Study on the Contribution of CO2 Emission Reducing of Yellow River Upstream LONGyangxia and LIUjiaxia Cascade Reservoirs

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Abstract

In order to analyze the contribution of energy saving and emission reducing of Yellow River upstream LONGyangxia and LIUjiaxia cascade reservoirs, the compensation regulation simulation model of the Yellow River mainstream cascade reservoirs is adopted to study the dynamic characteristics of emission reducing contribution of LONGyangxia and LIUjiaxia reservoirs in three level years of 2005, 2015 and 2020. The result indicates that the emission reducing contribution of LONGyangxia and LIUjiaxia reservoirs are 15.8077 million ton, 16.1808 million ton, and 13.3092 million ton in 2005, 2015, and 2020 level years. The change laws of the Long-Liu compensation system emission reducing contribution is the same as the one of LONGyangxia reservoir emission reducing contribution, which descends after ascending. The change laws of the LIUjiaxia reservoir emission reducing contribution is descending along with time.

Keywords: Hydropower engineering; Energy Saving and Emission Reducing; compensation dispatching

1. Introduction

The climate changing is a major issue on affecting the survival and development of mankind, the international community adopted a series of actions to respond to this challenge, including setting up the Intergovernmental Panel on Climate Change (IPCC), the constitution and issuance of "the United Nations Framework Convention on Climate Change," (1992), the constitution and entry into force (2005) of the "Kyoto Protocol" (1997), etc. China has actively participated in these series of major events, and in June 1, 2007 issued the "China's National Program on Climate Change."
Eleventh Five-year Development Plan " putting forward that in the period of China's "Eleventh Five-Year" the target of emission reduction is to reduce the energy consumption of GDP by 20% per unit, the total discharge of major pollutants reduced by 10%, on the Copenhagen climate conference a solemn commitment made by the Chinese Government is that comparing with 2005 by 2020 the emission of carbon dioxide in per-unit GDP will drop 40% to 45% , China's emission reduction tasks become more difficult. Implementation of reducing the CO₂ emission is the most critical step to slow down the global warming. Hydroelectric power uses potential energy, kinetic energy of water into electrical energy without bulk of fuel, while without exhaust gases emissions into the atmosphere, nor land and ocean dumping of waste to help combat climate changes. Electric power system with more hydroelectric power, and less fire-electricity, can save fuel consumption and help CO₂ emission reduction. According to the statistics, the Three Gorges and Gezhouba hydropower plants generates 100 billion kW·h annually, replacing at least 60 million tons of coal, and reducing 120 million ton of carbon dioxide emissions. The Yellow River upstream cascade reservoirs mainly refers to the Longyangxia and Liujiaxia reservoirs which have greater ability of regulating (simplified as Long, Liu two reservoirs). The emission reduction is one of the most compensation regulation significant benefits of the cascade reservoirs on upper reaches of the Yellow River. With the cascade’s sustainable development, contributions of emission reduction at different times should be dynamically changed. For a comprehensive, systematic and in-depth analysis of Longyangxia, Liujiaxia cascade reservoirs contribution to emission reduction, taking its dynamic characteristics into account, in the paper, the contribution to compensating regulation of emission reduction of Longyangxia, Liujiaxia cascade reservoirs on upper reaches of the Yellow River contribute is analyzed and calculated by three different level year 2005, 2015 and 2020, in order to study its changing regularity.

2. Compensation Regulation

2.1 Systematic analysis of compensation adjustment

Study divide the two sides of the Yellow River’s main watercourse into the following four parts: the compensator side includes LongYangxia Reservoir and Liujiaxia reservoir; the other side which be compensated includes provinces along the Yellow River (autonomous regions), the upstream runoff-cascade and the downstream Liujiaxia Reservoir and Sanmenxia Reservoir. Compensation System: Longyangxia Reservoir and Liujiaxia Reservoir. In the study the two reservoirs are considered as two independent subsystems whose alone and joint regulation of the middle and down reaches contribution of emission reduction were calculated separately, considering them as the compensation system in the Yellow River cascade reservoirs, and they are the system which give the whole Yellow River watercourse benefits. The upstream run-of-cascade compensated systems; the upstream run-of-cascade refers to all the run-of-power stations of the Yellow River upstream Long–Green River in the level year. The Sanmenxia and Xiaolangdi compensation system, Sanmenxia and Xiaolangdi Reservoirs are located in the middle and down reaches of the Yellow River; Sanmenxia has quarter-regulating, Xiaolangdi reservoir is a year-regulating one. Longyangxia and Liujiaxia Reservoirs’ regulating of hoarding flood and supplementing drought will ease Sanmenxia and Xiaolangdi Reservoirs’ pressure of resisting flood, and having an effect of easing the downstream water supply conflicts. Therefore, the Sanmenxia and Xiaolangdi Reservoirs are compensated being called the Sanmenxia and Xiaolangdi compensation system. Compensation systems of provinces along the Yellow River. It is that Longyangxia and Liujiaxia Reservoirs are in a fully compensating position, the upstream run-of-stairs is in a completely compensated position, relative to the Long-Liu compensating parties the Sanmenxia and Xiaolangdi compensation system in a compensated position, while for the downstream provinces along the Yellow River area it is in a compensating position provinces and regions along the Yellow River are completely in compensated position.
2.2 Enactment of reservoirs’ contribution to emission reduction calculation programs

The contribution of reservoirs’ emission reduction calculation is divided into three levels of year: 2005 status quo levels, 2015 levels and 2020 levels of years. When reservoirs’ contribution to emission reduction during the three levels of years is analyzed, Longyangxia and Liujiaxia reservoirs will be considered separately, calculate respectively, at the presence of them, their contribution to emission reduction to downstream. The study the contribution of reservoirs’ emission reduction calculation is divided into three levels of year, a total of nine programs, namely: 2005 "case 1 is Without Long and Liu", 2005"case 2 is Without LONG but with Liu", 2005 "case 3 is With LONG and Liu"; 2015 " case 4 is Without Long and Liu", 2015 " case 5 is Without LONG but with Liu", 2015 " case 6 is With LONG and Liu"; 2020" case 7 is Without Long and Liu", 2020 " case 8 is Without LONG but with Liu", 2020 " case 9 is With LONG and Liu". According to the Yellow River basin cascade’s rolling development plan, the power plants participate in compensation regulating are different in different level of year.

2.3 Compensation regulation simulation model

The model adopts the compensation regulation simulation model of the Yellow River mainstream cascade reservoirs; considering three types of objective function, namely, flood control objectives, ecological goals and water use objectives. Flood control objectives includes flood control, Ice Prevention goals, flood control objectives is controlling reservoirs’ water level and discharged flows of flood control, to provide the necessary protection for flood flow and dam safety downstream; ecological goals should ensure necessary water for ecology and environment, and maintain the watershed ecosystem balance of the Yellow River; water use objectives will pursue the shortage of water as minimum as possible, and a reasonable distribution, and on this basis, to improve power generation and enlarge reservoirs’ contribution to emission reduction. Specifically in the solution make the flood control goals and ecological objectives as constraints, the objective function of water use target is:


emission reduction goal,

\[
\max B_{ae} = \sum_{i=1}^{N} \sum_{t=1}^{T} (N(i,t) \times \Delta T(t))c
\]  

where, \( B_{ae} \) is the total CO2 emission reductions; \( N(I, t) \) is the average power of the No.\( i \) sub-system in the No.\( t \) period, \( c \) is CO2 reduction in a unit amount of electricity, t/kW•h, calculated according to producing 1 kW•h electricity with emission reduction of 1.2X10^{-8}t CO2 t^{-1}.

Water shortage goals, pursue the minimum shortage of water, and a reasonable distribution, focus on solving a reasonable allocation of water between regions, and the water allocation between different water-requiring sectors. In arid years, when water supply can not meet requirements, through reasonable regulating, optimize the spatial and temporal distribution processes of runoff, to make the shortage of water minimum, and the distribution reasonable.

\[
\min(w) = \sum_{i=1}^{N} \sum_{t=1}^{T} \{\theta(t)(QP(i,t) - QG(i,t))\Delta T(t)\}
\] 

Where, \( w \) is the shortage of water, \( i \) is the number of water supply subsystem, according to the node map, \( i = 1, 2, ..., 40 \); \( t \) is the total calculated time, \( t = 1, 2, ..., T \). \( \theta(t) \) is the discrimination index of water shortage in the \( t \) period, when \( (QP(i,t) - QG(i,t))\geq0 \), no water shortage, \( \theta(t) \) is 0, when \( (QP(i,t) - QG(i,t))<0 \), \( \theta(t) \) is 1.

The restricting conditions include reservoir water balance restriction, node water balance restriction, reservoir storage capacity restriction, flows out of reservoir restriction, Ice Prevention restriction, power
restriction, and variables is non-negative restriction and so on. Figure 1 shows a sketch of simulation model solution during one calculation time.

Fig. 1 Sketch of simulation model solution

2.4 Basic information of calculation

The runoff data uses the long series of natural runoff data from 1952.07 to 2005.06 which comes from 18 monitoring stations along reaches of the Yellow River, these data are from YRCC Council, in which the multi-year average water of Huayuankou Station is 57.508 billion m$^3$ [8]. Based on the analysis of the status quo of the exploitation and utilization of the Yellow River Basin’s water resources and the long-term trend of the Northwest China’s social and economic development, in 2015 level, 2020 level various national economic sectors’ requiring of water is predicted, water requirements data are from YRCC Council. Includes industrial water demand, agricultural water demand, life water demand, and out of basin water requirements.

Currently water requirements out of basin are mainly industrial and agricultural water use in Henan, Shandong, and supplying Hebei, and in status quo level year water supply quantity of the outside Yellow River basin is 9.72 billion m$^3$; in which there’s 10.372 billion m$^3$ in 2015 level year; 10.53 billion m$^3$ in 2020 level year. Therefore, in status quo level year the total water demand of the Yellow River Basin is 55.121 billion m$^3$; the total water demand in 2015 level year is 63.622 billion m$^3$; and 68.171 billion m$^3$ in 2020 year level. Low limit water requirements of ecological environment refers to: first, the impact of soil and water conservation on river runoff, in 2005 is 1 billion m$^3$, it is expected that in 2015 and 2020 water level year are 2.0 billion m$^3$ and 2.5 billion m$^3$; second, it refers to water requirements of sediment transport during the flood season, in 2005,2015 and 2020 the multi-year average needs are respectively 14 billion m$^3$, 13 billion m$^3$, 12.5 billion m$^3$; third ,it refers to the ecological base flow in non-flood season ,the total water demand is 5 billion m$^3$, the minimum flow into the sea is controlled above 50m$^3$ / s. Therefore, the low limit water requirement of ecological environment is about 20 billion m$^3$ as multi-year average. The exploitation quantity of groundwater of the Yellow River Basin is 11 billion m$^3$; Ice Prevention Control Sections are respectively selected as Lanzhou and Huayuankou section; According to the research reports of the Western exploration academe, Longyangxia’s evaporation and leaking loss of
water surface is calculated as 9.00 m³/s, Liujiaxia is 6.00 m³/s, Xiaolangdi is 5.00 m³/s, then the annual water loss of Yellow River's reservoir is approximate 631 million m³ [9].

3. Result analyses

By solving the simulation model of the Yellow River cascade reservoirs’ compensation regulating, the contribution to emission reduction that Long and Liu reservoirs give to the runoff-cascade power station’s electricity compensation of the upstream Long ~ Qing reach in three level years can be got. In 2005 there are only Li, Yan, Ba, Da and Qing five runoff power stations on the upstream Long ~ Qing reach and Sanmenxia and Xiaolangdi reservoirs downstream participating in calculation, the contribution to emission reduction of Long, Liu reservoirs can respectively be seen in Table 1.

| Project       | case2 to case1 | case3 to case1 | case3 to case2 |
|---------------|----------------|----------------|----------------|
| Lijiaxia      | 0              | 26.04          | 26.04          |
| Liujiaxia     | ——             | ——             | 50.16          |
| Yanguoxia     | 12             | 22.32          | 10.32          |
| Bapanxia      | 6.6            | 11.28          | 4.68           |
| Daxia         | 10.44          | 16.92          | 6.48           |
| Qingtongxia   | 1.68           | -1.92          | -3.6           |
| Summation of runoff | 30.72 | 74.64 | 43.92 |
| Sanmenxia     | 18.72          | 25.08          | 6.36           |
| Xiaolangdi    | 25.44          | 33.72          | 8.28           |
| Total summation | 74.88       | 133.44         | 108.72         |
| Longyangxia and Liujiaxia reservoirs themselves | 631.8 and 682.2 |

As can be seen from Table 1, on condition of Liujiaxia’s single regulation, the multi-year average contributions to emission reduction of Qingtongxia, Sanmenxia and Xiaolangdi power stations, have an increase of 16.8 thousand tons, 187.2 thousand tons and 254.4 thousand tons, while after Long and Liu reservoirs combine to regulate, the multi-year average contributions to emission reduction of Qingtongxia respectively have a decrease of 19.2 thousand tons and 3.60 million tons than the "Without Long and Liu", "Without LONG but with Liu"; contributions to emission reduction of Sanmenxia and Xiaolangdi are also drastically reduced. It is mainly because that water requirements of the reach above Qingtongxia reservoir are relatively concentrated; its percentage in water requirements of all the main stream is about 40%, including most of the water use of Gansu, Ningxia, Inner Mongolia and Shaanxi, which are the main areas of agricultural irrigation water demands. Liujiaxia individually involves in regulation, its regulating capacity is limited, its satisfaction level of agricultural water demand is not high; while Longyangxia reservoir participate in compensation, it exerts its great ability of multi-year regulating, in non-flood season of dry years discharges the water that is stored in many wet years, this has played a pivotal role in alleviating the contradiction of spring irrigation water for Ningxia-Inner Mongolia irrigation region. It is precisely because the good regulating ability of Longyangxia, delivery of water between the upstream and Qingtongxia is increased, so flows through Qingtongxia reservoir is relatively reduced, resulting in the power quantity of Qingtongxia power station has a reduce when comparing "With LONG and Liu" to "Without Long and Liu", and "With LONG and Liu" to "Without LONG but with Liu", that is, the phenomenon of reduce in contribution to emission reduction.

Contribution to compensating emission reducing of LONGyangxia and LIujiangxia reservoirs in level year of 2015 can be seen in Table 2.
As can be seen from Table 2, when Liujiaxia involves in regulating individually, contributions to emission reducing of the runoff-power stations above Liujiaxia are not be affected, including those from Nina to Sigouxia power station, so there’s no change in contribution to emission reducing when comparing "Without LONG but with Liu" to "With LONG and Liu", while there are different extents of growth in contribution to emission reducing of the runoff-power stations below Liujiaxia, Sanmenxia and Xiaolangdi power plants. After Long and Liu reservoirs are both involved in compensation regulating, except that there’re reductions in contribution to emission reducing of Qingtongxia, Sanmenxia and Xiaolangdi, there are growths in contribution to emission reducing when comparing other runoff-power plants to "Without LONG but with Liu", "Without LONG and Liu". After Long, Liu reservoirs are involving in compensation regulation, there’s a reduction in contribution to emission reducing of Qingtongxia, and its cause is the same with the cause of reduction in contribution to emission reducing in 2005.

Contribution to compensating emission reduction of Long, Liu reservoirs of 2020 level year can be seen in Table 3.

As can be seen from Table 3, the energy saving and emission reducing of the runoff-power stations above Liujiaxia are not be affected, including those from Nina to Sigouxia power station, so there’s no change in contribution to emission reducing when comparing "Without LONG but with Liu" to "With LONG and Liu", while there are different extents of growth in contribution to emission reducing of the runoff-power stations below Liujiaxia, Sanmenxia and Xiaolangdi power plants. After Long and Liu reservoirs are both involved in compensation regulating, except that there’re reductions in contribution to emission reducing of Qingtongxia, Sanmenxia and Xiaolangdi, there are growths in contribution to emission reducing when comparing other runoff-power plants to "Without LONG but with Liu", "Without LONG and Liu". After Long, Liu reservoirs are involving in compensation regulation, there’s a reduction in contribution to emission reducing of Qingtongxia, and its cause is the same with the cause of reduction in contribution to emission reducing in 2005.
As can be seen from Table 3, after Long, Liu reservoirs’ compensation regulating, not only Qingtongxia, Sanmenxia and Xiaolangdi, but also Shapotou station has a reducing in contributions to emission reduction. It is because that the 2020 level year’s total requirements of water increasing by 13.05 billion m$^3$ when compared to 2005’s, and by 4.549 billion m$^3$ compared with 2015 level year’s, if only depending on the annual regulatory of Liujiaxia reservoir, the impact on compensation of the upper reaches’ water shortage is limited; If Long and Liu reservoirs are both involved in compensation regulating, then the impact on compensation is distinct, the upstream water supply quantity is greatly increased, and water shortage can be greatly eased. Therefore, the increase in water demand in 2020 level year makes the multi-year regulatory of Longyangxia reservoir play a greater role, and reflects its compensation value as a leading reservoir, thus giving rise to the phenomenon that contributions to emission reducing of Long ~ Qing reach’s Shapotou, Qingtongxia reservoir and middle reach’s Sanmenxia and Xiaolangdi reservoir are gradually reducing.

Long, Liu reservoirs’ contributions to emission reducing include contributions to emission reducing of compensation for their own power generation and contributions to emission reducing of reservoirs’ compensation power generation on the main stream, contribution to emission reduction of Long, Liu reservoirs in three level years are gathered in Table 4.

### Table IV. The Dynamic Calculation Results of Energy Saving and Emission Reducing of the Yellow River Longyangxia and Liujiaxia Cascades in Different Level Years

|                  | Every level year | 2005   | 2015   | 2020   |
|------------------|-----------------|--------|--------|--------|
| "Without LONG with Liu" to "Without LONG and Liu" | 74.88  | 66.72  | 7.20   |
| "With LONG and Liu" to "Without LONG and Liu" | 133.44 | 174.48 | 60.60  |
| With LONG and Liu Without LONG but with Liu | 108.72 | 145.92 | 74.28  |
| When With LONG and Liu Longyangxia itself | 765.13 | 774.72 | 706.56 |
| When With LONG and Liu Liujiaxia itself | 682.20 | 668.88 | 563.76 |
| Summation of contribution to emission reduction of Long, Liu reservoirs | 1580.77 | 1618.08 | 1330.92 |

As can be seen from table 4, Long, Liu reservoirs’ compensation system gives an increase to contributions to emission reducing of the Yellow River cascade in 2005 by 1.3344 million tons, Long, Liu reservoirs’
total contributions to emission reducing are 15.8077 million tons; in 2015 level year it gives an increase to contributions to emission reducing of the Yellow River cascade by 1.7448 million tons, Long, Liu reservoirs’ total contributions to emission reducing are 16.1808 million tons; in 2020 level year it gives an increase to contributions to emission reducing of the Yellow River cascade by 606,000 tons, Long, Liu reservoirs’ total contributions to emission reducing are 13.3092 million tons.

4. conclusions

According to the Yellow River Cascade’s rolling development plan in different level of years, the paper analyzed the contributions to emission reducing of Long, Liu reservoirs upstream the Yellow River, the compensation regulation simulation model of the Yellow River mainstream cascade reservoirs was adopted to dynamically study in 2005 and the forecasted level year 2015, 2020 Long, Liu reservoirs’ contributions to emission reducing and its variation rule. In the three level years, when Long and Liu reservoirs combine to regulate, the change laws of the Long-Liu compensation system emission reducing contribution is the same as the Longyangxia reservoir emission reducing contribution, which descends after ascending; The change laws of the Liujiaxia reservoir emission reducing contribution is descending along with time. It can be inferred that: When the West Route of the "Water from south to north project" is implemented, on condition that there is sufficient water, the change trend of Longyangxia reservoir’s contribution to emission reducing will be from descending to ascending, making full use of Longyangxia reservoir’s multi-year regulating role, and reflecting its compensation value as a leading reservoir. The paper once again demonstrates the significant contribution to emission reducing of large-scale hydropower projects, providing reference for our nation’s water and power pricing and compensation policy-making.

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