Analysis of Energy Saving Effect of Large Double-speed Salient Pole Synchronous Motor in Renovation of Pumping Stations

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Abstract. The water levels influenced by seasons are varying, which needs a great variation of pumping head. The motor now used with complex speed equipment and high cost cannot satisfy the requirement. The paper takes the renovation and transformation of Song Long pumping station as an example, analyses the effect of using large double-speed salient pole synchronous motor. It offers a comparative analysis of the energy-saving benefit, which has three major evaluation indexes: device efficiency, unit energy loss and the benefits. The related research results can be referenced in the renovation and transformation of pumping station.

1. Introduction
At present, many domestic drainage pumping stations are forced to shut down because of the low drainage standard and the large variation of water level in the discharge area. For the reconstruction of this kind of pumping station, such as simply replacing the existing pump with the high lift pump, although it can solve the problem of over lift of the pump station, it is likely to be accompanied by serious deviation from the operation of the high efficiency area when the low lift occurs, which will cause new problems such as cavitation and vibration of the pump. The new technology of double-speed motor is to change the motor into a double-speed motor with high and low speed by renewing or changing the line on the basis of retaining the original water pump. So that the unit can operate at high speed when the pump station has high lift, and at low speed when the pump station has low lift, so that the unit can operate safely and economically in a wide range on the premise of meeting the operation requirements of the pump station with over lift.

The large-scale double-speed asynchronous motor has been applied in Dongshen water supply project, and the double-speed regulation technology of large-scale pole changing synchronous motor has made a breakthrough in recent years. Recently, it has been successfully applied in the actual project of Guanyingang pump station in Changde, Hunan Province. At present, the technology is mature and can be popularized in the construction and renovation of large-scale pumping station.
2. Large double-speed salient pole synchronous motor

2.1. Principle of pole changing regulation
The structure and performance characteristics of large double-speed salient pole synchronous motor and its comparison with the traditional motor structure are shown in Figure 1-4.

| Synchronous motor | Structural characteristics |
|-------------------|-----------------------------|
|                   | — New structure of rotor with non-uniform salient distribution |
|                   | — At least 3 slip rings are used for rotor circuit, which is convenient for pole changing |
|                   | — The harmonic content of the excitation magnetic potential of the rotor winding conductor is low under two pole numbers, and the effective utilization ratio of the material is equivalent to that of the standard motor |
|                   | — The overall performance of the motor under two pole numbers is equivalent to that of the standard motor with the same pole number. It has the advantages of high efficiency, small excitation current, convenient wiring, fast tangent and simple control |

Figure 1. Characteristics of Double-speed Salient Pole Synchronous Motor.

Figure 2. Single speed magnetic winding wiring diagram of common rotor.

Figure 3. Salient pole magnetic winding wiring diagram of present rotor.

Figure 4. Salient pole magnetic winding wiring diagram of new rotor.

This kind of double-speed salient pole synchronous motor has good reliability. At present, it has been successfully developed to adapt to the pole changing ratio of large-scale electric drainage and irrigation water pump units, including 24 / 20, 36 / 32, 44 / 36, etc.
2.2. **Energy saving advantages of pole changing regulation**

The motor does not need to be equipped with a special control cabinet, so the investment is relatively low. In normal energy-saving irrigation, the high-pressure double-speed motor can be operated at low speed; during flood period, the speed is increased and the motor is automatically switched to high-speed operation, which can fully meet the requirements of changing head operation of pumping station unit.

The use of double-speed synchronous motor pole changing regulation can ensure that the pump often works in the high efficiency area, not only reduce the energy loss, but also avoid the cavitation and vibration caused by the pump working in the low efficiency area for a long time.

3. **Application example**

3.1. **Typical project overview**

Songlong pumping station is located at the exit of Songlong River, Jindu Town, Gaoyao City, upstream of Lingyang gorge, Xijiang River, opposite Jinben River in Sanshui District. It is a large-scale drainage project with a total rainwater collection area of 268.24km² and a cultivated land area of 305700 mu.

Songlong pump station was started in July 1975 and put into operation in November 1977. The pump station is a causeway type and block based pump station, with an installed capacity of 3 × 1600 kW. The main water pump is 28CJ56 type, the blades are fully regulated by oil pressure, and equipped with TDL1600 large vertical synchronous motor. The inlet channel of the pump station is elbow type, the outlet channel is siphon type, and the top of the hump is equipped with a vacuum breaking valve.

In this paper, only the energy-saving effect of large double-speed salient pole synchronous motor is considered, so the selection of pump station main pump will not be discussed in this paper, only the selection results (see Section 3.4 for details).

3.2. **Energy saving effect of large double-speed salient pole synchronous motor**

Songlong pump station is equipped with 4 sets of 2.8CJ-56A fully regulated axial flow pumps (regulation range: -6°- +6°), the designed lift of the pump station is 5.6m, the rated flow of a single pump is 25m³/s (+4°), the rated speed is 150 r/min, and the matching power of the motor is 2000kW. The performance curve of water pump is shown in Figure 5 (n=150r/min, the number of pole pairs of motor is 20).

The selection of water pump in this station is reasonable, with high efficiency in low lift section and barely operation in high lift section. However, in the high lift section, the efficiency of the water pump is low, the flow is too small, the load rate of the unit is not high, and the working point may fall into the "saddle area" during the highest lift operation. In this regard, the speed can be increased moderately. A large-scale two speed synchronous motor is used to readjust the operation condition of the pump in Songlong pump station. Now, the second speed of the motor is n=188r/min (the corresponding pole pairs of the motor are 16, and the speed-up rate is 25%). See Table 1 for specific calculation results.

According to Table 1 (only meaningful for high lift section, the same below), the rated speed of motor is n=150r/min operation, the working time near the average head accounts for about 70% of the average annual operation time. When the pump works near the design head, the device efficiency is high, all of which are above 65%, meeting the requirements of the device efficiency after the pump renovation; while in the high head section, the pump device efficiency drops below 60%, and the flow is very small, the unit load rate is not high, so the potential of the unit cannot be fully exploited Ability. When the motor speed is increased to n=188 r/min, the efficiency of the pump at the highest head is 67.41%, which is about 7% higher than that at the same head condition. And it can be seen from Figure 5 that the high efficiency area of the pump is raised to between the design head and the maximum head of the pump station after the speed is increased. It can be seen that the efficiency of the pump is very high when the section is operated. However, the change of the speed of large-scale water
pump has a great influence on the mechanical efficiency. Increasing the speed may not only cause overload and cavitation, but also increase the stress in the pump parts. The more the speed is increased, the greater the mechanical loss is. When the speed is increased more, the critical speed of the main shaft, the flow passage capacity and the strength and rigidity of the motor beam must be checked. Therefore, it is further improved Speed needs to be careful.

![Figure 5. Working performance curve of axial flow pump.](image)

| Lift condition | Angle | Pump efficiency | Motor efficiency | Pipeline efficiency | Device efficiency | Pump efficiency | Motor efficiency | Pipeline efficiency | Device efficiency |
|----------------|-------|-----------------|------------------|---------------------|------------------|----------------|------------------|-------------------|------------------|
| Maximum lift   | -4°   | 71.60           | 90.54            | 91.08               | 59.04            | 80.00          | 92.59            | 91.00             | 67.41            |
|                | -2°   | 72.00           | 90.68            | 90.89               | 59.34            | 81.05          | 82.87            | 89.23             | 67.16            |
|                | 0°    | 73.50           | 91.07            | 90.46               | 60.55            | 82.18          | 93.00            | /                 | /                |
|                | -4°   | 80.30           | 90.98            | 89.89               | 65.67            | 75.75          | 92.29            | 74.37             | 51.99            |
| Design lift    | 0°    | 82.60           | 92.39            | 87.51               | 66.78            | 79.70          | 92.58            | 65.93             | 48.65            |
|                | 2°    | 83.20           | 92.95            | 86.42               | 66.83            | 81.40          | 92.87            | 62.09             | 46.94            |
|                | 4°    | 84.20           | 93.06            | 85.70               | 67.15            | 82.50          | 93.00            | 58.57             | 44.94            |
| Minimum lift   | -4°   | 51.00           | 86.66            | 31.47               | 13.91            | 47.50          | 87.71            | 22.83             | 9.51             |
|                | -2°   | 55.00           | 88.87            | 26.80               | 13.10            | 53.00          | 90.58            | 19.16             | 9.20             |
|                | 0°    | 57.50           | 89.82            | 23.61               | 12.19            | 57.50          | 92.19            | 16.47             | 8.73             |
|                | 2°    | 62.20           | 91.12            | 20.35               | 11.53            | 62.20          | 92.44            | 14.12             | 8.12             |
|                | 4°    | 65.20           | 91.80            | 18.42               | 11.03            | 65.20          | 92.53            | 12.63             | 7.62             |

According to the relationship between efficiency $\eta$ of pump station and energy consumption $e$ and $\eta$-$e$ relationship curve, the inefficient operation of pump station will lead to a large increase in energy consumption. According to the pump performance curves at different motor speeds of Songlong pump station, the unit energy consumption under different working conditions is calculated. See Table 2 for the specific calculation results.
Table 2. Unit energy loss of different condition.

| Lift condition | Angle | Device efficiency | Energy consumption kW·h/kt·m | Device efficiency | Energy consumption kW·h/kt·m |
|----------------|-------|-------------------|-------------------------------|-------------------|-------------------------------|
| Maximum lift   | -4°   | 60.51             | 4.5                           | 67.41             | 4.0                           |
|                | -2°   | 61.60             | 4.4                           | 67.16             | 4.1                           |
|                | 0°    | 62.66             | 4.3                           | /                 | /                             |
|                | -4°   | 65.93             | 4.1                           | 51.03             | 5.3                           |
|                | -2°   | 66.53             | 4.1                           | 49.81             | 5.5                           |
| Design lift    | 0°    | 66.62             | 4.1                           | 48.34             | 5.6                           |
|                | 2°    | 66.35             | 4.1                           | 46.65             | 5.8                           |
|                | 4°    | 66.62             | 4.1                           | 44.67             | 6.1                           |
|                | -4°   | 13.91             | 19.6                          | 9.51              | 28.6                          |
|                | -2°   | 13.10             | 20.8                          | 9.05              | 30.1                          |
| Minimum lift   | 0°    | 12.19             | 22.3                          | 8.54              | 31.8                          |
|                | 2°    | 11.53             | 23.6                          | 8.01              | 34.0                          |
|                | 4°    | 11.03             | 24.7                          | 7.56              | 36.0                          |

It can be seen from Table 2 that when the pump operates at low speed under the condition of high head, the unit energy consumption increases by 0.4 kW·h/kt·m compared with the design head, reaching 4.5 kW·h/kt·m, while at high speed, the unit energy consumption of the pump station under...
the condition of high head is basically the same as that under the design head at low speed, about 4.1 kW·h/kt·m.

Now, select step $\Delta h = 0.50\,\text{m}$, determine the working points under the head of each device within the range of 6.0-7.5m of high lift, and compare the device efficiency, energy consumption and drainage flow. See Table 3 for the calculation results (low speed is only meaningful for low lift section, high speed is only meaningful for high lift section).

From Table 3, it can be seen that the efficiency of the device within the range of 6.0-7.5m of high head increases by about 3% on average compared with that under the condition of low speed. According to the calculation of the total installed capacity of the Songlong pump station of 8000kw, the annual total energy consumption of the Songlong pump station is 9.6 million kW·h, equivalent to 4.8 million yuan. Under the condition of high lift, the operation time of the pump station is about 3/10 of the total annual operation time, i.e. 360h, and the total power consumption is 2.88 million kW·h, equivalent to RMB 1.44 million. After the efficiency of the device is increased by 3%, the annual total energy consumption is reduced by 72000 kW·h, equivalent to 36000 yuan. During the 20-year operation period of the pump station, Songlong pump station has saved 1.44 million kW·h of electric energy, equivalent to 720000 yuan.

4. Conclusion
Taking the renovation of a typical pumping station in Songlong, Gaoyao, Guangdong Province as an example, this paper selects three main evaluation indexes, i.e. device efficiency, energy consumption and economic benefit of the pumping station, and analyzes and compares the energy-saving effect of adopting general speed regulation technology and large-scale two speed synchronous motor.

The analysis results show that if the large-scale two speed synchronous motor is used in the station, the efficiency of the pump unit is increased by about 3% on average under the condition of high head (6.0m-7.5m), the unit energy consumption is reduced by 0.2 kW·h/kt·m, the unit efficiency at the highest head point is increased by 7%, and the unit energy consumption is reduced by 0.4 kW·h/kt·m, which can ensure the safe and stable operation of the pump at high head. The operation time of the station under high lift condition is about 3/10 of the total annual average (288h), and the total power consumption is about 2.880 million kW·h, equivalent to about 1.440 million yuan of electricity fee. Based on an average increase of 3% in the efficiency of the high-speed pump with high head, the annual total power consumption is reduced by 72000 kW·h and the electricity cost is saved by 36000 yuan. During the 20-year operation period of the pump station, the accumulated electric energy saved is about 1.44 million kW·h and the electric cost saved is 720000 yuan. Considering the fact that the pump station adopts two speed motor, the flow increases greatly in the period of strong drainage, and the indirect economic benefit of the pump station is 31.12328 million yuan per year, that is, 7.7922 million yuan per unit per year, when the drainage flow of a single unit increases by 7.51m$^3$/s and the total flow of the pump station increases by 30.04m$^3$/s. This is only for the benefit of replacing the two speed motor, which is far more than the additional cost of using the double-speed motor.

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