ADAPTIVE PLC INTELLIGENT CONTROL BASED ON THE INTEGRATED SYSTEM OF SMART GRID THERMAL ENERGY CONVERSION

by

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During the construction of smart grids, due to technological limitations, traditional sequential control systems have been unable to meet the needs of grid operation, exposing problems such as single control methods and functions, low operational efficiency, inability to independently complete complex tasks, and poor anti-interference ability, which in turn affect the power supply quality and operational stability of the grid, and fail to truly achieve the reliability, safety, and reliability of smart grids Economic and efficient goals. For this purpose, the author describes an adaptive intelligent control method for an integrated biomass energy heat conversion system consisting of more than one suction biomass gasifier, biomass gas burner, and steam boiler. The system uses PLC as a tool and takes the boiler outlet steam pressure as the control parameter. Based on the changes in the boiler outlet steam pressure, it automatically adjusts the feed and gas production of the gasifier, and subsequently adjusts the air supply of the burner. Ultimately, it achieves the goal of automatically adjusting the boiler heating volume with changes in steam pressure. The integrated heating and adaptive intelligent control system based on biomass gasification has been reliably verified in industrial applications.

Key words: *smart grid, integrated thermal energy conversion system, adaptive, PLC intelligent control*

Introduction

Compared with traditional control systems, PLC control systems have the characteristics of reliability, simple programming, complete functional modules, fast operation speed, and flexible configuration. Among them, reliability characteristics refer to the system with PLC as the core, and the controller is composed of a certain number of single-chip microcomputers, with an integration level much higher than that of relays. The PLC device itself has functions such as circuit protection and self diagnosis, and can self detect and handle fault problems without manual intervention, maintaining the efficient operation of the PLC control system. The simple feature of programming refers to the PLC control system program, which adopts the control ladder diagram method. The feature of complete functional modules refers to the PLC control system being able to simultaneously connect on-site signals such as switching values, voltage, current, digital quantities, and corresponding components to the input/output terminals of the module, providing diversified usage functions and effectively meeting the control needs

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of the smart grid. The characteristic of fast operation speed refers to the PLC control system adopting a program control execution method, which makes the system's operating efficiency and on-site signal processing ability far exceed traditional relay logic control systems. The flexible configuration feature refers to the innovative adoption of a modular structure in the PLC system, formed by the assembly of several module units. During the changes in smart grid control requirements and the upgrading and renovation of the PLC control system, staff only need to adjust the system structure, add or remove module units, and can change the system scale and functional configuration structure [1]. From the perspective of operational efficiency, the PLC system can efficiently handle the massive data continuously generated during the operation of the power grid, maintain the actions executed at a second level to achieve control objectives such as online monitoring of components, timely response, and rapid diagnosis. For example, in the decision support scenario of the 1 million volt level ultra-high voltage AC project of the Yellow River crossing, the PLC system continuously collects, categorizes, and transforms massive system data into understandable information for staff, and provides decision analysis suggestions to reduce decision time and improve the feasibility of decision plans. The use of renewable energy to establish a sustainable energy system is of great significance for promoting national economic development and environmental protection. In recent years, the use of biomass energy in upward suction gasifiers, downward suction gasifiers, and circulating fluidized bed gasifiers has achieved rapid development in applications such as power generation, rural heating, and drying. In addition, theoretical research on the mechanism, process, and influencing factors of biomass gasification has achieved significant progress and accumulated rich experience in the study of the structure and performance of gasifiers. The author conducted research on the control process of an integrated thermal energy conversion system composed of a fixed bed suction biomass gasifier and a steam boiler, exploring the automatic control methods of gasifier feeding, gasifier blowing, boiler negative pressure combustion, and boiler burner based on the boiler outlet steam pressure, and obtaining reliable verification in practical applications.

Introduction smart grid dispatching and control system

The smart grid dispatching control system co-ordinates the production and management needs of power regulation institutions at all levels, follows the service-oriented architecture (SOA) idea, and has four types of transmission buses: real-time dynamic message bus with self-documenting code function, simple service bus with security authentication function, simple message mail bus supporting trans regional transmission, and real-time data communication bus based on standard application layer protocol, it can achieve *horizontal integration the edge and vertical penetration the bottom*. Provide standard and standardized exchange services, model services, data services, graphic services, and application services to achieve the exchange and sharing of power grid models, graphics, and real-time data among various specialties within the dispatch system and among the dispatch system, achieving *source end maintenance and global sharing*.

Method

Structure and control content of biomass gasification thermal energy conversion integrated system

The integrated system for biomass gasification and heat energy conversion consists of three parts: gasifier, burner, and boiler. The system structure is shown in fig. 1. Biomass, mainly consisting of waste wood scraps from furniture factories, undergoes pyrolysis and oxidation-reduction in a high temperature and anoxic state in a gasifier, generating small molecular weight combustible gases such as CO, H_2, and CH_4. During the gasification process, gasification agents such as air need to be added [2]. Biomass gas is transported through pipe-lines to the biomass gas burner, mixed with air, and burned in the boiler furnace. The boiler absorbs heat to generate high temperature steam, which is then transported to the steam consuming enterprise through the pipe-line network. Biomass gas can replace diesel to provide cheap energy for boilers, and can replace coal to provide clean and environmentally friendly energy for boilers [3, 4].

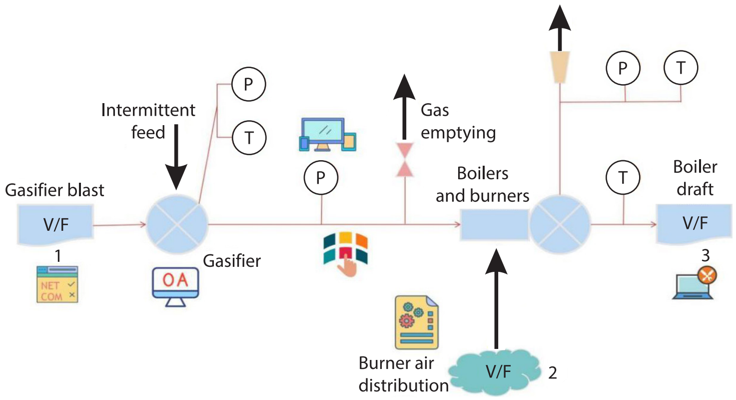

Figure 1. Integrated system for biomass thermal energy conversion

The integrated control of biomass gasification furnace, burner, and boiler is to achieve the best gasification efficiency and facilitate safe operation and use by users. The control content of these three parts is as follows. Gasifier: ignition start, 1 shutdown, feeding hopper operation control, material level detection, top cover opening and closing control, raw material inlet secondary gate valve opening and closing control, ash removal control, blower air volume control, as well as temperature and pressure detection in the drying zone, pyrolysis zone, and combustion zone of the gasifier. Burner: front and rear blowing control, ignition control, stable combustion control, flameout protection control, combustion air distribution control, and flame detection. Boiler: steam supply control, induced draft and negative pressure control, water level detection and replenishment control, steam pressure detection, exhaust gas temperature and oxygen content detection. The boiler of the thermal energy conversion system is mainly aimed at 2-6 tonne per hour boilers applied in textile factories, material processing, food processing, and environmental protection industries. The biomass is mainly composed of residual wood from furniture factories, and its irregular shape cannot be continuously fed by spiral conveyor. Therefore, the hopper method is used for intermittent feeding [5, 6].

Basis for gasification intensity control based on boiler outlet steam pressure

Under the premise of a certain water level in the boiler, the change in steam pressure at the outlet of the boiler is related to both the fuel supply to the furnace and the output steam flow rate. The fuel supply depends on the gasification of the gasifier and the gas output, and the steam output flow depends on the load demand of the user. When the opening of the output flow control valve is constant, the gas supply increases, and the outlet steam pressure and steam flow rate also increase. If the gas supply is constant and the opening of the regulating valve increases, the output steam flow rate immediately increases, and the pressure decreases accordingly. Therefore, the control of gasifiers based on steam pressure must consider the disturbance factor of steam output flow, and change the corresponding control rules when the steam output regulating valve changes. Under stable operating conditions, the fuel heating capacity, Q, required by the boiler per hour can be calculated:

$$Q = \frac{Q_1}{\eta} - Q_2 \tag{1}$$

where Q_1 is the heat output of steam per hour. Based on the pressure of steam output from the boiler, the enthalpy value of steam under this parameter is determined by checking the enthalpy entropy chart of water vapor. Combined with the hourly steam production of the boiler, Q_1 is obtained, Q_2 is the amount of heat contained in the hourly makeup water, which can be calculated based on the heat capacity, temperature, and hourly makeup water volume of the boiler's makeup water. Although the intermediate process of fixed bed gasification is quite complex, the final product is a relatively simple gas mixture, and the amount of blast air supplied to the gasifier is directly related to the gas output of the gasifier. When the amount of biomass raw material is fixed, the air-flow increases, the oxidation reaction temperature increases, which is conducive to the gasification, thus increasing the combustible gas content. When the air-flow reaches a certain value, the combustible gas composition reaches the maximum value. But as the air-flow continues to increase, the content of combustible gases decreases due to the increase in CO_2 and N_2 content in the gas. When the opening of the boiler output steam regulating valve is constant, there is a corresponding relationship between the outlet steam pressure and the gasification drum air volume of the gasifier. The basic principle of the adaptive control model of the gasifier and boiler combustion hydronics is: Determine the pressure of the steam output according to the user's requirements. In order to keep the pressure constant, when the pressure has an increasing trend, reduce the gasification blast volume of the gasifier.

Integrated control structure and design

The biomass gasification and combustion hydronics includes gasifier, burner and boiler. In order to achieve the best relationship between steam output and gasification intensity, it is difficult to achieve the goal by relying on the separation control of the original controllers of the aforementioned three parts, therefore, it is necessary to adopt an integrated control method when using biomass gas as fuel for boiler transformation. When integrating control, the following basic requirements need to be considered: Control requirements for boilers. The output steam volume needs to adapt to changes in load. For a 2 tonne per hour boiler, the load variation range is 0~2 tonne per hour. The set value range of output steam pressure is usually 0~1.2 MPa, and the corresponding steam temperature is 79~1889 °C. The allowable deviation range of output steam pressure is 1~3%. The negative pressure of the furnace is maintained at around 0.5 kPa.

Control requirements for gasifiers. For a 2 tonne per hour boiler, maintain an hourly feed rate of 300 kg and a blast rate of around 300 m^3 for the gasifier. Maintain the pressure inside the gasifier and the output pressure of the gas at around 0.5 kPa positive pressure. The height of the biological material layer in the gasifier shall not be less than 80% of the maximum material layer height. During the gasification process, the temperature of the combustion layer is maintained between 900 °C and 1100 °C . The fixed bed suction gasifier with discontinuous feeding through a hopper reduces the blowing rate to the minimum during each feeding to prevent flue gas overflow. The biomass material supply for the gasifier is intermittently supplied by the hopper, and the material level detection sensor and hopper control program ensure the material layer height. Therefore, the feeding factor can be ignored in the steam pressure control program. The water level of the boiler also has a water level detection sensor and a water level control program to ensure the height of the water level, so the water level factor is not considered similarly. The integrated control principle structure designed with PLC as the core is shown in fig. 2 [7].

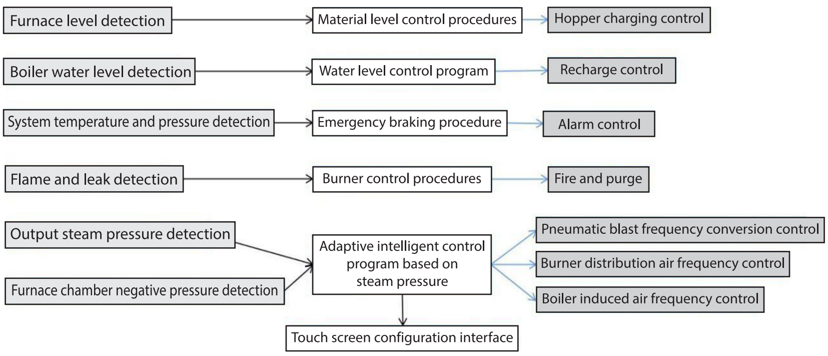

Figure 2. Integrated control structure diagram

Integrated system main control procedures

Integrated control includes gasification furnace material level detection and feeding control program, boiler water level detection and replenishment control program, emergency braking program based on temperature and pressure, gasification furnace gasification intensity control program based on steam pressure, boiler furnace negative pressure control program, and burner control program. The amount of air supplied to the gasifier within a certain range is directly related to the gas output of the gasifier. Based on this, a control schematic diagram is designed as shown in fig. 3. The PLC control system mainly consists of a CPU module, a DA module for adjusting the output of control variables, and an AD module for inputting feedback variables. The 4-20 mA signal Pt output from the steam pressure transmitter is fed into the A/D conversion module FX2N-4AD, which has four analog input channels with a 12 bit resolution, accuracy of +1%, and conversion speed of 15 m/s. The converted steam pressure current value data is stored in the PLC internal data register. The PLC calculates the deviation P_e and deviation change rate P_{ec} based on the set value P_s and the current value data P_v, calculates the control quantity P_m according to adaptive intelligent control rules, and converts it into a voltage signal of 0-10 V through the D/A conversion module FX2N-4DA. It is sent to the gasifier blast control frequency converter to adjust the fan air volume, control the output of combustible gas and the heat supplied to the boiler, and then control the boiler outlet steam pressure. Adaptive intelligent control rules: the FX2n series PLC has PID instructions designed based on conventional PID algorithms. The main problem in application is parameter tuning. Once the tuning calculation is completed, it remains fixed throughout the entire control process. However, in the thermal energy conversion system composed of a gasifier boiler, the system has characteristics such as large lag, non-linearity, and time-varying, making it difficult for the moisture content and composition of biomass to be consistent, the control based on conventional PID algorithm is difficult to achieve the best effect, so an adaptive intelligent control rule with segmented deviation intervals is adopted. Determination of initial control value: based on empirical data from actual operation, establish the boiler steam pressure shown in tab. 1 and fig. 3, and use segmented operation initial value reference data. Based on this reference value, combined with adaptive intelligent control rules, the boiler steam pressure can quickly reach a stable state [8].

Table 1. Initial parameter setting table

Team pressure of the boiler P_s [MPa]	Air supplied to gasifier V/F (1) rated value [%]	Air supplied to gas combust V/F (2) rated value [%]	Output air of induced fan V/F (3) rated value [%]
Ignition	20	20	30
Feed	10	10	20
0.5	62	25	63
0.6	70	30	80
0.7	78	35	80
0.8	80	40	85
0.9	83	40	88
1.0	85	50	90
1.1	90	55	95
1.2	95	60	100

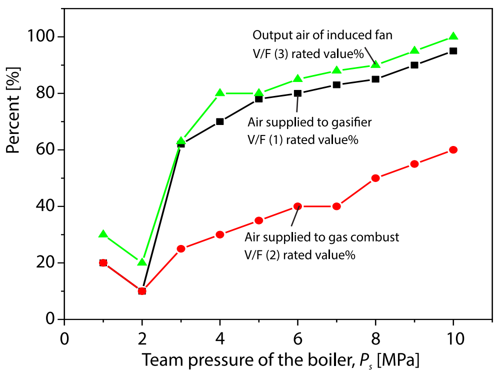

Figure 3. Initial parameter setting

The negative pressure control of the furnace is mainly achieved by adjusting the induced air volume of the boiler induced draft fan. When biomass gas and burner combustion air distribution need to be increased, the negative pressure of the furnace will inevitably decrease towards the positive pressure direction, in order to ensure negative pressure, the adjustment method is to increase the induced air volume. When biomass gas and burner combustion air distribution need to be reduced, the negative pressure in the furnace will inevitably increase towards the negative pressure direction. At this time, the adjustment method is to reduce the induced air volume. The control parameters of negative pressure need to be related to the gasifier blowing and burner air distribution, and the initial control parameters are included in tab. 1 and fig. 3. The control process is after the system is started, the gas pressure is detected first, and then the combustion fan of the burner is started to detect the combustion air pressure and purge the furnace [9]. At the same time, valve group leakage detection and valve position detection are carried out. After all the previous processes have passed, the liquefied gas ignition gun will be ignited upon reaching the set time.

Adaptive intelligent control effect and analysis

The integrated control method described by the author has been successfully operated in the 2~6 tonne per hpour biomass gasification centralized steam supply system of one hundred new energy companies in Dongguan City. The operation is stable and reliable for a long time, and the outlet steam pressure and flow meet user requirements. Adopting adaptive intelligent control rules effectively avoids the impact of changes in biomass moisture content and composition on the control results. The steam pressure curve recorded using a configuration type recorder is shown in fig. 4. In tab. 2, the deviation between the steam pressure and the set value of 0.8 MPa is less than the maximum allowable deviation of 3%. The significant fluctuation around 450 seconds is caused by reducing the blast of the gasifier to the minimum when adding biological materials.

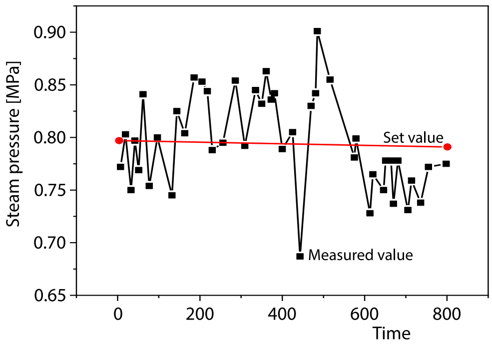

Figure 4. Run chart of steam pressure intelligent regulation

Table 2. Trends in Intelligent adjustment of steam pressure

Time [second]	Steam pressure	Time [second]	Steam pressure
7.07	0.78	380.591	0.85
19.26	0.81	400.26	0.8
32.85	0.76	424.57	0.81
42.02	0.81	442.64	0.691
51.09	0.78	470.15	0.84
61.81	0.85	480.79	0.85
76.88	0.76	485.42	0.91
96.67	0.81	515.72	0.86
131.52	0.75	574.83	0.79
143.76	0.84	579.391	0.81
163.47	0.81	612.71	0.74
186.31	0.87	620.35	0.78
204.52	0.86	646.14	0.76
218.17	0.85	650.72	0.79
230.25	0.791	664.39	0.79
256.06	0.791	670.41	0.75
286.49	0.86	681.09	0.79
309.19	0.791	705.32	0.74
335.06	0.85	714.46	0.77
350.22	0.84	735.68	0.75
360.89	0.87	755.46	0.78
372.991	0.85	797.97	0.79

Suggestion for the application of PLC control system in smart grid

Structural design

In order to ensure the stable operation of the PLC control system and meet the control requirements of the smart grid, it is necessary to do a good job in structural design, with the PLC device as the core of the system, set a certain number of acquisition points, and rely on Ethernet to maintain the connection control status between the main control modules, split the system structure into modules such as information collection, power monitoring, main control, loop control, and human-machine interface. Among them, the information collection module is responsible for continuously collecting on-site data and monitoring signals generated during the operation of the power grid, reducing and converting the on-site data proportionally, and independently collecting voltage and current transformer data, convert and classify the collected data before uploading it to the power monitoring module. The power monitoring module is responsible for sampling, amplifying, precision full wave rectification, and hysteresis comparison processing of the obtained current signal, and filtering out high frequency interference in the signal, upload the processed signal to the main control module.

Hardware selection

In the PLC control system, there are differences in the capacity, usage function, and performance quality of different types of hardware equipment. Only by combining the control needs and construction scale of the smart grid with reasonable selection can we effectively meet the control needs of the smart grid, avoid hardware equipment performance waste, or affect the power grid control effect and the actual service life of the PLC system. Taking the selection of PLC as an example, it should be comprehensively considered from multiple dimensions such as model, number of functional modules, capacity, response speed, communication networking ability*, etc.* based on the engineering situation. For example, in some smart grid projects, the 226 type PLC in the S7-200 system launched by Siemens is selected. This type of PLC device has the advantages of powerful functions, many expansion and switching points, and built-in power supply, and the PLC system has good scalability, when the component load exceeds the power supply rating, this problem can be solved by directly adding power modules and providing expansion modules to the DC power supply [10]. In addition, in order to facilitate system upgrades, maintenance, equipment repairs, and other work, power companies can configure PLC devices of the same model as much as possible, adopting a consistent structural style. In small-scale smart grid projects, small and low cost integrated PLC devices are adopted, while in large-scale smart grid projects, modular PLC devices with strong scalability, flexible configuration, and multiple types of I/O modules are adopted.

Conclusion

The wide application of PLC control system provides a new opportunity for the development of smart grid, and is unanimously considered as the future development trend of smart grid. The fixed bed suction biomass gasifier has broad requirements for biomass raw materials, so most of the remaining wood waste from furniture enterprises can be directly disposed of without the need for crushing and drying, reducing the cost of biomass utilization. Due to the *integrated* application, the distance between the gasifier and the boiler is relatively close. While fully utilizing the heat generated by the combustible gas, the tar component can also be directly burned in the boiler furnace, therefore, the total thermal efficiency of a gasification system containing tar and combustible gas can reach over 90%. The control method described by the author, although aimed at fixed bed suction biomass gasification devices with intermittent feed to the hopper, also has certain reference significance for continuous feed or circulating fluidized bed gasification devices.

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