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Simulation and Consideration of Hydropower Units Operating In Isolated Grid

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Abstract. The Belt and Road Initiative enables China's hydropower industry to go out. In order to improve the qualities of the design and operation of hydropower units in Asia and Africa, the reliability of the isolated grid operation should be considered. A simulation model for the typical operation of hydropower units is established. The influence of flow inertia time constant and unit inertia time constant on the operation characteristics of isolated network is analyzed. It is pointed out that the inertia ratio of units should be reduced as much as possible in the design process of hydropower stations. Based on the frequency characteristics of hydropower units under different frequency dead zone, an improved controlling strategy of turbine governor is proposed to provide technical support for the operation of hydropower units in isolated grid.

1. Introduction

Under the background of "One Belt And One Road" strategy, China's hydropower industry has gradually become the main force promoting the development of world hydropower [1]. In the process of cooperation and promotion of relevant projects, attention should be paid to the improvement of the quality of the whole industry such as design, equipment manufacturing, operation, etc. High quality should be ensured to shape the new business card of sinohydro maintain the national image of China. At present, China's hydropower output is mainly concentrated in Southeast Asia, South Asia and Africa, among which some national power grids are of small scale and low reliability [2]. Because hydropower is mostly distributed in mountainous areas with low load requirement, such power networks are easy to form the operation mode of isolated hydropower networks in case of failure of external transmission channels caused by natural disasters or war turmoil [3] During the operation of the isolated network, there are fewer generating units in the system, and the impact of load disturbance on the isolated network is increased. Therefore, in order to provide clean and stable electric energy, it is necessary to consider the isolated network operation in the process of hydropower construction.

Based on the characteristics of hydropower station and power grid, Zhan [4] put forward the regulation rules and parameters suitable for the speed regulation system of small power grid. Cai [5] analyzed the isolated network accident of Zang-mu power station, and proposed corresponding adjustment control optimization measures and working condition identification methods. Zhou [6]

analyzed the main reasons of the high frequency of the isolated power network in Guizhou and its operation accidents, and put forward the measures to restrain the high frequency and stabilize the system. Wang [7] studied and understood the regulation characteristics of hydropower units in case of a series of faults, and improved the speed regulation control system. Chen [8] studied the additional control method of synchronous generator speed regulation system based on bias power feedback and its effect on frequency stability of isolated network. In general, the stability and frequency control of isolated network of hydropower units still need to be studied deeply.

In this paper, based on Matlab/Simulink platform, a simulation model for the operation of the isolated network of a typical hydropower generating unit is established. Then the influence of hydraulic system parameters on the operation characteristics of isolated network is analyzed. Regarding the frequency characteristics of the turbine governor in different frequency dead zones, an improvement of the frequency control strategy for the turbine governor is proposed. Therefore, the paper made some suggestions on domestic and foreign hydropower construction to improve the reliability of isolated network operation.

2. Simulation model of isolated grid operation of hydropower unit

Based on Matlab/Simulink platform, a hydraulic turbine governor combined with a parallel PID control structure [9] and an electro-hydraulic servo system [10] which includes nonlinear links are established. We also set up a pressurized water system with elastic water impact and the simulation modules of main links such as turbine [11] based on the model comprehensive characteristic curve. Besides, a simulation model for the operation of the isolated network of a hydroelectric generating set is established, as shown in Fig. 1.
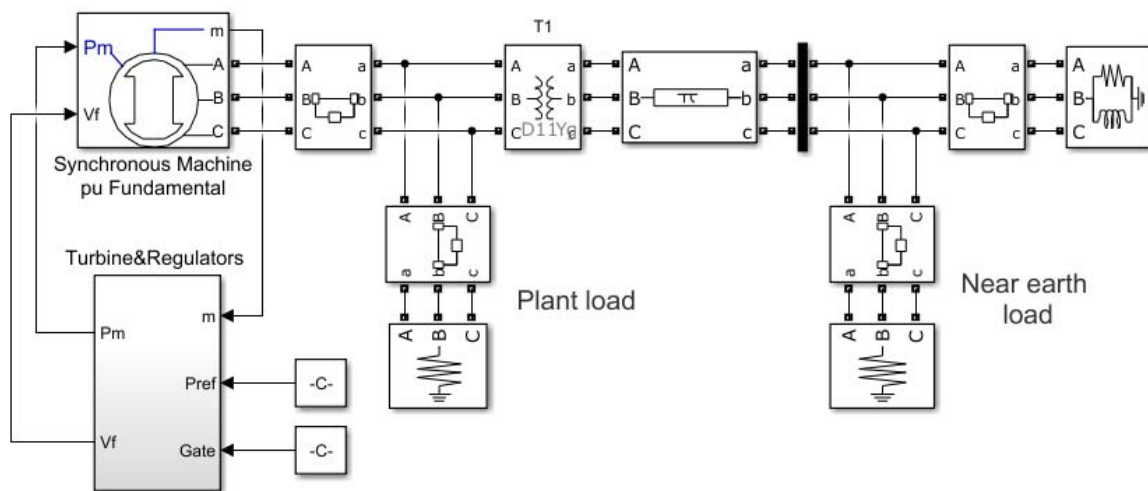

Figure 1. Simulation model of single unit

The main simulation parameters are shown in Table 1.

Table 1. Parameters of water turbine governor system.

T_w	T_r	h_f	K_P	K_I	K_D	Ta
1.63	1.18	0.026	2.7	0.33	2.3	3.7

3. Influence of hydraulic system parameters on the operation of isolated network

3.1. The inertia time constant

The inertia time constant of the unit water flow provided by the power station design organization is the value under the rated head and rated power conditions of the unit.However, the inertia time constants of water flow, which play an actual role in turbine governing system, are different for different operating heads of units.

Assuming that the unit has rated load under the rated head and 20% of rated load was discharged at the beginning of the simulation, for three different T_w values 1.63, 2.63 and 3.63 respectively, the operating characteristic curves of unit speed, mechanical power, flow rate and guide vane relay stroke have been shown in Fig. 2.
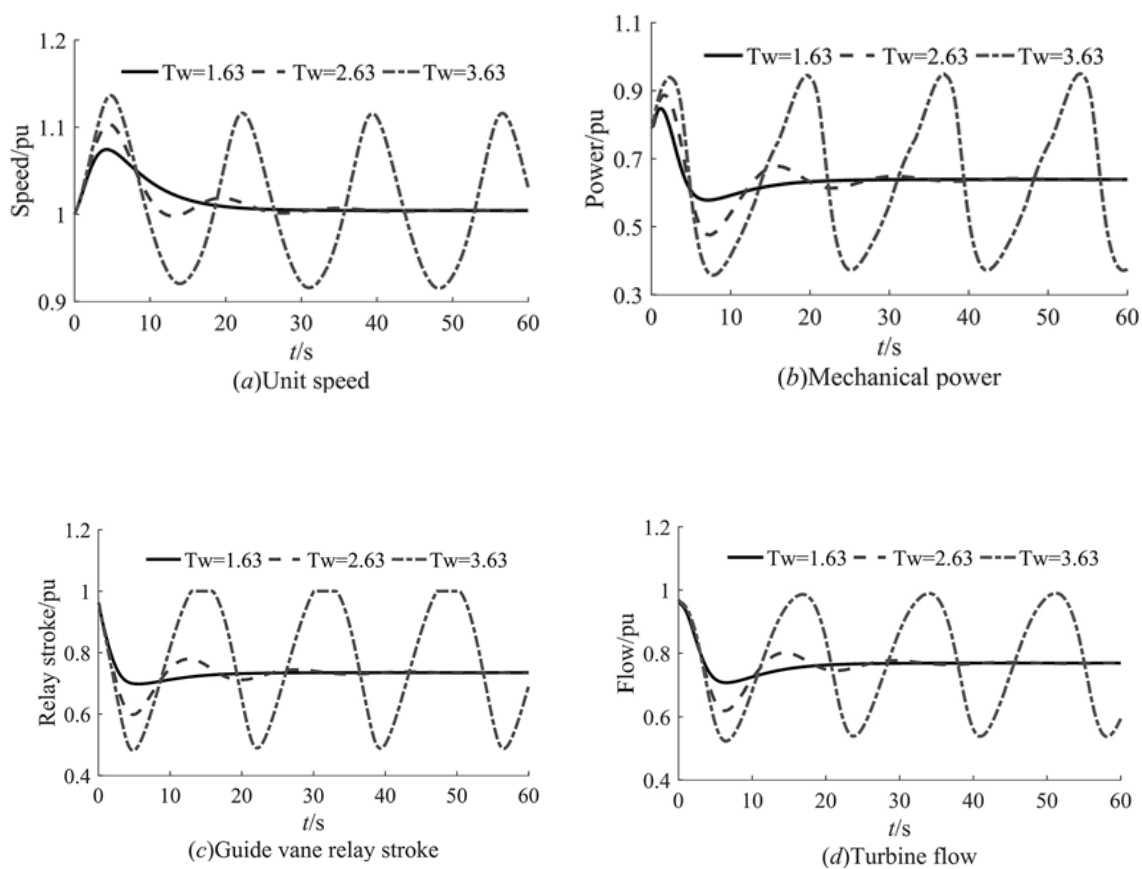

Figure 2. Operating characteristics under different T_w.

It can be observed from Fig. 2(a) that: The smaller T_w, the smaller the maximum deviation of unit speed, the faster the recovery speed of unit speed to the stable value. Inversely, larger T_w increases the maximum value of the unit speed deviation and elongates the adjusting time. If T_w is large enough (i.e. $T_w = 3.63$), a quasi-sinusoidal oscillation will occur. -Analogous to the speed, the actuating range of the relay during the dynamic process, the reverse regulation of the turbine power, the adjusting process of unit mechanical power, relay stroke and flow and the time to reach the stable value all have the similar correlation with T_w (Fig. 2(b-d)). The quasi-sinusoidal oscillation can also be clearly identified for each parameter.

3.2. Unit inertial time constant

The inertial time constant T_a of unit is not a parameter that can be changed at will in hydropower station, and the inertial time constants of unit of Francis turbine, axial-flow turbine, and through-flow turbine and impulse water turbine generator sets can vary greatly in value.

If the unit is equipped with rated load at the initial stage under the rated water head, and 20% rated load is thrown at the beginning of simulation. For three different T_w values 2.3, 3.7 and 5.7 respectively, the operating characteristic curves of unit speed, mechanical power, flow rate and guide vane relay can be obtained, as is shown in Fig. 3.
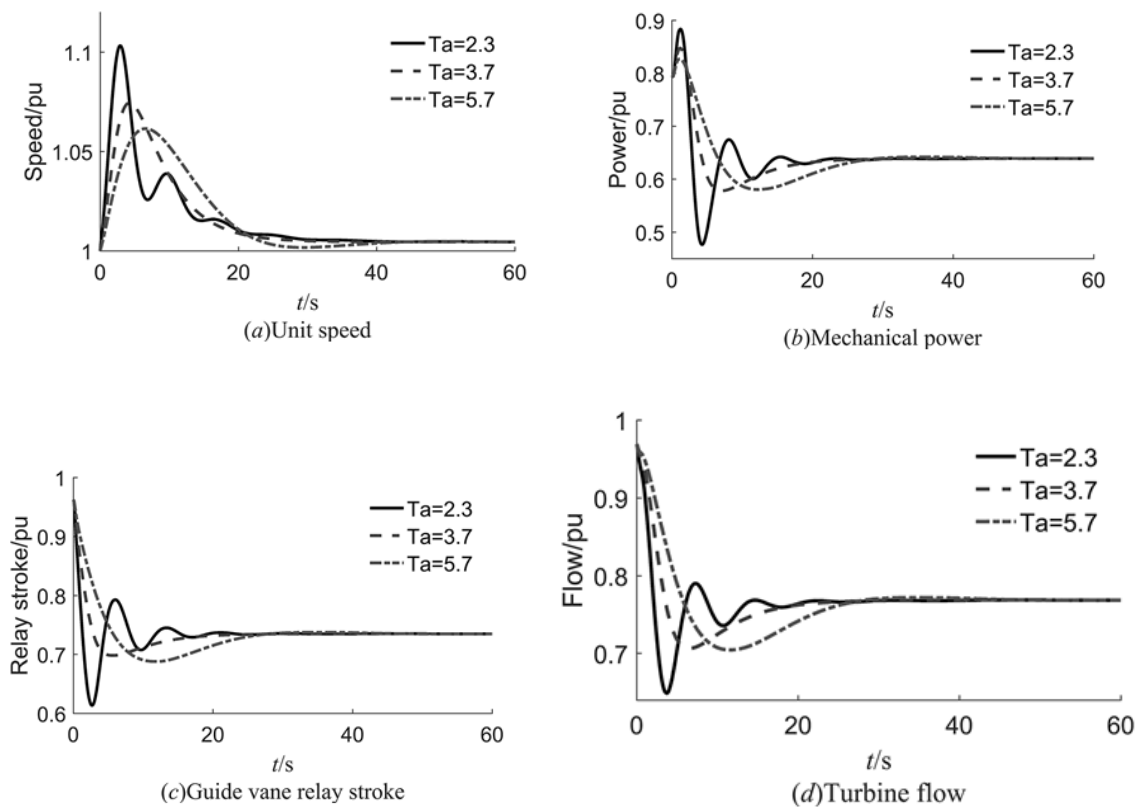

Figure 3. Operating characteristics under different T_a.

It can be seen that the value of the inertia time constant T_a of the unit plays an important role in the dynamic characteristics of the sudden load reduction of the hydropower unit running in the isolated network. In Fig. 3(a), the smaller T_a is, the greater the maximum deviation of the unit speed is, and the faster the unit speed recovers to the stable value. Fig. 3(b), (c) and (d), the smaller T_a is, the faster the relay operation speed and the unit flow decreases will be, leading to the increase of water hammer pressure, a more serious reverse of turbine power, and a faster response time of unit speed. However, if T_a is too small, more oscillation times will occur in the adjustment process of the unit's mechanical power, flow rate and the guide vane relay's stroke. As a result, more time is required to reach the stable value.

3.3. Unit inertia ratio

Wei [12] firstly used the term "unit inertia ratio" to describe the ratio of T_w and T_a, and calculated the unit inertia ratio under the above simulation conditions. The results are shown in Table 2.

Table 2. Unit inertia ratio under various simulation conditions.

Numble	T_w/s	T_a/s	unit inertia ratio	Simulation result
1	1.63	3.7	0.441	Fig. 2,3
2	2.63	3.7	0.711	Fig. 2
3	3.63	3.7	0.981	Fig. 2
4	1.63	2.3	0.709	Fig. 3
5	1.63	5.7	0.286	Fig. 3

It can be seen from Fig. 2 and Fig. 3 that the smaller the unit's inertia ratio, the better the dynamic regulation performance of the single-load isolated network will be. In the engineering practice, it requires that the inertia ratio of the hydropower unit generating set not be greater than 0.4. Therefore, in the design process of hydropower station, the inertia ratio of the generating should be reduced as much as possible while meeting the requirements of the technical conditions.

4. Operating frequency characteristics of the isolated grid operation of hydropower unit
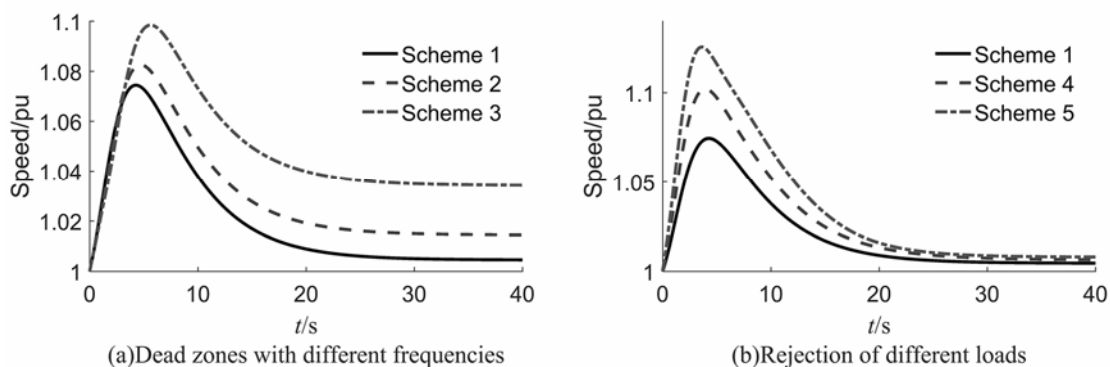
4.1. Influence of frequency dead zone on the isolated grid operation

In the actual operation, the hydro-generating units are often set up with artificial frequency dead zones. If the artificial frequency is too small, the unit will be frequently adjusted, which has a negative effect on the stable operation and will affect the power grid frequency stability. On the other hand, if the frequency is too large, the variable load cannot be timely and effectively assumed when the frequency of power network changes dramatically.

When the hydro-generating unit operates in the isolated network, the impact of the artificial frequency dead zone is more direct. In order to study the influence of the artificial frequency dead zone on the frequency regulation characteristics of the isolated network, the parameter configuration scheme is shown in Table 3, and the speed variation curve of each scheme unit is shown in Fig. 4.

Table 3. Parameter configuration scheme.

Scheme	1	2	3	4	5
Depth of load rejection(ε)	20%	20%	20%	30%	40%
Frequency of dead zone(e_f)	0	0.01	0.03	0	0

(a)Dead zones with different frequencies   (b)Rejection of different loads

Figure 4. Regulating characteristics of isolated single unit under different parameter configurations.

It can be seen from Fig. 4(a) that the setting of artificial frequency dead zone has a significant influence on the adjustment process of the unit speed. At the same load rejection depth, the larger the artificial frequency dead zone is, the larger the maximum rotation speed deviation and the steady-state deviation are. The maximum deviation and steady-state deviation of the unit speed increase

proportionately with the size of the artificial frequency dead zone. It can be observed from Fig. 4(b), that when the dead zone of the same artificial frequency is used, the maximum deviation of unit speed and steady-state deviation increase proportionally with the increase of load rejection.

4.2. The control strategy of frequency modulation in the isolated grid operation of hydropower unit
As analysed above, according to the traditional static characteristics and PID regulation characteristics, the turbine governor can only achieve one-time frequency modulation, and it is impossible to restore the grid frequency to an allowable range near the rated frequency. Hence, a secondary frequency modulation is needed. If the secondary frequency modulation is not timely in the case of fault, large deviation and oscillation of system frequency cannot be avoided. Therefore, an improved control structure of hydraulic turbine governor is proposed in this paper, as shown in Fig. 5.
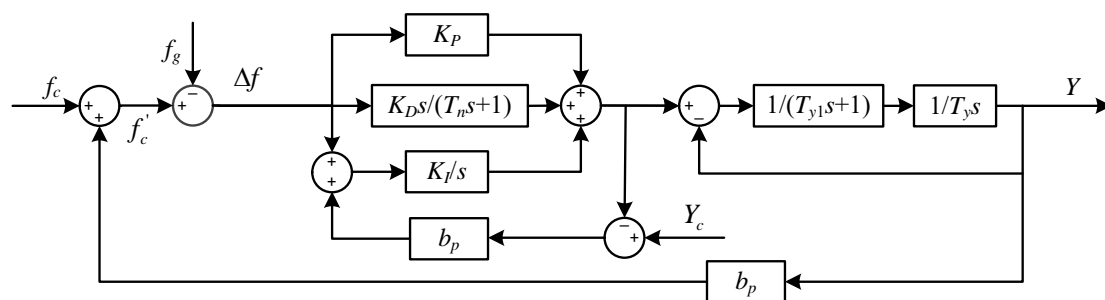

Figure 5. Control structure improvement of hydraulic turbine governor.

Where K_P, K_I and K_D are the proportional gain, the integral gain and the differential gain respectively, T_n is the differential filtering time constant, f_c is frequency setting, f_g is the frequency of the unit, Y_c is setting the opening, bp is a constant slip coefficient, T_{y1} is the auxiliary relay reaction time constant, T_y is the main relay reaction time constant, Y is the stroke of the relay (guide vane open). $f_c{'}=f_c+b_P \cdot Y$, where $f_c{'}$ will be considered as the actual set speed value.

As shown in Fig. 6, point A is set as the initial stable condition. When the load is reduced, the turbine governor adjusts the travel of the guide vane relay according to the static characteristics AB, The relay stroke is adjusted from y_1 to y_2. At this time, according to the formula $f_c{'}=f_c+b_P \cdot Y$, the frequency given value is adjusted from f_c to f_{c1} correspondingly. The static characteristics of the governor are shifted from AB to CD, and then the turbine governor adjusts the guide vane relay stroke according to the static characteristics CD until a new balance is reached. Because the given frequency changes with the stroke of guide vane relay at all times, the static characteristic of governor changes at all times. The final static characteristic curve of turbine governor should be an approximate linear ADF, which is equivalent to the simultaneous realization of primary and secondary frequency modulation.
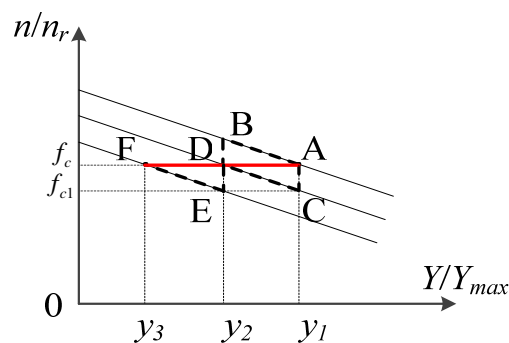

Figure 6. Frequency regulating process of improved control strategy.

Before and after adopting this control strategy, the regulation characteristics of the hydropower station unit 1 and 2 in Table 3 are shown in Fig. 7. It shows that the maximum speed deviation of the unit is reduced by the improved control strategy, implying that the improved control strategy can effectively suppress the maximum speed rise; the adjustment time is about 30 seconds, suggesting that the improved control strategy can quickly and effectively achieve frequency control. The final speed of the unit is stable to the rated speed under scheme 1 without deviation, which shows that the improved control strategy can achieve the speed adjustment without deviation in time, and the frequency can be stabilized near the rated value. Fig. 7 (b) adopts the improved control strategy, in which the steady-state deviation of the unit speed is 0.01, (scheme 2 sets the artificial frequency dead zone of 0.01). When the speed deviation is not beyond 0.01, the speed deviation has no effect on the regulating system, so a steady-state deviation of 0.01 is formed. It can be concluded that when a single unit operates in isolated network with load, the improved control strategy can ensure the frequency stability within the range.
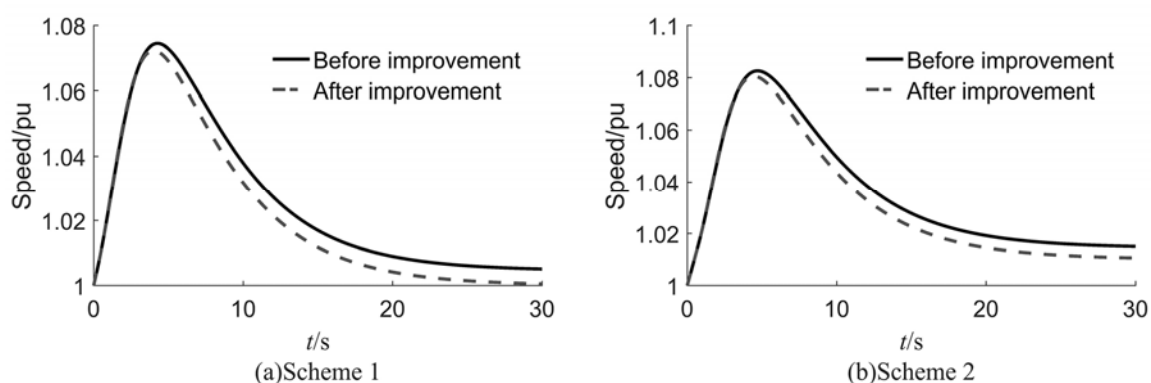

Figure 7. Regulating characteristics of isolated unit before and after improvement.

5. Conclusion
The simulation results show that: (1) the smaller the flow inertia time constant and the larger the unit inertia time constant, the smaller the maximum deviation of the unit speed will be. In the design process of hydropower stations, the inertia ratio of units should be reduced as much as possible.(2) The dead zone of artificial frequency and the depth of load rejection will affect the maximum speed deviation of hydroelectric unit in isolated network operation. There is a steady-state deviation under the common frequency regulation mode of turbine governor. (3) The improved control structure of hydro-turbine governor can quickly and effectively make frequency adjustment without difference. By setting a certain artificial frequency dead zone, the frequent regulation of governor can be avoided without affecting the frequency stability near the rated value, which provides technical support for the operation of hydro-electric isolated network.

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