DESIGN OF EXCITATION REGULATION SYSTEM AND CONTROL PROGRAM FOR HYDROELECTRIC GENERATOR BASED ON PROGRAMMABLE LOGIC CONTROLLER

Bingsen CHEN[1], Qixing DENG[2,*], Rong LIAO[3], Zhengquan TANG[4], Huali HU[5], Lingyan HE[6]

In order to reduce the cost of the excitation system for small hydro generators and achieve computer regulation control, a small hydro generator excitation regulation system based on Siemens S7-200 series PLC was developed. The excitation system adopts a self parallel excitation method, consisting of an excitation transformer, a three-phase fully controlled bridge type thyristor rectifier circuit, and a demagnetization switch to form the excitation main circuit. The adjustment control circuit is composed of a PLC and corresponding signal processing circuit. The excitation adjustment control program is written using PLC ladder diagram language to detect the electrical signal and working status of the generator, and PID adjustment calculation is achieved. Finally, each thyristor trigger control pulse is generated, realize the regulation and control of the excitation DC current of the generator rotor winding. The design results have been put into production and successfully applied in multiple small hydropower stations.

Keywords: generator; excitation regulation; PLC; programming.

1. Preface

When the generator is working, it is necessary to first establish the electromagnetic field required for energy conversion. The generator excitation regulation system is to provide adjustable and controllable excitation current for synchronous generators, forming an electromagnetic field that can be regulated during normal operation of the generator, thereby maintaining the generator or

[1] Bingsen CHEN, Guangxi Vocational College of Water Resources and Electric Power, China, e-mail: 82412777@qq.com
[2*] Qixing DENG, Guangxi Vocational College of Water Resources and Electric Power, China, corresponding author's e-mail: 84924767@qq.com
[3] Rong LIAO, Guangxi Vocational College of Water Resources and Electric Power, China, e-mail: 575795886@qq.com
[4] Zhengquan TANG, Guangxi Vocational College of Water Resources and Electric Power, China, e-mail: 2289838186@qq.com
[5] Huali HU, Guangxi Vocational College of Water Resources and Electric Power, China, e-mail: 176458303@qq.com
[6] Lingyan HE, Guangxi Vocational College of Water Resources and Electric Power, China, e-mail: 497228377@qq.com

power station bus voltage at a given level, controlling the reasonable distribution of reactive power of parallel operating units, and improving the operational stability of the power system[1,2].

With the development of control theory and electronic device development and application technology, the excitation equipment of generators has evolved from mechanical to electromagnetic and electronic, from analog to digital, and the excitation method has also evolved from exciter excitation or phase compound excitation to static excitation. Modern static excitation of generators uses thyristors as controllable rectifier components and microcomputers as excitation regulation controllers[3-6]. It not only has the advantages of simple main circuits and excellent regulation performance, but also has high reliability and easy maintenance, making it the most widely used excitation regulation system for generators.

Large and medium-sized generators have a significant impact on the safety and stable operation of the power system. Therefore, it is required that the microcomputer excitation regulator of the generator should have a fast response speed, and be equipped with functions such as the power system static stabilizer PSS [7,8], automatic voltage control AVR, and improved and optimized PID control that require a large amount of complex calculations[9,10]. Therefore, most large and medium-sized generators use dedicated excitation regulation controllers developed with high-performance microprocessors to meet their requirements for speed and complex computing capabilities. For small hydro generators, especially those with a single unit capacity of 250-1600kW, their impact and influence on the power system are very small. The power system does not have high requirements for excitation regulation, and PSS and AVR functions are not specified to meet the basic technical requirements of the excitation system for small and medium-sized synchronous motors[11]. Therefore, due to cost constraints, a PLC with high reliability, strong anti-interference ability, convenient use and maintenance, simple programming and debugging, and low price can be used as the excitation regulation controller to achieve excitation regulation control for small hydro generators.

2. Overall design scheme of generator excitation regulation system

The overall design of the generator excitation regulation system is shown in Fig. 1. The excitation of the generator adopts a self parallel excitation method. The excitation current of the generator rotor winding required for normal operation of the generator GS comes from the output end of the generator. The three-phase AC power output by the generator stator winding is reduced by the excitation transformer TSH[12], and then converted into controllable DC (L1+, L1-) through a three-phase fully controlled bridge rectifier circuit composed of 6 thyristors VS1~VS6. It is then sent to the generator rotor excitation winding through the demagnetization switch QFM[13], In order to regulate and control the magnetic field intensity during the operation of the generator, and finally achieve the regulation and control of the output voltage and reactive power of the generator. RC circuits connected in parallel at both ends of each thyristor are used for thyristor commutation overvoltage protection.

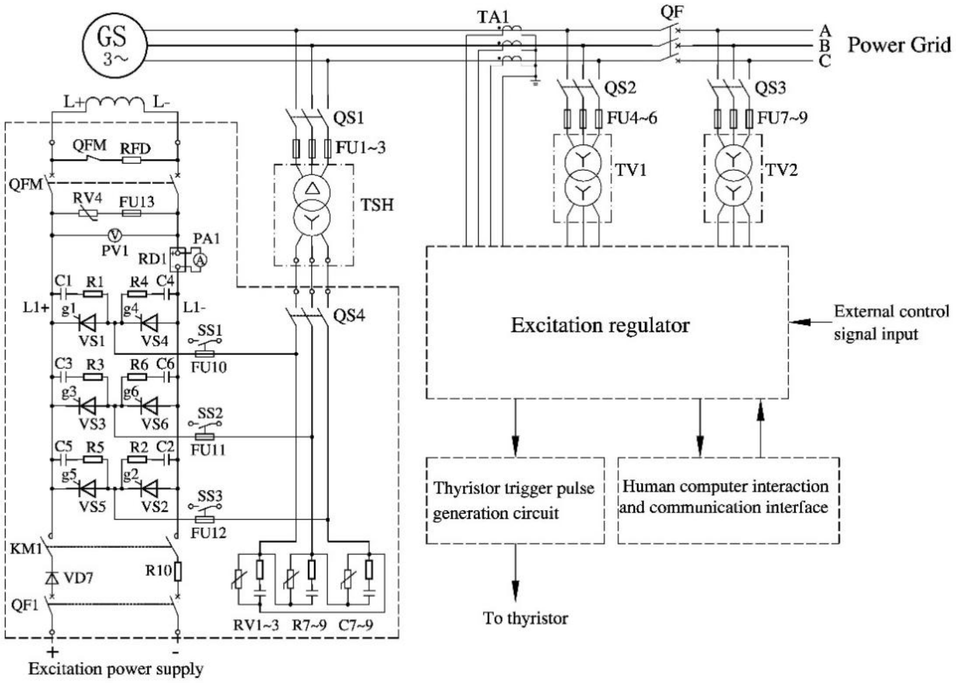


Fig. 1 Overall design plan of generator excitation system

To protect the excitation main circuit, fuses FU1-3 are installed on the high voltage side of the TSH circuit, while fast fuses FU10-12 and excitation circuit overvoltage protection composed of RV1~RV3, R7~9, and C7~9 are installed on the low voltage side. A demagnetization circuit composed of normally closed QFM contacts and discharge linear resistor RFD is installed, and RV4 is used for overvoltage protection of the DC output part of the thyristor.

In order to avoid the insufficient residual voltage of the generator (generated by the residual magnetic field of the rotor during idle operation) to achieve self parallel excitation and voltage building of the generator, an external DC excitation circuit is set up, which is connected by the external DC excitation power supply through circuit breaker QF1, diode VD7, contactor KM1, and demagnetization switch QFM to the generator rotor winding. After the generator voltage building reaches the set value, it automatically exits.

The excitation regulator collects the voltage and current signals at the generator outlet through the voltage transformer TV1 and current transformer TA1[14], the grid voltage signal through the voltage transformer TV2, the excitation current signal from PA1 through the DC transmitter, and the position signals of the generator circuit breaker QF and the demagnetization switch QFM through the auxiliary contacts, which are used to detect the generator voltage, current, grid voltage, and excitation current values, Detect whether QFM is in the closed position and determine whether the generator is in parallel operation with the power grid. In addition, it also receives external control signal inputs and human-machine interaction signals. Finally, based on the collected data, status information, and control commands, corresponding adjustment operations and logical control are carried out to obtain the thyristor control angle. Through the thyristor trigger pulse generation process, trigger pulse signals g1~g6 of the thyristors VS1~VS6 are generated, Realize the regulation and control of the excitation current of the generator; When the operating data of the unit reaches the pre-set limit protection value, the generator set is limited to operate within the normal and safe range to ensure safe and reliable operation of the generator set.

3. Electrical design of generator excitation regulator based on PLC

According to the overall design scheme of the generator excitation regulation system[15], Siemens S7-200 series PLC is selected as the excitation regulation controller. The specific configuration includes one CPU 224XP (14 switch signal inputs/10 switch signal outputs/2 analog signal inputs/1 analog signal output) PLC and one EM235 (4 analog signal inputs/1 analog signal output) expansion module, Simultaneously equipped with one TK6070i touch screen as a human-computer interaction device. The allocation of PLC input/output addresses is shown in Tables 1-2.

Table 1

PLC switching signal input/output address allocation table

Input Address	Signal and Function	Output address	Signal and Function
I0.0	Generator current (pulse)	Q0.0	Manual Control (J3)
I0.1	Unit automatic control	Q0.1	QFM closing operation (J4)
I0.2	Trigger pulse loss	Q0.2	Deexcitation operation(J5)
I0.3	Generator frequency (pulse)	Q0.3	Excitation start operation (J6)
I0.4	Quick fuse blown	Q0.4	PLC malfunction (J7)
I0.5	Manual control effective	Q0.5	Fault alarm ringing
I0.6	Unit protection action	Q0.6	Tracking the power grid
I0.7	Inverter effective	Q0.7	QF closing operation
I1.0	Excitation start signal		
I1.1	QF closing position		
I1.2	QFM closing position		
I1.3	Excitation increase		
I1.4	Excitation decrease		
I1.5	Excitation fan shutdown		

Table 2

PLC analog signal input/output address allocation table

Address	Signal and Function	Wiring location
AQW0	PID Output	CPU 224XP
AIW0	Excitation current input	CPU 224XP
AIW2	Generator voltage input	CPU 224XP
AIW4	Generator reactive power input	EM235
AIW6	Generator power factor input	EM235
AIW8	Manual control of given value input	EM235
AIW10	Grid voltage input	EM235

According to Table 1 and the PLC switch signal input wiring required for generator excitation regulation control, as shown in Fig. 2 (2), the generator current from TA1 and the generator frequency waveform signal from TV1 are converted into pulse signals through signal processing circuits and input to the I0.0 and I0.3 terminals of the PLC, respectively. The measurement of generator current and frequency is then completed using the built-in high-speed counter of the PLC. I0.1 is the automatic control signal of the generator set input externally; I0.2 is taken from the triggering pulse generation stage of the thyristor. The PLC outputs a PID control signal, but this signal is triggered when the triggering pulse generation stage of the thyristor does not generate the triggering pulse; I0.4 takes relay KA3 controlled in parallel with SS1-3 contacts in Fig. 1, and triggers this signal when any fast fuse blows; I0.5 is the excitation manual control signal; I0.6 is taken from the relay KX1 contact of the generator set accident signal control; I0.7 is the effective signal for generator shutdown and inverter demagnetization; I1.0 is taken from the contact of the excitation control contactor KM2 on the screen/remote generator start; I1.1 and I1.2 are taken from the contacts of the circuit breaker QF position reset relay KA1 and the demagnetization switch QFM, respectively; I1.3 and I1.4 are taken from the contacts of relays J1 and J2 for on screen/remote control excitation increase/decrease signal control (in Fig. 2 (1)); I1.5 takes the contact of the control relay KA6 for the self-excited cooling fan.

The output wiring of PLC switch signal is shown in Fig. 2 (3). The output terminals of PLC switch signal Q0.0~0.7 are controlled by relay or direct control to complete manual/automatic switching of excitation mode, QFM closing operation, shutdown and demagnetization operation, generator excitation start operation, PLC fault alarm, fault alarm bell, tracking power grid, QF closing operation, etc. In Fig. 2 (3), both ends of each relay are connected in parallel with freewheeling diodes to protect the PLC output port from damage caused by the self induced potential of the relay.

From Table 2, it can be seen that the control angle voltage signal obtained by PLC through PID calculation is output from the analog AQW0 port to the thyristor trigger pulse generation circuit. The analog signals that PLC needs to collect, including generator excitation current, generator terminal voltage, generator reactive power, power factor, manual control set voltage, grid voltage, etc., are first transmitted through the corresponding transmitter and then connected to the corresponding analog input terminals AIW0~10 of PLC, Then, the PLC completes the conversion, calculation, and adjustment of analog to digital signals for control and status display.

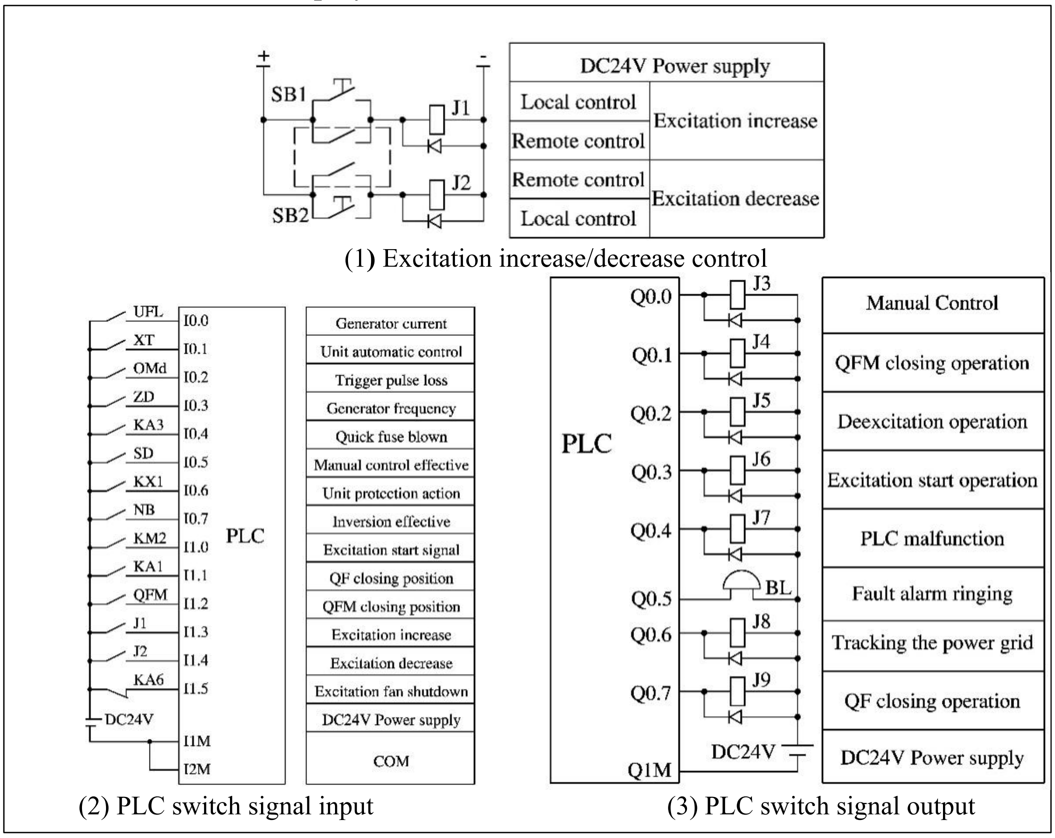
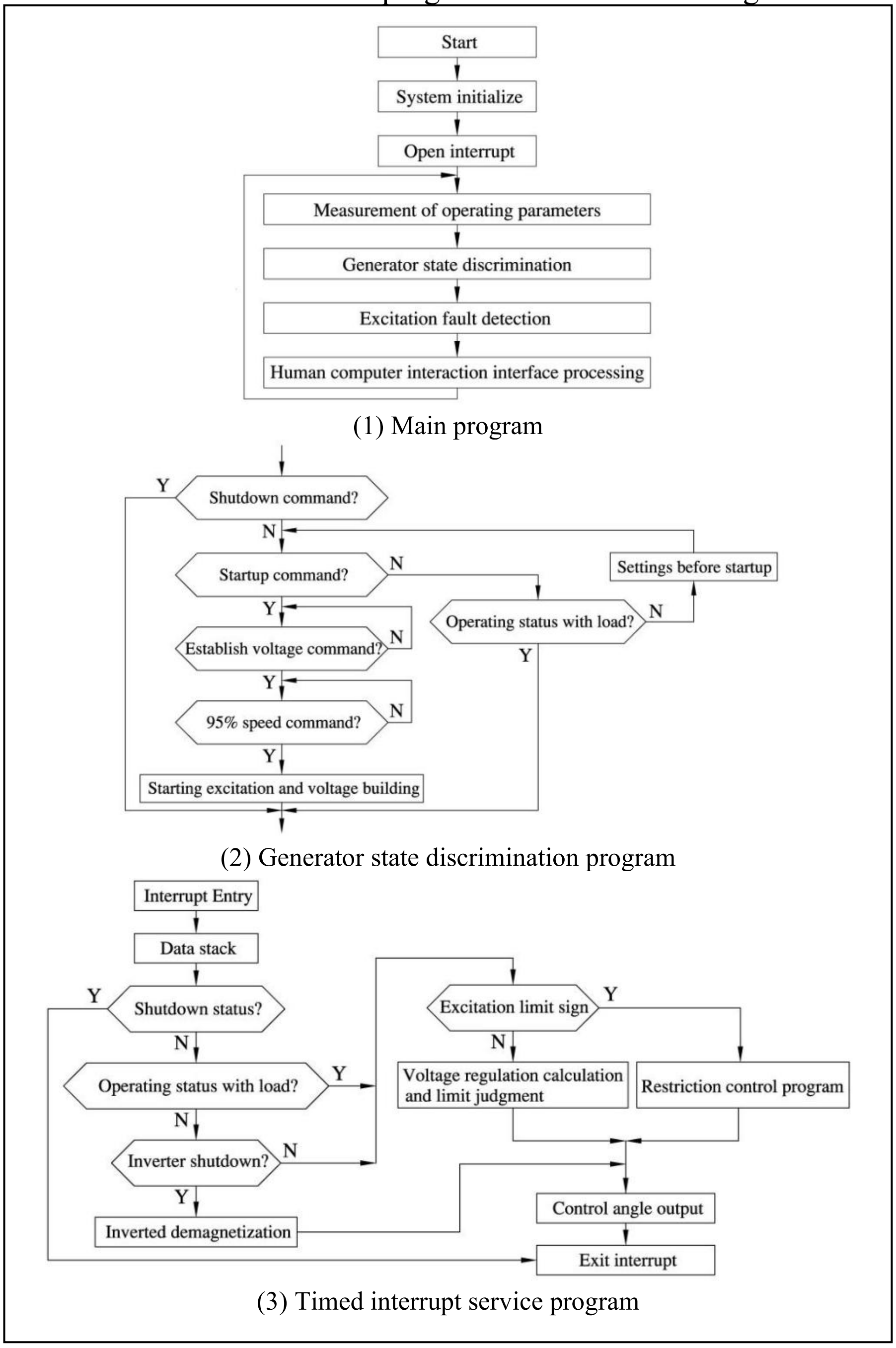


Fig. 2 PLC switch quantity wiring schematic diagram

4. Design of generator excitation adjustment control program based on PLC

4.1 Overall idea of program design

The excitation regulation control program of the generator based on PLC is developed using STEP 7-Micro/Win V4.0 software and ladder diagram programming language, consisting of the main program, subroutines, and timed interrupt service program. After completing system initialization and opening interrupts, the main program cycles through subroutines such as unit operation parameter measurement, unit status discrimination, excitation fault detection, human-machine interface processing, etc. The timed interrupt service program is mainly used to output the thyristor control angle under different working conditions at a fixed time. The main control program flow is shown in Fig. 3.



(1) Main program

(2) Generator state discrimination program

(3) Timed interrupt service program

Fig. 3 Main control program flow of PLC

To adjust the excitation current of a generator under normal working conditions, it is necessary to first measure the relevant operating parameters of the generator, then calculate the deviation between the measured value of the generator terminal voltage (or reactive power) and the given value, use the PID parameters set in each link to perform PID operation, and finally obtain a control signal. Then, through phase shifting contact, a thyristor trigger control pulse is generated to achieve the regulation and control of the generator excitation current. The S7-200 PLC has 8 built-in PID control circuits, one of which can be selected and the PID set value range can be configured using a wizard. The proportional gain, integration time, differentiation time, and sampling time of the PID circuit are calibrated, the process variables and output value range of the circuit are calibrated, the circuit alarm options are determined, the PID storage area is allocated, the automatically created PID initialization subroutine and interrupt service program are named, thereby simplifying the programming of the PID calculation part.

4.2 Main program

The control process is shown in Fig. 3 (1). Firstly, using the SM0.1 in the SM special function register where the PLC first scans as 1, the PID initialization subroutine PID0-INIT is called to load the initial values of the PID circuit. At the same time, SM0.1 is used to open the timing interrupt. After each sampling time interval, the timing interrupt service program collects the measurement value and re executes the PID operation. The result is output from AQW0 and then interrupted and returned. In addition, The initialization of the system also includes loading various parameters into corresponding storage units, completing the data connection between the touch screen and PLC, etc. Afterwards, the main program calls each subroutine in a loop, and each subroutine will also call the next level subroutine to complete the corresponding adjustment and control tasks based on the running mode and unit status.

4.3 Sub program

There are many sub program for generator excitation regulation, which can be set as needed. The most important sub program is the generator state discrimination sub program, as shown in Fig. 3 (2). Firstly, determine whether the generator is currently in a shutdown, startup, or grid connected with load operation state. If a shutdown command is currently received, set the shutdown status to execute the shutdown demagnetization command until the generator shutdown is completed and the generator voltage and speed (frequency) are zero. If the current startup command is received, continue to wait for the generator to establish the voltage command. When the generator establishes the voltage command and the generator speed reaches 95% of the rated speed (corresponding to the generator frequency of 47.5Hz) or above, execute the generator excitation establishment voltage subroutine, and the generator enters the no-load state. Afterwards, wait for the generator monitoring system to complete the generator grid connection operation. After the circuit breaker QF is in the closed position, automatically confirm that the generator has entered the load state and call the PID parameters of each link in the load state to perform PID calculations, thereby obtaining the required adjustment performance of the generator under both no-load and grid connected operation conditions.

4.4 Timed interrupt service program

The control process is shown in Fig. 3 (3). Firstly, determine the status of the generator. In the shutdown state, do not perform PID operation and output, and directly exit the interrupt; In the state of no-load inverter (i.e. shutdown inverter demagnetization), execute the inverter demagnetization sub program, output the control angle that allows the thyristor to enter the inverter working condition, and achieve inverter demagnetization; In the state of startup, no-load or grid connected with load operation, first determine whether to enter the limiting excitation current working condition. If so, the limiting control subroutine outputs the limiting excitation control angle and exits the interrupt; If not, perform PID adjustment calculation and output the corresponding control angle, and finally exit the interrupt.

5. Conclusion

A self parallel excitation small hydroelectric generator excitation regulation system developed based on Siemens S7-200 series PLC consists of an excitation transformer, isolation switch, fast fuse, three-phase fully controlled bridge thyristor rectifier circuit, and demagnetization switch to form the excitation main circuit. At the same time, an external power source excitation circuit is configured; A PLC excitation regulation controller is composed of one CPU 224XP and one EM235 expansion module, equipped with corresponding signal processing circuits and transmitters. It samples, detects and calculates the operating parameters and equipment working status of the generator, uses the built-in PID command of the PLC to complete the PID calculation of the generator excitation regulation, and finally generates thyristor trigger control pulses to regulate and control the generator excitation current, fully meeting the basic technical requirements of small and medium-sized synchronous motor excitation systems. Compared with the excitation regulation system of hydroelectric generators professionally designed and developed using high-performance microprocessors and high-resolution A/D converters, this design is weaker in terms of information processing and response speed, but it achieves the design goals of low cost, high reliability, and easy use and maintenance, which can meet the needs of excitation regulation for small hydroelectric generators.The FKL-PLC fully controlled bridge programmable generator excitation system produced according to this design has been put into use in multiple hydropower stations, with stable operation and good performance.

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