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The ApplicationResearch of Optimal Control Arithmetictopumpsoperation

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***ABSTRACT** :In order to solve the problem that how to adjust the operation of all units of the pump station and control the speed of pumps on time, in the changing condition of manufacture procedure, to optimize the pumps combination and adjusting-speed strategy, this paper builds a mathematic model of pumps operation control system, adopts the method of system identification to calculate system parameters on-line, and brings forward a optimal control arithmetic for saving energy. The data analysis of running spot indicates that the arithmetic can save energy of pump station obviously, and also has the good function of equipment maintenance, so it has the higher engineering application value.*

***KEYWORDS**- pumps combination, adjusting speed strategy, system identification, optimal control for saving energy Aerodynamics*

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I. INTRODUCTION

It is still difficult for China to adjust and make real-time control of the rotating speed of group motors in pump station, carry out the combination way of water pumps in pump station and optimize the speed control strategy for improving the efficiency of pump station and saving energy through speed control, when production technical process changing in water supply industry. Many researchers have done many works on it[1][2][3]. The paper makes on-line calculations on system parameters in use of system parameters identifying and concludes the controlling algorithm for improving the efficiency of pump station and saving energy of group motors through farther analysis on energy control system model based on reference 4, that has been applied in the water supply station in Shenzhen Water Group.

II. MATHEMATIC DESCRIPTION OF CONTROL SYSTEM FOR ENERGY OPTIMIZATION

Total energy consumption in pump station is different with different working scheme and efficiency for a certain of water supply conditions （Q_{duty}，H_{duty}）

（Q is fluid amount, H is pump head）in pipe net, and the working scheme with least energy consumption is the best working scheme.

Mathematic model could be set up as follows:

（1）Target function of optimization control

Energy consumption of working pump groups in pump station is lowest for a certain condition as follows:

$$N_{duty} = Min\left(\sum_{j=1}^{M}\omega_{i,j}N_{i,j}\right) \quad (1)$$

In Eq. (1), N_{duty} is the lowest energy consumption, M is the value of numbers of working pumps, $N_{i,j}$is axis power of pump of type i, unit j, $\omega_{i,j}$ is status function,$\omega_{i,j}$ =0 means stop of pump unit j，ωi,j =1 means working of pump unit j.

（2）Status equation groups of control system

Status equation groups of control system include:

①status equation of working water pumps in parallel, total fluid amount is the sum of fluid amount of each pump, and all pumps head is same,

②relation of head, power, efficiency, flow of pump type i, unit j , namely curve equation of pump characteristics,

③serving point must move along the curve of pipe characteristics in system, namely curve equation of pipe characteristics in system,

④constant efficiency curve equation of single working pump,

⑤similarity law equation of the centrifugal pump.

（3）Constraints of working control system

①required water pressure value in most no use point：

$h_{no-use} \geq \mathrm{H}_1$ (2)

h_{no-use} is pressure value in most no use point, it must greater than a constant value H_1.

②changing value of water level in absorbing well：

$\mathrm{H}_2 \geq h_{absorbing} \geq \mathrm{H}_3$ (3)

$h_{absorbing}$ is water level of absorbing well, it has top limit H_2 and low limit H_3.

③changing value of water level in clean water pond：

$\mathrm{H}_4 \geq h_{clean} \geq \mathrm{H}_5$ (4)

h_{clean} is water level of clean water pond, it has top limit H_4 and low limit H_5.

④high efficiency range of working single pump：

$\alpha \geq \varepsilon_i \geq \beta$ (5)

In Eq. (5), ε_i is efficiency of pump, and α、β are critical conditions for high efficiency range of working water pump.

Control optimizing algorithm for energy saving in pump group station is to acquire status function of working groups and optimal solution of running speed which make station energy consumption lowest when water supply flow and pressure are constant.

III. Construction of control system and optimal control algorithm

3.1 Online calculation of control system parameters

Curve equations of all kinds of water pump characteristics and system pipe characteristics are fitted according to original design parameters of water pumps in water supply control, but during real production curves of water pump characteristics and system pipe characteristics often varies, so on-line calculation for its parameters is necessary and fitting values should be kept modifying in use of update testing data. In the optimal control algorithm, the recursive least square method is applied to modifying the parameters for fitting in control system [5].

Degree of characteristic equation is known as m, parameter a_{ij}（a_{ij} is characteristic parameter for relation of flow and head）,water flow in time k, testing head data are marked as：

$Q = \theta H$ (6)

$\theta = [a_0, a_1, \cdots, a_m]^T$ (7)

$Q(k) = q(k)$, $H(k) = h(k)$ (8)

When $\phi(k) = [1, q(k), \cdots, q^m(k)]$

Tested data N（N>m+1）is written as matrix

$$\phi_N = [\phi(1), \phi(2), \cdots, \phi(N)]^T$$

$$= \begin{bmatrix} 1 & q(1) & \cdots & q^m(1) \\ 1 & q(2) & \cdots & q^m(2) \\ \cdots & \cdots & \cdots & \cdots \\ 1 & q(N) & \cdots & q^m(N) \end{bmatrix} \quad (9)$$

Concerned fitting characteristic curve equations of water pump is

$H_N = [h(1), h(2), \cdots, h(N)]^T$ (10)

After testing new data group $h(N+1)$ and $q(N+1)$,with same recursive least square method in ϕ_{N+1} and Y_{N+1}, recursive formula with fitting parameter θ of water pump group is shown as:

$$\begin{cases} \theta_{N+1} = \theta_N + K_{N+1}[h(N+1) - \phi^T(N)\theta_N] \\ K_{N+1} = P_N\phi(N)/[1 + \phi^T(N)P_N\phi(N)] \end{cases} \quad (11)$$

$$P_{N+1} = P_N - \frac{P_N \phi(N)\phi^T(N)P_N}{1+\phi^T(N)P_N\phi(N)}$$

In the Eq. (11), θ_N is the solution for canonical Eq. (12).

$$(\phi_N \phi_N^T)\theta_N = \phi_N^T H_N \quad (12)$$

Repeating this procedure, with recursive least square method power parameter b_{ij} , efficiency parameter c_{ij} , friction factor K_{Pi} along pipe, loss factor K_{Mi} of partial faucet.

3.2 Online calculation of control system parameter

(1) (Q_{duty} , H_{duty}) stationary head h_i in system pipe characteristics is acquired according to constrains of ①、②、③ (required water pressure value, water level of absorbing well, water level of clean water pond in most no use point of pipe line) in working control system, then water supply condition in that moment can be gotten with system status equation ③ (curve equation of system pipe characteristics) .

(2) Flow amount $Q_{i,j}$ of each pump is acquired through head H_{duty} of water supply and flow curve $H_{i,j}=f_i(Q_{i,j})$ of water pump head in system status equation ②. Constant speed water pump $Q_{i,j}$ is at fixed point, and $Q_{i,j}$ of adjusted speed water pump varies in large range, under constraint ④ (high efficiency range of single pump), varying range of $Q_{i,j}$ of adjusted speed water pump can be down when adjusting accordingly target efficiency.

(3) By status equation of parallel working water pumps

$$Q_{duty} = \sum_{i=0}^{M} \omega_{i,j} Q_{i,j} \quad (13)$$

Status function $\omega_{i,j}$ can be acquired through selecting combination of water pumps (numbers of adjusting speed pumps and constant speed pumps);

(4) Axis power of single pump can be calculated by the flow curve

$N_{i,j}=\varphi_i(Q_{i,j})$ of water pump power in system status equation ②regarding to constant speed pump; power consumption $N_{i,j}$ and concerned rotating speed n_2 can be calculated by system status equation ⑤(similarity working principle of water pump);

(5) To calculate all kinds of combination power and find lowest power combination which is best optimized;

(6) Lastly, to output status function $\omega_{i,j}$ in best combination and rotating speed n_2 of adjusting speed pump to controller, then return to next starting point.

IV. Experimental data and real running results analysis

Control optimizing algorithm for energy saving in pump group station has been applied in Shenzhen Water Group after finishing. The paper sampled production data of a certain day in Shenzhen Water Group for analysis randomly and gave figures of energy consumption comparing under different adjusting method in water supply pump station, then concluded as following:

(1) Energy saving effect is obvious. It can be found from the total energy consumption data（KWh）（Fig. 1 and 2） of each day: before optimal controlling real production data is 48696KWh per day, after optimal controlling it is 45737KWh per day, saving 2959KWh. Suppose saving 2000KWh per day (considering real running efficiency), if 360 production days per year, then total saving energy is 700,000 KWh per year.

(2) High efficiency and less maintenance for working pump groups. It can be found from the data of running efficiency of working groups: before optimal controlling average efficiency is 76% in that day (Fig. 3), after optimal controlling it is 81%. For groups efficiency per hour (Fig. 4), before optimal controlling values varies much, highest value is 85%, lowest value is 65%, after optimal controlling values vary from 80% to 85% which indicates that pump groups keep stable running in high efficiency with less maintenance and less expense.

(3) Before optimal controlling adjustment is random, after optimal controlling it is strict. It can be found from the data per hour of running efficiency of working groups. Before optimal controlling adjustment is random, it is difficult to keep groups always in high efficiency working conditions, and after optimal controlling groups efficiency can keep varying in the range of from 80% to 85%.

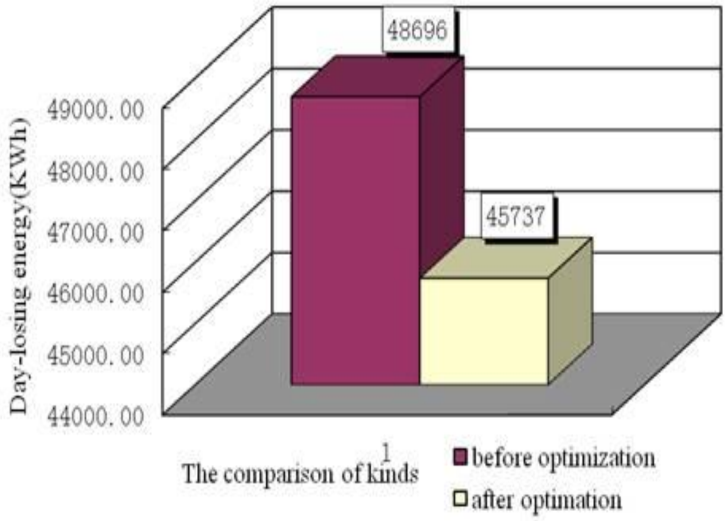
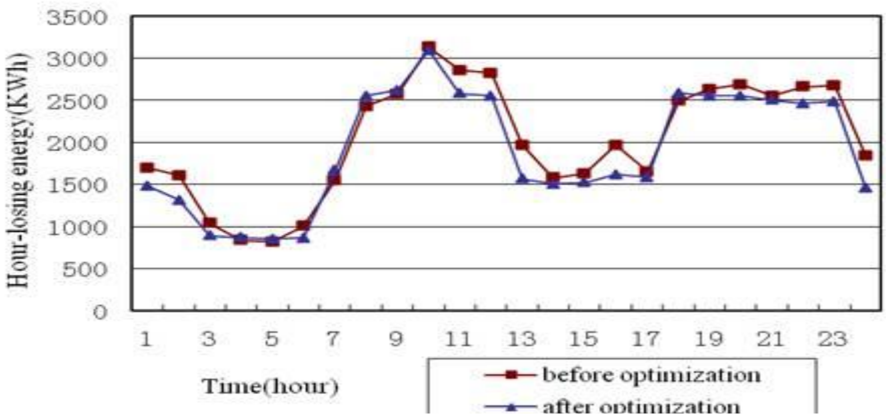


Fig. 1: The comparison of day- losing energy fore-and-after Optimization



Fig, 2: The comparison of hour-losing energy in a day fore-and-after optimization

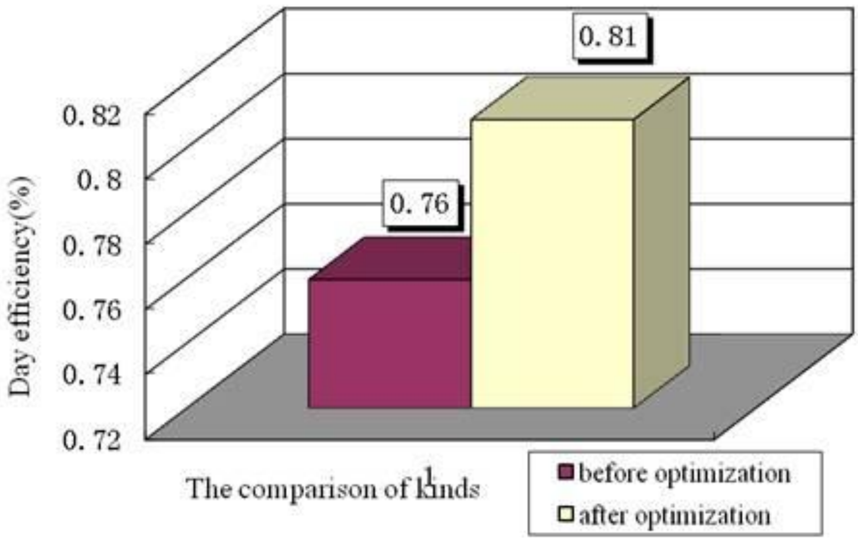


Fig. 3: The comparison of day-efficiency fore-and-aft optimization

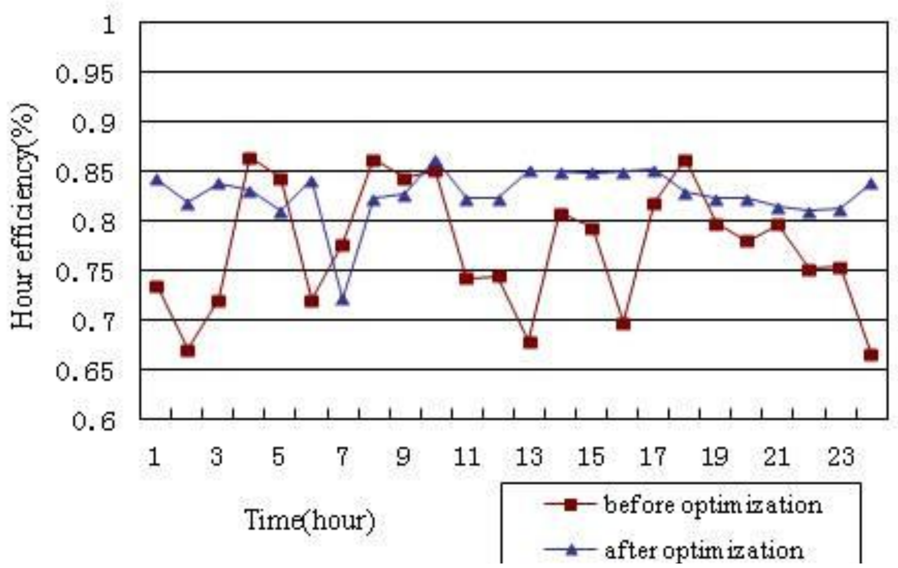


Fig. 4: The comparison of hour-efficiency fore-and-after optimization

V. Conclusions

The paper makes on-line fitting for the system parameters with recursive least square method based on the analysis of the system mathematic model for energy consumption control of the water pump groups and gives an optimal control algorithm for energy saving of the whole pump groups which increases pump working efficiency and is proved to be highly useful for engineering application by the experiences in Shenzhen Water Groups.

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