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Research on the Safe, Reliable and Low-Cost Transmission of Multiple Signals between Different Control Systems

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Abstract: With the gradual development of smart power plants and large-scale centralized control, there is a need to exchange a large number of signals between different DCS systems and between DCS and PLC systems. Different control systems have different brands and cannot communicate directly via networks. Moreover, due to network security concerns, the main control of unit units and the auxiliary control system of the entire plant cannot communicate directly via networks either. The commonly adopted methods for signal exchange between control systems are hardwiring and 485 communications. Both have obvious drawbacks, where hardwiring requires a large number of channels and cable laying; 485 configuration is difficult, not easy to maintain, and faults are hard to locate. This paper studies how to strike a balance between the two, using a minimal amount of hardwiring to transmit a large number of signals, which is safe, reliable, cost-effective, and can be maintained by any control personnel without network security risks.

Keywords: Control systems; Signal exchange; Safety and reliability; Low cost; Easy maintenance

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1. Introduction: Conventional control situation

With the gradual development of smart power plants and large-scale centralized control, a large amount of data needs to be transmitted between different DCS systems as well as between DCS and PLC systems. Due to the variety of brands among different control systems, direct network communication is not feasible.

Currently, two methods are used for signal transmission between different control systems: one is direct connection via hardwiring, which means connecting the AO (analog output) of one control system to the AI (analog input) of another, or the DO (digital output) of one control system to the DI (digital input) of another; the other is signal transmission between control systems via RS485 serial communication, requiring both control systems to be equipped with RS485 serial communication ports or cards along with necessary isolation and anti-interference measures [1]. The advantages and disadvantages of hardwiring and RS485 serial communication are documented in **Table 1**.

Table 1. Comparison of hardwiring and RS485 serial communication

Aspects	Hardwiring	RS485 serial communication
Advantages	(1) Being intuitive and clear (2) Have high reliability (3) Simple maintenance (4) No network security issues	A single communication interface can transmit a large number of signals [2]
Disadvantages	Each signal occupies two DCS channels (one output and one input) and a two-core cable: Only suitable for transmitting a small number of signals	(1) Protocol is vulnerable to attacks (2) Requires reasonable network structure design, implementation of security strategies, and improvement of equipment security performance (3) Communication is susceptible to interference from complex on-site environments (4) Troubleshooting is cumbersome [3]

The following is the traditional control loop design of control systems. To transmit a signal between two control systems, each system must have a corresponding AO, AI, DO, or DI channel, or transmission can be done via 485 communications (**Figure 1**, **Figure 2** and **Figure 3**).

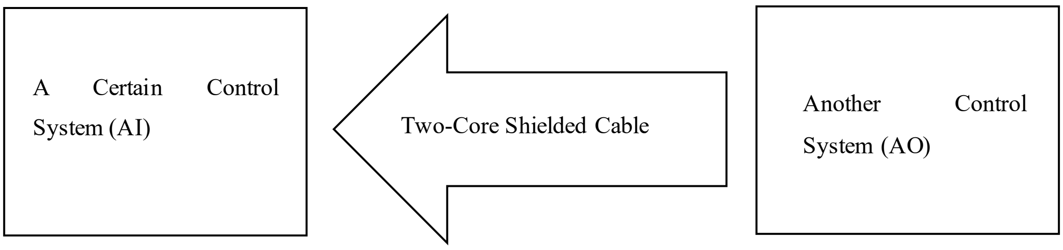

Figure 1. Transmission of 1 analog signal via hardwiring.

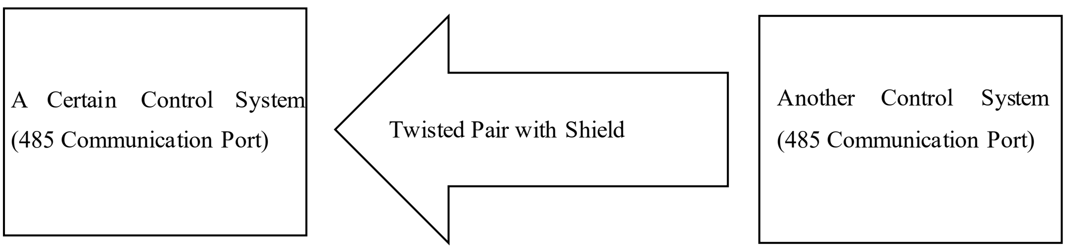

Figure 2. Transmission of 1 digital signal via hardwiring.

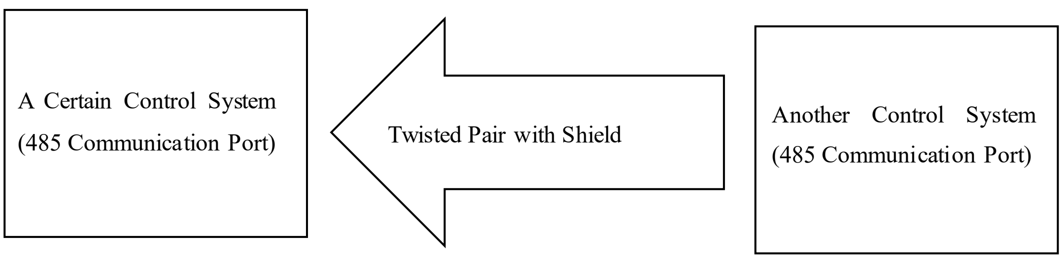

Figure 3. RS485 serial communication.

2. Main existing problems

Both hardwiring and RS485 serial communication in existing technologies have obvious drawbacks.

The existing hardwiring is not suitable for transmitting large amounts of data between DCS systems, but only for a small number of important signals. Transmitting more than 100 signals would require adding new control cabinets, a large number of boards, and laying over 200-core cables. Especially when the physical distance between control systems is long, the workload of laying a large number of cables is enormous, resulting in high costs. The RS485 serial communication network has a complex structure and high technical requirements for maintenance. In case of a fault, all signals will lose their transmission function. Moreover, it has high requirements for network security protection between control systems and is susceptible to interference from complex on-site environments, leading to unstable communication [4].

3. Optimization and improvement measures

This research processes multiple signals through control logic, enabling the transmission of multiple signals within a single hardwired signal loop. The proposed method not only retains the advantages of being intuitive, highly reliable, easy to maintain, and free from network security issues but also has the advantage of transmitting multiple signals through a single signal channel. The specific optimized designs are shown in **Figure 4** and **Figure 5**.

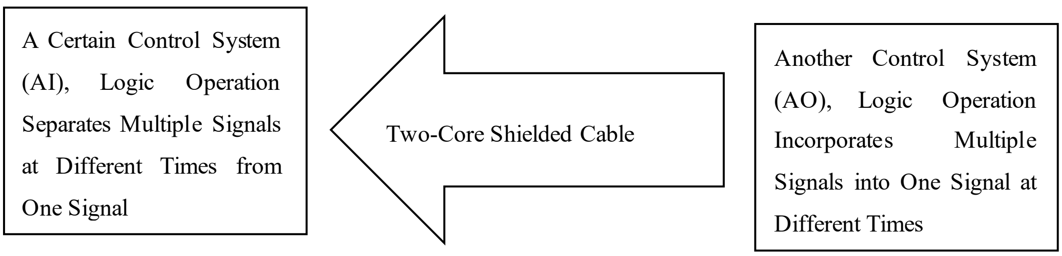

Figure 4. Transmission of multiple analog signals via one pair of hardwiring connections.

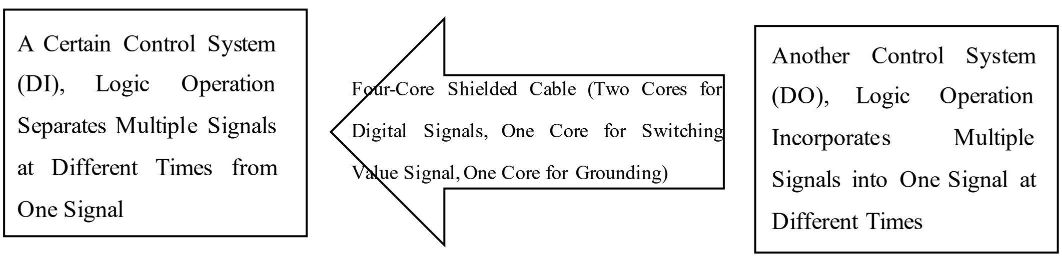

Figure 5. Transmission of multiple digital signals via two pairs of hardwiring connections.

3.1. Description of the loop after optimization research

3.1.1. Method for fusing multiple analog signals into one signal output

Multiple analog signals are initially normalized to a unified range of 0–100. An analog switching function block, combined with a timing function block, triggers an over-range signal of 120% during the opening 200 ms of each cycle. During the next 200 ms interval, the analog switching and timing blocks output the first analog signal through hardwired routing. In the following 200 ms interval, the second analog signal is output in the same manner [5]. By extension, the $(n-1)^{th}$ analog signal is output in the n^{th} 200 ms interval. The cycle concludes once all required analog signals have been sequentially transmitted. At the start of the subsequent cycle, the 120% over-range signal is again generated during the opening 200 ms, and the entire sequence repeats continuously [6].

3.1.2. Method for separating multiple analog signals from one analog signal

Continuous monitoring is performed on the analog signal. When an over-range value of 115% is detected and subsequently falls to 110%, a pulse signal is issued to trigger the separation of the first analog signal. Using the analog switching function block, this signal is isolated, latched, and converted back to its original range. After a 200-ms delay, another pulse signal initiates the separation and latching of the second analog signal, again restoring it to the original range [7]. With an additional 400-ms delay, the third analog signal is separated and latched in the same manner. By extension, a delay of n×200 ms triggers the separation and latching of the $(n+1)^{th}$ analog signal. The cycle concludes once all required analog signals have been extracted, after which monitoring resumes and the process repeats continuously [8].

Digital signal transmission follows an equivalent workflow, with the analog switching function block replaced by a digital switching function block, and a dedicated digital signal used to initiate each transmission cycle [9]. During the initial 200-ms interval, the first digital signal is output directly through the DO channel, while a separate DO channel outputs a logic-1 start-of-transmission signal, which remains high for the duration of the cycle. On the receiving side, two DI channels collect the incoming signals. Once the start signal is detected as logic 1, the value of the second DI channel is assigned to the first digital signal. During the next 200-ms interval, the second digital signal is output, with the start signal remaining high. The receiving side again uses the DI channels to assign the delayed input value (offset by 200 ms) to the second digital signal. This pattern continues until all digital signals have been transmitted. When transmission is complete, the start signal is set to 0 to terminate the cycle, which then restarts.

In the traditional hardwired approach, transmitting a single signal requires two channels and a 2-core cable. Consequently, transmitting 100 signals demands 200 channels and 400-core cables. Establishing communication of this scale between two independent control systems may even require installing two additional control cabinets. The cost is further increased by the high price of analog I/O modules [10].

3.2. Precautions after optimization research

Through a single hardwired analog signal transmission loop, multiple analog signals can be fused and separated using control logic, enabling the transmission of 5 analog signals (with a module scanning cycle of 200 ms and analog signals changing once per second), 10 analog signals (with a module scanning cycle of 200 ms and analog signals changing once every 2 seconds), 20 analog signals (with a module scanning cycle of 200 ms and analog signals changing once every 4 seconds), and so on.

Through two hardwired digital signal transmission loops, multiple digital signals can be fused and separated using control logic, allowing the transmission of 5 digital signals (with a module scanning cycle of 200 ms and digital signals changing once per second), 10 digital signals (with a module scanning cycle of 200 ms and digital signals changing once every 2 seconds), 20 digital signals (with a module scanning cycle of 200 milliseconds and digital signals changing once every 4 seconds), and so on. The module scanning cycle is set to 200 milliseconds, a relatively slow rate, considering the varying performance of control systems from different eras. In reality, most modern control systems can easily achieve a scanning cycle of 50 milliseconds, or even 20 milliseconds or 10 milliseconds, leading to better performance in practical applications.

This method is particularly suitable for retrofitting projects where additional signal transmission is needed between two already built control systems. It can utilize spare cores and spare channels to complete the retrofitting, significantly saving equipment costs and cable laying work [11,12].

3.3. Practical application status after optimization research

Practical application tests have been conducted between the Shanghai Xinhua DCS system and the GE Xinhua DCS system (the same applies to DCS and PLC systems), with favorable results in actual use. The control configuration logic is shown in **Figure 6**, **Figure 7**, **Figure 8**, and **Figure 9**.

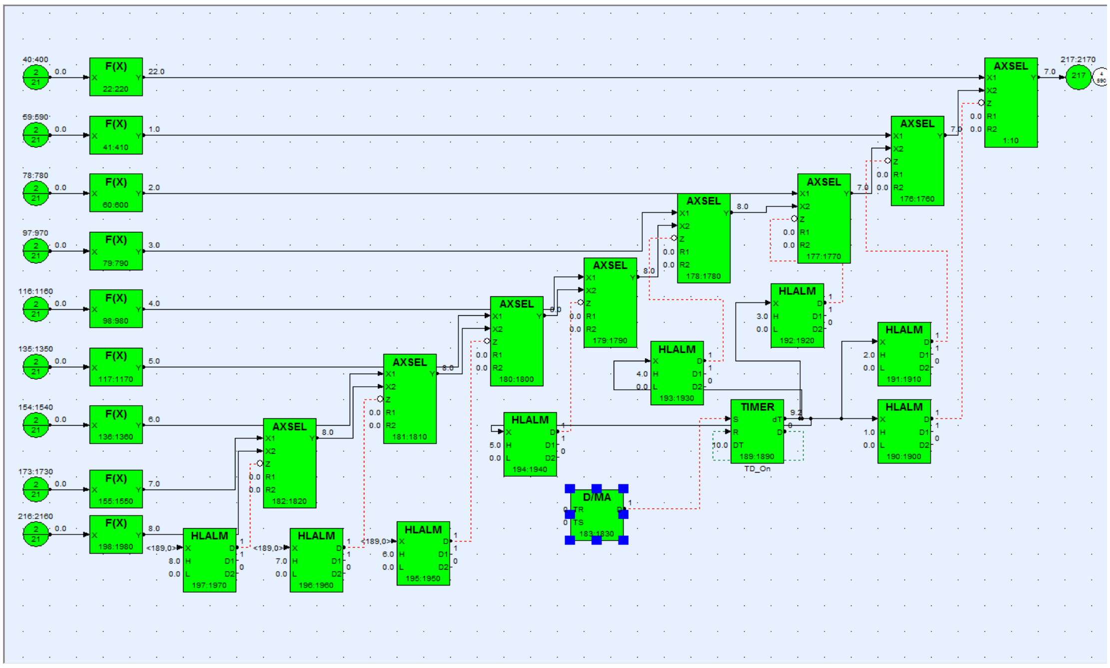

Figure 6. Conversion of 8 analog signals to a unified range and fusion into one signal.

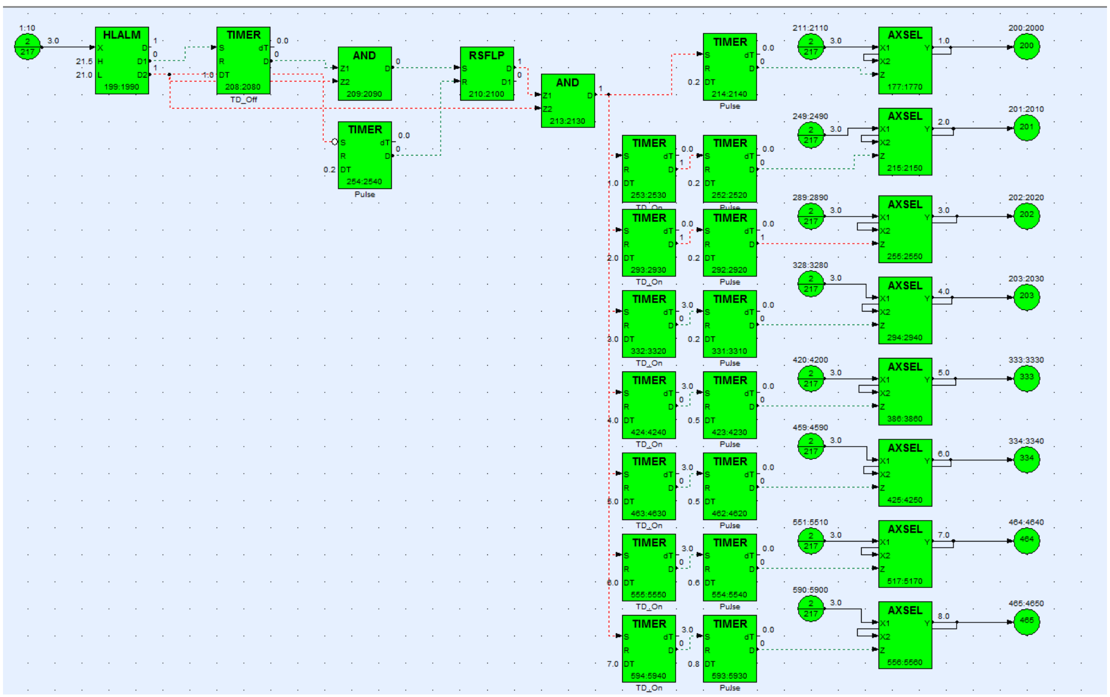

Figure 7. Separation of 8 signals at different times from one analog signal.

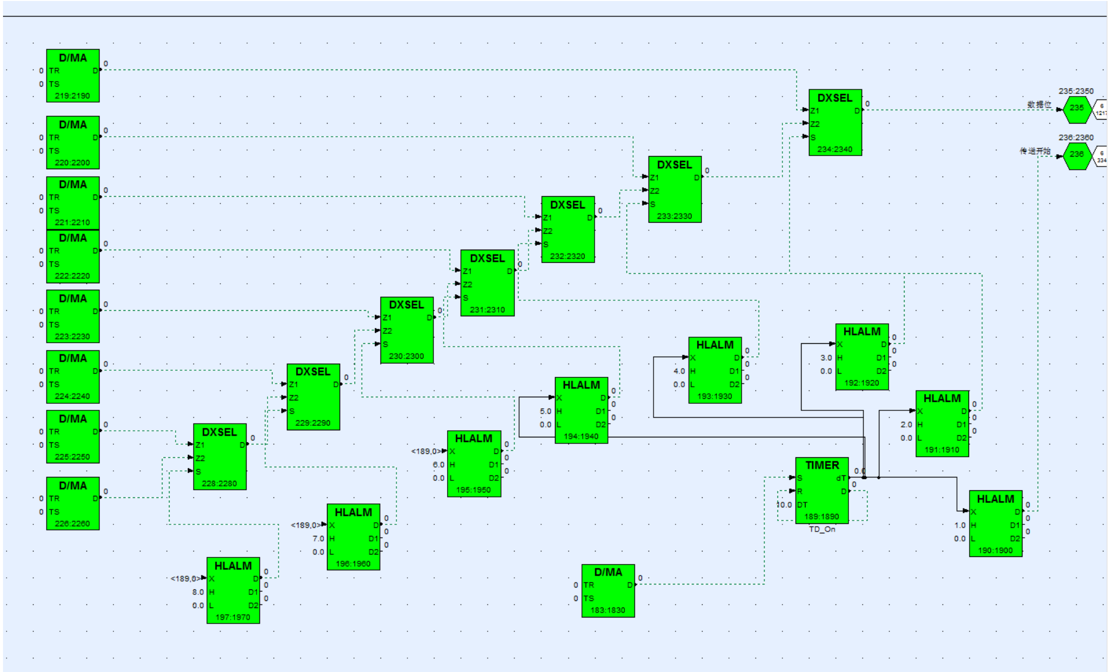

Figure 8. Fusion of 8 digital signals into one signal.

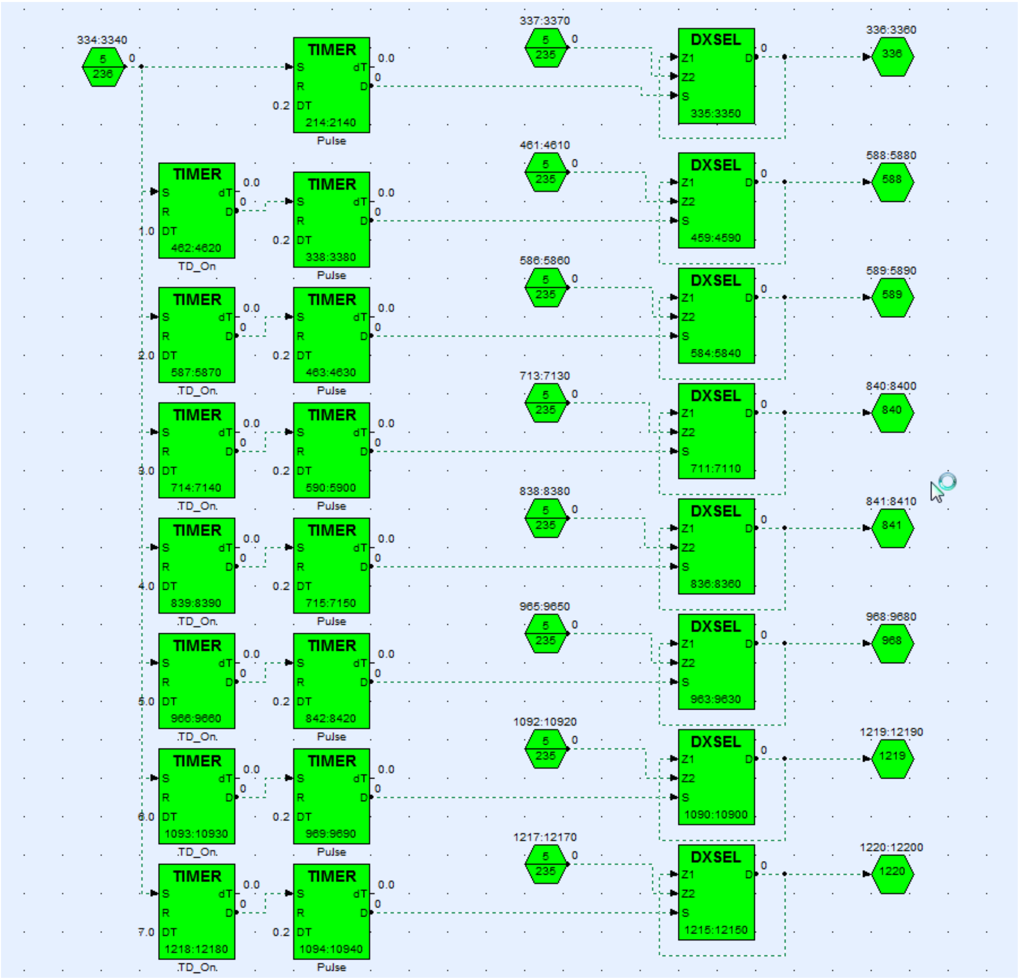

Figure 9. Separation of 8 signals at different times from one digital signal.

4. Conclusion

This study presents an innovative method for transmitting multiple signals between different control systems through a single hardwired connection, without requiring any hardware modifications and incurring virtually zero material cost. The proposed approach employs logical operations to encode multiple signals into distinct time segments of a single transmission channel and to decode them accordingly on the receiving side. For analog signals, multiple inputs are normalized to a unified range, and the over-range value serves as the trigger for initiating signal reception. For digital signals, two channels are used, with one functioning as the start-of-reception trigger.

The method operates with a short and cyclic timing sequence. Because each cycle is initiated by the start-of-reception pulse, variations in internal clock frequencies among different control systems do not affect data transmission. As a result, communication remains both stable and reliable. Moreover, the approach continues to rely on hardwired transmission, thereby avoiding network-related security risks, while the inherent anti-interference characteristics of 4–20 mA analog signaling further enhance transmission robustness.

The control logic is straightforward and easy to implement. By significantly reducing cabling requirements and minimizing the number of I/O channels needed, the method also lowers construction and installation costs. After more than a year of successful practical operation, the approach has demonstrated strong performance and proves the feasibility of replacing hardware with software, supporting the low-carbon development goals of modern control systems. A related patent is currently under review, and the method shows strong potential for wider adoption.

Disclosure statement

The author declares no conflict of interest.

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