Variable Frequency Water Intaking Fuzzy PID Control System

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Abstract: The water intaking system of a water works usually controlled the rotation rate of water pumps manually according to experiences, with low accuracy rate and poor energy-saving effect in the past. Combining with the system status, this paper brings forward constructing a variable frequency water intaking control system with PLC and inverter as the core, and by means of fuzzy PID control. During operation of the system, PLC will get the standard inlet flow required for the clean water tank through PID operation according to the difference between the set water level and actual water level of the clean water tank. Then, PLC will compare the standard inlet flow and actual inlet flow of the clean water tank, output control signals through fuzzy PID operation, control the working frequency of inverter, and then control the rotation rate of water pump, adjust the inlet flow of clean water tank, and realize stable liquid level of clean water tank in water supply workshop. The operation and experiment demonstrates that the system make the work of water intaking automated in some degree. It is good for energy saving and improving the management of water works. Copyright © 2013 IFSA.

Keywords: Automatic water intaking system, Water pumps, PLC, Inverter, Fuzzy PID control.

1. Introduction

A water works has a water intaking pump house beside the Yangtze River. The water intaking pump house, with designed capacity of 27,000 m³/h, mainly provides source water of the Yangtze River for the water supply devices of this water works, and meanwhile, provides rough water of the Yangtze River for surrounding water works. The water intaking pump house has six pumps in total, one inverter is adopted to control the cyclic work of multiple water pumps, and all the six motors may be set to work under the mode of frequency conversion. The inverter may control the ON/OFF of electric pumps, provide over-voltage, under-voltage, over-load and output short-circuit protection, etc., realize stepless speed regulation of electric pumps, and thus control the liquid level balance of clean water tank in water supply workshop. Before reconstruction, the system usually controlled the ON/OFF and rotation rate of water pumps manually according to experiences, with low accuracy rate and poor energy-saving effect. After reconstruction, we have established the water intaking control system with the united control of PLC and inverter, and realized automatic fuzzy PID control. After being put into operation, the system has realized the starting and operation of water pumps automatically, and greatly raised the water supply reliability, stability, and economic benefits of this water works [1-5].
In this paper, combining with the automatic water intaking system, a fuzzy PID control method applied to the system with PLC and inverter [6-7]. We firstly research into the overall schematic design of the system, and then hardware design and software design of the system are discussed. Furthermore, it pays attention to introduce the comprising of fuzzy PID controller and methods how to realize, and the fuzzy PID control algorithm to be realized with PLC is given according to the condition of variable frequency water intaking control system. The system overcomes weakness of traditional regulator, has advantages of controlling flexible, programming convenient, adapting well, and increasing the accuracy of the system.

2. Overall Schematic Design of the System

2.1. Technical Requirements of the System

1) The standard water level of the clean water tank is set to be 4m, and the water level is allowed to fluctuate within the scope of ±1 %.
2) The system adopts six water pumps for water intaking, and can realize automatic and manual control.
3) The system operates safely and reliably, and has the functions like short-circuit, over-load, under-voltage and power-off protection, as well as hardware self-locking, inter-locking, and fault alarm, etc.
4) The system can avoid frequent ON/OFF due to inlet flow fluctuation of clean water tank at peak time of water supply.
5) The system has the functions like data communication, acquisition, monitoring, management, and real-time display, etc.

2.2. Composition of Control System

According to the abovementioned technical requirements, the system adopts AC variable-frequency speed-regulating water intaking control scheme. The composition block diagram of the control system is as shown in Fig. 1. The system mainly consists of PLC, inverter, water intaking machine, water intaking pipeline network, various sensors, and instruments.

![Fig. 1. Block diagram of variable frequency water intaking PLC control system.](image)

2.3. System Control Process

During operation of the system, firstly, power shall be supplied to start 1# pump under the mode of frequency conversion, and PLC will determine whether to start the next pump according to the each sensor and output frequency of inverter. In case the output frequency of inverter reaches the upper limit (50 Hz) and the liquid level of clean water tank doesn’t reach the lower limit yet, here PLC will determine to start the next pump, bypass the inverter from the major loop of 1# pump, make 1# pump operate at power frequency, and prepare to start 2# under the mode of frequency conversion, and so forth, until the liquid level of clean water tank reaches the standard value; when the output frequency of inverter...
reaches the lower limit (30Hz) and PLC detects that 
the liquid level of clean water tank reaches the upper 
limit, PLC will firstly stop the pump operating at 
power frequency, in order to reduce the inlet flow of 
clean water tank. If the above-mentioned two signals 
still exist, PLC will stop another motor operating at 
power frequency, until the last pump is controlled 
with inverter, and the liquid level of clean water tank 
reaches the standard value.

In order to avoid oscillatory start & stop of pumps, 
and influences on the service life of electric motors, 
water pumps and electrical equipment, two timers are 
designed in PLC control device to control the start 
and stop of water pumps respectively. Namely, when 
PLC detects that the change of water level reaches 
the upper limit or lower limit through sensor, it will 
restart or stop water pumps after proper time delay, 
and thus avoid the wrong start or stop of water pumps 
due to instantaneous pressure fluctuation.

3. System Hardware Design

According to the actual production requirements 
of the water works, and combining with the performance-price ratio of various control systems, this paper has determined to adopt the technical scheme, namely Schneider ATV71HU22N4 inverter for the control system, Modicon Compact PLC for the lower monitor, and industrial personal computer of ADVANTECH for the upper monitor [8].

Control system consists of the following parts:
1) The lower monitor adopts Modicon Compact PLC, and as a control-level microcomputer, it is the core of the system. It mainly completes the data acquisition, logic control, state identification and feedback, etc. during production process. Modicon’s 140CPU43412 clock speed is 66 MHz, maximum IEC1131-3 programming memory is 896 K, and discrete magnitude is 65,535. After receiving a command, PLC will interpret user’s program automatically, output the operating result to electric control element through I/O module according to logic sequence, control the ON/OFF of controlled electric circuit, and realize the automation of production.

2) The upper monitor adopts ADVANTECH’s industrial personal computer, of which, the configuration is E5300 CPU, 2GB DDR3 EMS memory, 500 G hard disk. It ensures the high-speed processing and reliable storage of massive data.

3) Schneider ATV71HU22N4 inverter is adopted. It includes the main functions of modern variable frequency control, and meanwhile, it can monitor the important parameters during operation of motors directly.

4) Paperless recorder EN880-04 introduces records and retains all monitoring data, and this saves the working procedures of printing out the report forms.

5) The control cabinet integrates PLC, I/O module, relay, terminal block, manual/ automatic switch and local control button, etc., and this is convenient for on-site construction and wiring. Wherein, relay plays the role of enlarging PLC control signals, realizing the transformation of control mode, reflecting the working state and safety protection for controlled equipment; while manual/ automatic switch and local control button are installed for facilitating examination & repair, test run, and emergency stop.

In terms of monitoring, PLC realizes real-time communication with upper monitor through the RS232 interface of communication module [9]. The upper monitor adopts the iFix industrial control configuration software of Intellution Company, completes the functions like data acquisition, sorting-out, alarm, and report form output, etc., and realizes the modification and manual control, etc. of control parameters through human-machine interface.

4. System Software Design

4.1. Cascade Control Design of Water Intaking Pump House

In order to realize liquid level balance of clean water tank in water supply workshop, and the inverter control system of water intaking pump house is designed to be of cascade control. Firstly, technical personnel input the standard water level value of clean water tank into PLC through the human-machine interface of computer, and then, according to the difference between the standard water level and actual water level of clean water tank, PLC will automatically get the standard inlet flow required for clean water tank through PID operation; and according to the difference between the standard inlet flow and actual inlet flow of clean water tank, PLC will get the frequency value required through fuzzy PID operation, and output this value to the analog input port of inverter, and in such case, the inverter will change the frequency, adjust the rotation rate of motor, and make the inlet flow of clean water tank meet requirements. The water level of clean water tank is taken as the primary controlled variable, the water level controller is taken as the primary controller, the inlet flow of clean water tank is taken as the secondary controlled variable, and the flow controller is taken as the secondary controller. The system has primary and secondary controlled variables, and primary and secondary controllers, which form primary and secondary circuits, and realize cascade control of the system. The set value of the primary controller in the system is regulated according to technical requirements, while that of secondary controller is given by the primary controller during adjustment [10, 11]. The schematic diagram of cascade control is as shown in Fig. 2.

The inverter control of water intaking pump house is designed to be a cascade control system, which has the following functions:
1) It can overcome the turbulence caused by accessing the secondary circuit quickly. If only the turbulence affects the secondary controlled variable, the adjustment process will start immediately, and the dynamic deviation of primary controlled variable will be greatly reduced. Once the inlet flow of clean water tank is affected by the dredging of flocculation basin and horizontal flow tank, and the backflushing of filter chamber, the secondary controller will adjust the frequency of inverter immediately, maintain the inlet flow of clean water tank, and relieve the influences on the water level of clean water tank.

2) The existence of secondary circuit accelerates the response of primary circuit.

3) The existence of secondary circuit greatly reduces the influence of change in process characteristics inside the circuit on the primary controlled variable, and realizes more accurate adjustment of manipulated variables.

4.2. Controller Design

The variable frequency water intaking control system is a time-varying, non-linear, large time-delay, and unstable-model system. Therefore, adopting only PID control will result in relatively poor dynamic performance of the system, namely not only long adjustment time, but also possibly relatively severe overshoot and oscillation, and even instability of the system. For such system with fluky parameters, fuzzy control can well embody its superiority [12-14].

In this system, we have constructed the fuzzy PID controller of self-adjustment modifying factors by combining PID control and fuzzy control [15], and adding the thought of self-adaption. The thought is to modify PID parameters by taking error $e$ and error change rate $\frac{de}{dt}$ as input, and making use of fuzzy control rules. The schematic diagram of control is as shown in Fig. 3.

Fig. 3. Schematic diagram of fuzzy PID control of self-adjustment modifying factors.

Fig. 4 shows the block diagram of fuzzy PID control system of the secondary control circuit in this system. The block diagram of this system consists of two parts, and the flow rate of water intaking pipeline network is controlled with the fuzzy controller or PID controller of self-adjustment modifying factors according to different control policies. The basic principle for selection of control policies is as shown below: With the error of flow as the condition for selection, and within a big error scope, fuzzy control of self-adjustment modifying factors will be adopted to raise the speed of dynamic response and strengthen the ability of self-adaption; and within a small error scope, PID control will be adopted to eliminate static error and raise control precision. Meanwhile, in order to prevent over-frequent control switching, the system regulates no switching of control policies at the switching point of errors, but maintaining the previous action.

The actual operation of the system has proved that, the control mode has not only fast dynamic response and good control precision, but also good robustness and adaptation ability in case of change in object parameters and structure.

Fig. 4. Block diagram of fuzzy PID control system of secondary control circuit.
4.3. Control Program Design

The PLC control program design of the system mainly covers the configuration of hardware, the allocation of I/O address, the division of program structure, the design of program flow, and the compilation of ladder diagram. All works are realized mainly by means of program design with Modicon Concept V2.2 programming tool. It is an advanced programming tool based on Windows environment, and supports all the five languages in IEC1131-3 international standard, namely sequence function chart (SFC), functional block diagram (FBD), ladder diagram (LD), structuralized text (ST) and instruction list [16]. By using standardized programming unit, users may create application programs which integrate control, communication and diagnosis logic.

By means of programming, we have realized the main program of system, motor control subprogram, PID control subprogram, self-adjustment modifying factor fuzzy control subprogram, fault detection and alarm processing subprogram, liquid level set subprogram, liquid level detection subprogram, analog processing subprogram, parameter display subprogram, and communication data processing subprogram, etc. Wherein, the flow chart of the main program of system is as shown in Fig. 5.

The main program of system first complete the system initialization, and make the expansion module (communication module, A/D module, etc.), touch screen, inverter and other equipment to transfer data with PLC normally. When the system is running, the program can detect the fault in order to prevent equipment damaged and accidents. If the system fails, information will be displayed on the touch screen to alarm, it will be convenient for service personnel to repair the system failure. If the system is normal, we can set some of the initial value on the touch screen, such as the liquid level. Constant water level control will be operated after the system starts automatically.

The flow chart of self-adjustment modifying factor fuzzy control subprogram is as shown in Fig. 6.

This subprogram is transferred for specific task through timing interception, and realizes constant inlet flow of clean water tank by adjusting the rotation rate of water pumps. Firstly, when the main program system is initialized, the error clearing unit and error change unit will read the output of analog expansion module from the subprogram, and get the current actual inlet flow of clean water tank. Based

Fig. 5. The flow chart of the main program of system.

Fig. 6. Flow chart of self-adjustment modifying factor fuzzy control subprogram.
on this flow rate minus the set value of flow rate, we can get the current error quantity; based on this error quantity minus the previous one, we can obtain the change of error; and by calculating the current error e and error change rate $e_c$, we can inquire fuzzy control table, and get the fully control quantity, namely $K_p$, $K_i$, $K_d$ in PID control, for the transfer of PID subprogram, in order to realize constant inlet flow of clean water tank.

The flow chart of motor control subprogram is as shown in Fig. 7. The program can complete the control of six water pumps running and stopping. Because the inverter output frequency and the rotation rate of the pump are directly related to water consumption, the inverter output frequency and the rotation rate of the pump are increased with higher water consumption, and decreased with lower water consumption. The program can determine and control the working status of the pump according to the inverter output frequency.

### 4.4. Configuration of Upper Monitor

The upper monitor of this system adopts the iFix industrial control configuration software of Intellution Company. Here, iFix is a powerful HMI/SCADA system, which can realize graphical process monitoring, data acquisition and management, real-time and historical trend drawing, and has extremely strong interactivity and dynamic demonstration function [17]. This configuration interface mainly consists of five functional parts:

1. Main flow chart: Used to monitor process flow parameters, equipment state and alarm, and pump operation;
2. Valve location control: Used to operate valve switch, and monitor valve state;
3. Historical trend: Used to display the historical curve of each operating parameter;
4. Channel point table: Used by maintenance personnel of instruments and electric appliances; and to be accessed after keying in password;
5. Parameter setting: Used to set up and modify system parameters, such as parameters of PID regulator, and upper and lower limits of liquid level of clean water tank, etc.; to be accessed after keying in password.

The main process flow of this water intaking pump house is as shown in Fig. 8.

### 5. Conclusions

According to the actual change of liquid level of clean water tank in water supply workshop, this variable frequency water intaking control system may adjust the rotation rate of water pumps automatically and the flow rate of water intaking smoothly, maintain the stable water level of clean water tank, and realize unattended operation, high-efficiency &
Fig. 8. Process flow configuration chart of water intaking pump house.

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