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To cite this article: Xiaocong He et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 366 012008

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Study on Flood Resources Utilization Dispatching Method of the Three Gorges Reservoir Based on the Demand of Power Generation

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Abstract: In order to give full play to the power generation benefits of the Three Gorges Project, this paper based on the concept of floodwater utilization, studied the flood control modes of the Three Gorges Reservoir in flood season by combining the hydrological forecast in the middle and upper reaches of the Yangtze River. The benefit and risk of flood resource utilization was compared. The results show that through the implementation of flood control and utilization scheduling of the Three Gorges Reservoir in flood season, under the controllable of flood risk, the power generating capacity of the Three Gorges Reservoir in flood season can be increased by 933 million kW⋅h, and power generation overflow decreased 4.1 billion m³ per year, which can effectively raising the power generation benefit of the Three Gorges Reservoir and providing important technical support for the scientific dispatch of the Three Gorges Reservoir.

1 Introduction
Water can benefit, also can become a catastrophe. With the social-economic development and improvement of living standards of people, the demand for water for production, domestic utilization and ecological protection continues to increase [1]. The shortage of water resources has become the major contradiction in the water issue in China. After years of construction of water conservancy projects, the improvement of hydrological and meteorological forecasting, as well as the accumulation of experience in flood control and drought relief, the people's ability to control floods has been continuously enhanced. The understanding of floods has been changed from passive defence to proper use while defensive. The utilization of water resources in flood season has become a great potential for water resources utilization [2].

The Three Gorges Reservoir located at the middle of the Yangtze River in China. It is a key backbone project for harnessing the Yangtze River and for the development and utilization of water resources [3]. The normal water storage level is 175m, the flood control limit level is 145m [4]. The reservoir has flood control capacity of 22.25 billion m³ and beneficial storage capacity of 16.5 billion m³, has a huge capacity of water storage and transportation, flood control, power generation, shipping and other comprehensive utilization tasks. Since the Three Gorges Reservoir was put into operation, it has provided a large amount of clean energy for the country, effectively promoted the economic development and created favourable conditions for the national energy conservation and emission reduction. With the increasing demand for electricity and the gradual implementation of energy
conservation and emission reduction measures, there is a higher demand for implementing optimal reservoir operations to improve the efficiency of power generation. Utilizing flood resources without affecting the flood control safety is an effective measure to improve the efficiency of the comprehensive utilization of water resources for Three Gorges Reservoir.

2 Dispatching mode of Three Gorges Reservoir

2.1 Conventional dispatching method
Flood control is the primary task of the Three Gorges Reservoir in flood season [5]. Its major flood control targets are Zhicheng and Chenglingji in the middle reaches of the Yangtze River, with safety flow of 56700 m³/s and 60000 m³/s respectively [6]. The dispatching schedule of the Three Gorges Reservoir in flood season adopts a graded compensation schedule, which divides the 22.5 billion m³ flood control storage capacity into three parts from the bottom up. The first part has a storage capacity of 5.65 billion m³ and the corresponding water level is from 145m to 155m, for flood control in Zhicheng and Chenglingji, to control the maximum flow at Chenglingji station not exceeding 60000 m³/s as well as the maximum flow at Zhicheng station not exceeding 56700 m³/s. The second part of the storage capacity is 12.85 billion m³, the corresponding water level is from 155m to 171.32m, only for flood control in Zhicheng, to control the maximum flow at Zhicheng station not exceeding 56700 m³/s. The third part of the storage capacity is 3.65 billion m³, the corresponding water level is from 171.32m to 175m, reserved for extraordinarily large flood control at Jinjiang river reach, to control the maximum flow at Zhicheng station not exceeding 80000 m³/s.

It identified the existing flood control rules of the Three Gorges Reservoir as a conventional dispatching method for not considering the utilization of flood resources. The conventional dispatching method is shown as follows:

a. When the Three Gorges reservoir water level is equal to 145m,

\[ q_{s,t} = \min(p_{s,t}, s_{p_{z,t}}, s_{c_{t,t}}) \]  
(1)

\[ s_{p_{z,t}} = 56700 - q_{z,t} \]  
(2)

\[ s_{c_{t,t}} = 60000 - q_{c_{t,t+2}} \]  
(3)

Where, \( p_{s,t} \) is outflow of the Three Gorges reservoir when time \( t \); \( s_{p_{z,t}} \) is outflow of the Three Gorges reservoir when guarantee the safety of Zhicheng when time \( t \); \( q_{z,t} \) is interval flow between the Three Gorges Reservoir and Zhicheng when time \( t \); \( s_{c_{t,t}} \) is outflow of the Three Gorges reservoir when guarantee the safety of Chenglingji when time t; \( q_{c_{t,t+2}} \) is interval flow between the Three Gorges Reservoir and Chenglingji two days later than time \( t \).

b. When the Three Gorges reservoir water level is between 145m to 155m,

\[ q_{s,t} = \min(s_{p_{z,t}}, s_{c_{t,t}}) \]  
(4)

c. When the Three Gorges reservoir water level is between 155m to 171.32m,

\[ q_{s,t} = s_{p_{z,t}} \]  
(5)

d. When the Three Gorges Reservoir water level is higher than 171.32m,

\[ q_{s,t} = 80000 - q_{z,t} \]  
(6)

Normally, \( s_{p_{z,t}} \) and \( s_{c_{t,t}} \) are larger than the full power generation flow, which is around 30000 m³/s. So when the inflow of the Three Gorges Reservoir is larger than 30000 m³/s, the water resource exceed 30000 m³/s will be abandoned and the utilization of flood resources will not be sufficient. The distribution of runoff in the Yangtze River is uneven and the water resources in the flood season is much more abundant than dry season. Table 1 shows the daily discharge of Yichang Hydrological Station (the representative hydrological station of the Three Gorges reservoir, and after
constructed the data is the inflow of the Three Gorges reservoir) from June to September from 1881 to 2013.

Table 1. Different discharge level percentage at Yichang Hydrological Station

| Inflow        | Percentage |
|---------------|------------|
| <20000        | 32.9%      |
| 20000~30000   | 38.2%      |
| 30000~40000   | 19.6%      |
| 40000~50000   | 6.9%       |
| ≥60000        | 2.4%       |

It can be seen from the table that the average daily flow of more than 30000m$^3$/s accounts for 28.9% of the days, which exceeds the full power generation flow of the Three Gorges Reservoir and must be abandoned without power generation, resulting in the inability to fully utilize the water resources.

2.2 Dispatching method of flood resource utilization

The implementation of flood resource utilization under the premise of not affecting the flood control safety is one of the effective measures to improve the comprehensive utilization efficiency of water resources in the Three Gorges Reservoir. In recent years, there had been many practices on the utilization of flood resources [7]. Floodwater resources are generally used through the allocation of water volume within the river basin and inter-basin water diversion, water storage and power generation, water diversion and recharge, ecological water and groundwater supplement. For the Three Gorges Reservoir, it can make use of the floodwater resources during the flood season by generating electricity [8].

The Three Gorges reservoir flood resources utilization method introduced in this paper was when the inflow is larger than the full power generation flow of 30000m$^3$/s, and less than sp$_{z,t}$ and sp$_{c,t}$ in the next few days by hydrological forecasting, part of the flood control capacity may be utilized to reserve inflows larger than 30000m$^3$/s, and increase the outflow when the inflow of the Three Gorges Reservoir is less than 30000m$^3$/s, which would reduce the amount of abandoned water and increase power generation benefits.

Take the inflow from July 1st to July 22$^{nd}$ in 2013 for example, Zhicheng and Chenglingji had flood control damage until July 21$^{st}$. For the conventional scheduling, the outflow before July 21$^{st}$ equalled to the inflow of the Three Gorges Reservoir, the water resource would be abounded when the inflow exceeded 30000m$^3$/s, which called power generation overflow. The inflow, outflow, power flow and power generation overflow according to the conventional scheduling was shown in Figure 1.

![Figure 1](image-url)
But for flood resource utilization dispatching method, the flood control capacity could be used for regulating power generation overflow, when the inflow exceeded 30000 m$^3$/s, it reduced outflow to 30000 m$^3$/s and storage water, and the water level went up. When the inflow was less than 30000 m$^3$/s, it increased outflow to 30000 m$^3$/s, and the water level went down. The inflow, outflow, power flow and power generation overflow according to the conventional scheduling was shown in Figure 2.

**Figure. 2** The flow according to dispatching method of flood resource utilization

The water level process in the two kinds of scheduling of the Three Gorges reservoir is shown in Figure 3.

**Figure. 3** The water level process in the two kinds of scheduling
The maximum flood protection capacity for flood resource utilization can be calculated by the following formula,

\[ V_{\text{max}} = \sum_{t=1}^{N} \left( \min \left( s_{p\xi t}, s_{pct} \right) - q_{s\xi t} \right) \cdot \Delta t \] (7)

Where \( V_{\text{max}} \) is the maximum flood protection capacity for flood resource utilization, and \( \Delta t \) is the time step, for example when the time step is daily, then the \( \Delta t \) is equal to 86400s.

### 3 Power generation benefits and flood control risk analysis

According to the current hydrological forecast level in the Three Gorges Reservoir dispatching, the \( \Delta t \) is 5 days. According to flood control status of Zhicheng and Chenglingji, the safety outflow of the Three Gorges reservoir was taken as 42000 m\(^3\)/s.

The actual discharge process of Yichang Hydrological Station in flood season from 1881 to 2013 was used to simulate the calculation. The power generation capacity, the amount of power generation overflow and the flood control effect by the two methods were shown in Table 2.

**Table 2.** The power generation and flood control risk by the two methods

| method                        | average power generation every year(billion kW·h) | average power generation overflow every year(billion m\(^3\)) | average outflow exceed 42000 m\(^3\)/s every year((billion m\(^3\)) | The number of years when the maximum level is higher than 155m of the Three Gorges Reservoir |
|-------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| Conventional Dispatching Method | 43.52                                         | 24.54                                           | 1.15                                            | 15                                            |
| Dispatching method of flood resource utilization | 44.46                                         | 20.38                                           | 1.15                                            | 15                                            |

It can be seen from the table that according to the proposed flood resource utilization mode, the power generation is larger than that of the conventional dispatching method, and the amount of power generation overflow is reduced. The power generation increased by 3.25% from 43.52 billion kW·h to 44.46 kW·h during flood season per year, and the spillage decreased by 21.19% from 24.54 billion m\(^3\) to 20.38 billion m\(^3\) during flood season per year. At the same time the outflow exceeding 42000 m\(^3\)/s and the years with the maximum water level exceeding 155m did not increase, which shows that the proposed flood resource utilization mode would not increase flood control risk by pre-discharging stored water to reduce the reservoir water level to its flood control level 145m before the next flood.

### 4 Conclusions

Aiming at the problem that conventional dispatching mode of Three Gorges reservoir in flood season cannot make full use of flood resources, this paper presents a method that utilizes part of flood control capacity to integrate flood control with water resources utilization based on flood forecasting. The proposed pre-discharge measure could reduce the flood risk of using flood control capacity. The results show that this method could help the reservoir benefit more from power generation in flood season.

**Acknowledgement**

This work is supported by the National Key R&D Program of China (Item Nos. 2016YFC0402203).

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