Application Research on Deflectors for Pelton Turbine Generator Units: Postprint

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Abstract

Analyzing potential issues following high-frequency generator tripping in the Nujiang power grid, investigating deflector application functions in Pelton turbine generating units based on the grid' s hydroelectric unit composition, and proposing practical solutions are of significant importance for the safe and stable operation of the isolated grid after tie-line fault tripping.

Full Text

Application Research of Jet Deflectors on Pelton-Type Hydro-Generator Units

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Abstract

This paper analyzes potential issues following over-frequency generator tripping in the Nujiang power grid. Considering the composition of hydro-generator units within this grid, we investigate the application and effectiveness of jet deflectors on Pelton turbine generator units. We propose practical solutions based on jet deflectors for managing frequency rise without over-frequency generator tripping in the Nujiang isolated grid after interconnection line faults between the Nujiang power grid and Yunnan main grid. These solutions are crucial for ensuring secure and stable operation of the Nujiang power grid.

Keywords: Hydro-generator units, over-frequency generator tripping, jet deflector, isolated power grid

1 Introduction

Over-frequency generator tripping serves as a critical defense line for the secure and stable operation of regional power grids, particularly for export-oriented networks. When interconnection lines trip, this mechanism prevents isolated grids from collapsing due to excessive frequency. However, the unpredictability of generator startup configurations, power output, and load patterns creates significant challenges. During over-frequency tripping operations, over-tripping may trigger under-frequency load shedding. If excessive load is shed, it can cause generator over-frequency tripping again, reducing synchronized units and creating large frequency fluctuations. Additionally, capacitive effects between transmission lines and ground cause substantial reactive power flow into the system when lines operate unloaded or lightly loaded after faults. Since over-frequency tripping reduces voltage regulation capability, voltage rises dangerously high, threatening isolated grid stability and potentially causing collapse. Jet deflectors on Pelton turbine generator units offer irreplaceable advantages compared to conventional over-frequency tripping.

Pelton turbines utilize a special water diversion mechanism (nozzles) to generate free jets with kinetic energy that impinges on buckets, rotating the runner and converting hydraulic energy to mechanical energy. Flow regulation is achieved by moving the needle, controlled by a governor-operated servomotor. During load rejection, the nozzle must close quickly to reduce flow and prevent speed and frequency rise. However, excessively fast closure creates water hammer in the penstock, causing dangerous pressure increases. Therefore, deflectors are installed between the runner and nozzle as automatic control devices for impulse turbines. They rapidly intercept the jet, partially or completely diverting it away from the runner to prevent excessive speed and frequency rise. Once frequency drops to a set value, the deflector returns to its normal position.

This paper investigates the application of Pelton turbine deflectors in the Nujiang power grid, considering its generator composition, and proposes practical solutions essential for secure and stable operation after interconnection line faults.

2 Overview of Hydro-Generator Units in the Nujiang Power Grid

As of July 31, 2016, the Nujiang power grid had 235 hydro-generator units synchronized to the main grid with a total installed capacity of 1.3725 million kW, comprising exclusively Pelton and Francis turbines distributed across Lushui, Fugong, Gongshan, and Lanping counties. System-wide, there were 118 Pelton turbine units with single-unit capacity 1,000 kW, totaling 1.0695 million kW (77.92% of synchronized hydro capacity). Forty-seven Francis turbine units 1,000 kW totaled 267,000 kW (19.45% of synchronized hydro capacity).

County-level breakdowns reveal similar patterns. In Gongshan County, synchronized hydro capacity reached 392,500 kW, with 20 Pelton units 1,000 kW totaling 287,900 kW (73.35% of county capacity) and 10 Francis units 1,000 kW totaling 98,400 kW (25.06%). Fugong County had 445,300 kW total capacity, with 46 Pelton units 1,000 kW totaling 356,500 kW (80.06%) and 14 Francis units 1,000 kW totaling 76,800 kW (17.25%). Lushui County operated 406,200 kW total capacity, with 32 Pelton units 1,000 kW totaling 313,100 kW (77.08%) and 19 Francis units 1,000 kW totaling 84,800 kW (20.88%). Lanping County had 128,500 kW total capacity, with 20 Pelton units 1,000 kW totaling 112,000 kW (87.16%) and 4 Francis units 1,000 kW totaling 7,000 kW (5.40%). These statistics demonstrate that Pelton turbines dominate both in unit count and installed capacity throughout the Nujiang grid, creating favorable conditions for deflector application.

3 Load Rejection Without Deflectors

During instantaneous 100% rated load rejection, ignoring generator power losses, the prime mover output equals the generator’ s rated power P_n, with corresponding torque $T = P_n/\Omega$, where Ω is the generator’ s mechanical angular velocity (rad/s). With no electromagnetic torque present, the accelerating torque equals T, yielding the equation of motion. The resulting generator frequency change rate can be derived accordingly.

If the regional grid exports active power P_s, the frequency acceleration of the isolated grid after interconnection line tripping is calculated using the total moment of inertia J_s of all synchronized generators. Without deflectors, the turbine needle cannot close rapidly during load rejection, maintaining nearly constant hydraulic output while generator output ceases. This causes generator frequency to rise sharply, triggering isolated grid over-frequency and consequently activating over-frequency tripping.

4 Problems with Over-Frequency Generator Tripping

Over-frequency tripping measures constitute an important defense for regional grid security, but their simple criteria and large capacity discreteness create limitations. These measures cannot fully coordinate with diverse operating conditions, inevitably resulting in over-tripping or under-tripping scenarios that compromise grid stability.

5 Application of Pelton Turbine Deflectors in the Nujiang Power Grid

Pelton turbine stations typically feature high heads and long penstocks. From a penstock safety perspective, rapid nozzle closure during load rejection is prohibited, as it would cause extreme pressure rise. Regulations specify that needle servomotor closure time from fully open to fully closed should be 15–30 seconds during full load rejection. Without additional measures, such slow jet cutoff would cause unacceptable speed rise rates and frequency increase. While adding flywheels can reduce the angle between water velocity vectors, the problem remains unsolved, necessitating deflector installation.

5.1 Working Principle of Pelton Turbine Deflectors

Deflectors are positioned between nozzles and runners, controlled by a coordinated operating mechanism. During normal operation, the mechanism adjusts deflector position with jet diameter, maintaining a 2–4 mm clearance from the jet surface without obstructing normal flow [Figure 1: see original paper]. When sudden load reduction increases frequency beyond a set value, the mechanism rapidly inserts the deflector into the jet (within approximately 2 seconds), diverting flow directly downstream to prevent excessive speed and frequency rise. This allows nozzles to close slowly within the specified time, ensuring penstock safety. When frequency drops to a set value, the deflector returns to its normal position beside the jet, restoring power to maintain frequency within allowable limits and preparing for subsequent actions. Deflector activation and return times vary by unit and must be determined through load rejection tests.

The working principle is illustrated in [Figure 2: see original paper]. During load rejection, electrical signals from protection devices are converted to hydraulic pressure signals via electro-hydraulic transducers, transmitted to the main distribution valve, and then through hydraulic pipelines to the deflector servomotor. The servomotor piston movement drives linkages to close the deflector.

5.2 Deflector Application in the Nujiang Power Grid

Deflector settings for Nujiang grid Pelton turbines follow the principles shown in [TABLE:N]. Units with capacity 12.5 MW exhibiting minimum frequency acceleration during 100% load rejection and shortest deflector activation times are divided into two groups: the first group activates at 51.5 Hz, the second at 52 Hz. Units with capacity between 7 MW and 12.5 MW with moderate frequency acceleration and short activation times receive similar treatment.

5.3 Effectiveness Analysis

After interconnection line faults, isolated grids with generation exceeding load experience increased generator speed and frequency. Deflectors offer several irreplaceable advantages over conventional over-frequency tripping:

First, when frequency reaches the deflector activation threshold, the deflector diverts load from all Pelton units in that group while governors slowly close needles or guide vanes across all units. Since Pelton units remain synchronized, the total moment of inertia J_s remains unchanged while residual active power P_s decreases, rapidly reducing frequency acceleration and preventing excessive frequency rise. When P_s reaches zero, isolated grid frequency peaks. As frequency remains above nominal, needles continue closing, making generation less than load. This reduces frequency, causing deflectors to return sequentially until nominal frequency is restored and needles stop closing, allowing the isolated grid to stabilize under governor control.

Second, during minor load rejections where deflector activation makes generation less than load, deflector return capability prevents under-frequency load shedding action. Deflectors function as protective devices; without deflector action during sudden load reduction, speed and frequency would rise excessively. Rapid deflector insertion minimizes speed and frequency rise rates while nozzles adjust gradually to new load positions, preventing pressure surges in long penstocks. After nozzles stabilize, deflectors return beside the jet, ready for subsequent actions, with generator output controlled by nozzles to avoid low frequency.

Third, deflectors remain inactive during normal operation, engaging only when speed or frequency suddenly exceeds set values, and returning when speed drops below the reset value. This dual regulation ensures both small-disturbance regulation quality and large-disturbance protection requirements. When regional grids import power from the main grid, interconnection faults may cause under-frequency load shedding over-tripping. Deflector action prevents the vicious cycle of subsequent over-frequency tripping, significantly enhancing grid disturbance resistance.

Fourth, over-frequency tripping exacerbates voltage rise caused by capacitive effects of unloaded transmission lines after faults, as reduced generation capacity impairs voltage regulation. With deflectors, all units remain operational to absorb excess reactive power, substantially mitigating overvoltage.

6 Conclusion

Deflectors provide irreplaceable advantages over over-frequency tripping. To maximize effectiveness, technical modifications should reduce activation and return times for slower deflectors, ensuring minimal frequency rise after grid separation.

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