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Optimal pump station operation based on the single variable-frequency speed regulation

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ABSTRACT

Aiming at the situations that pumps of the same model are used in most pump stations and the price of frequency converter is too high， the reasons are analyzed for the low efficiency of pump assembly operating under the single frequency converter configuration condition. In multipled pump assembly equipped with pumps of the same model, adding an extra pump operating as a transitional pump whose maximum flow rate is half of the previous ones' will reduce variable-speed pump's speed regulation ratio. According to this, a model for optimising operation of pump station is constructed with the minimum shaft power being objective function and solved by simulated annealing genetic algorithm. And then a comparison analysis about energy consumption and economical efficiency is made toward these three speed regulation strategies. Energy consumption analysis results indicate that single speed regulation with transitional pump consumes a little more energy than that of all speed regulation, while economical efficiency analysis results show that it cost only one twelfth of all-speed-regulation in extra investment and its payback period is one eighth of the latter's. The effect of energy saving of this strategy of speed regulation is obvious and solves well the problem that pump station equipped with the same model of pump operates at low efficiency when equipped with a single frequency converter.

Keywords： single frequency converter, genetic algorithm, Transitional pump, speed regulation ratio

INTRODUCTION

When speed regulating devices are configured in pump station, three strategies are usually adopted: all speed regulation[1,2], partial speed regulation[3,4], single speed regulation[5,6]. Some experts hold the opinion that the all speed regulation can enhance the adjusting ability of the system and also have a strong advantage in improving the operational efficiency of pumping systems. Moreover, it has no strict requirements for the configuration of the pump assembly. But the price of large-capacity frequency converter is very expensive, high voltage and power ones even cost 10 times as much as the low ones. Besides, some factors such as the cost of their installation and debugging reduce the input-output ratio of the system, prolong the energy saving period, and even influence the implementation of the energy saving project because of too high cost.

At present, the research on single speed regulation in pump units is mainly about the same model of pump, while few people study the energy consumption of pump units under the condition of different models of pump. In pump stations, of which pumps are the same model, when the variable-speed operation transfers from one pump to another, the variable-speed pump will runs at low speed at the transition point and its flow rate will be too small, causing serious deviation from its high efficiency zone. As a result, energy conservation is impossible. This is why the adjustable-speed pump assembly based on the traditional single frequency converter configuration operates at low efficiency. Therefore, it is not feasible to save energy in pump station operation using a single model of pump.

A single model of pump can't meet the pump station design requirement of a wide range of variation in water supply. Instead, if there are too many models of pump, it will lead to much trouble to the control of pump station operation[7]. So an advisable arrangement is to use two models of pump in a pump unit. It is stated in reference [8] that if an extra pump operating as a transitional pump is added to pump assembly equipped one frequency converter and a single model of pump, the variable-speed pump will operate at high efficiency because of reduction in its power unload by the transitional pump, of which the rated maximum flow is half of the previous ones'. But further demonstrations are lacked about whether this strategy is superior to other speed regulation methods.

In this paper, a mathematical model for optimising pump station operation is constructed with the minimum shaft power to be objective function and solved by simulated annealing genetic algorithm (SAGA). A compared analysis for energy dissipation and operation cost is made among the three followed speed regulation strategies: all speed regulation without transitional pump, single speed regulation without transitional pump, single speed regulation with transitional pump. Example results indicate that the single speed regulation with transitional pump has obvious advantages in the investment and operation of pump station.

NOMENCLATURE

Q	Flow rate	(m^3/h)
H	Head	(m)
P	Shaft power	(kW)
η	Efficiency	(%)
t	Time	(month)
s	The speed regulation ratio	
w	The state factor	
β	An appropriate positive number	

1 Mathematical Model for Optimising Operation

Optimising pump station operation, on the premise condition that the head of water and flow rate can meet the demands, is to obtain an optimal combination of pumps for parallel operation and keep the water pump assembly in optimum running status and minimum energy consumption.

1.1 Performance Curves of Water Pumps

Generally, performance of water pumps can be described by flow-head(Q-H),flow-power(Q-P),flow-efficiency(Q-η) curves. In the research on pump operation, many scholars, in order to simplify the process of solving the equations, established the Q-H characteristic curves equation by subtracting virtual total head loss in the pump at the point where the flow rate is Q from the virtual total head at the point where the flow is zero. This is virtually taking the high efficiency zone of pumps for one part of cubic parabola [9]. Actually, few pumps' performance could meet the ideal equation above. Therefore, it will bring large errors in this optimising model of pump station. As a common method of fitting pump performance curves, the least square method comparing with parabola method is complex in solving equation but high in precision.

Using the least square method to fit Q-H,Q-P curves gives equations as follow:

$$H = a_0 + a_1 Q + a_2 Q^2 \tag{1}$$

$$P = b_0 + b_1 Q + b_2 Q^2 + b_3 Q^3 \tag{2}$$

Pump performance during regulating speed period can be presented in:

$$H = a_0 s^2 + a_1 Q s + a_2 Q^2 \tag{3}$$

$$P = b_0 s^3 + b_1 Q s^2 + b_2 Q^2 s + b_3 Q^3 \tag{4}$$

Where s equaling to n/n_0 is speed regulation ratio.

1.2 High Efficiency Zone of Pump Operation

In Fig.1, A,B respectively corresponds to the two endpoints of high efficiency zone($\eta_{\max} - \Delta\eta$, $\Delta\eta$ usually is 5%～7%) on the performance curves of pumps running at rated rotational speed. OA,OB represent two similar work condition parabolas(iso-efficiency curve) passing through point A,B ,respectively.

The values of pump's head and flow rate corresponding to point A,B can be obtained in the pump product manual. And then the coefficients of similar work condition parabolas are figured out according to the similitude law:

$$k_A = \frac{H_A}{Q_A^2}, \quad k_B = \frac{H_B}{Q_B^2} \tag{5}$$

Considering the requirements of pump operation and cavitation characteristics, the variable-speed pump can not operates under unlimitedly adjusting speed and the speed regulation ratio should has a minimum limit $s_{\min}$. Obviously, in the range of speed regulation ratio variation $s_{\min} \le s \le 1$, the speed $n_{\min}$ corresponding to the $s_{\min}$ is the pump's minimum speed. There exists a characteristics curve matching along with $n_{\min}$. $A_{\min}$,$B_{\min}$ are the two intersection points where this characteristic curve and the similar work condition parabolas meet together. Pump runs at high efficiency only when the work point falls in the $ABB_{\min}A_{\min}$ zone. As presented in Fig.1, when the head of pump under parallel operation is H, the high efficiency zone of variable-speed pump is line CD.

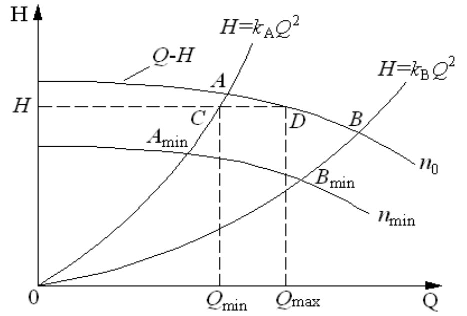

Fig.1 range of adjustable-speed pump's high efficiency zone

$$Q_{i\min} = \begin{cases} \sqrt{\dfrac{H}{k_A}}, & H \ge H_{A\min i} \\ \dfrac{-a_1 s_{\min} - \sqrt{a_1^2 s_{\min}^2 - 4a_2\left(a_0 s_{\min}^2 - H\right)}}{2a_2}, & H \le H_{A\min i} \end{cases} \tag{6}$$

$$Q_{i\max}=\begin{cases}\dfrac{-a_1-\sqrt{a_1^2-4a_2\left(a_0-H\right)}}{2a_2}, & H\geq H_{Bi}\\ \sqrt{\dfrac{H}{k_B}}, & H\leq H_{Bi}\end{cases} \tag{7}$$

1.3 Model for Optimising Operation

There are n pumps (including m adjustable-speed pumps and the others constant-speed pumps) running in parallel in some pump station, of which the total flow rate is Q and the total head is H. Determining the operating state of every pump by optimising makes the total power of pump station minimum. According to the P-Q characteristics curves, flow distribution among pump units is accomplished as per genetic algorithm. Pump units whose flow distribution is zero will keep out of work. And then the objective function of optimum model is given by:

$$\min P=\sum_{i=1}^{n}P_i\left(Q_i,s_i\right) \tag{8}$$

The total flow rate is limited by :

$$\sum_{i=1}^{n}w_iQ_i=Q \tag{9}$$

The head is limited by:

$$H=a_{0i}s_i^2+a_{1i}Q_is_i+a_{2i}Q_i^2 \tag{10}$$

The flow rate of a single pump is limited by:

$$Q_{\min}\leq Q_i\leq Q_{\max} \tag{11}$$

The speed regulation ratio is limited by:

$$s_{\min}\leq s_i\leq 1 \tag{12}$$

Where P is the total shaft power of pump assembly; i is pump index; P_i , Q_i ,s_i , w_i are the shaft power, the flow rate, the speed regulation ratio and the state factor, respectively. And here w_i=0 indicates the pump is in cease while w_i=1 means the pump is working.

2 Solution of Model by SAGA

In this paper，the above optimization equation with limit conditions will be solved by simulated annealing genetic algorithm.

Using a binary code and standard genetic operator, a penalty function describing the limit condition is designed as follows:

$$\rho\left(Q\right)=\begin{cases}\beta\left(\sum\limits_{i=1}^{n}w_iQ_i-Q\right), & Q<\sum\limits_{i=1}^{n}w_iQ_i\\ 0 \quad , & Q=\sum\limits_{i=1}^{n}w_iQ_i\\ \beta\left(Q-\sum\limits_{i=1}^{n}w_iQ_i\right), & Q>\sum\limits_{i=1}^{n}w_iQ_i\end{cases} \tag{13}$$

Where β is an appropriate positive number, called penalty coefficient. And then fitness function is defined by:

$$P=\min\sum_{i=1}^{n}P_i\left(Q_i,s_i\right)+\rho\left(Q\right) \tag{14}$$

3 Comparison Analysis of Different Speed Regulation Strategies

Assume three single-stage double-suction centrifugal pumps whose rated voltage is 10kV and rated power is 710kW and a transitional pump whose rated flow is half of the mentioned above ones'. Ⅰ,Ⅱ represents the models of these two types of pump. The parameters of pump Ⅰ are as follows: flow rate 2850m^3/h， head 58m， rotational speed 960r/min， efficiency 86%， and the characteristics data shown in Fig.2； the parameters of pump Ⅱ are as follows: flow rate 1425m^3/h， head 58m， rotational speed 960r/min， efficiency 84.7%， and the characteristics data shown in table Fig.3.

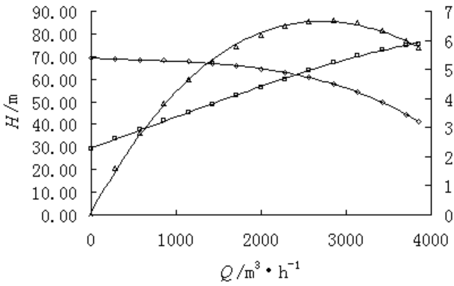

Fig.2 performance curve of pump Ⅰ

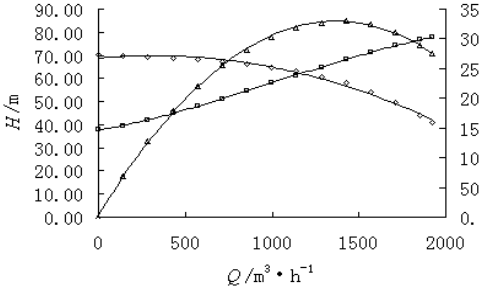

Fig.3 performance curve of pump Ⅱ

The change pattern of water supply of pump station is described in Fig.4.

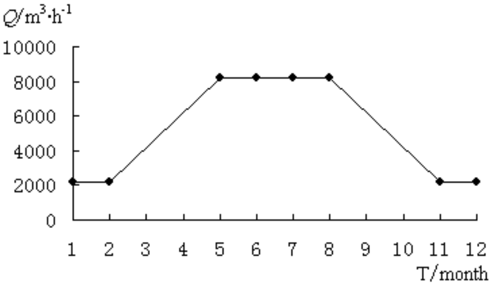

Fig.4 change pattern of water supply in a year

Fig.4 can be expressed by:

$$Q(t)=\begin{cases}2200 \quad , & 11\leq t<2\\ 2000t-1800 \ , & 2\leq t<5\\ 8200 \quad , & 5\leq t<8\\ -200t+24200, & 8\leq t<11\end{cases} \tag{15}$$

Determine $\Delta\eta$=7%, and thus the primary fitted parameters of pump Ⅰ,pump Ⅱ are listed in table 1,table2, respectively.

Table 1 primary fitted parameters of pump Ⅰ

Q-H curve parameters			Q-P curve parameters				Flow range in high efficiency zone		Peak efficiency
a_0	a_1	a_2	b_0	b_1	b_2	b_3	$Q_{\min}$/m³·h⁻¹	$Q_{\max}$/m³·h⁻¹	$\eta_{\max}$/%
67.843	0.00365	-2.646×10^{-6}	230.506	0.10249	5.826×10^{-6}	-2.0996×10^{-9}	1948	3602	86

Table 2 primary fitted parameters of pump Ⅱ

Q-H curve parameters			Q-P curve parameters				Flow range in high efficiency zone		Peak efficiency
a_0	a_1	a_2	b_0	b_1	b_2	b_3	$Q_{\min}$/m³·h⁻¹	$Q_{\max}$/m³·h⁻¹	$\eta_{\max}$/%
68.769	0.00688	-1.076×10^{-5}	146.429	0.04998	4.400×10^{-5}	-1.4439×10^{-8}	985	1775	84.7

Combine these two models of pump in different speed regulation ways and do the corresponding simulation experiments.

3.1 All Speed Regulation without Transitional Pump

In this strategy, three pumps Ⅰ are combined in parallel with all of them operating at variable speed. And then the fitness function of optimization model can be written as:

$$P=\min\sum_{i=1}^{3}w_i(d_{0i}s^3+d_{1i}Q_is^2+d_{2i}Q_i^2s+d_{3i}Q_i^3)+\rho\left(Q\right)\qquad(16)$$

The simulation results are presented in table 3.

Table 3 simulation results of all speed regulation without transitional pump

water supply		all speed regulation without transitional pump														
				datas of 1# variable-speed pump				datas of 2# variable-speed pump				datas of 3# variable-speed pump				total shaft power kW
Qe m³/h	He m	state factor	speed regulation ratio	flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	
2213.60	43.07	001	0.8513	0	0	0	0	0	0	0	0	2213.60	43.07	308.127	84.23	308.127
2835.20	43.75	001	0.9057	0	0	0	0	0	0	0	0	2835.20	43.75	404.208	83.54	404.208
2912.60	43.85	001	0.9133	0	0	0	0	0	0	0	0	2912.60	43.85	417.912	83.19	417.912
3500.60	44.67	011	0.8347	0	0	0	0	1750.30	44.67	263.878	80.66	1750.30	44.67	263.878	80.66	527.755
3555.10	44.76	011	0.8384	0	0	0	0	1777.60	44.76	267.524	80.96	1777.60	44.76	267.524	80.96	535.047
3921.30	45.35	011	0.8535	0	0	0	0	1960.70	45.35	292.970	82.62	1960.65	45.35	292.970	82.62	585.939
4176.30	45.80	011	0.8649	0	0	0	0	2088.20	45.80	312.088	83.42	2088.20	45.80	312.088	83.42	624.176
4188.70	45.83	011	0.8655	0	0	0	0	2094.40	45.83	313.102	83.45	2094.40	45.83	313.102	83.45	626.203
4200.00	45.85	011	0.8660	0	0	0	0	2100.00	45.85	313.974	83.48	2100.00	45.85	313.974	83.48	627.947
5000.00	47.45	011	0.9063	0	0	0	0	2500.00	47.45	382.240	84.48	2500.00	47.45	382.240	84.48	764.480
5500.00	48.59	011	0.9344	0	0	0	0	2750.00	48.59	431.597	84.28	2750.00	48.59	431.597	84.28	863.194
6000.00	49.85	011	0.9645	0	0	0	0	3000.00	49.85	486.729	83.64	3000.00	49.85	486.729	83.64	973.457
6500.00	51.21	011	0.9963	0	0	0	0	3250.00	51.21	547.900	82.69	3250.00	51.21	547.900	82.69	1095.800
7000.00	52.68	111	0.9337	2333.34	52.68	399.020	83.86	2333.34	52.68	399.020	83.86	2333.34	52.68	399.020	83.86	1197.060
7500.00	54.26	111	0.9565	2500.00	54.26	438.217	84.27	2500.00	54.26	438.217	84.27	2500.00	54.26	438.217	84.27	1314.650
8000.00	55.95	111	0.9805	2666.70	55.95	480.903	84.46	2666.70	55.95	480.903	84.46	2666.70	55.95	480.903	84.46	1442.710
8200.00	56.65	111	0.9904	2733.30	56.65	498.943	84.48	2733.30	56.65	498.943	84.48	2733.30	56.65	498.943	84.48	1496.830

3.2 Single Speed Regulation without Transitional Pump

In this strategy, three pumps Ⅰ are combined in parallel with one of them operating at variable speed and the other two at constant speed. And then the fitness function of optimization model can be given by:

$$\begin{aligned}P=\min\Big[&w_1(d_{01}s^3+d_{11}Q_1s^2+d_{21}Q_1^2s+d_{31}Q_1^3)\\&+\sum_{i=2}^{3}w_i(d_{0i}+d_{1i}Q_i+d_{2i}Q_i^2+d_{3i}Q_i^3)\Big]+\rho\left(Q\right)\end{aligned}\qquad(17)$$

The simulation results are shown in table 4.

Table 4 simulation results of single speed regulation without transitional pump

water supply		single speed regulation without transitional pump														
		state factor	speed regulation ratio	datas of constant-speed pump				datas of constant-speed pump				datas of variable-speed pump				total shaft power kW
Q_e m³/h	H_e m			flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	
2213.60	43.07	001	0.8513	0	0	0	0	0	0	0	0	2213.60	43.07	308.127	84.23	308.127
2835.20	43.75	001	0.9057	0	0	0	0	0	0	0	0	2835.20	43.75	404.208	83.54	404.208
2912.60	43.85	001	0.9133	0	0	0	0	0	0	0	0	2912.60	43.85	417.912	83.19	417.912
3500.60	44.67	001	0.9761	0	0	0	0	0	0	0	0	3500.60	44.67	535.772	79.45	535.772
3555.10	44.76	001	0.9823	0	0	0	0	0	0	0	0	3551.10	44.76	548.092	78.94	548.092
3921.30	45.35	011	0.8424	0	0	0	0	2159.90	45.35	457.907	58.23	1761.40	45.35	269.682	80.63	727.589
4176.30	45.80	011	0.8565	0	0	0	0	2226.60	45.80	464.427	59.77	1949.70	45.80	294.820	82.45	759.247
4188.70	45.83	011	0.8571	0	0	0	0	2232.50	45.83	465.000	59.90	1956.20	45.83	295.824	82.50	760.824
4200.00	45.85	011	0.8576	0	0	0	0	2237.90	45.85	465.524	60.00	1962.10	45.85	296.685	82.54	762.209
5000.00	47.45	011	0.8707	0	0	0	0	3034.80	47.45	536.529	73.06	1965.20	47.45	308.474	82.29	845.003
5500.00	48.59	011	0.9821	0	0	0	0	2211.10	48.59	462.918	63.18	3288.90	48.59	530.621	81.99	993.539
6000.00	49.85	011	0.9826	0	0	0	0	2797.60	49.85	516.870	73.45	3202.40	49.85	525.400	82.71	1042.270
6500.00	51.21	011	0.9959	0	0	0	0	3254.50	51.21	553.408	81.98	3245.50	51.21	546.992	82.71	1100.400
7000.00	52.68	111	0.9005	2323.00	52.68	473.720	82.91	2929.40	52.68	527.969	79.57	1747.60	52.68	318.432	78.70	1320.120
7500.00	54.26	111	0.9211	2321.00	54.26	473.529	83.94	3259.60	54.26	553.783	86.94	1919.30	54.26	351.958	80.55	1379.270
8000.00	55.95	111	0.9872	2263.80	55.95	468.032	84.67	2980.60	55.95	532.163	85.31	2755.60	55.95	496.775	84.49	1496.970
8200.00	56.65	111	0.9981	3040.00	56.65	536.944	84.94	2326.50	56.65	474.054	75.68	2833.50	56.65	517.372	84.46	1528.370

3.3 Single Speed Regulation with Transitional Pump

In this strategy, three pumps Ⅰ and one pumpⅡ are combined in parallel with one of pump Ⅰ operating at variable speed and the others at constant speed. And then the fitness function of optimization model can be given by:

$$P = \min\Big[w_1(d_{01}s^3 + d_{11}Q_1 s^2 + d_{21}Q_1^2 s + d_{31}Q_1^3) + \sum_{i=2}^{4} w_i(d_{0i} + d_{1i}Q_i + d_{2i}Q_i^2 + d_{3i}Q_i^3) \Big] + \rho(Q) \tag{18}$$

The simulation results are presented in table 5.

Table 5 simulation results of single speed regulation with transitional pump

water supply		single speed regulation with transitional pump																			
		state factor	speed regulation ratio	datas of transitional pump				datas of constant-speed pump				datas of constant-speed pump				datas of variable-speed pump				total shaft power kW
Q_e m³/h	H_e m			flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	flow rate m³/h	head m	shaft power kW	efficiency %	
2213.60	43.07	0001	0.8513	0	0	0	0	0	0	0	0	0	0	0	0	2213.60	43.07	308.127	84.23	308.127
2835.20	43.75	0001	0.9057	0	0	0	0	0	0	0	0	0	0	0	0	2835.20	43.75	404.208	83.54	404.208
2912.60	43.85	0001	0.9133	0	0	0	0	0	0	0	0	0	0	0	0	2912.60	43.85	417.912	83.19	417.912
3500.60	44.67	0001	0.9761	0	0	0	0	0	0	0	0	0	0	0	0	3500.60	44.67	535.772	79.45	535.772
3555.10	44.76	0001	0.9823	0	0	0	0	0	0	0	0	0	0	0	0	3551.10	44.76	548.092	78.94	548.092
3921.30	45.35	1001	0.8717	1676.50	45.35	285.852	75.55	0	0	0	0	0	0	0	0	2244.80	45.35	329.308	84.15	615.160
4176.30	45.80	1001	0.8780	1807.00	45.80	295.220	75.97	0	0	0	0	0	0	0	0	2369.30	45.80	349.969	84.41	645.189
4188.70	45.83	1001	0.8853	1804.60	45.83	295.057	76.00	0	0	0	0	0	0	0	0	2384.10	45.83	352.311	84.43	647.368
4200.00	45.85	1001	0.8857	1812.00	45.85	295.556	76.02	0	0	0	0	0	0	0	0	2388.00	45.85	353.022	84.43	648.578
5000.00	47.45	1001	1.0000	1450.40	47.45	267.425	77.51	0	0	0	0	0	0	0	0	3549.60	47.45	573.825	79.90	841.250
5500.00	48.59	0101	0.9821	0	0	0	0	2211.10	48.59	462.918	80.05	0	0	0	0	3288.90	48.59	530.621	81.99	993.539
6000.00	49.85	0101	0.9826	0	0	0	0	2797.60	49.85	516.870	80.99	0	0	0	0	3202.40	49.85	525.400	82.71	1042.270
6500.00	51.21	0101	0.9959	0	0	0	0	3254.50	51.21	553.408	81.95	0	0	0	0	3245.50	51.21	546.992	82.71	1100.400
7000.00	52.68	1101	0.9500	1627.00	52.68	282.033	81.74	2805.40	52.68	517.539	82.91	0	0	0	0	2567.50	52.68	436.068	84.44	1235.640
7500.00	54.26	1101	1.0000	1680.90	54.26	286.185	82.74	2761.60	54.26	513.767	83.84	0	0	0	0	3057.50	54.26	538.339	83.89	1338.290
8000.00	55.95	0111	0.9872	0	0	0	0	2263.80	55.95	468.032	84.67	2980.60	55.95	532.163	84.67	2755.60	55.95	496.775	84.49	1496.970
8200.00	56.65	0111	0.9981	0	0	0	0	2326.50	56.65	474.054	84.94	3040.00	56.65	536.944	84.94	2833.50	56.65	517.372	84.46	1528.370

The variation relationship between the total shaft power of each of the three strategies and flow rate, namely $P=P(Q)$, is charted in Fig.5.

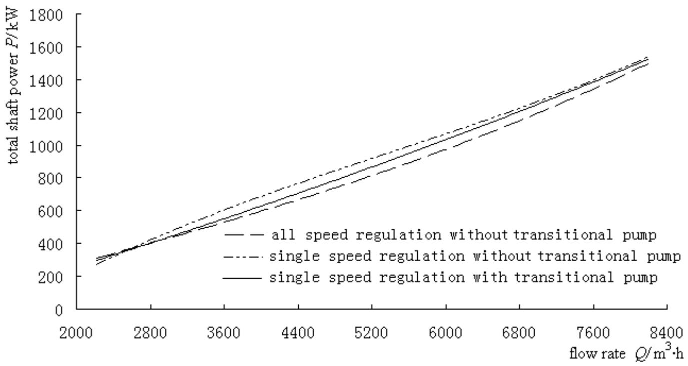

Fig.5 P=P(Q) comparison among three strategies

It is known from Fig.5 that the total shaft power of pump assembly running at single speed regulation without transitional pump is much higher than that of the other two strategies, and that the total shaft power of pump assembly running at single speed regulation with transitional pump is a little higher than that of all speed regulation without transitional pump.

4 Economic Analysis

The total shaft power of pump unit changes with flow rate as the function $P=P\ (Q)$, and the flow rate change with time accord with a function assumed to be $Q=Q\ (t)$. Combine these two functions and obtain a new function $P=P\ (t)$, which shows that the shaft power changes with time going. Therefore, the mechanical energy E consumed by pumps in some time can be calculated by：

$$E=\int_{T} P(t)dt \qquad (19)$$

Make the hypothesis that the price of electricity is￥0.6 per kW • h. The average price for one high voltage frequency converter of 10kV-710kW is￥1,000,000. Besides some other expenses such as installation, the cost of one frequency converter will be about￥1,500,000. The all speed regulation is in need of three frequency converters while the single speed regulation demands only one. In the meanwhile, one transitional pump including high-voltage electromotor and installation cost about ￥250,000. The cost of a pump station adopting different strategies is listed and compared in table 6.

Table 6 economic comparison of three strategies

strategy	electrical fee /million RMB	electrical fee savings / million RMB	extra investment expense / million RMB	payback period /year
all speed regulation without transitional pump	10.15	0.56	3.00	5.4
single speed regulation without transitional pump	10.71	—	—	—
single speed regulation with transitional pump	10.34	0.37	0.25	0.68

From table 6, it is obvious that the single-speed-regulation costs only one twelfth of all-speed-regulation in extra investment, saving￥2,750,000, and shortens payback period for eight times, that is less than 7 months. When the former's total profit is just equal to investing cost，the latter's net profit is already￥1,766,400. From then on, the profits of the two strategies change with time accord with curves in Fig.6.

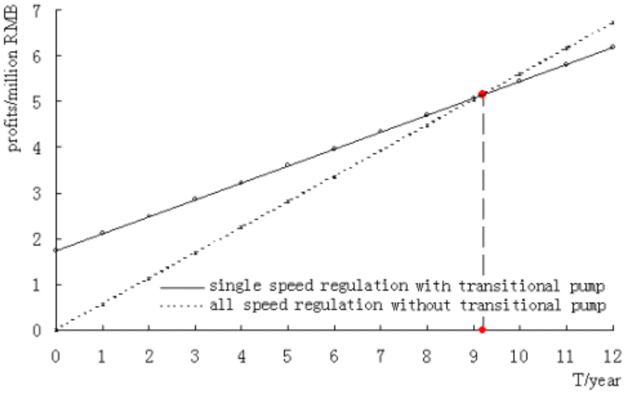

Fig.6 relationship curves of the profits of the two strategies with time

Fig.6 shows that the revenue of all speed regulation can catch up with single speed regulation with transitional pump after 9.2 years. To all speed regulation, the more pump assemblies needed in pump station, the more frequency converter in need for match. But nothing else increasing investment cost is in need for single speed regulation. So it has more outstanding advantages in economical efficiency.

5 Conclusion

This paper analyzes the reasons why the efficiency of pump assembly is low under a single frequency converter configuration condition. A model for optimising operation of pump station is constructed with the minimum shaft power being objective function and solved by simulated annealing genetic algorithm. Simulation and calculation are made for all speed regulation,single speed regulation without transitional pump and single speed regulation with transitional pump. Energy consumption analysis results indicate that single speed regulation with transitional pump consumes a little more energy than all speed regulation does while economical efficiency analysis results show that it cost only one twelfth of all-speed-regulation in extra investment and its payback period is one eighth of the latter's. In the meanwhile, it is derived from calculation that the profit of single speed regulation can be caught up with by the all speed regulation after 9.2 years and that the effect of energy saving is obvious. This strategy of speed regulation solves well the problem that pump station configured with pump of same model operates in low efficiency when configured with a single frequency converter.

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