Design of Infrastructure for Pumped Storage Power Station and Automatic Monitoring System Using Geographic Information System

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Abstract. The pumped storage power station realizes grid connected power generation through the conversion between the potential energy of surface water and mechanical energy. It has become the strategic resource of UHV power grid with its low valley peak regulation and emergency standby function. The green basic design and design of the pumped storage power station needs systematic research. Based on the collaborative analysis method of production and ecological safety of storage disk, this paper takes Ninghai pumped storage power station as an example to carry out green infrastructure planning and design research. Through the comprehensive evaluation and analysis of construction land based on GIS, from the perspective of adaptability of power station construction to mountain creek pit environment, the function of horizontal layout is constructed in parallel and vertical layout, and a modular and distributed spatial structure of green infrastructure is constructed; Then, based on the continuous recycling of water resources, the monitoring and early warning system of power plant production ecological safety is constructed, which is "one water, two lines and three slopes". It is hoped that the correlation between the production and the ecological dispatching of the storage tray can be found through the dynamic tracking of multiple factors and quantitative analysis of production cycle, which can provide reliable basis for timely mitigation of damage and formulation of compensation strategies, Scientific control of green infrastructure planning, design and construction.

1. Introduction
The rapid development of clean energy and its infrastructure puts forward new requirements for its ecological environment quality and safety pattern. The construction and operation and maintenance of pumped storage power station is increasingly valued in the process of energy system upgrading guided by clean, efficient and multi-source complementary. In view of the high attention paid by developed countries to the supervision of energy industry environmental protection and the reform of power market, the attention of green infrastructure planning and design has been continuously improved, so the transformation of existing power station with pumped storage technology has become a hot research topic. Based on the discussion of the function characteristics, automation control technology and hydropower engineering construction technology of power plants, the research on the power industry in developing countries represented by China has developed rapidly in recent years on the correlation...
between the construction, operation and ecological environment protection of pumped storage power plants [1], production safety and ecological environment security have become one of the collaborative research contents.

In the current sustainable development strategy and ecological civilization perspective, the construction of the balance between production safety and ecological safety of pumped storage power station is not only related to the structural choice of future energy supply in cities and towns, but also the inevitable requirement of industrial 4.0 transformation. The fusion point is the planning, design and construction and operation and maintenance of green infrastructure of pumped storage power station [2]. This paper takes Ninghai pumped storage power station in Zhejiang Province as the research object, combs out the internal relationship between the function characteristics and location selection of the pumped storage power station, and explores a green infrastructure planning and design strategy based on the interactive feedback of safety analysis, adaptive construction and dynamic monitoring and early warning.

2. Functional characteristics of Pumped Storage Power Station

2.1. Irreplaceable of pumped storage power station in the new stage of UHV power grid
Taking China as an example, since 2009, the national grid has been upgraded to a new stage of UHV grid as the backbone grid. During the period, the power structure is becoming more and more diversified, and the new power supply is mainly non-fossil energy installation, among which the installed proportion of pumped storage power station increases significantly (4.16%), and the importance of power grid safety and reliability is increasing [3].

In this context, the development and construction of pumped storage power station is highly valued by the government and regarded as a strategic resource to ensure the safe operation of power system. In UHV power grid, the irreplaceable of pumped storage power station is highly related to its function characteristics. First, the emergency standby function of the power station is not available by other (energy) units, while peak load and valley filling function is second to clean coal-fired units (conventional). Secondly, UHV power grid is more vulnerable than traditional power grid. In case of serious destructive emergencies, there are few effective methods to deal with the loss of large power generation load. In view of the outstanding performance of Pumped Storage Technology in peak regulation and emergency standby, its irreplaceable performance is further strengthened [4].

2.2. Requirements for site selection and engineering design of power station realized by function

The power generation function of pumped storage power station is realized by the conversion between potential energy and mechanical energy of surface water. This puts forward strict safety requirements for the project location, mechanical and electrical equipment operation and building design [5].

As for the site selection of power station, the drop difference of the upper and lower water reservoir is generally 400-600 meters, and it is also adjacent to the power load center. The former means that only mountain valley with large elevation difference can meet the implementation conditions of energy conversion, while the latter must maintain reasonable spatial connection with urban construction area and nuclear power station with high population density [5], and the suitable location is mostly in the natural environment around the built environment. As for electromechanical equipment, the daily operation of the power station is guided by meeting the needs of the power grid. The start-up and stop dispatching of electromechanical equipment are more frequent and complex. The energy conversion process involves 10-20 conversion and protection conditions respectively. It is necessary to ensure the real-time and reliability of a large number of data exchange [6]. This depends on the support of computer monitoring system. The relevant building safety design is for fire protection strict requirements for waterproofing [7] are proposed.

3. Location conditions of Ninghai pumped storage power station
Ninghai Power Station is a daily regulating pure pumping storage power station, located in the low and low mountains and hills of Ninghai County, Zhejiang Province, adjacent to several fossil energy power
stations and railway and sea transportation facilities. The designed installed capacity of the power station is 1400MW.

3.1. Ninghai is a highly vulnerable area where geological disasters and climate change disasters overlap

It is worth noting that Ninghai County has been a high incidence of geological disasters. As early as 2002, 88 geological disaster sites have been recorded in the county, of which mountainous areas account for more than 80% of the total; the main disaster types are landslide, followed by collapse. The local meteorological observation records show that the rainfall intensity in 2009 is over 120 mm/h, and more than 100 landslides are caused; the rainfall intensity in 2019 reaches 87 mm/h and the landslide area reaches 15000 m$^3$. Ninghai has become a highly vulnerable area where geological disasters and climate change disasters overlap.

3.2. The interaction between internal and external factors is the reason for frequent landslides in Ninghai

The internal factors that cause geological disasters include geological structure, geographical conditions and local climate [8]. Ninghai is a southeast fault fold area, mainly composed of volcanic sedimentary rocks, and the terrain is mainly low and medium mountains with an altitude of 50-500 meters. The combination of geographical conditions and current monsoon makes Ninghai one of the four heavy rain centers in Zhejiang Province. The heavy rainfall scour the loose soil, which is easy to induce landslides and collapses.

The external factors include artificial construction activities and climate change. The artificial construction activities leading to landslides are all disturbed by artificial construction such as road construction and land expansion [9]. At the same time, since 1960, the precipitation events of Zhejiang Province in two years and 100 years have been significantly increased, and climate change and secondary disaster risk coexist with the rapid growth of urban construction.

The mountainous area in Northeast Ninghai County, which contains the project location, is not a relatively safe area to avoid geological disasters, and it has uncertainty to deal with potential geological hazards such as landslides [10]. In order to explore the balance between the construction, operation and local ecological environment of Ninghai Power Station, the planning of power station starts from two aspects of protection construction and construction protection, and through the field data collection and quantitative analysis to deal with the uncertainty in the process of energy development and utilization, and to clarify the relationship between the production safety and the ecological safety of the storage disk.

4. Adaptability of Ninghai pumped storage power station to mountain creek environment

Ninghai pumped storage power station should focus on the planning guidance for the safe utilization of Mountain Creek environment, and make adaptive utilization by combining the function parallel on the plane layout and the function coordination on the vertical distribution.

4.1. Function parallel in plane layout

Due to the complex changes of the topography in the middle and low mountains, the construction land condition of the hydropower station is more fragmented than that of the Dahe hydropower station. Modularized and distributed land use structure is the first choice for power station spatial planning. Rolling hills and numerous rivers shape the hydrological characteristics of small watershed in mountainous area [11], and the construction of power station needs to build connections between multiple small watershed units.

At the spatial level of small watershed, the dam sites of the upper reservoir and the lower reservoir are respectively located at the confluence of surface runoff. Although these natural runoffs and the natural vegetation along the line do not belong to the scope of the power station, they are directly related to environmental safety and sustainable development. From the beginning of the construction of the power station, it needs overall study and judgment [12]. On the one hand, the implantation of new
functions must be compatible with the old functions in production and ecological security, on the other hand, the old functions should also adapt to the external environmental changes triggered by the new functions, which are difficult to reverse [13].

At the spatial level of the power station, considering the technical characteristics of pumped storage, the site selection of the hoist room, switch station, water diversion system, underground powerhouse and other important mechanical and electrical equipment, hydraulic buildings (structures) should not only meet the specific functional design requirements, but also try to avoid geological hazards. Under the multiple constraints of land suitability, mountain accessibility, construction cost, etc., Realize the connection between the functional modules. At the same time, build some functional and landscape space nodes along the mountain road, such as fire observation station, traffic portal, water inlet and outlet, turn back bend and so on.

4.2. Function collaboration in vertical distribution
The land use conditions of pumped storage power station are characterized by large height difference, varied slope and aspect. In order to achieve the goal of potential energy and mechanical energy conversion, the functional modules located at different elevations must also keep cooperative operation in vertical space and accept the joint scheduling of computer control system [14].

Water is the main medium of energy conversion, and there are three sources of water for power station production: first, natural rainfall, which brings abundant rainfall in plum and typhoon seasons every year, flows into the reservoir through streams and rivers and soil mass of Chashan; The second is reservoir water dispatching, in which water resources will be exchanged repeatedly between the upper reservoir and the lower reservoir due to the multi condition transformation of pumping power generation [15]; Thirdly, the water storage of the reservoir will cause the microclimate change of the surrounding environment, the temperature and humidity of the air will increase, and the rainfall of the reservoir will increase by about 3% compared with that before the water storage [16].

In addition, the tea garden, bamboo grove and Xikeng in the land of Ninghai pumped storage power station are preserved in the form of residual patches after slope cutting and land expansion. With the cyclic movement of pumping and discharging, the repeated change of the self-weight of reservoir water may induce the deformation of damaged rock mass and soil mass. If it is washed by heavy rainfall again, the landslide and landslide will occur and the probability of collapse and other geological disasters will increase significantly. This puts forward high requirements for the balance relationship between the artificial construction elements and the ecological environment elements of Ninghai pumped storage power station, and requires accurate analysis [17] (Fig. 1)

![Figure 1. Vertical distribution of main functions of Ninghai pumped storage power station.](image)

4.3. Modular and distributed land use pattern based on GIS multi factor comprehensive evaluation
The planning and design first decompose the power station function into eight modules: upper and lower reservoir, water diversion system, underground powerhouse, hoist room, switch station, owner's camp
and mountain road. According to the construction requirements of each functional module, the scope of permanent and temporary land acquisition for power station construction is defined. On this basis, using GIS spatial data analysis platform, elevation, slope, aspect, flooded area after impoundment and other factors are included in the comprehensive evaluation of site selection, and the reasonable site selection location and land use scope of each functional module are obtained by superposition evaluation [18].

Through GIS multi factor comprehensive evaluation and analysis, the characteristic environmental nodes are selected along the owner's camp, upper and lower reservoir and mountain road, and the firefighting observation points, upper reservoir management rooms and traffic openings are set according to the open degree of vision. Through the slope analysis, the 10° slope is set as the critical value of construction land, taking into account the slope aspect, sunshine and other factors, the suitability degree of land acquisition scope is analyzed, and the permanent land acquisition between 3-8° slope is preferred for all functional modules, which is presented as group construction [19]. Based on the analysis of the water surface visual field after the upper and lower reservoirs are submerged, five important functional areas with wide field of vision and large depth are selected as the upper reservoir dam head and left and right bank, lower reservoir dam head and reservoir tail, which are also the key points for the ecological security monitoring of the reservoir [20].

5. Build the ecological security monitoring and early warning system of "one water, two lines and three slopes"

Based on the clue of water resources security and recycling, the disturbance of natural environment caused by the construction and operation of power station is quantitatively monitored to provide reliable basis for planning control and formulation of mitigation and compensation strategies. The premise is to accurately measure the type, location and degree of damage, and evaluate the correlation between different types of damage [21]. Therefore, according to the environmental characteristics of Ninghai pumped storage power station, the ecological security monitoring and early warning system of "one water, two lines and three slopes" is constructed.

One water is reservoir water ecological security monitoring, two lines are shoreline and cliff line ecological protection monitoring, and three slopes are Chashan Forest Farm slope, dam slope, and natural slope between upper and lower reservoirs [22]. By accumulating big data of long time series, whole production cycle and multi factor real-time tracking, the paper provides reliable basis for computer modeling and analysis of the correlation between pumped storage power generation and reservoir ecological operation, balances the relationship among flood control, production water and ecological water use in upstream and downstream of the reservoir, and puts forward optimization suggestions for slope land use within the scope of reservoir.

5.1. Ecological security monitoring of reservoir water

In view of the fact that the core function of pumped storage power station is realized by the conversion between potential energy and mechanical energy of surface water, the ecological safety of upper and lower reservoirs is directly related to the sustainable operation of the power station. Combined with the geographical and climatic conditions of Ninghai, the ecological security of reservoir water has the following four dimensions.

(1) In rainy season and typhoon season, it is necessary to balance the relationship between reservoir flood control, power station safety and ecological protection. In view of the frequent occurrence and uncontrollability of extreme precipitation since 2008, in order to prevent and control the possible damage to important equipment of reservoirs and power stations caused by mountain torrents, flood control operation should be prior to ecological operation.

(2) Reservoir impoundment will change the dynamic water environment of natural streams into the static water environment of artificial lakes, which will lead to sediment deposition and water eutrophication.

(3) After impoundment, the upper and lower reservoirs will show the typical characteristics of sub deep water lakes, that is, seasonal stratification of water body. Relevant studies show that compared
with shallow water type and deep water type, the ecosystem of sub deep water type lakes (with an average water depth of 10-50m) is particularly vulnerable, and once deteriorated, it is more difficult to repair.

(4) In order to maintain the ecological water demand, natural characteristic flow pattern and hydrological cycle of the downstream river, it is necessary to evaluate the gain and loss between the operation benefits of the power station and the ecological security of the small watershed, and formulate the ecological scheduling and compensation strategy of the reservoir water based on the long-term. Therefore, it is necessary to monitor the water level, water temperature, inflow, discharge, sediment composition, nutrient content, species and abundance of phytoplankton and other ecological factors with long time series and high spatial resolution.

At present, in-situ observation techniques such as microelectrode and composite DGT have been used to study the influence and driving mechanism of superimposed coupling of multiple interfaces on biogeochemical processes in sub deep water reservoirs. Based on the long-term positioning observation of the ecological environment of reservoir water, the intensive tracking monitoring is focused on the sensitive period of water body de stratification, the occurrence process and driving mechanism of sudden water quality deterioration time are explored, and the water environment quality prediction and early warning technology of sub deep water reservoir is established [23].

5.2. Ecological protection monitoring of the two lines

The modular and distributed land layout of the power station and the fluctuating site conditions of mountain streams and pits make the power station present the spatial organization characteristics of different types of boundary shoreline, cliff line and staggered extension [24].

5.2.1. Shoreline. The upper and lower reservoirs of the power station are connected with the natural stream respectively, and the water bank contour line formed by it is not only the best place to experience the forest style of Xikeng, but also the reservoir bank inspection line related to the safe operation of the power station. (Fig. 2, Fig. 3) The water pumping and power generation conversion of the power station is jointly regulated by the superior power grid, and the water level change of the reservoir is regulated by the computer control system. The automatic regulation of reservoir water level guided by the service grid will make the water level fluctuation zone of the reservoir in an unstable environment with anti-seasonal cycle and frequent exposure submergence fluctuation.

The high temperature and rainy summer is not only the peak of power load, but also the season with the highest sediment inflow. From the perspective of ecological security, it is necessary to ensure the flood control function of the reservoir, reduce the reservoir water level and discharge sediment as much as possible; from the perspective of production demand, it is required to raise the water level and close the sluice as much as possible. Spring with pleasant temperature and humidity is not only the low load period of power grid, but also the breeding period of animals and plants in the reservoir area and its upstream and downstream; From the perspective of power grid security, it is required to start the pumping condition to maintain the stability of the active frequency of the whole network. The fluctuating zone of reservoir is a highly sensitive area directly affected by this equilibrium relationship. Under the trend of climate warming, the erosion of heavy rainfall will also aggravate the soil erosion of the exposed water level fluctuating zone, and then damage the function of water and soil conservation and water purification of the water level fluctuating zone.

In addition to the damage of shoreline ecosystem, the new reservoir will also induce geological hazards. The impoundment process is the process of surface water potential energy increasing, which will inevitably change the original stress state of reservoir rock mass, and cause general reservoir bank deformation under the action of reservoir water gravity, including bank wall collapse, bank sedimentation and bank slope deformation. Therefore, Ninghai pumped storage power station plans to set up horizontal displacement and vertical deformation monitoring control network along the coastline before the reservoir impoundment. There are 8 horizontal displacement monitoring lines, 4 for the upper reservoir and 4 for the lower reservoir, which are distributed between the elevations of 140-614m. They
are used to monitor the bank deformation of the reservoir and its upstream and downstream, and focus on drawing the deformation duration curve of the reservoir bank during each pumping discharge cycle. The vertical deformation monitoring is mainly arranged on the left and right bank of the reservoir; 10 and 15 vertical deformation leveling points are set in the upper reservoir and lower reservoir respectively. From the initial stage of impoundment, whether each measuring point has synchronous parallel upward lifting phenomenon when impoundment reaches the normal water level is traced.

![Figure 2. Three-dimensional simulation of Upper Reservoir Shoreline.](image1)

![Figure 3. Three-dimensional simulation of Lower Reservoir Shoreline.](image2)

5.2.2. **Cliff line.** Cliff line refers to the platform, access tunnel, steep slope and artificial retaining wall formed by the artificial disturbance of natural topography caused by the construction of power station, which constitute the boundary of the construction land of power station. The geological disaster warning and ecological restoration of the cliff line are directly related to the overall safety of the power station, and the organization of the climbing route is also better to parallel the cliff line.

Cliff line is a highly sensitive area to induce landslide. The geological disaster protection of cliff line needs to start from two aspects of slope support and soil and water conservation at the same time, and strengthen the monitoring of important positions. In the planning of Ninghai pumped storage power
station, the rock slope shotcreting method is firstly adopted to re support the front edge of the slope; Secondly, in the section design of rock slope, planting slots are reserved at the top of slope, berm and toe of slope; Thirdly, in order to strengthen the protection of the important mechanical and electrical equipment and hydraulic structures of the power station, the artificial retaining wall is added outside the construction land, the green buffer belt is reserved between the construction land and the new road, and the soil creep (or deformation) monitoring line is laid.

5.3. Monitoring of soil and water loss on three slopes
Slope is the main source of soil erosion and channel sediment. The loss of soil nutrients, sediment deposition and debris flow will bring serious negative effects on the production of power station and reservoir ecology. To slow down soil erosion and prevent rill erosion is an indispensable part of the ecological environment safety of the reservoir disk, and an important interface for monitoring potential geological hazards [25].

(1) As far as the natural vegetation slope is concerned, the slope land utilization is the direct factor of soil erosion. Under the same soil water conditions, the vegetation with good water conservation and sediment reduction benefits was shrub forest or original ecological natural vegetation > Artificial Forest > artificial shrub forest > slope cultivated land. It can be seen that the potential impact of tea mountain forest farm on the safety of the power station, especially the ecological of the upper reservoir, needs careful examination, based on the field monitoring data.

(2) As far as ecological dam slope is concerned, climate change and rainfall are the main factors affecting soil erosion. It is difficult for ecological dam slope to be washed by strong rainfall or soaked by continuous rainfall. Although the dam slope is laid with artificial drainage (rainwater) network, the short-term rain intensity of extreme precipitation may exceed the interception capacity of drainage network and the strength of soil cover infiltration. The runoff of dam slope which cannot be timely dredged will directly flow to the lower slope adjacent to it, which will aggravate the soil erosion degree of the latter.

(3) As far as the natural slope between the upper and lower reservoirs is concerned, slope, slope length and rainfall are the important causes of the potential soil and water loss. At the same time, the slope, slope length, rainfall and other factors often have superimposed influence, which makes the natural slope between the upper and lower reservoirs become a highly sensitive area of soil erosion, and there is a hidden danger of rill erosion development, which will directly endanger the ecological safety of the reservoir area and the production safety of the nuclear equipment such as the opening and closing station and the hoist room.

In conclusion, the soil and water loss of the three slopes is the result of interaction between the internal factors (slope, slope length, soil nature, etc.) and external factors (slope utilization mode, rainfall, climate change, etc.). Among these factors, the internal factors cannot be changed once the site is selected, and the construction of power station can only adapt to it; the external factors such as rainfall and climate change have high uncertainty; only the slope utilization is a control variable that can be manually intervened at present. According to the characteristics of different slopes, the rational choice of slope land use mode, the optimization of land use combination mode, the priority of the original ecological, forest structure of vegetation mixed vegetation, to alleviate the runoff (mainly soil flow) runoff runoff runoff sediment yield; On the other hand, it is necessary to monitor the sediment production and runoff of all kinds of slopes from the beginning of the power station construction, and dynamically evaluate the soil and water conservation effect of the slope land, so as to make timely adjustment. The sampling and monitoring intervals of 5m and 10m are taken as sampling and monitoring intervals on the slopes of artificial dam and natural slope; the monitoring data include three dimensions, soil properties, meteorological changes and topography characteristics.

6. Conclusion
With the continuous growth of power demand and the transition from traditional power grid to UHV power grid, pumped storage power station has become a strategic resource in the power supply structure,
and its irreplaceable nature comes from the functions of peak regulation and emergency standby. The planning practice of Ninghai pumped storage power station shows that the related research needs to study and establish a green infrastructure which can interact feedback between pumped storage and ecological environment protection from the perspective of adaptation, mitigation and compensation based on the collaborative analysis of the technical characteristics and location conditions of pumped storage.

The adaptability of the construction of pumped storage power station to mountain creek environment can be divided into two levels: parallel function on plane layout and function coordination on vertical layout. Based on GIS spatial data analysis platform, the land demand of the hydropower station hub function and the multi factors such as elevation, slope, slope direction, flood area prediction after impoundment are comprehensively evaluated, Then, the suitable location of each function module and the road selection between them are obtained. The mitigation and compensation, based on the continuous recycling of water resources, quantitatively monitors the types and extent of damage caused by the construction and operation of the power station to the mountain creek pit environment, and provides a reliable basis for the timely formulation of mitigation and compensation strategies.

Meanwhile, the ecological safety monitoring and early warning system of power station "one water, two lines and three slopes" is constructed scientifically, and the ecological environment elements data and production factor data of the power station are accumulated for a long time series, so as to build the balance relationship between daily production and storage and disk production dispatching through correlation analysis and model prediction.

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