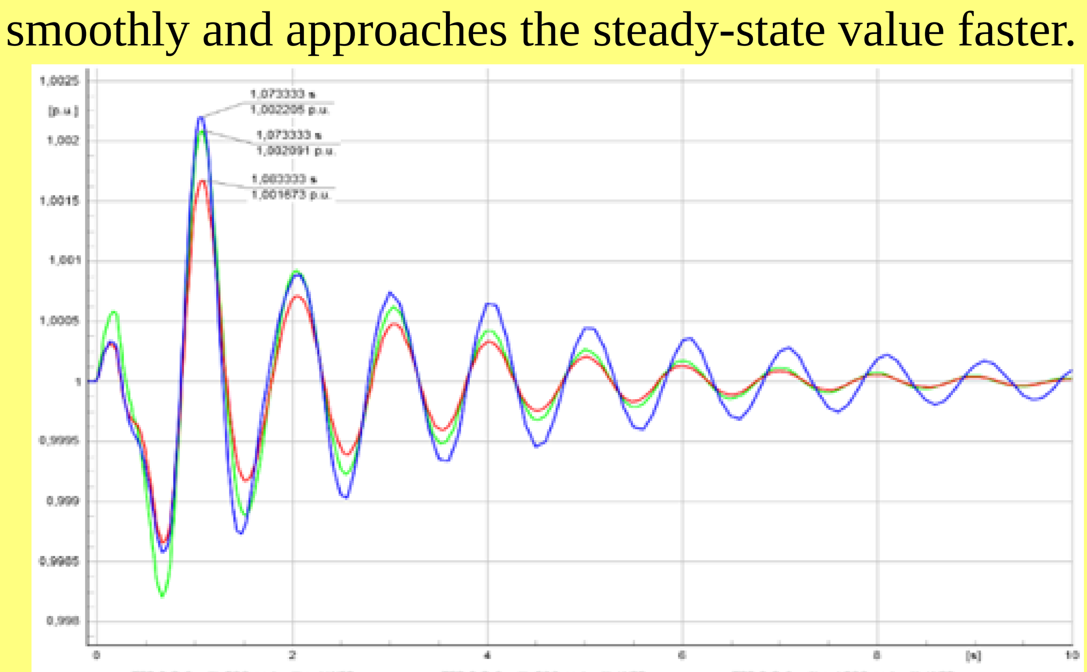

Fig. 5. Rotor speed of TPP-2 G-6 in 3 scenarios.

Market Implications of WPP Integration

The integration of a wind power plant affects not only grid stability, but also the operation of Kazakhstan's electricity market. In deficit-prone regions such as the Almaty area, local wind generation can reduce dependence on imported electricity from surplus northern regions, ease pressure on long-distance transmission corridors, and partially replace conventional thermal generation. As a result, WPP integration can contribute to reducing regional energy deficit and improving the balance between local generation and demand.

Conclusions

This study has shown that the regional energy deficit in Kazakhstan is driven not only by insufficient local generation, but also by deeper structural challenges within the electricity market, including regional imbalance of supply and demand, transmission bottlenecks, aging thermal infrastructure, and limited operational flexibility. These factors reduce system efficiency and increase the vulnerability of deficit-prone regions, particularly in the South The analysis also confirms that renewable energy integration, particularly wind power, can play an important role in mitigating regional deficit when deployed in structurally weak areas such as the Almaty region. system operation, and sufficient balancing capability.

Acknowledgements

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