Analysis and Study for Main Influence Factor of Comprehensive Conversion Efficiency in Pumped Storage Power Station

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Abstract. Comprehensive conversion efficiency reflects the operation benefit of pumped storage power station. Analysing and studying the main influence factor for the comprehensive conversion efficiency is important to the overall design of power plant and to the improvement of comprehensive conversion efficiency. This paper adopts the method of combining field efficiency test with daily operation data analysis. By comparing and checking the test results with the model test results and the unit performance acceptance test results, the unit efficiency characteristics are defined. Through the analysis of daily operation data, the influence of unit operation mode on efficiency is clarified. Finally, it is concluded that the level of unit efficiency and generation operation mode are the main factors affecting the comprehensive conversion efficiency of power plants.

1. Introduction

Comprehensive conversion efficiency is one of the important factors in design of pumped storage power station. It reflects the transformation effect and the operation benefit in grid. With the continuous improvement of the design and manufacturing level of units, the comprehensive conversion efficiency has gradually increased from 65% to 75%, or even higher. The analysis and study of the factors affecting the comprehensive conversion efficiency will promote the study of effective measures to improve the comprehensive conversion efficiency and the design of new power stations.

2. The Affecting Factors for Comprehensive Conversion Efficiency

The comprehensive conversion efficiency is defined as the ratio of the power on the grid to the power off the grid, that is, the ratio of the actual power generation and the power consumption after considering the influence of line loss and auxiliary power consumption. Statistical results show that the line loss, auxiliary power consumption and other loss account for less than 1% of the power generation, occupying a smaller proportion of power consumption. So, the turbine output, pump input and the corresponding operation time are the main factors. That is to say, the unit efficiency characteristics directly affect the comprehensive conversion efficiency. Unit efficiency is mainly related to turbine efficiency, pump efficiency, generator efficiency, waterway efficiency, motor efficiency and transformer efficiency. The generator, transformer and waterway efficiency are usually fixed values. Therefore, this paper focuses on turbine and pump efficiency.

3. Efficiency Test

Through carrying out field efficiency test, and compared with model and performance acceptance test results, the efficiency characteristics are obtained.

3.1. Testing principle and equipment

The efficiency test of unit is divided into turbine and pump condition. The formula is as follows:

$$\text{For turbine: } \eta_t = N_t / (\rho g Q H) \times 100\% \tag{1}$$

$$\text{For pump: } \eta_p = (\rho g Q H) / N_p \times 100\% \tag{2}$$

In the form: η_t——efficiency of turbine,%; η_p——efficiency of pump,%; N_t——turbine output, kW; N_p——pump input, kW; ρ——water density, kg/m^3; g——acceleration of gravity, m/s^2; Q——discharge, m^3/s; H——head, m.

Discharge is measured by ultrasonic flowmeter installed in the intake pipe section between the intake valve and the spiral case inlet. The flowmeter type is GER9000.

Head is divided into two parts, including the static head and the dynamic head. The formula is as follows:

$$\text{For static head: } H_1 = (p_1 - p_2) / (\rho g) \tag{3}$$

$$\text{For dynamic head: } H_2 = (v_1^2 - v_2^2) / (2g) \tag{4}$$

In the form: H_1——static head, m; H_2——dynamic head, m; p_1——inlet pressure of spiral case, Pa; p_2——outlet pressure of draft tube, Pa; v_1——inlet velocity of spiral case, m/s; $v_1=Q/A_1$,A_1 is the area of spiral case inlet section; v_2——outlet velocity of draft tube, m/s; $v_2=Q/A_2$,A_2 is the area of draft tube outlet section; ρ——water density, kg/m^3;g——acceleration of gravity, m/s^2.

The turbine output and pump input are calculated by the measured value of power transmitter and generator efficiency. Sensors are directly connected with the acquisition system, and guide vane opening, upper and lower water level, frequency and power factor are recorded simultaneously.

3.2. Turbine efficiency test

Efficiency tests have been carried out on loads of 50%, 60%, 75%, 90% and 100% respectively and the results are shown in Table 1. Generator efficiency is considered according to 98.6%. It can be seen that the turbine efficiency increases with the load increase, and the maximum value is on 90% rated load, followed by a slight decrease.

Table 1. Field efficiency test results in turbine mode

Output (MW)	Guide vane opening (%)	Upper level (m)	Lower level (m)	Spiral case inlet pressure (kPa)	Draft tube outlet pressure (kPa)	Head (m)	Discharge (m^3/s)	Turbine efficiency (%)
102	44.86	558.91	85.71	5106.79	510.28	475.42	25.86	86.00
120	50.9	558.77	85.67	5079.23	507.46	474.96	30.23	86.64
151	59.57	558.53	85.69	5028.64	509.59	473.05	36.45	90.77

By comparing with the prototype characteristic curve and performance acceptance test results, it is found that the flow measurement value is consistent with the prototype predicted value and performance acceptance value. The efficiency value is basically consistent with the performance acceptance test results, and most results are better than the predicted value.

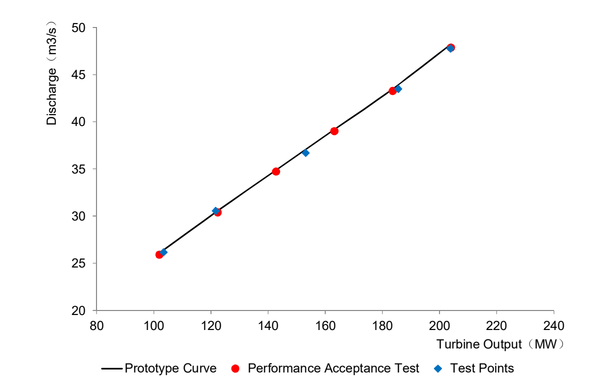

Figure 1. Discharge comparison in turbine mode

Figure 2. Efficiency comparison in turbine mode

3.3. Pump efficiency test

The pump efficiency test results are shown in Table 2. The installation position of ultrasonic flowmeter can not meet the requirements of "IEC60041 Field acceptance test to determine the hydraulic performance of turbine, storage pumps and pump turbines" .The poor flow in the measuring pipe section leads to the larger deviation of measuring value. In performance acceptance test, the measurement deviation was given to be 2.5% by manufacturer according to the past experience. Fig. 3 shows that the pump efficiency is similar to the performance acceptance test. According to the deviation given by manufacturer, Fig. 4 shows the correction efficiency is consistent with the predicted values. It indicates that the ultrasonic flow values in pump mode is small, and the deviation is reasonable.

Table 2. Field efficiency test results in pump mode

No.	Input (MW)	Spiral case inlet pressure (kPa)	Draft tube outlet pressure (kPa)	Head (m)	Discharge (m^3/s)	Pump efficiency (%)
1	-207.8	4975.49	496.14	471.09	-39.72	89.35
2	-207.8	4976.92	508.71	470.12	-39.97	89.73
3	-207.5	4980.69	506.80	470.65	-39.90	89.80
4	-207.3	4984.17	508.31	470.80	-39.82	89.74
5	-205.7	5022.44	495.40	475.56	-39.12	89.74

3.4. Pump turbine efficiency analysis

Through analyzing above, it is found that the turbine flow measured values are more accurate and the efficiency is better than predicted values. There is a large error in the pump flow measured values, but the 2.5% deviation is reasonable. The efficiency level is consistent with the acceptance results of the initial stage of commissioning; the unit's efficiency characteristics have little change after years of operation.

Usually, the operation condition of the storage unit is changeable, the pump usually runs under full load, so, the influencing factors of unit efficiency mainly consider the turbine efficiency. Test results have proved that the turbine efficiency meets and is superior to the predicted value. Therefore, in the subsequent analysis of daily operation data, this paper calculates the turbine efficiency through the protype curve. The values do not represent the actual efficiency, but only aiming at the influence of operation mode for turbine efficiency.

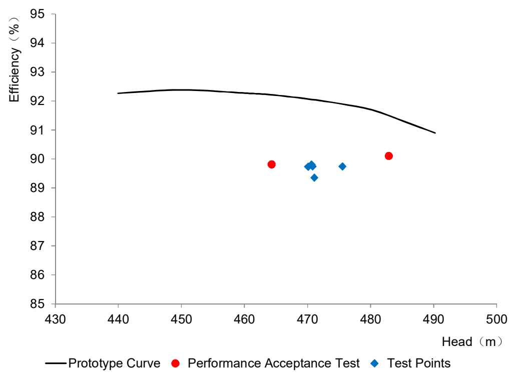

Figure 3. Efficiency comparison in pump mode

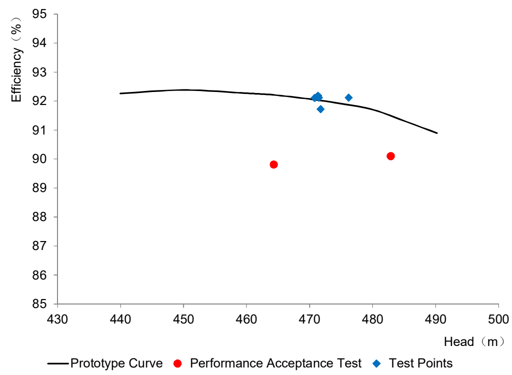

Figure 4. Correction efficiency comparison in pump mode

4. Daily operation data analysis

4.1. Analysis of unit efficiency level difference

The typical operating conditions of a single unit are selected to analyze the difference of efficiency level between the four units. Fig.5 shows that under the same head, the efficiency of the four turbines is in good agreement with each other when they are running alone. Fig.6 shows that the higher head in large load, the higher turbine efficiency.

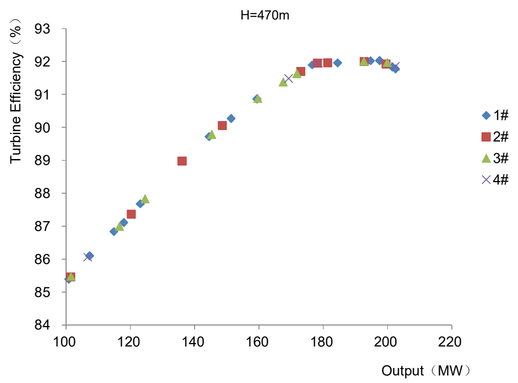

Figure 5. Turbine efficiency distribution of each unit

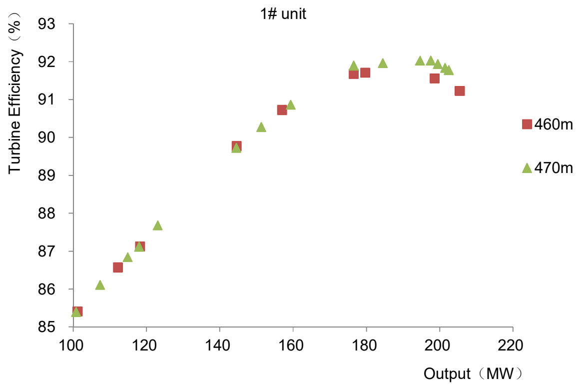

Figure 6. Turbine efficiency distribution of 1# unit under different heads

4.2. Influence of operation mode

Year statistical data show that, the total generating time under different loads is 6488.24 hours, and the operating time of each unit is quiet. Fig.7 shows that the time under full load is longest, followed by about 50% rated load. The maximum efficiency (about 90% rated load) operation time is significantly less than full load and 50% load. According to the turbine efficiency under each load and the corresponding time, the turbine operating efficiency of this year is 89.86%. The 50% rated load has a significant impact on the turbine efficiency.

Table 3. Summary of generating units running time at various loads

Output (MW)	190~210	180~190	170~180	160~170	150~160	140~150	130~140	120~130	110~120	90~110
Operation time (h)	2564.97	528.58	442.09	364.13	310.74	293.66	284.05	273.37	318.22	1108.43
Efficiency (%)	91.10	91.60	91.63	91.17	90.56	89.79	92.91	87.90	86.84	85.39
Proportion (%)	39.53	8.15	6.81	5.61	4.79	4.53	4.38	4.21	4.90	17.08

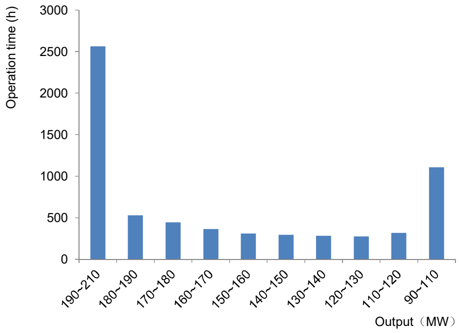

Figure 7. Generating operation time

5. Analysis and Discussion on comprehensive conversion efficiency

From the analyzing above, it can be seen that the performance design level of pump turbine and generation operation mode directly affect the comprehensive conversion efficiency. In view of the full-load operation of the pump, the weighted average efficiency of the prototype pump is 92.4% as a reference value, and the other factors are 99.7% of the transformer, 98.6% of the generator, 98.56% of the motor, 97.59% of the generating waterway and 98.25% of the pumping waterway. The unit efficiency is calculated equal to 76.91%. Considering the influence of water loss caused by reservoir evaporation and seepage on the comprehensive conversion efficiency of power station, the correction coefficient is 98%. Considering the electricity loss, the coefficient is 99%, and the comprehensive conversion efficiency is 74.62%. Because the values used in the above calculation are based on the model reference values and the original design values, the calculation results only reflect the comprehensive conversion efficiency level and are not accurate. And according to power on the grid and the power off the grid, the comprehensive conversion efficiency is 74.09%. Two the numerical level is comparable, which shows that the above analysis is reasonable.

6. Conclusion and suggestion

Based on the analysis and discussion of the field efficiency test and daily operation data of a certain storage power plant, this paper holds that:

(1) Among the many factors affecting the comprehensive conversion efficiency of pumped-storage power station, the efficiency of the unit occupies the main position.

(2) On the premise that the design level of pump-turbine is certain, the power generation operation mode, i.e. the distribution of operation under various load conditions, has a greater impact on the efficiency of the unit.

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