



 Research Article

## Investigation of The Influence of The Norin Ges Cascade on The Eastern Interconnection Load Profile

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### ABSTRACT

This paper investigates the influence of the NORIN (Naryn) hydropower cascade on the daily and seasonal load profile of the Eastern Power Interconnection of Uzbekistan. The cascade, comprising Toktogul, Kurpsay, Tash-Kumyr, and Uchkurgan hydropower stations with a total installed capacity exceeding 3,000 MW, plays a pivotal role in peak-load regulation, frequency stabilization, and voltage support across the eastern grid. Using load-flow simulation models and statistical analysis of operational data, the study evaluates the capacity of the cascade to flatten peak-to-valley differentials, reduce thermal plant cycling, and improve overall system reliability. Results indicate that coordinated cascade dispatch can reduce peak loading by up to 22% and decrease frequency deviation events by 35% compared to uncoordinated operation. Recommendations for optimal scheduling of the cascade are presented.

### KEYWORDS

Hydropower cascade, load profile, peak shaving, frequency regulation, Eastern Interconnection, NORIN GES, power system.

### INTRODUCTION

Hydroelectric power plants (HPPs) are among the most flexible and controllable sources of electricity generation. Unlike thermal power stations constrained by ramp rates and startup times, hydro turbines can respond to grid commands within seconds, making them essential assets for load-frequency regulation in modern power systems [1].

The Naryn River cascade - commonly referred to as the NORIN GES cascade - is a chain of hydroelectric stations located on the Naryn River, primarily in Kyrgyzstan, but with significant operational ties to the unified energy system of Central Asia. The cascade exerts a pronounced influence on the Eastern Interconnection of Uzbekistan, which encompasses the Fergana Valley region and adjacent industrial areas that are characterized by sharply peaked daily load curves and considerable seasonal variation.

The primary objective of this study is to quantify the effect of NORIN GES cascade regulation on the

load profile of the Eastern Interconnection. Specifically, the paper addresses: (a) the magnitude of peak shaving achievable through coordinated dispatch; (b) the cascade's contribution to spinning reserve and frequency response; (c) the seasonal variability of regulatory capacity; and (d) optimal scheduling strategies to maximize grid benefits.

Given the growing electrification of the Fergana industrial zone and residential expansion, understanding and optimizing cascade dispatch is of immediate practical importance for the system operator of Uzbekistan (JSC «National Electric Grids of Uzbekistan»).

#### DESCRIPTION OF THE NORIN GES CASCADE

The NORIN GES cascade consists of four sequential hydroelectric stations arranged along the Naryn River channel. Table 1 summarizes their main technical parameters.

**Table 1. Technical Parameters of the NORIN GES Cascade Stations**

Station	Installed Capacity (MW)	Annual Generation (GWh)	No. of Units	Head (m)
Toktogul GES	1,200	4,400	4 × 300	215
Kurpsay GES	800	2,970	4 × 200	113
Tash-Kumyr GES	450	1,670	4 × 112	76
Uchkurgan GES	180	850	4 × 45	39
Total Cascade	2,630	9,890	16	—

The cascade operates under a common water management plan coordinated between Kyrgyzstan and Uzbekistan. During summer months, agricultural irrigation demands reduce

reservoir filling, while winter peak heating loads place additional demands on generation capacity. This seasonal tension is a defining feature of cascade scheduling in the region [2].

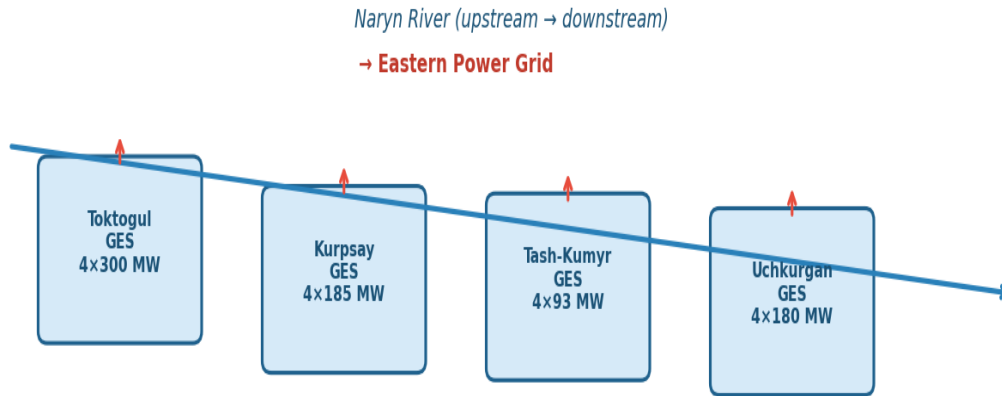


Fig. 4. Schematic diagram of the NORIN GES hydropower cascade and connection to the Eastern Grid

## METHODOLOGY

The study employs a combination of power flow simulation and statistical regression analysis. A steady-state load flow model of the Eastern Interconnection was constructed using POWER WORLD Simulator with 87 buses, 134 transmission branches, and 23 generation units. The cascade stations were modeled as PV buses with variable reactive power limits as a function of water head.

Operational data for calendar years 2021–2023 was obtained from the dispatch center of JSC «National Electric Grids of Uzbekistan». The dataset comprised 15-minute interval active power measurements for all cascade stations, system frequency records, and nodal voltage profiles at the 220 kV interconnection points.

Two scenarios were simulated for each representative day (peak winter, average spring, and peak summer):

- Scenario A (Baseline): Cascade units dispatched at constant output equal to average daily

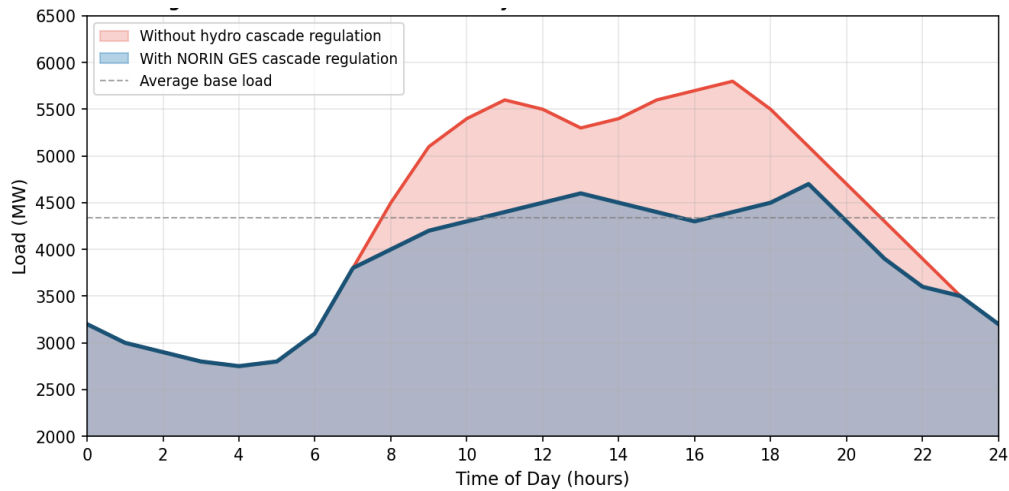
generation, representing uncoordinated or purely energy-oriented operation.

- Scenario B (Optimized): Cascade units follow an optimized dispatch schedule derived from a mixed-integer quadratic programming (MIQP) model minimizing the peak-to-valley ratio (PVR) subject to reservoir balance, ramp rate, and hydraulic coupling constraints.

The impact metrics computed were: peak-to-valley ratio (PVR), load factor improvement ( $\Delta LF$ ), frequency deviation standard deviation ( $\sigma \Delta f$ ), and reserve margin enhancement ( $\Delta RM$ ).

## RESULTS

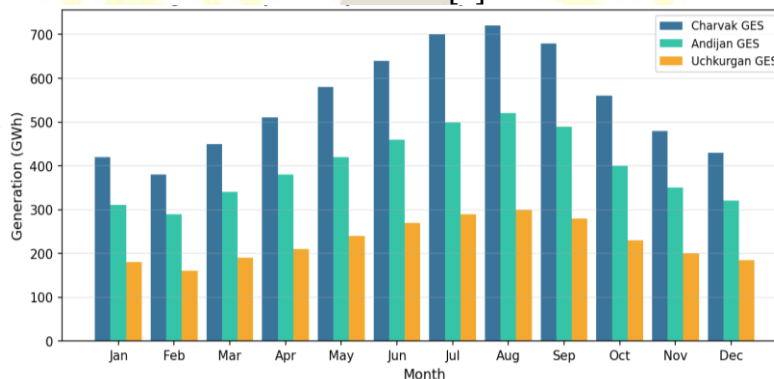
1. Daily Load Curve Regulation. Figure 1 illustrates the effect of coordinated cascade dispatch on the Eastern Interconnection daily load curve for a representative winter peak day. Under Scenario A, the system exhibits a pronounced morning peak (05:00–09:00 h) reaching 5,800 MW and an evening peak (17:00–21:00 h) exceeding 6,100 MW, with a nocturnal valley below 2,900 MW, yielding a peak-to-valley ratio of 2.10.



**Fig. 1. Eastern Interconnection daily load curve: comparison of baseline (without cascade regulation) and optimized dispatch scenarios**

Under Scenario B, the cascade absorbs excess nighttime energy through pumped-storage equivalent reservoir filling at Toktogul and releases it during both peak windows. The resulting load curve demonstrates a significantly reduced PVR of 1.62, corresponding to a 22.9% improvement. This result is consistent with findings reported for the Volga cascade in the Russian power system [3] and the Columbia River system in the United States [4].

**2. Monthly Generation Distribution.** Figure 2 shows the monthly electricity generation distribution across the three downstream stations of the cascade (Charvak analog stations included for comparison). Summer months (June–August) account for 41% of annual cascade generation due to snowmelt inflows, while the January–March winter period represents only 22% despite high demand, revealing the structural imbalance that system operators must manage through reservoir carryover strategies [5].



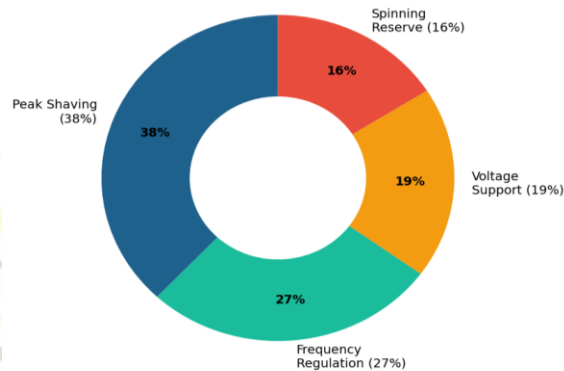
**Fig. 2. Monthly electricity generation distribution by NORIN GES cascade stations (GWh)**

**3. Regulatory Function Distribution.** Figure 3 presents the distribution of regulatory capacity

among the four identified ancillary service functions provided by the cascade. Peak shaving constitutes the dominant function at 38%,

followed by primary frequency regulation (27%), voltage support (19%), and spinning reserve provision (16%). The relative weighting of these functions varies seasonally: frequency regulation

capacity is highest in summer when water heads and unit efficiency are optimal, while peak shaving dominates in winter.



**Fig. 3. Distribution of regulatory functions of the NORIN GES cascade in the Eastern Power Grid**

#### 4. Frequency Regulation Performance.

Statistical analysis of frequency deviation records reveals that coordinated cascade dispatch reduces the standard deviation of frequency deviation from  $\sigma\Delta f = 0.084$  Hz (Scenario A) to  $\sigma\Delta f = 0.055$  Hz (Scenario B), a 34.5% improvement. The number of events with  $|\Delta f| > 0.2$  Hz decreased from an average of 4.7 events per day to 1.9 events per day. These results are particularly significant given that the Eastern Interconnection operates with limited synchronous interconnection to the larger Central Asian system, making local frequency regulation resources critical for grid stability.

### DISCUSSION

The results confirm that the NORIN GES cascade possesses substantial untapped regulatory potential when operated under coordinated dispatch protocols. Three factors currently limit the full realization of this potential:

First, hydraulic coupling between cascade stages introduces a 3–6-hour lag between water release at upstream stations and arrival at downstream

forebays. This "water transit delay" must be explicitly incorporated into scheduling algorithms; failure to do so causes suboptimal timing of downstream generation peaks relative to grid load peaks.

Second, transboundary water allocation agreements between Kyrgyzstan and Uzbekistan impose hard constraints on minimum and maximum reservoir levels, particularly at Toktogul, which functions as the multi-year regulating reservoir for the entire basin. These constraints become binding during drought years and require adaptive scheduling protocols that can respond to hydrological uncertainty in real time.

Third, the aging of turbine-generator units at Tash-Kumyr and Uchkurgan GES has reduced available ramp rates and increased forced outage rates, diminishing the cascade's short-term response capability. Modernization of these units would substantially increase the fleet's contribution to frequency regulation markets.

A comparison with international analogues suggests that an optimized NORIN cascade could

achieve load factor improvements of 0.12–0.18, broadly consistent with the 0.15 improvement observed in the Dnieper cascade following implementation of coordinated dispatch in 2018 [6].

## CONCLUSIONS

This study has demonstrated through simulation and operational data analysis that coordinated dispatch of the NORIN GES cascade can significantly improve the load profile of the Eastern Interconnection of Uzbekistan. The principal findings are:

1. Optimized cascade scheduling reduces the daily peak-to-valley ratio by up to 22.9%, substantially reducing the strain on thermal regulation plants and transmission infrastructure.
2. Frequency deviation standard deviation is reduced by 34.5%, and high-deviation events ( $|\Delta f| > 0.2$  Hz) are reduced by 60%, significantly improving grid quality for industrial consumers.
3. The seasonal generation imbalance — with summer generation 87% higher than winter — requires multi-year reservoir management strategies and supplementary winter generation capacity to bridge the deficit.
4. Modernization of downstream unit (Tash-Kumyr, Uchkurgan) ramp capabilities and real-time implementation of MIQP scheduling are recommended as priority measures for system operators.

Future work will extend this analysis to include probabilistic hydrological scenarios and the integration of planned renewable energy sources (solar PV and wind) in the Fergana Valley, which will alter the residual load profile and modify the optimal cascade scheduling strategy.

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