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Who's Afraid of Control in the Field?

Eugenio F. da Silva Neto & Peter Berrie
Endress+Hauser Process Solutions AG
Christoph-Merian-Ring 23
4153 Reinach/BL
Switzerland

Abstract

The possibility of placing control function blocks in field devices is an important feature of FOUNDATION Fieldbus technology, but what does it mean in practice? This paper takes a look at the advantages and limitations of control in the field, with illustrations from a recently completed installation.

Key Words

Control, DCS, Input selector, Instantiation, LAS, Link, Loop integrity, Macrocycle, PID block, PLC , Ramp, Redundancy

Introduction

Who's afraid of control in the field? It is an indication of how far control technology has progressed in the past decade, that most control engineers, if not admitting directly that they would not use it, would at least express reservations. This is an opinion confirmed by many salesmen: "When we are selling Foundation Fieldbus, control in the field is not a big issue - in fact we avoid mentioning it where possible".

One reason for this scepticism might be that many first-wave fieldbus users are migrating from a Distributed Control System (DCS) or Programmable Logic Controller (PLC) environment based on analogue instrumentation, where powerful controllers are traditionally located remote from the field. Many will already be operating and monitoring their process from a central control room. Those who are not, have probably selected fieldbus technology to realise such a scenario. One of the benefits of fieldbus technology is improved information flow, and where better to acquire, collate, evaluate, act upon and store it than at a central location: Is that not where the intelligence, man and machine, is located?

Since monitoring, operation and control are today perceived as part of the same activity and often executed by the same people, proposing control in the field appears to be contradictory to fieldbus philosophy. This is false. Control in the field offers more flexibility and cost efficiency in system design, and when implemented properly, more security and better optimisation of process control.

Back to the Future

In the early days of process automation all control was distributed in the field, see Fig. 1. Every control loop had its own pneumatic (later analogue) controller. Each control "loop" could be physically seen: the measuring device, the air piping going to the controller and the air piping going to the control valve. Instrument technician, operator, process control “engineer” were all one and the same person.

In the sixties mainframe computers made their way into administrative departments. Soon the process control engineers started dreaming of using this technology for controlling their plant. Hopes were high: every possible control algorithm should be put into the computer to lift the level of process control. Despite enormous investments on both supplier and customer sides, however, mainframe “central” process control computers were doomed to failure. The most obvious reason is that the “central” mainframe computers did not have the MTBF (Mean Time Between Failure) required to control a process environment. A second, but maybe even more important reason was that all intelligence had to be “programmed” into the computer. Everything, from the simplest PID control algorithm to the most complex control schemes had to be written in programming code before it could be executed. The complexity of such process control programs was simply too high to be practical.

In the seventies Distributed Control Systems (DCS) made their entry. Cheap microprocessors made it possible to distribute the process control over a number of autonomous process control modules each controlling a limited part of the plant. This clearly resolved the problem of reliability. The second problem was also addressed by these DCS systems: the systems became configurable! Pre-programmed modules were now available to execute simple and more complex process control tasks.

The fact that DCS systems are configurable is of great importance when discussing “control in the field”. During the years that followed their introduction, DCS systems were used throughout the most diverse process industries in both continuous and batch applications. Exposure to these different control environments made them increasingly mature: hundreds of configurable modules for every possible control problem were developed and stored in the system library. (A similar development could be observed in the PLC market, where demands centred on sequential and centralised process control.) This also differentiated the various DCS systems. Some were more exposed to chemical process control applications while others were typically used in the electricity market. Some systems had a high exposure to complex batch applications with a lot of discrete control. High demands on historians and alarming were typical for yet another process industry.

In the following years the hardware became even more reliable. Redundant systems were developed on both the process module and communication sides. Soon process controllers were able to handle tens, hundreds, even thousand of control loops without jeopardising the reliability of the complete system. Distributed control was the name, but in reality the degree of distribution was being constantly lowered. In fact, DCS systems became synonymous for “easy to configure” (pre-programmed) but proprietary process control computers that fitted perfectly the needs of the process control industries by providing an inexhaustible library of control blocks with many parameters.

Finally, in the nineties, people started “digitizing” the missing link between the process controllers and the field instruments. The fieldbus idea began to get supporters. Two camps were formed: fieldbus with control in the field (FOUNDATION Fieldbus) or fieldbus without control in the field (PROFIBUS). Field devices would become intelligent and equipped with microprocessors. Control could once again, like in the old days, be distributed in the field.

Ten years on, with FOUNDATION Fieldbus a reality, control in the field is struggling for acceptance. One obvious reason is lack of power: DCS vendors are, understandably, unwilling to pool their well-matured control blocks in an open standard. There must be other reasons, however, because: single loop controllers are still sold in large quantities, proving that there is a market for these simple applications. A lot of customers need a low level of automation that can be provided by a number of single loop controllers with simple PID algorithms. The "angst" is not for the concept, therefore, but for the change from a paradigm that has dominated process control for the last twenty years. This fear is also extended to a certain extent to fieldbuses in general.

Control Hierarchy Mindset

Despite the increasing interest shown in fieldbus technology, it is safe to say that the majority of today's DCS and PLC-based control systems use 4–20 mA signals to realise continuous control. In view of the fact that these signals carry no information other than the measured value, there is a natural separation between the control and field level as regards the functions performed, see Fig. 2. Sensors provide the process value, controllers derive the action, and actuators realise the action and provide feedback. Since there is a standardised interface between controller and field device, the user has freedom of choice in the equipment he uses and can benefit from a corresponding reduction in costs.

When the microprocessor appeared in the late seventies, it not only revolutionised DCS systems and made possible today's PLCs, it also spawned a new generation of intelligent field devices that offered much richer process information than could be transmitted via 4 - 20 mA signals. Fieldbus devices were first exhibited in 1989, and not long afterwards, the ISA SP50 committee was formed to write the specification for a new, universal fieldbus. Obviously, the new standard had to offer the same freedom of choice as analogue technology, thus not only was a communication interface required, there also had to be a standardised user interface. This was to be realised by function blocks, the eighth layer on top of the ISO model [1].

Forgetting the so-called fieldbus wars, it is interesting to note that PROFIBUS, the rival fieldbus standard that emerged directly from SP50, uses essentially the same function block process as FOUNDATION Fieldbus. The major difference lies in the possibility of embedding control blocks in FF devices. In view of the fact that the role played in PROFIBUS controller/device interaction fits so neatly in the traditional control hierarchy, however, the function block application process has never been an obstacle to sales. It was only a gradual change to a new paradigm but not a radical one. Customer concerns are those shared by FOUNDATION Fieldbus: certification, integration, interoperability and the fieldbus itself.

FOUNDATION Fieldbus devices can, of course, be made to fit into the traditional control hierarchy as peripherals of a DCS system. No doubt many of the systems sold to date do just that. It is, however, ducking the issue. If intelligence is already available in the field because practically all field devices have a microprocessor driving the measurement and communication, why do we not make full use of it? Control in the field has decided advantages, and any customer fears must be addressed and shown to be unfounded. When the facts are on the table before him, the user can still decide to operate traditionally, but at least he has made an informed choice.

Hocus Pocus

It is always difficult for users to take risks and overcome the barriers that the adoption of a new technology inevitably throws up. It is still more difficult when “old dogmas” still hold stakes in the ground. It should also be admitted that at this stage of the game, some solutions currently on offer are not ready to compete in a completely new fieldbus scenario. It is not surprising, therefore, that many potential users are hesitating. Typical reactions are:

- I do not know how to use fieldbus in my plant.
- I do not feel comfortable enough to implement it now.
- I have concerns about fieldbus, therefore, I prefer to keep my plant conventional.

These reactions come even when fieldbus is the most viable solution. There are several concerns and fears caused mainly by a lack of knowledge and experience. Decisions regarding deployment of an emerging technology cannot be undertaken without an intimate understanding of the relationship between the technology and its limitations and advantages. It is necessary to train and support in order to ensure that the user has a positive experience. It is also very important for the user to seek a partner that understands all necessary elements for a successful fieldbus project, from concept, through implementation to deployment.

The arguments for using fieldbus solutions range from cable savings through expandability to simple commissioning. The real benefit to the user, however, is the quality of information provided during normal operation. Past experience has shown that innovative solutions are necessary if overall plant performance is to be maximised: when safe and economic production is the goal, it becomes hard to justify the continued use of dated technology. Not only does FOUNDATION Fieldbus provide intimate knowledge of the devices in the field, it also provides a wealth of information from the control loop itself.

These benefits, however, are not to be had when fieldbus devices are used "conventionally". For years, users have bought HART devices but never used the communication because there is no financial disadvantage. For fieldbus devices, there is currently a price disadvantage that must be justified by operational benefits. Wait-and-see strategies are expensive. In this situation, Return on Assets (ROA) becomes just as important as Return on Investment (ROI). For Foundation Fieldbus, getting the best return on assets means committing to control in the field. Since process information is available at every part of the system, operation becomes simpler, more profitable and much safer.

There is no doubt the economic arguments for control in the field are convincing, but there is still an element of black magic in the technology itself. It must be seen to work, not only theoretically, but also in industrial environments.

Control in the Field

Basics

Control in the field is no more than the execution of control function blocks in field devices. A control loop is set up by linking together the inputs and outputs of the constituent function blocks, exactly as if the control was running in the controller. The only difference is that the control blocks themselves will be "attached" to field devices. Depending on the host system configurator, it may be as simple as dragging and dropping the function block to a field device rather than a linking device or controller, see Fig. 3.

As the control strategy is built up in the foreground, a list of all the links is compiled in the background. In addition to those between function blocks, links are also added to enable the parameters in each of the function blocks employed to be viewed by the host system. When the project is downloaded to the real network, every link is mapped onto a communication channel or so-called Virtual Communication Relationship (VCR). A VCR is like a telephone line that allows two or more devices to talk to each other. In reality, three types of VCR are used by FOUNDATION Fieldbus: publisher–subscriber, client–server and report distribution. Publisher–subscriber VCRs are used for links between blocks and are scheduled. Client–server VCRs are used for the unscheduled transfer of view data. Report distribution, also known as source–sink, is use to distribute trend and alarm information.

Communication on the fieldbus is controlled by the Link Active Scheduler (LAS). This normally resides in the controller or linking device, but may also be located in a field device. The LAS directs the scheduled traffic by means of the so-called Compel Data (CD) schedule. This lists all the publishers with the exact instant and period they should be given permission to publish. The LAS synchronises control by working successively though the list, compelling each block to publish in turn. All devices requiring the published value (subscribers) are updated at the same instant in time. In the periods between scheduled traffic the LAS handles system requests for view data, write commands or broadcasts administrative data. The time taken to refresh the process data of the complete system is determined by the macrocycle, which comprises the CD schedule plus an additional fixed period for unscheduled traffic. It should be noted that depending on macrocycle length and amount of unscheduled traffic, it can take more than one macrocycle to update HMI data.

Optimising Macrocycle

One way to optimise control is to reduce the macrocycle by cutting the scheduled traffic on the bus. This means reducing the links required to execute the control. Fig. 4 shows an example of a PID control loop, where a flowmeter is used to control the valve positioner. There are three methods by which the control can be done:

1. When the PID loop is located in the controller, three external links are required:
   – to send data from the transmitter AI block to the PID block.

– to send the result of the PID execution to the actuator AO block.
– to send the back calculation data from the actuator AO block to the PID block.

2. When the PID loop is located in the transmitter, two external links are required:
– to send the result of the PID execution to the actuator AO block.
– to send the back calculation data from the actuator AO block to the PID block.

3. When the PID block is located in the actuator, only one external link is required:
– to send data from the transmitter AI block to the PID block.

For a single loop, the savings are relatively small compared to the execution time of the blocks, especially when it is considered that loop execution is quicker in the controller. When several loops are running simultaneously, however, the execution time becomes much less significant, and the number of links becomes the decisive factor in optimising the macrocycle. Moreover, reducing the number of external links increases the loop integrity. In this respect, Method 3 offers the highest integrity. From the example above it can be seen that there is an immediate advantage in placing control in the field, but are there any limitations?

Function Blocks

One obvious limitation is the number and type of device function blocks available to the system. The more there are, the better they can be used to optimise the performance of the system. Most function blocks address continuous control, Flexible Function Block technology, however, offers the possibility to seamlessly integrate continuous and discrete control (hybrid). For sequential control, there are definite weaknesses because on one hand timing is critical and on the other there is, as yet, not much support for sequential logic.

It makes no sense, however, to overburden a device with function blocks that will probably not find application, as this places an unnecessary load on device memory. FOUNDATION Fieldbus offers a solution in instantiation, allowing function blocks to be created ad hoc or to be downloaded to the devices from the system library. Thus, the user has the freedom to distribute them anywhere in the field and has the flexibility to decide where the control should be. Unfortunately, not all host and device manufacturers support instantiation, and up until very recently, its mere declaration in the device configuration file (.CFX) was sufficient to cause interoperability problems. Thankfully, the Fieldbus Foundation have recognised this problem and provided a solution.

To guarantee maximum flexibility and scalability, it is also important that the same blocks are operating in the controller and devices. Where fixed blocks are in use, it must be guaranteed that they are identical throughout the system. This ensures uniform configuration and standard parameters. Although the list is getting longer, less than half of the blocks included in the FF specification are currently included in the interoperability tests. More will be included later but for the present, the remainder, plus any manufacturer specific or custom blocks, should be carefully examined with regard to device replacement strategies. If you are unsure of interoperability, ask the manufacturers whether their function blocks operate with the selected host. Most have excellent fieldbus laboratories and test in a multi-vendor environment.

Virtual Communication Relationships (VCRs)

As described earlier, a VCR is like a telephone line, and a device must have one line for each external link. Devices may offer fixed numbers of VCRs of a given type or may offer complete flexibility of use. Some devices support very few VCRs, a limiting factor if several links are required. This is the case in more sophisticated control strategies that cater for device redundancy, alarming or cascade control with block recovery/override facilities. While not being a knock-out criterion for control in the field, devices offering as many VCRs as possible certainly increase loop integrity and the flexibility of system design.

Multi-Variable Optimisation

The function block parameters of a field device are made available to the host in four standardised views. The whole view is transmitted, even if only one parameter is required. The host data base is updated by unscheduled communication in a client-server relationship, each view taking around 50 ms to transmit. When control blocks are executed in the field, the view traffic increases – a situation that can be exacerbated if the parameters selected for monitoring are in different views. If the control task dictates a short macrocycle, therefore, it may take more than one cycle to refresh the view data.

The unscheduled traffic can be significantly reduced, and hence response time improved, if the host system supports another Foundation Fieldbus specification, Multi-Variable Optimisation (MVO). A device supporting this feature will bundle together view parameters from several function blocks into a single object. This can then be transferred in one transaction, greatly reducing the traffic on the bus. This results in a significant improvement in refresh time.

Horror Scenarios

Having determined the advantages and limitations of control in the field, what about the fears? Every control engineer has his own particular horror scenarios, but some come up more often than others. It is part of the risk analysis to assess what action, if any, should be made in response to such situations, the result might be a system similar to that shown in Fig. 5. In the following, four common fears have been selected, the consequences of each discussed and possible solutions presented.

Zombies

A device dies on me in the middle of the night. I loose the loop.

This can occur in any system. The actual consequences will depend on the role of the device in the control loop. With some roles, it is possible to design a recovery strategy, with others the device must be replaced.

1. When the device dies, function blocks awaiting input from the dead device will flag bad status, and the associated loops will assume the programmed fail-safe mode.
2. For devices providing input to a loop, it is possible to automatically recover to a redundant counterpart by using the input selector block.

3. Devices running control blocks must be replaced, because at the moment most host systems do not provide function block redundancy. The loop will flag bad status and any outputs will assume the programmed fail-safe mode. If the control block is in the actuator itself, the mechanical override of the valve will cause it to assume the fail-safe mode selected.
4. All function blocks used in the dead device must also be present in its replacement. If non-standard function blocks are in use, then the replacement device must correspond exactly to the dead one. Depending on the configuration tool, it is a simple matter to set up the new device and partially download the control strategy. The loop will then run again.

Godzilla

Something comes along and chews up the fieldbus cable to the controller: I loose the control in all the devices on the segment.

Cable breaks can occur in any system and the consequences are always that at least one loop is lost. What is quicker, to hook up the two bus wires or locate and repair an analogue connection?

1. Since power is normally lost, the mechanical override on the valves will cause them to move to the fail-safe position selected.
2. Since communication is lost, any loops in other segments requiring data from the affected devices will flag bad input status and default to the programmed fail-safe state.
3. If the loop was designed with power redundancy only, the back-up LAS will take over control, and all loops within the affected segment will function normally. External loops will react as in Item 2.
4. If power, controller (hardware) and control (application) redundancy has been provided, the back-up controller will take over control and all loops will act normally.

Psycho

The controller is taken out, I loose all control.

In other systems yes, but with Foundation Fieldbus it depends on the control strategy you have selected. Assuming there are no function blocks being executed in the controller:

1. Normally, the back-up LAS in each segment will become active and all loops with in the connected segments will run normally (assuming there is still power). Any cross-segment loops will fail and default to the programmed fail-safe state.
2. If controller redundancy has been provided, the back-up controller will take over control and all loops will act normally.

If there are function blocks being executed in the controller:

3. Normally, the back-up LAS in each segment will become active and all loops within the connected segments will run normally (assuming there is still power) with the exception of those with blocks being executed in the controller. These, together with any cross-segment loops, will fail and default to the programmed fail-safe state.

4. If controller and control redundancy have been provided, the back-up controller will take over control and all loops will act normally.

Headless Horseman

The HMI system goes. I am blind and have no idea what is going on.

If this has ever happened to you, then you will have provided a back-up system. High Speed Ethernet is part of the Foundation Fieldbus Specification, so depending on your control system, this does not have to be expensive, since Components-Of-The-Shelf (COTS) can be used to support network redundancy.

1. Losing the HMI has no effect on the controller and devices: all loops will continue to work.
2. Providing that the OPC Server is also redundant, if a back-up HMI is present, it will take over.
3. It is perfectly feasible to provide central or local emergency panels and buttons. FF function blocks include discrete inputs that allow manual override of critical loops, switching them to fail-safe mode.

Where Does Control in the Field Make Sense?

Although it might sometimes be a case of preference, control in the field usually makes sense when there are economical or technical benefits to the user. When comparing the cost of FOUNDATION Fieldbus to other systems, every control block used in a field device replaces an analogue channel on a DCS. Within a FOUNDATION Fieldbus system itself, however, there is no obvious economic benefit from running the control blocks in the devices, unless the controller is limited in the number of blocks or links it can handle, a high degree of loop integrity is required or the controller is not necessary at all.

As discussed in Section 4, where blocks are running, control in the field does have an effect on the macrocycle length. By careful design of both segment and control strategy, most applications can be effectively solved. Limitations are set by the number and type of blocks available and the number of links that can be supported. These in turn depend on the field device and host system. The examples that follow indicate what control in the field looks like in practice, see Fig. 6. The host and devices used supported multivariable optimisation.

Simple feedback flow control

As illustrated in Section 4.1, the optimal location for the PID block of a control valve is the positioner itself, see Fig. 4. Not only does this reduce the number of links and loop integrity, it also ensures that the block assumes fail-safe mode when the input is bad. There is no intervention by operator or other devices in the network.

Temperature control in a distillation column

As a continuous process, the regulation of temperature in distillation columns (or boilers) provides an ideal application for control in the field. In the application shown, see Fig. 6, solvents were distilled in batches, meaning that there had also to be some kind of ramp control over the initial boiler heating phase. This was done by means of a characteriser and arithmetic block, which together with a constant block for tracking, were run in the valve positioner. In all, five external publisher links were required. Had the application been implemented in the controller more than twice as many links would have been required, making a noticeable impact on macrocycle time and decreasing the degree of loop integrity. When many loops are necessary, the reduction in cost becomes more apparent because it is not necessary to replicate local controllers that execute each temperature control loop independently.

Motor control from a field I/O device

As mentioned earlier, currently Foundation Fieldbus is not very strong in logical control. The general method of managing analogue and digital I/O signals is to add I/O cards to the controller. There are, however, several possibilities to integrate PLC platforms into Foundation Fieldbus or to use FF field I/O devices. The latter, mounted locally on the H1 segment, was the solution selected. By using a flexible function block, a small degree of logical control is available in the field. This was ideal for the motor control centre in the distillation plant just described.

Simple is Beautiful

Does Control in the Field have a future? As control systems have increased in size and capabilities, the remoteness and complexity generated by a proliferation of smaller, faster and cheaper technological components in a large system has been forgotten. Could this be one of the main reasons why people are "afraid"? Is it the thought of relying on thousands of components to work together reliably - components that no longer deliver information to one source, but which, in order to control a process, distribute it, apparently without supervision, across the field ?

From the technical point of view, there is no longer a need for a centralised control room. "(Today's) control systems are advanced enough that the control room is not needed to co-ordinate the control" [2]. Perhaps the way ahead is to go back to the field and create small, manageable units, capable of operating by themselves, but reporting regularly to the supervisory system. FOUNDATION Fieldbus is ideal for such systems, since a segment can also be operated without a "controller", indeed without control, when required.

At the same time there is a need for “simplicity”. Simplicity does not preclude users from undertaking skilled tasks such as connecting up the equipment, rather it implies that they would like to see a lot more plug and play in device integration, configuration and design of the control strategy.

Undeniably, Fieldbus is an “enabling” technology, but let us not forget the people who must work with it. Manufacturers can make fieldbus reality much simpler and more effective. As result, fears and concerns will no longer find the nourishment to sustain them. When the Zombies can be exchanged and put to rest at the push of a button, and the plant manager can sleep well at night, the goal will have been reached.

Acronyms

AI	Analog Input (Block)
AO	Analog Output (Block)
CD	Compel Data
DCS	Distributed Control System
FF	FOUNDATION Fieldbus
I/O	Input/Output
ISA	Instrument Society of America
LAS	Link Active Scheduler
MTBF	Mean Time Between Failure
MVO	Multi-Variable Optimization
OPC	Object (Link Embedding) for Process Control
PID	Proportional-Integral-Derivative (Block)
PLC	Programmable Logic Controller
VCR	Virtual Communication Relationship

References

[1] International Standard Organisation/ International Electrotechnical Commission, ISO/IEC 7498-1 “Information technology -- Open Systems Interconnection -- Basic Reference Model: The Basic Model”, 1994

[2] G. K. Totherow, Instrument Engineers' Handbook, 3rd Edition, Process Software and Digital Networks, Chapter 3.1, Operator Interface Evolution.

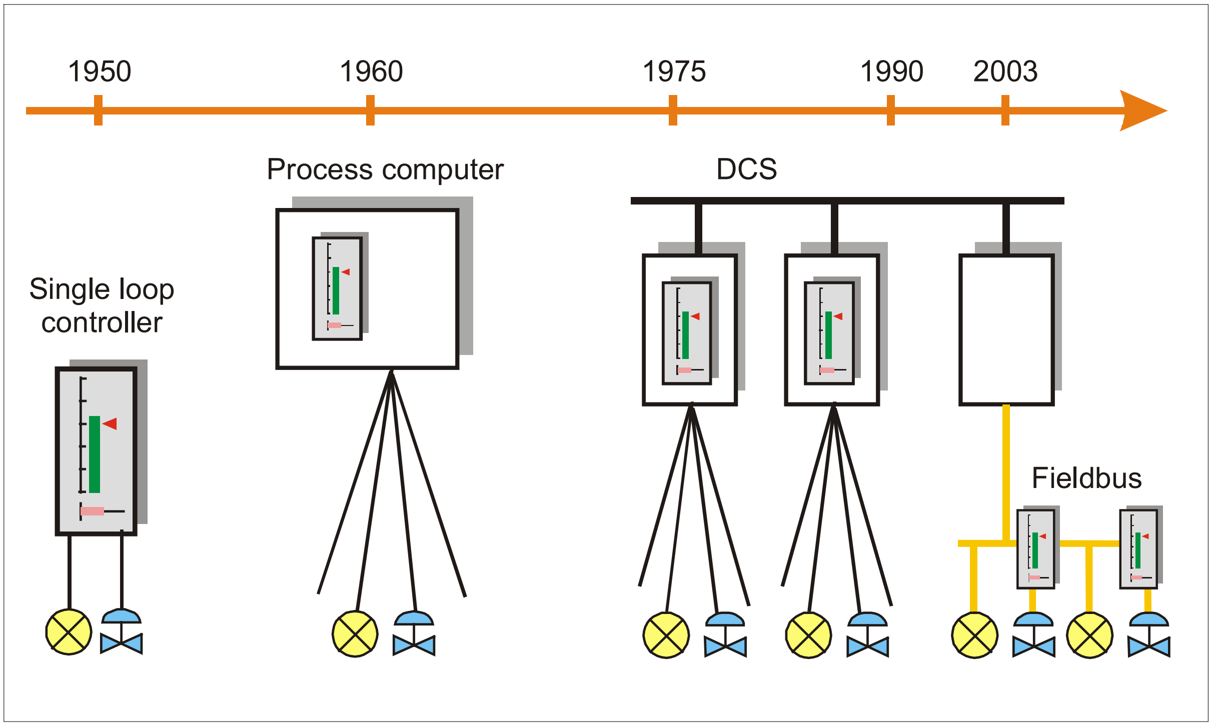

Fig. 1: Development of distributed control systems

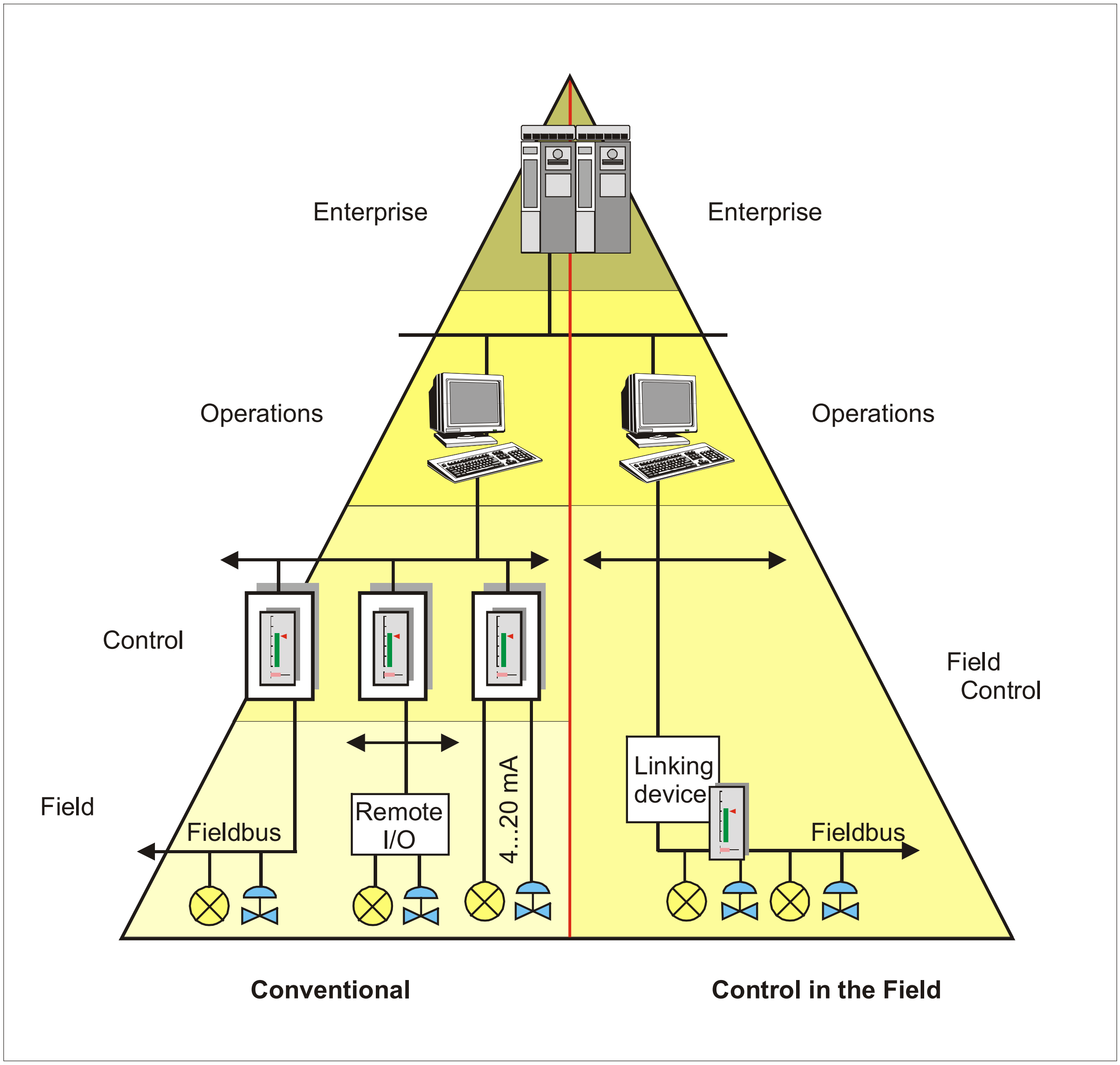

Fig. 2: Conventional and field control hierarchies

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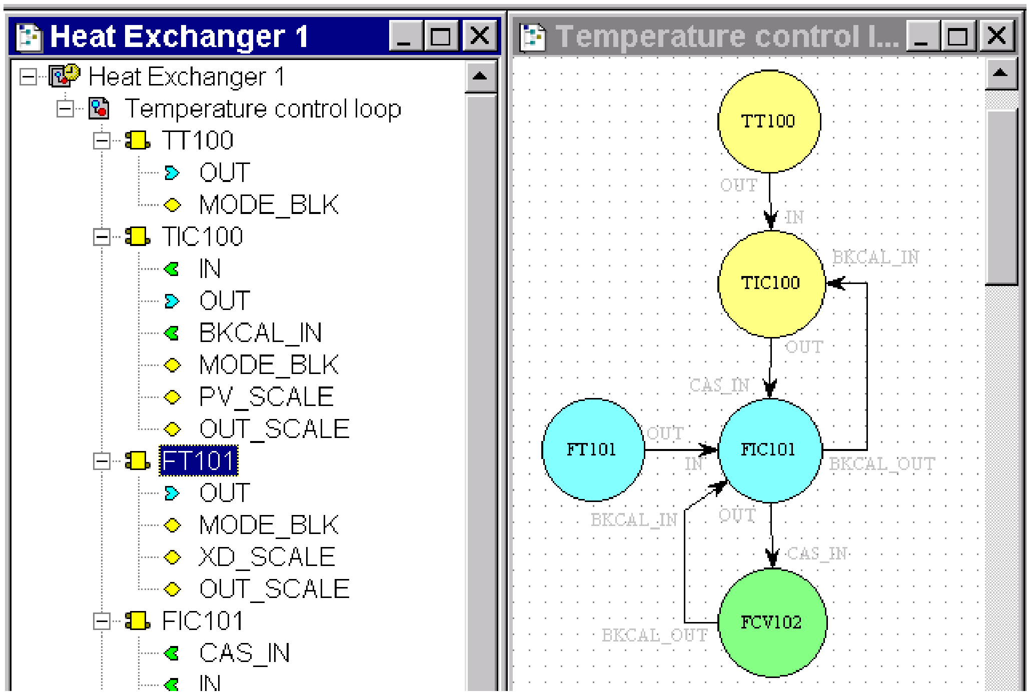

Fig. 3: Example showing the configuration of a cascade control loop in a host configurator

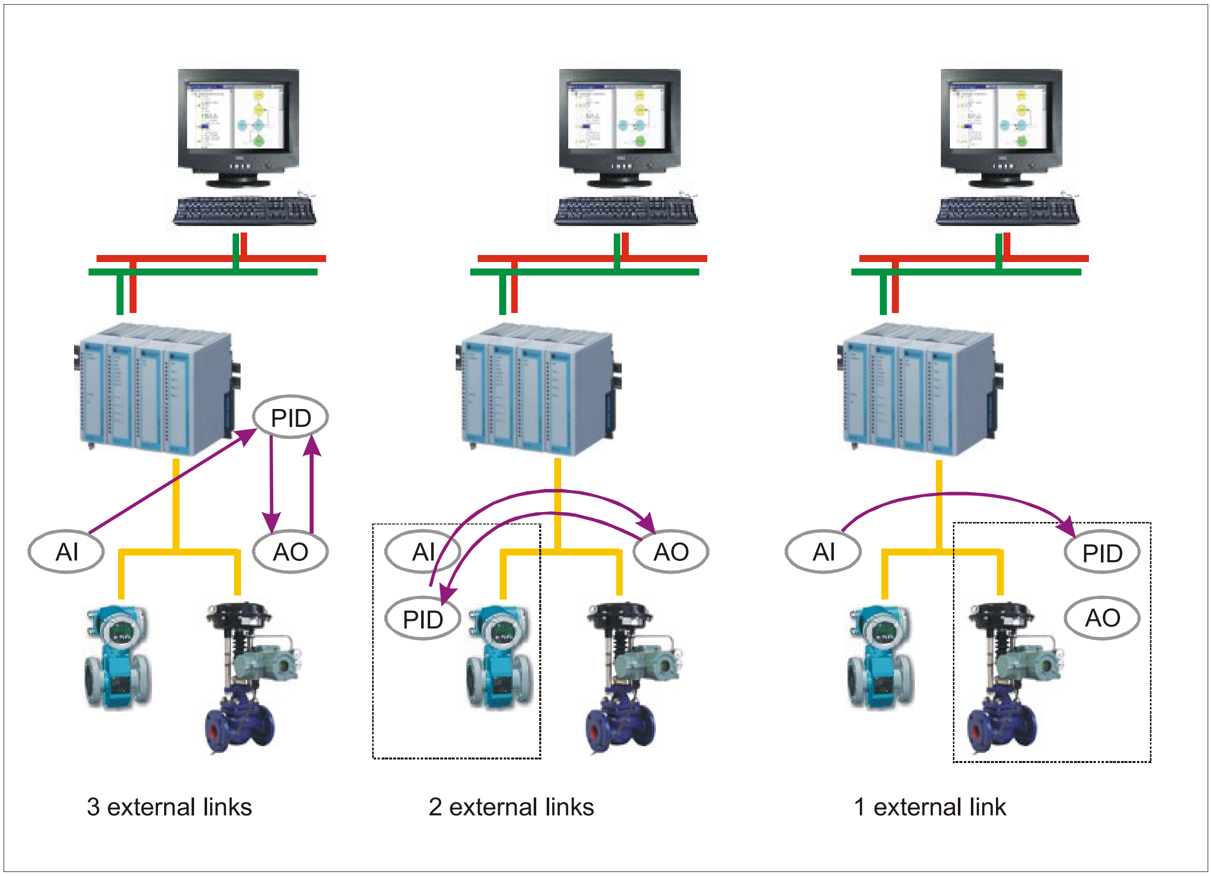

Fig. 4: Examples of control strategies and the effect of location of function blocks

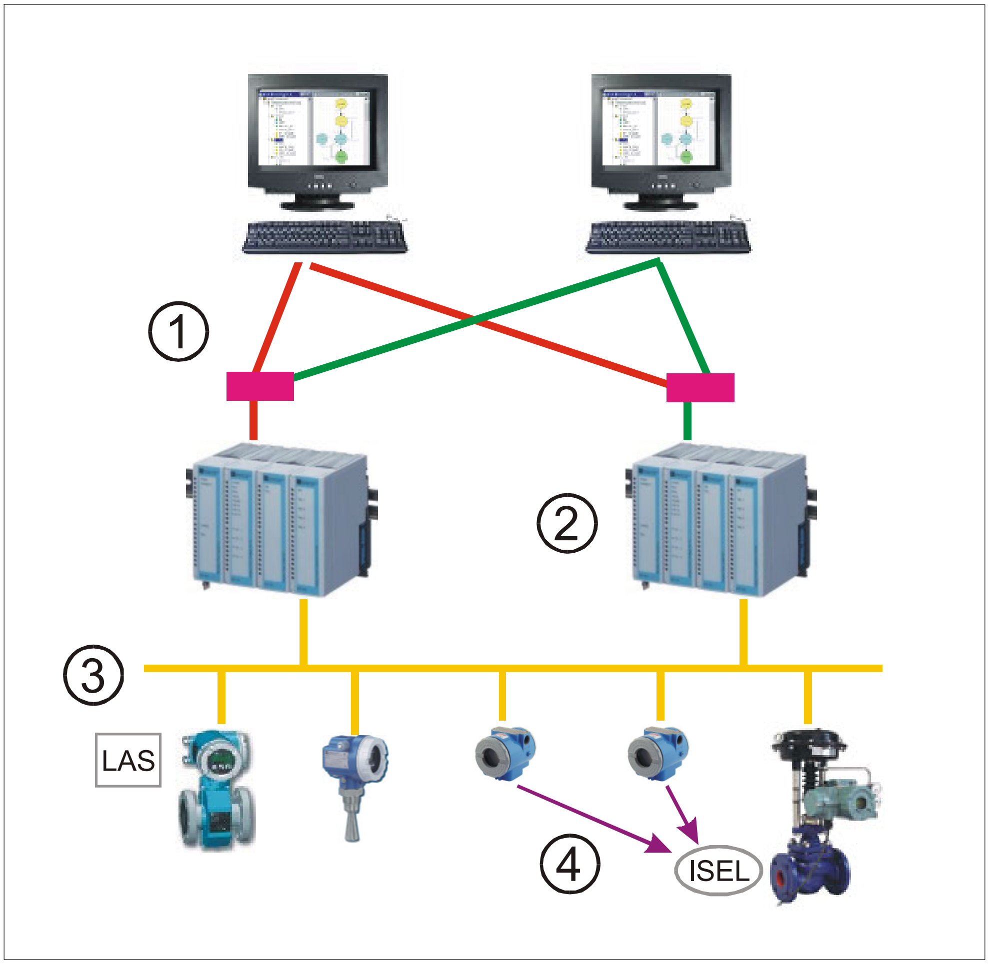

Fig. 5: Fieldbus system with redundancy at several levels

1. **HMI redundancy with off-the-shelf components**
2. **Controller/linking device/power supply redundancy**
3. **Schedule redundancy by back-up LAS**
4. **Device input redundancy by redundant device and input selector block**

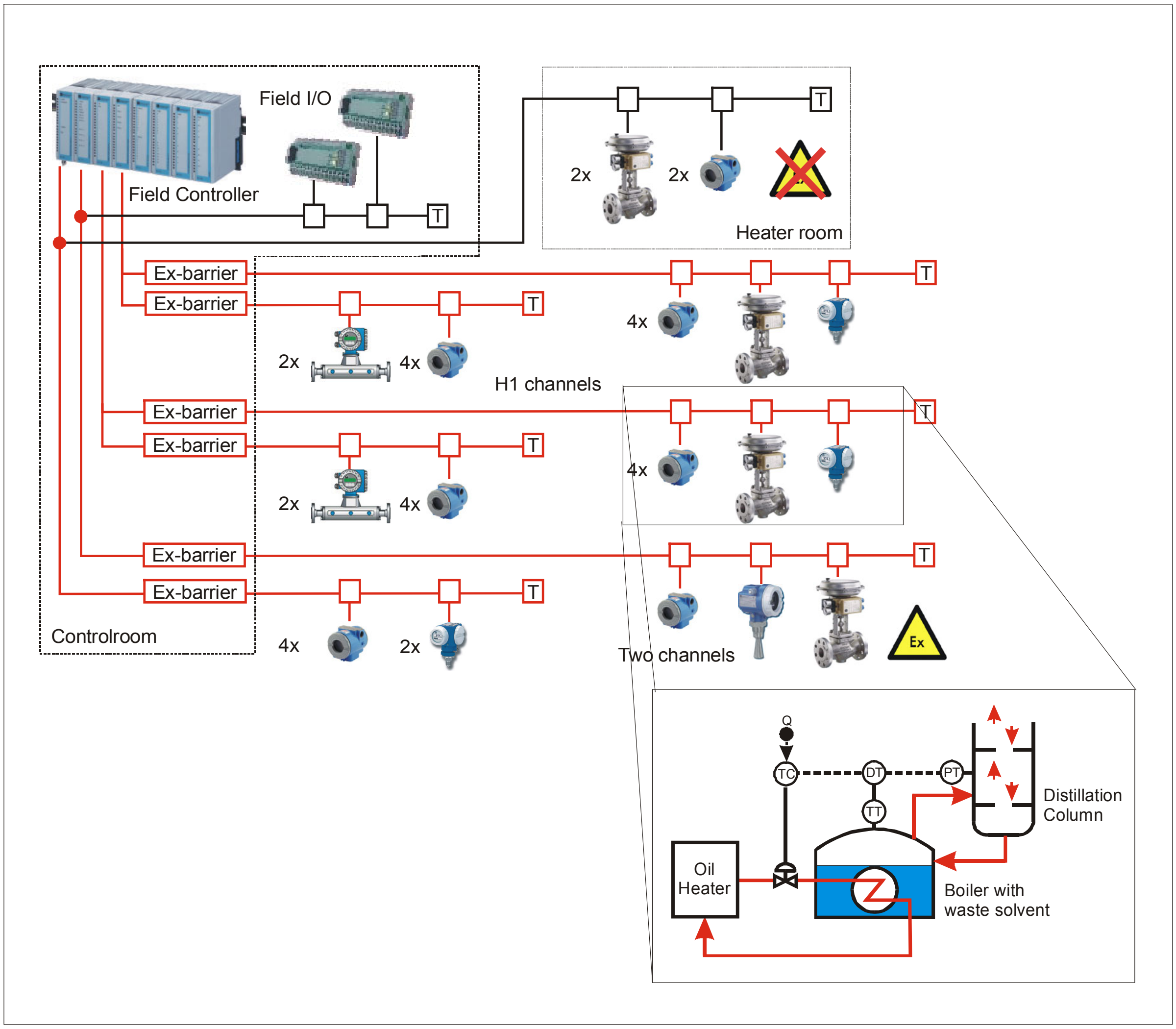

Fig. 6: Example of field control system in a distillation column.
The field I/O was used for motor control, simple flow control (flowmeter and valve) was located in the valve positioner as was the temperature control in the column (temperature sensor, pressure sensor and valve positioner).

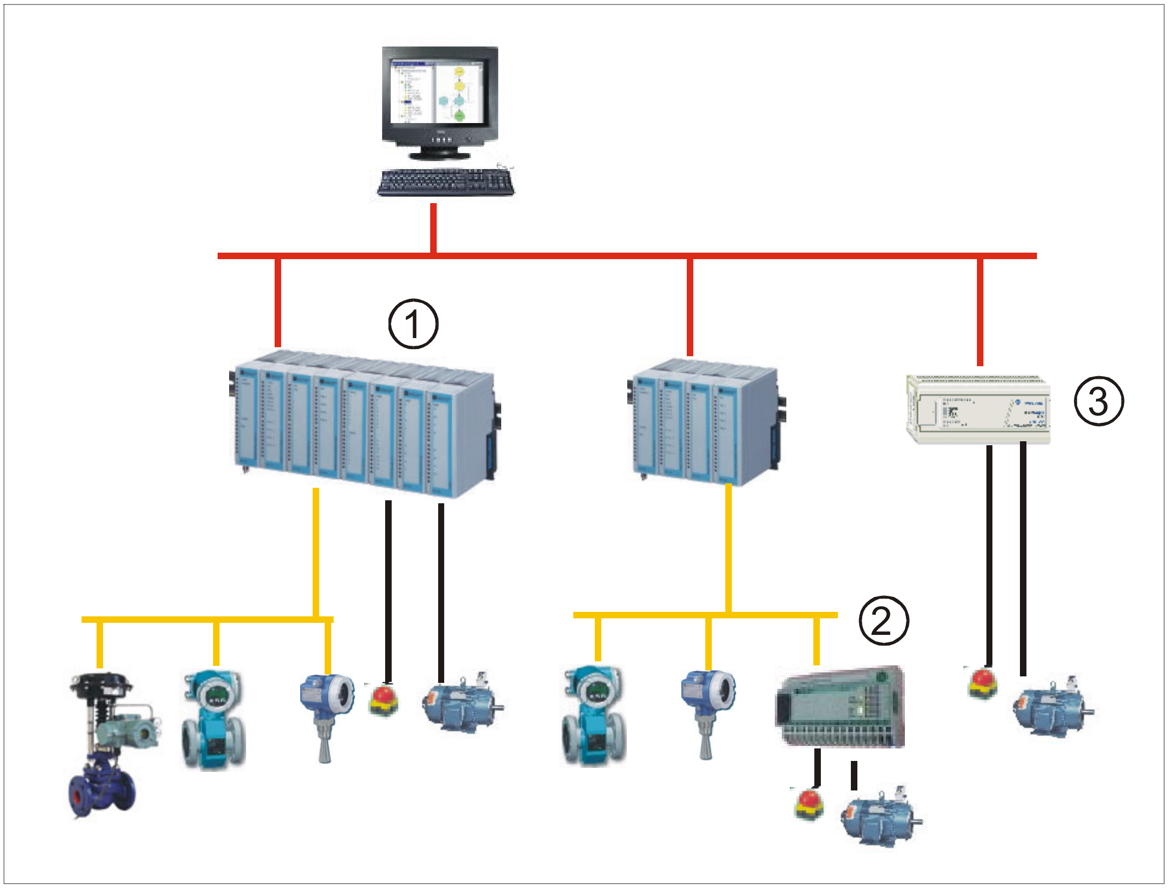

Fig. 7: Possibilities for providing logical control in a FOUNDATION Fieldbus system

1. **Local I/O connected to field controller**
2. **Field I/O device with flexible function blocks for discrete control and interlocks**
3. **PLC connected via Ethernet for sequential control**