

KEY TECHNOLOGIES FOR ENERGY SAVING AND EMISSION REDUCTION OF HEATING FURNACES IN PETROCHEMICAL PLANTS

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Original scientific paper

<https://doi.org/10.2298/TSCI2104159W>

The safety instrumented system is a system that is independent of the petrochemical production process control system and can independently complete the safety interlock protection function. It can avoid significant hazards to production equipment caused by process production failures, field instrument failures, system power supply failures, etc., and ensure safe operation of production equipment. In petrochemical plants, it is imperative to configure a safe, reliable, and timely safety instrumented system. Combined with applying the burner management system of the heating furnace in a refinery, the paper focuses on the technical realization of the hardware structure, system configuration, logic programming, man-machine interface configuration system debugging of the TRICON system. Practical application shows that TRICON's safety instrumented system is a set of safety instrumented systems with comprehensive functions, safety and reliability, and easy to learn.

Key words: *petrochemical plant, safety instrument system, heating furnace, system configuration, energy saving and emission reduction*

Introduction

Refining and chemical equipment have the characteristics of high temperature, high pressure, inflammable, explosive, complicated process and strong continuity, and high safety requirements. To minimize the probability of the occurrence of malignant accidents of the equipment, reduce unplanned shutdowns, and avoid major personal injuries and significant economies in the event of a loss, the heating furnace device needs to apply a safe, reliable and timely safety instrumented system (SIS). The SIS is a safety interlock protection system for large installations independent of the production process control system. The SIS provides safety protection for the health of personnel, equipment and the environment during the start-up, shutdown phase, operation and maintenance operation of the production plant [1]. Whether it is the danger caused by the production device's failure or the danger caused by human factors and the danger caused by some irresistible factors, the SIS should immediately respond correctly and give the corresponding logic signal to make the production device safe interlock or stop. Prevent the occurrence of danger and the spread of accidents, and minimize the harm.

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Interlocking protection of heating furnace device

The heating furnace of the oil refinery uses natural gas as fuel, the heated medium is heavy oil, and the furnace type is a multi-burner harmful pressure furnace. The precise control of the temperature of heavy oil is achieved by adjusting the fuel gas-flow rate. The conventional signal detection, display and medium temperature control of the heating furnace device adopt the DCS system, and the burner management system (BMS) adopts the TRICONSIS system. The BMS helps the operator prevent maloperation during the fuel preparation and the start and stop of the combustion equipment to prevent possible damage to the fuel preparation system and the combustion equipment. It monitors the fuel status, ignition gas and primary flame status to ensure proper purging and ignition procedures are performed [2]. When the heating furnace runs abnormally, the DCS system first alarms and the operator should make adjustments in time to make the alarm parameters return to average values. Suppose the operator's operation intervention is invalid and the process value reaches the interlock value. In that case, the interlock system will be activated to shut down the heating furnace safely.

Cut off the interlock protection of the permanent light system

When one of the following situations occurs, stop the permanent beacon: the gas supply pressure of the permanent beacon is low, the gas supply pressure of the beacon is high, the pressure of the permanent beacon before the gas spray is high, and the pressure before the gas of the permanent beacon is low, the flames of all the burners are extinguished. At this time, close the shut-off valves at the root of the permanent light pipe of all burners, close the double shut-off valves of the main pipe of the permanent light, and open the vent valve at the same time.

Cut off the paramount flame system interlock protection

Stop the central fire when one of the following situations occurs: the primary gas supply pressure is low, the primary gas supply pressure is high, the pressure before the central gas injection is high, the pressure before the main gas injection is low, the central flame of all burners is extinguished, and the flue gas pressure in the convection section is high. The flue gas temperature in the convection section is high, and the flue baffle valve is closed. At this time, close the shut-off valves at the root of the main gas pipe-line of all burners, close the double shut-off valves of the main gas main pipe-line, and open the vent valve simultaneously.

Boiler shutdown interlock protection

When one of the following situations occurs, stop the long beacon and central fire, the on-site control panel shutdown signal and the DCS remote shutdown signal. Close the permanent light gas pipe-lines of all burners and the shut-off valve at the root of the main gas pipe-line, close the double shut-off valves of the permanent light gas pipe-line and the main gas main pipe-line, and open the vent valve.

Application of improved PID algorithm in the system

Overview of PID algorithm

The temperature control system uses the power controller to heat the heating elements of the heating furnace electrically. The heating elements are distributed on the lateral surface of the heating furnace. The control system's hardware configuration adopts SIEMENS S7-300 PLC, and the man-machine interface installs Siemens WinCC software on the industrial computer for screen operation and serves as an engineer station.

Under the premise of minimizing changes to the original system, the heating furnace is divided into two heating areas. The areas are connected to form a multi-input multi-output coupled non-linear, time-varying and sometimes extended complex system [3]. Considering the characteristics of heating components and actual production needs, the final required stable temperature point is above 900 °C. For this reason, the traditional PID algorithm is used for testing. When the heating furnace is stable at 800 °C for some time, the control effect of changing the temperature setting to 1150 °C is shown in fig. 1. The entire healing process takes 68 minutes, the overshoot is 15 K, and the adjustment time is 35 minutes. It can be seen from the aforementioned control effect that the overshoot has a more significant impact on the adjustment time.

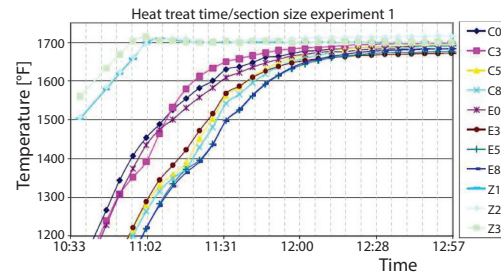


Figure 1. Heating furnace 800~1150 °C heating curve (1500~2100 °F)

Heating furnace temperature control based on predictive thinking

Because the original heating system uses the traditional PID algorithm, the control effect is not ideal, so this paper proposes a PID control algorithm based on predictive thinking and combines the integral separation PID to optimize the traditional PID. The block diagram of the heating furnace algorithm based on the prediction idea is shown in fig. 2.

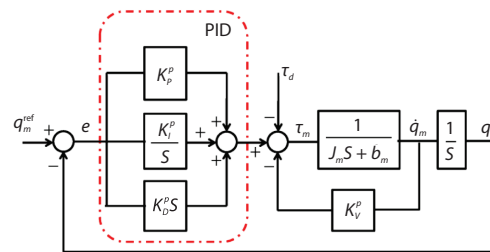


Figure 2. Block diagram of the algorithm

The simplest form of the prediction algorithm in fig. 2:

$$P'_v(K+1) = \overline{P_v(K+1)}Ta + P_v(k+1) \quad (1)$$

where P_v , $P_v(K+1)$ after the prediction algorithm at the time $P'_v(K+1)$ is the measured temperature value at the current time and Ta – the predictive factor. After repeated experiments, it is found that the fluctuation range of Ta is the smallest when entering the steel pipe at 3-5:

$$\overline{P_v(K+1)} = \begin{cases} \frac{P_v(k+1) - P_v(k)}{\Delta t} & \overline{P_v(K+1)} \leq M \\ M & \overline{P_v(K+1)} > M \end{cases} \quad (2)$$

where $\overline{P_v(K+1)}$ is the rate of temperature change, Δt is 1 second, M – the empirical limit value, which is $M = 10$. If it is required to ensure the rapidity, the PID idea similar to integral separation can be adopted. At low temperature, set $P'_v(K+1) = P_v(k+1)$, that is, to shield the effect of prediction. At high temperature, add prediction, and at the same time change the PID algorithm to integral separation PID at the same temperature section.

The main idea of integral separation control is: when the controlled quantity deviates significantly from the set value, the integral action is canceled to avoid the decrease of system stability, and the increase of overshoot due to the integral action. When the controlled quantity is close to the given value integral control is introduced to eliminate static error and improve control accuracy:

$$u(k) = K_p e(k) + \beta K_i \sum_{j=0}^k e(j)T + \frac{K_d [e(k) - e(k-1)]}{T} \quad (3)$$

$$\beta = \begin{cases} 1 & |e(k)| \leq \varepsilon \\ 0 & |e(k)| > \varepsilon \end{cases} \quad (4)$$

where T is the sampling time, β – the switching coefficient of the integral term, and ε – the heating section, which requires trial and error to obtain the optimal value.

Introduction TRICONSIS system

The TRICON system uses the most advanced TMR hardware technology and the mature and reliable TRISTATION 1131 software system, with complete device interlock protection functions, system self-diagnosis and SOE functions. All components of the controller meet the IEC61508SIL3 level and pass the TUVAK6 level certification. All input and output cards meet the ANSI37.90 impact resistance test requirements [4]. The TRICON system's hardware core is a fault-tolerant controller based on a triple-module triple-redundancy fault-tolerant (TMR) structure. The system has three processors, a 32-bit floating-point operation, 50 MHz, 16MBRAM, and working mode. For 3-2-1-0 or 3-2-0, all I/O signals in the system must be voted by hardware. Its structure is shown in fig. 3.

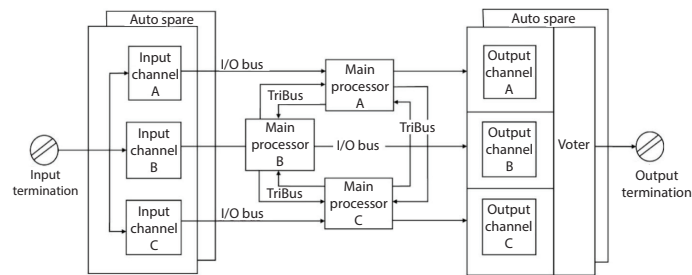


Figure 3. The TMR structure of SIS

The TRICON system is a rack-extended structure. Triple redundant I/OBUS connects the racks. The system has at least one main rack, and according to the number of I/O points, up to 14 expansion racks can be connected. A basic TRICON system consists of the following components: a rack to accommodate each module, various types of I/O modules, ETP terminal boards, programming workstations or operating stations. The TRICON racks are divided into main racks, extended racks and remote racks. The TRICON system's mainframe is equipped with the main processor module and up to 6 I/O module groups, and each expansion frame can support up to 8 I/O module groups. The expansion rack is connected to the main rack through a triple RS485 two-way communication port. Each rack has a different bus address, and each module in the rack determines its specific address by its location or slot [5]. The system also supports remote racks with a maximum distance of 12 km.

The TRICON system modules mainly include the digital input module, digital output module, analog input module, analog output module, and communication module. The digital input signal is divided into three isolated channels in the DI module and is sent to the three leading processors through three independent channels for three-out-of-two voting; the data, after correcting any deviation, passes through 3 I. The O bus, is sent to the DO module, and the DO module is voted again through the patented *square voting circuit* hardware. The DI and DO

modules are isolated from the field by photoelectric isolation. The analog input signal is divided into three isolated channels in the AI module. The analog quantity is converted into a 12-bit digital quantity through the analog-to-digital converter of each sub-circuit on the AI module, processed by a 32-bit coprocessor. Each central processor uses the intermediate value algorithm to read the correct value and correct any sub-circuit deviation. The central processor's analog signal output is selected in the analog output selector in the AO module to ensure the output signal accurate [6]. The communication module (TCM) of the TRICON system supports the standard MODBUS communication protocol. Each TCM card has 4 RS232/485 serial communication ports and 2 RJ45 ports. The TRICON system's central processor can allocate 16 storage areas for SOE record storage, with a maximum of 100000 events recorded. The SOE resolution in milliseconds. The sequence event recording station can separately record the alarm and action events of each controller. Documents can also be stored in the hard disk as permanent storage and can be printed out. The records of alarm and shutdown events are time-stamped and recorded according to the time the event occurred.

In the TRICON system design, the configuration of man-machine interface and hardware and logic realization is realized by two software types, respectively. The hardware configuration, logic realization, SOE function realization, *etc.*, are realized by the software of TRICONEX, including three kinds of software such as TRISTATION 1131, SOE and DDE. The man-machine interface configuration is realized with INTOUCH developed by WONDERWARE. Both software's have potent functions, convenient and straightforward to use.

Design of the BMS of the heating furnace

System configuration

The heating furnace BMS hardware adopts a TRICON SIS controller composed of a CPU cabinet and remote I/O cabinet. The CPU cabinet is placed in the central control room (CCR). The cabinet mainly includes a main-frame for installing the central processor and a remote frame for installing remote communication cards. An engineer station is set up to realize SOE functions and system maintenance functions. The remote I/O cabinet is placed on site. The cabinet mainly includes a remote rack for installing remote communication cards and an expansion rack for installing input and output cards [7]. The cabinet door is equipped with an operation screen and some button switches, which can realize the heating furnace Stop the furnace operation. The communication between the CPU cabinet and the remote I/O cabinet is realized through the optical fiber. The BMS configuration is shown in fig. 4.

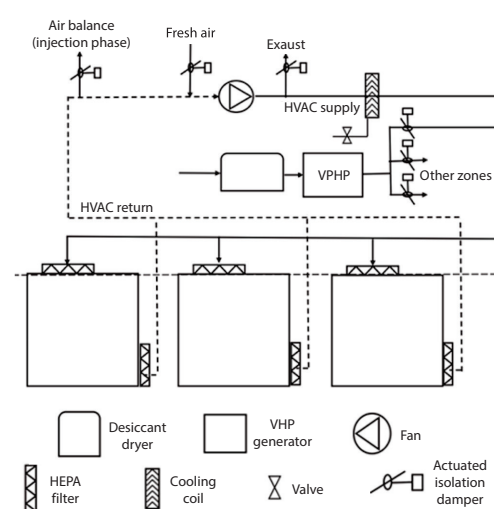


Figure 4. The BMS configuration of a heating furnace

Hardware configuration

The hardware configuration of BMS is determined according to the number of input and output points. According to the number of input and output points, and considering at least

15% spare capacity, the primary hardware configuration of the heating furnace SIS includes DI/DO/AI, input/output of various I/O cards, isolation between channels and power supplies, and I/O. The card has the function of identifying open circuit or short circuit of the field wiring and issuing an alarm. The various cards are independent of each other and are optically isolated on the scene. These cards can withstand the electrical shock of 1500 V per minute overvoltage [8]. The AI module selects model 3721, 32 points, differential, DC coupling; sub-circuit isolation 200 k Ω ; resolution 12bit; three sub-circuits are entirely isolated from each other and work independently, and each sub-circuit receives a voltage signal from the input point, and convert it into a digital signal and send it to three central processors; the module has a 6% over-limit measurement capability. Each channel of the AI card has an independent A/D converter with an accuracy of 0.15%.

The DI module selects the model 3503E, 32 points, isolated type 1500VDC; three sub-circuits are entirely isolated from each other and work independently; the system and the field are all optically isolated. The module can test the phenomenon of *STUCK ON* (means that the module cannot detect the on-site signal disconnection). Intrinsically safe input signal plus DI safety barrier. The DI card input end can withstand 220VAC, 50 Hz overvoltage.

The DO module selects model 3664, 32 points, isolated type 1500VDC; contact output; three sub-circuits are entirely isolated from each other and work independently in the module; a particular *square voting device* is used to output signals. They are voted before they are sent to the load; the OVD diagnosis (output voter diagnosis) ensures complete fault coverage. Add a DO safety barrier to the DO signal of the on-site solenoid valve, MCC or other places, and add a safety relay to the DO signal of another set of SIS. The output terminal (ETP) has a fuse. It has the function of identifying open circuit or short circuit of field wiring and issuing an alarm. Each I/O card has a one-to-one corresponding spare card slot, a redundant online maintenance slot so that the failed card can be easily replaced online. All SIS module slots have metal lock keys to ensure that they cannot be inserted into any other slots by mistake [9]. Only the same type of modules can be inserted into the corresponding slots. The system rack configuration is shown in tab. 1.

System configuration

Hardware configuration, logic realization, SOE function realization, *etc.*, are realized by TRICONEX's software, including TRISTATION 1131, SOE, DDE and other software. IN-TOUCH developed by WONDERWARE realizes the man-machine interface configuration. Each software has powerful functions and use. In this project, the signals coming in from the field and the signals' output are all wired in a fail-safe type. The system configuration is also configured following the fail-safe type, that is, when the normal working state is required, the equipment is live, and when the power is lost (cut off, power down), safety system action.

The BMS hardware configuration

The internal configuration of the system is completed with the software TRISTATION 1131 developed by TRICON. The hardware configuration is the most fundamental part of the control system. It determines the CPU card model, the distribution and selection of the I/O card, the allocation of I/O addresses, the definition of variable addresses, and so on.

- *Card configuration*: complete the model selection and location-allocation of all cards used in this project.
- *I/O point configuration*: All I/O points needed in the SIS are assigned addresses so that each process point corresponds to which channel of which card in which rack.

Table 1. Heating furnace BMS rack configuration table

CHASSIS1#8110	CHASSS2#8112	CHASSIS3#8112
POWER 8310	POWER 8312	POWER 8312
MP 3008	PRXM 4210	SPXM 4211
MP 3008	PRXM 4210	SPXM 4211
MP 3008	PRXM 4210	SPXM 4211
SPARE 8105 SLOT2 SPARE AI 8105	SPARE 8105 SLOT2 SPARE AI 8105	SPARE 8105
SPARE 8105 SLOT3 SPARE DO 8105	SPARE 8105 SLOT3 SPARE AI 8105	SLOT2 AI 3721
SPARE 8105 SLOT4 SPARE DO 8105	SPARE 8105 SLOT4 SPARE DO 8105	SPARE 8105
SPARE 8105 SLOT5 SPARE DI 8105	SPARE 8105 SLOT5 SPARE DO 8105	SLOT3 DO 3664
SPARE 8105 SLOT6 SPARE DI 8105	SPARE 8105 SLOT6 SPARE DI 8105	SPARE 8105
SPARE 8105 SLOT7 TCM 4351B	SPARE 8105 SLOT7 SPARE DI 8105	SLOT4 DI 3503E SPARE 8105
TCM 4351B	SPARE 8105	SLOT5 DI 3503E SPARE 8105
		SLOT6 DI 3503E SPARE 8105
		SLOT7 SPARE DI 8105
		SPARE 8105
CHASSS4#8111	CHASSIS5#8111	
POWER 8310 SLOT1 SPARE AI B105	POWER 8310 SLOT1 SPARE AI 8105	
SPARE B105	SPARE 8105	
SLOT2 DO 3664	SLOT2 DO 3664	
SPARE 8105	SPARE 8105	
SLOT3 DO 3664	SLOT3 DO 3664	
SPARE 8105 SLOT4 SPARE DO 8105	SPARE 8105 SLOT4 SPARE DO 8105	
SPARE 8105	SPARE 8105	
SLOT5 DI 3503E SPARE 8105	SLOT5 DI 3503E SPARE 8105	
SLOT6 DI 3503E SPARE 8105	SLOT6 DI 3503E SPARE 8105	
SLOT7 DI 3503E SPARE 8105	SLOT7 DI 3503E SPARE 8105	
SLOT8 SPARE DI 8105	SLOT8 SPARE DI 8105	
SPARE 8105	SPARE 8105	

After defining a hard address for each process point, the system automatically generates a soft address for each process point. This soft address is sent to the control station when the project is downloaded. The INTOUCH communicates with the control station through the DDE communication protocol, and this address can be used directly. Define a unique tag name (TAGNAME) for each I/O point, and quote these tag names as global variables in the logic program. The hardware configuration of the heating furnace BMS is shown in fig. 5.

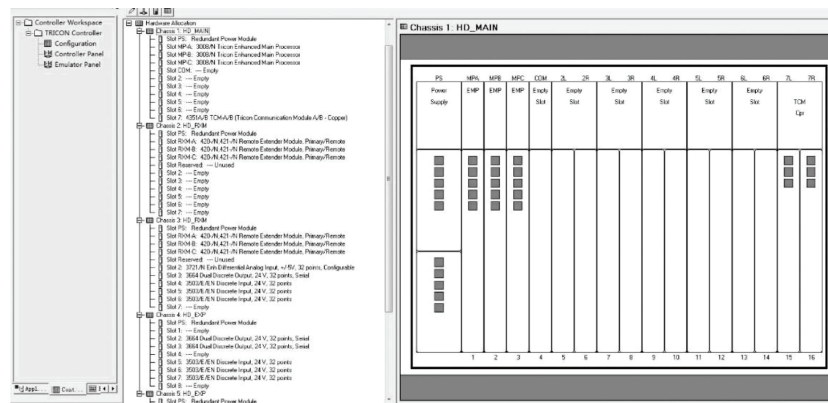


Figure 5. The BMS hardware configuration of the heating furnace

System software configuration

Programming: TRISTATION 1131 is the primary software development platform of the TRICON SIS system. The programming languages provided to the buyer include function block (FBD), ladder diagram (LD), and structured text (ST) languages. The software supports IEC1131-3 standard library and system process control and fire and combustible gas function block library. These function blocks include analog input, exponential filtering, PID, lead-lag, integration, median selection, analog output, gas detector, Online monitoring, printing and other special function blocks. The TRISTATE 1131 software has functions such as process operation, instrument simulation operation, alarm operation, system configuration, program online modification and download, online monitoring, program debugging, and system fault diagnosis [10]. The software can add I/O points online without updating the program, configure, download and modify online, have fault tolerance, and obtain TUV certification.

The heating furnace BMS control program is written in function block language (FBD). This language uses wires to connect functional blocks to form a loop, and the functional blocks transfer binary and other types of data through connecting wires. The characteristics of this graphical programming language are straightforward and easy to understand. Logic programming is a crucial part of SIS. It is related to whether the system's logic program can fully meet the control requirements of the process. All logic programs need to be repeatedly debugged and confirmed before being put into use. The heating furnace control program mainly includes AI-PROCESS (AI signal processing), SOE (order of events), MOS (system maintenance bypass switch), LOGIC (point shutdown control), COMM (communication with DCS), SYS_ALM (system alarm), and other parts, as shown in fig. 6.

Man-machine interface design: The man-machine interface configuration design uses INTOUCH software. The INTOUCH software is the engineering design software of WONDERWARE company based on WINDOWS environment. The software is easy to compile, flexible

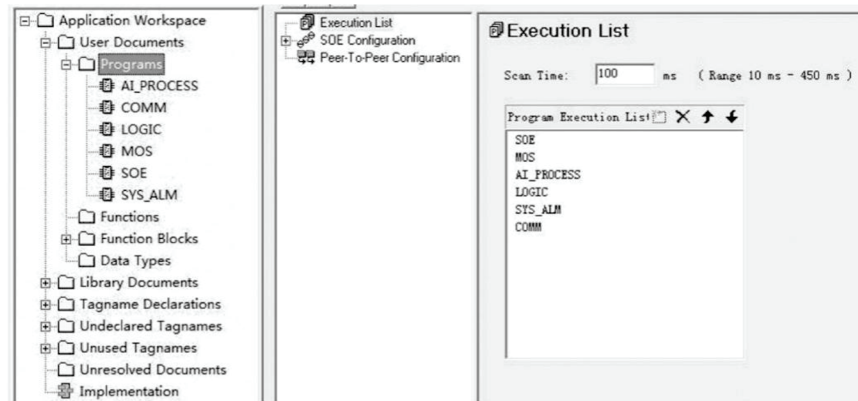


Figure 6. The BMS control program structure of the heating furnace

and powerful. The INTOUCH includes two environments, WINDOW Maker and WINDOWS Viewer. The WINDOWS Maker is a programming environment, and WINDOW Viewer is an environment for running applications, an operator interface. In the heating furnace system, the HMI screen is developed by WINDOWS Maker and displayed and monitored by WINDOWS Viewer, including the heating furnace flowchart screen, alarm screen, parameter setting screen, soft bypass screen and user management window, *etc.*, as shown in fig. 7.

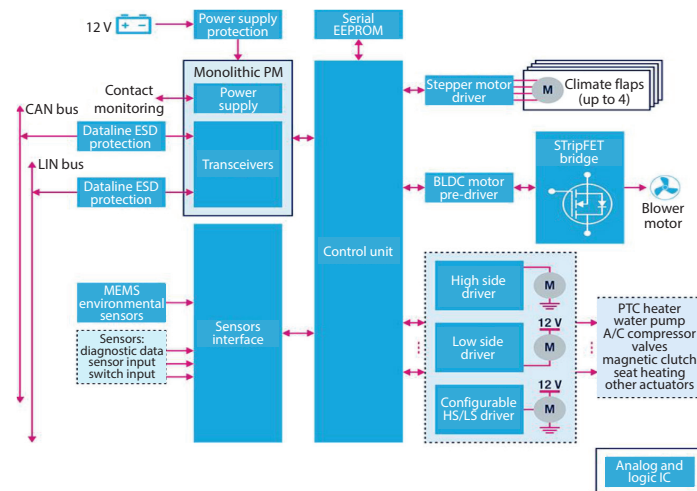


Figure 7. The BMS man-machine interface of the heating furnace

Communication and clock synchronization with DCS: the SIS performs serial communication with DCS through the RS-232/485 interface of the redundant multi-function communication TCM card and executes the MODBUS TCP/IP communication protocol due to the communication distance between the heating furnace BMS and DCS. Far away, the project uses optical fiber for communication, with DCS as the primary and TRICON SIS as the slave. The synchronous clock signal of SIS comes from the clock synchronization server (SNTP) of DCS. The TRICON SIS can use TCP/IP or RS485 communication protocol or hard-wired trigger mode to realize clock synchronization with DCS.

System debugging

System debugging is the final key stage of the heating furnace BMS configuration. The debugging process is a comprehensive test of the system to check the logic program, SOE, alarm prompt, and ease of operation. The overall test is divided into two-stages: first offline simulation test, and then online test. The offline simulation test checks whether the logic is correct, whether the man-machine interface's dynamic connection is correct, whether the SOE function and the alarm function are perfect, *etc.*, by giving the forced signal to the logic program running under TRISTATION 1131 simulation. In addition completing the various tasks of offline testing, online testing focuses on checking whether the logic program's input and output can meet the needs of various devices on site. After completing the program's overall test, download the program to the controller, and finally, put it into operation in the device.

Conclusion

A large number of applications in petrochemical enterprises show that the commissioning of SIS dramatically improves the reliability and safety of the safe production of the device, and at the same time, plays an active and essential role in avoiding industrial disasters and reducing industrial accident losses. It provides an optimal choice for critical control that requires maximum safety and continuous production. The application also shows that TRICON's SIS is a comprehensive, safe, reliable, and easy-to-learn safety instrumented system.

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