White paper

NETWORKED SAFETY TECHNOLOGY IN MACHINE ENGINEERING

DIVERGENT CONCEPTS FOR SAFE INSTALLATION AND OPERATION – FOCUS: SERIAL DIAGNOSTICS

SCHMERSAL
THE DNA OF SAFETY

CONTENT

1. THE PROBLEM

For some time now, industrial environments have become used to the ongoing trend of ever more comprehensive automation of machinery and systems. In conjunction with the increasing prevalence of automation measures, the requirements on safety measures have also been on the increase.

It is important that safety technology does not restrict the increasingly tight cycle of industrial processes or lower the availability of the machinery and systems. In addition, increased complexity must not give rise to longer periods of downtime for maintenance and servicing. There are also requirements designed to ensure that human-robot collaboration is as intuitive and productive as possible.

Finally, there is a trend towards more elaborate safety functions, which manifests in the following effects:

- The number of installed components is increasing.
- With the growing number of components comes an exponential increase in the number of potential sources of error.
- This in turn leads to more time-consuming troubleshooting procedures and

longer periods of downtime and reduced productivity as a result. The investment required for new system is also increasing due to higher costs for components, installation and commissioning.

2. SOLUTION APPROACH

There are several approaches to mastering the increasing complexity of safety measures. The first approach is derived from the systematic risk analysis for risk reduction in accordance with ISO 13849-1. This gives rise to dedicated safety functions. System analysis helps to ensure that potential hazards are dealt with properly and separately. A practical outcome of this is the creation of separate de-energising circuits that allow targeted elimination of hazards through targeted de-energising and activation of individual system parts, thereby preventing damage. In addition, they also allow for more focused inspection and maintenance, as component malfunctions can be tracked down more quickly.

With the number of de-energising circuits on the increase, the use of a safety PLC (programmable logic controller) can offer benefits, whether configured as part of the functional PLC or as a separate, standalone safety controller. Use of a PLC can usually reduce the installation effort considerably when multiple de-energising circuits are present. In addition, the options for configuring the safety logic are considerably more extensive when using a safety PLC than when using traditional safety modules.

Another option for reducing installation effort is to move away from standard parallel wiring, where the signals from all safety components are routed individually/in parallel to the logic components. This requires more inputs to the safety logic, and increases the number of cable connections within the system. There are now two ways to counter this:

1. Series connection of safety switchgear devices
2. The formation of nodes, e.g. with fieldboxes, i.e. star wiring

2.1. SERIES CIRCUITRY

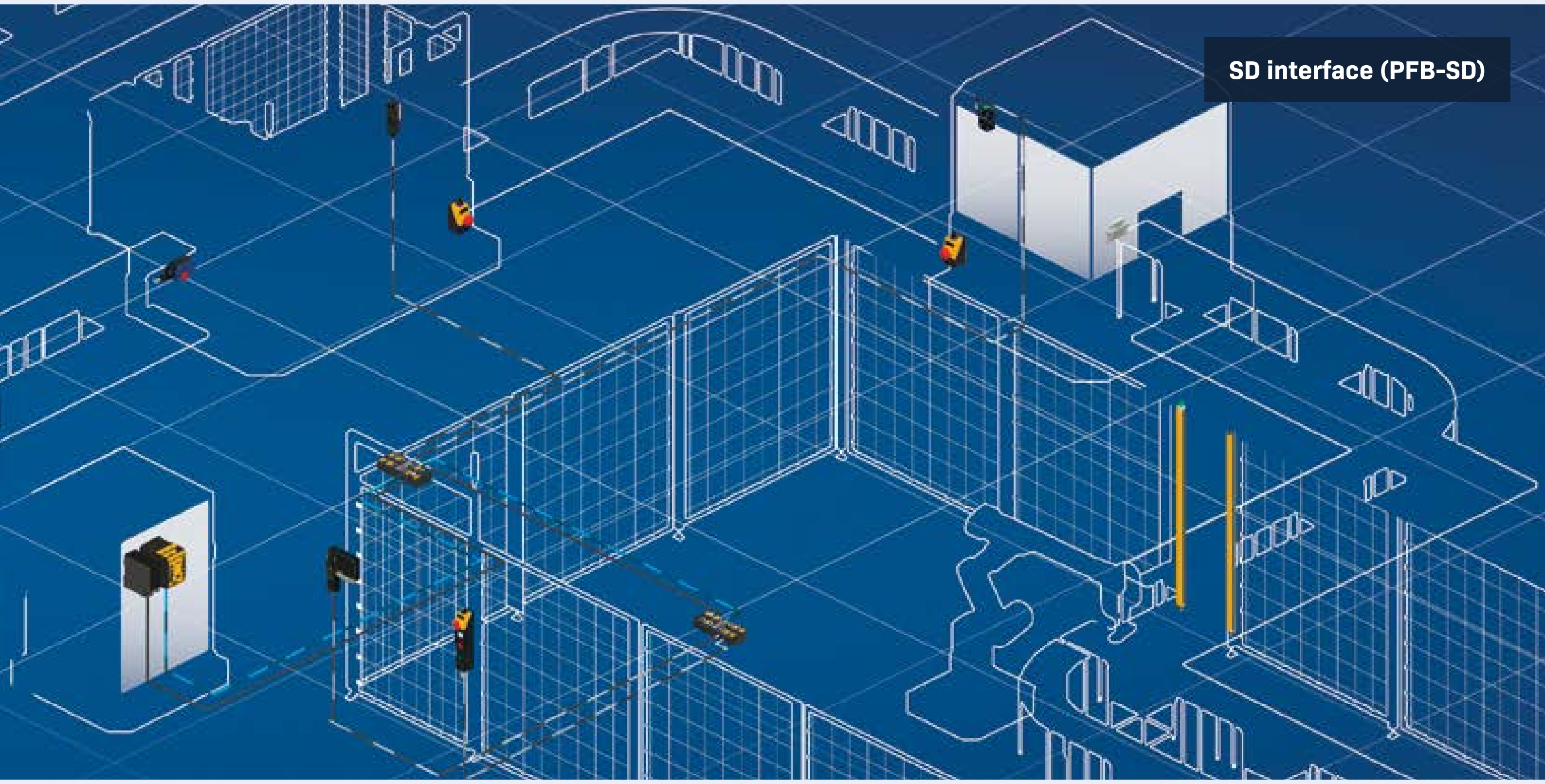

Figure 1: System wired in series

A series circuit is beneficial in that it lowers the number of connections and number of secure inputs required in the safety logic. Albeit with a loss of information. With a series circuit, it is not possible to establish which link in the chain has disrupted the chain without taking additional measures, which tends to complicate diagnostics and troubleshooting considerably.

A communication interface can offer a remedy by allowing individual subscribers to transmit diagnostics data. In the case of a system with star wiring, this could include the use of intelligent nodes that detect which subscriber or port has failed or been actuated and report this information to the upstream node. Serial diagnostics are usually used in a series circuit, with each link in the chain transmitting individual diagnostics data in addition to the safety signal. With both procedures, information on diagnostics and the status of the devices is preserved.

A further drawback of series circuitry is that the power consumption of all links in the chain is added together, which means that the maximum number of subscribers is physically limited due to the voltage drop along the line. This only has practical significance when a higher number of high-consumption components are used, such as solenoid interlocks.

As a matter of principle, the status of the safety outputs of all links in a series circuit is linked logically with AND.

2.2. STAR WIRING

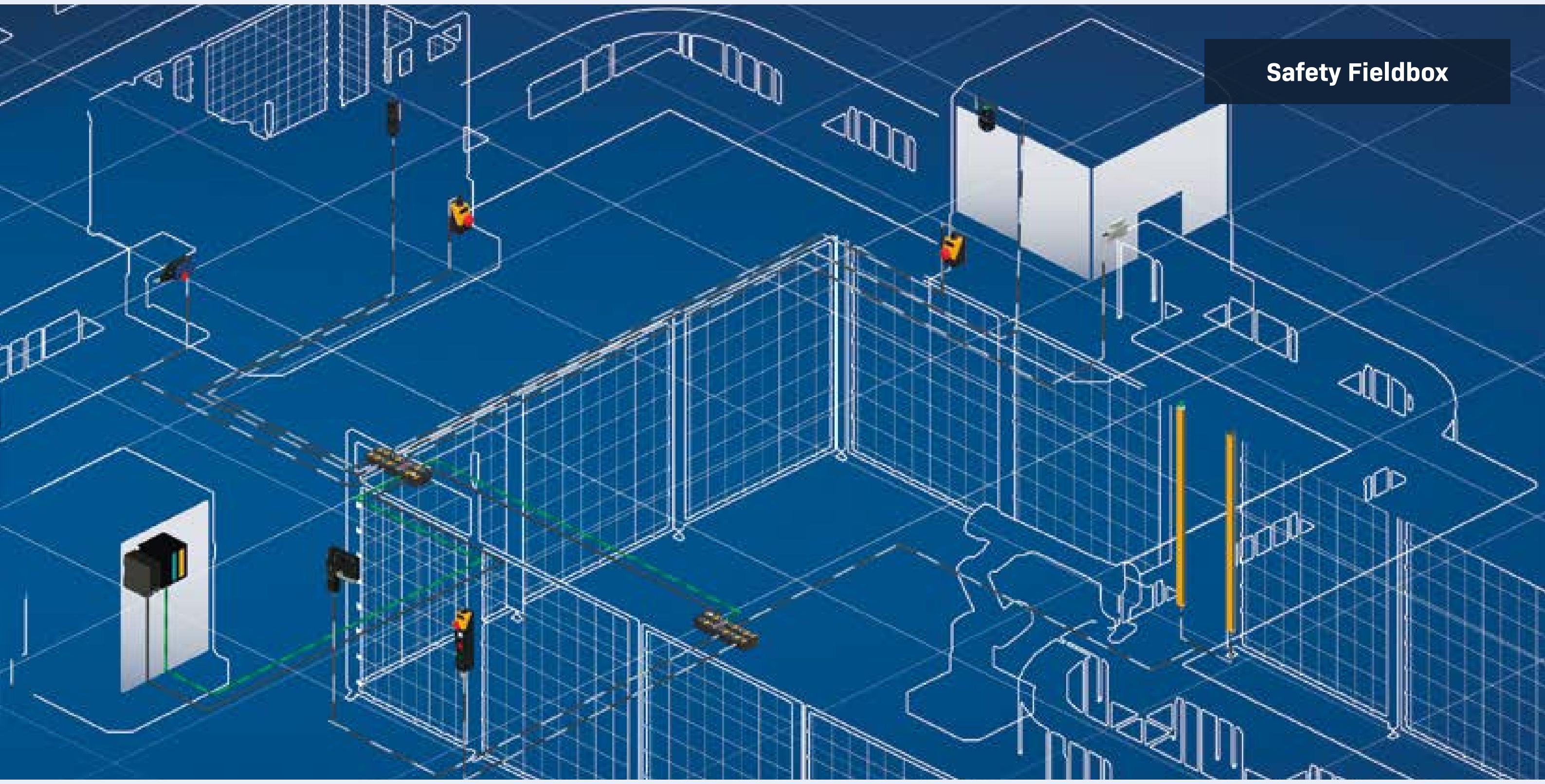

Figure 2: System with star wiring

The star wiring approach is based on the creation of nodes (or stars) to which the safety switchgear devices can be connected. This also helps to reduce wiring effort considerably. Due to the nature of the system, however, there will be a loss of information if no additional measures are taken. This can be countered by carrying out a separate evaluation of the connected safety switchgear devices at each node and reporting the outcome of the evaluation to the higher level of the safety logic (e.g. safety controller). This can be achieved with the aid of (secure) bus systems, for example.

A benefit over series circuitry is that the power consumption of the connected components is not added together, as they typically receive their power supply in parallel to the nodes, which means that the nodes in turn can be supplied separately. Installations of this kind are thus more suitable for the use of components with high power consumption levels.

A drawback of this variant is that the nodes themselves must have a certain level of safety logic. If each node also has a (secure) communication interface, each node itself is a component with high technical complexity, which goes hand in hand with higher acquisition costs and requirements on the user.

2.3. SUMMARY

In order to counter increasing complexity in the installation of industrial automation applications, especially safety technology, it is better to choose approaches that are based either on series circuitry or the formation of nodes. The loss of information can be avoided with the use of communication interfaces.

Here, series circuits are suitable for the formation of de-energising circuits, where the status of subscriber devices is linked logically with AND.

Star wiring can be used to implement more demanding logics, provided that the individual connections of a node/star can be evaluated separately. Processing can be carried out locally on the node itself or remotely, on a separate safety logic. This requires the device itself to have the right capability and, if applicable, a corresponding (secure) communication interface.

The following focuses on safe series circuits combined with the serial diagnostics interface SD from Schmersal.

Other installation systems from Schmersal include the safety SFB Safety Fieldbox (star wiring with secure fieldbus interface – see here) or safety switchgear devices with As-i interface (see here).

The Safety Fieldbox – universal, safe and cost-effective

3. SAFE SERIES CONNECTION FROM SCHMERSAL – FOCUS ON SD

The SD bus from Schmersal is a system designed for performing serial diagnostics of series circuits. It takes the form of a communication interface that is integrated into safety switchgear devices of the corresponding type. It is configured as a single-wire bus routed parallel to the secure signals and power supply (integrated into the connection cable/ connector in the case of SD safety switchgear).

This communication interface has two roles. The first is to capture the status of the secure outputs of the individual series links – without the use of an appropriate interface, this information is lost in a series circuit. The second role is to transfer enhanced diagnostics data from the device (see also Table 1: Example diagnostics data from SD safety switchgear devices [AZM300]).

The following safety switchgear devices are available with an SD interface:

- Safety sensors in the CSS and RSS product groups
- Safety switches with separate actuators in the AZ201 and AZ300 groups
- Solenoid interlocks in the AZM201 and AZM300 groups
- Control panels with emergency-stops of type BDF200

In addition to the status of the secure outputs (actuated, unactuated), there are various other diagnostics data that can help to simplify commissioning and troubleshooting for system owners.

Bit no.	Call byte	Response byte	Diagnostics error warning	Diagnostics error messages
Bit 0:	Solenoid on, irrespective of operating or quiescent current principle	Safety output switched on	Error at output Y1	Error at output Y1
Bit 1:	---	Protective device closed AND lock/unlock possible	Error at output Y2	Error at output Y2
Bit 2:	---	Actuator detected and locked	Cross-fault	Cross-fault
Bit 3:	---	---	Excess temperature	Excess temperature
Bit 4:	---	Input status X1 and X2	---	Incorrect or defective actuator, bracket breakage
Bit 5:	---	Valid actuator detected	Internal device error	Internal device error
Bit 6:	---	Error warning	Communication error between fieldbus gateway and safety switchgear device	---
Bit 7:	Error acknowledgement	Error (release path de-energised)	Turnstile in impermissible intermediate position	Turnstile in impermissible intermediate position

Table 1: Example diagnostics data from SD safety switchgear devices (AZM300)

3.1. CONNECTIVITY

There are a number of options available for processing these data for a higher-level functional PLC or HMI. The SD-I-U universal gateway can be used with an integrated functional and safe PLC (e.g. the Siemens F-CPU with secure input and output elements). This both forms the master for the SD bus and establishes the connection to the F-CPU via fieldbus. This approach is recommended if only one or two de-energising circuits are required and traditional safety modules are used.

In the case of multiple de-energising circuits or mixed operation of series circuitry and parallel wiring, use of the PSC1 safety controller can be beneficial. The latter has a safety logic as well as secure inputs and outputs to cat. 4 PL e and, at the same time, an integrated SD fieldbus gateway. This approach offers all of the benefits of a freely programmable safety controller, enhanced diagnostics and more comprehensive connectivity via fieldbus (protocol can be switched on the software side).

PSC1	SD-I-U	SD-I-DP-V0-2
Profinet IO	Profinet IO	Profibus
Ethernet/IP	Ethernet/IP	
EtherCAT	EtherCAT	
CANopen*	ModbusTCP	
OPC UA*	CANopen	
	CC Link	
	DeviceNet	

* On request

Table 2: Overview of connectivity, SD master

3.2. INSTALLATION

TThe safety switchgear devices are installed via 8-pole M12 connectors and corresponding connecting cables. The SD master (gateway or controller) and a power supply unit to the control cabinet represent the start of the chain.

Field wiring can now be accomplished with three different installation types:

- Y adapter
- PFB fieldbox
- PDM control cabinet distributor

3.2.1. Y ADAPTER

Installation using a Y adapter provides a separate connection point within the chain for each device of an SD series circuit by using one Y-adapter per device.

The Y adapter has three connections:

1. M12 connector, 8-pole Connection of previous link in series circuit
2. M12 socket, 8-pole Connection, device
3. M12 socket, 8-pole Connection of next device in series circuit or terminating plug

Y-adapters have two mounting holes which can be used to mount them to any flat surface.

In view of the comparatively high voltage drop along the chain, this type of installation is primarily suitable for series circuits with a limited number of devices or for devices with lower power consumption (e.g. RSS type sensors). In the case of increased power consumption by the series circuit, e.g. when using multiple solenoid interlocks, a 'power adapter' can also be used at the first point in the series circuit. This creates an additional feed-in point for the power supply.

The final link in an installation with Y-adapters is always the terminating plug.

Figure 4: Example wiring, SD with Y adapters

3.2.2. PFB FIELDBOX

An additional approach to installing a system with SD is use of the PFB-SD passive fieldbox. This fieldbox has several functions: The first is to allow connection of up to four safety switchgear devices. The second – each fieldbox offers its own feed-in point for the power supply to the safety switchgear devices that are connected to it. Within the restrictions of the SD bus specification, any number of PFBs can be connected in series. No terminating plug is required at the end of the circuit.

This procedure rectifies one of the main defects of wiring using Y adapters: the PFB supplies each of the connected devices in parallel. As such, this wiring system is particularly useful for devices with increased power consumption. One of its drawbacks, however, is its slight departure from the philosophy of series circuitry. Each PFB forms a node around which the safety switchgear devices are arranged in star formation – a mixed form of series and star circuitry. The PFB forms a node and supplies the devices in parallel; the safety and diagnostics paths remain internally series connected.

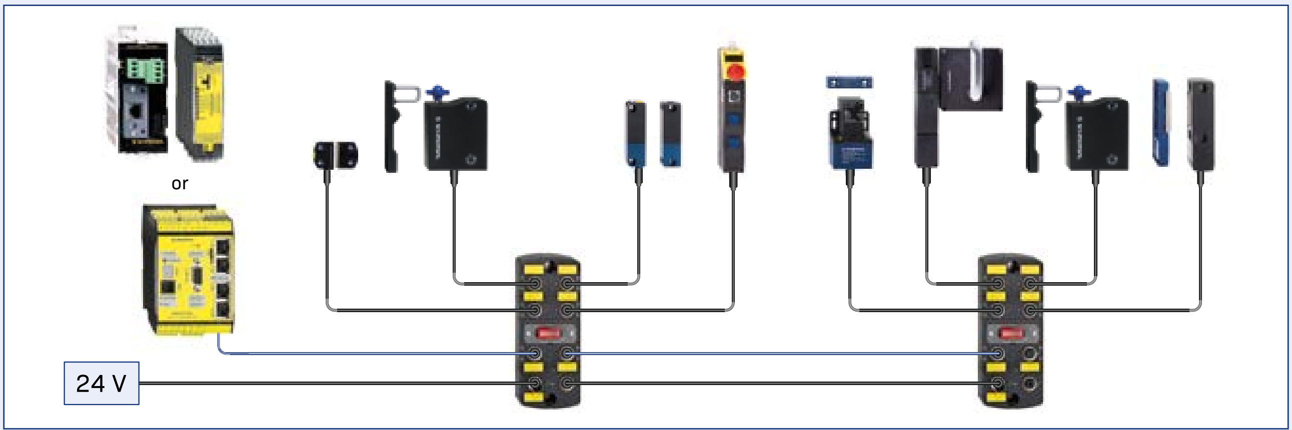

Figure 5: Example wiring, SD with PFB fieldbox

3.2.3. PDM CONTROL CABINET DISTRIBUTOR

From a functional perspective, the PDM-SD passive distributor module is similar to the PDB-SD passive fieldbox. The difference is that the PDM is intended for mounting in a control cabinet. This means that the cable connections of the safety switchgear devices must be routed into the control cabinet so that they can be connected to the PDM. From a use perspective, the module offers the same benefits as the PFB.

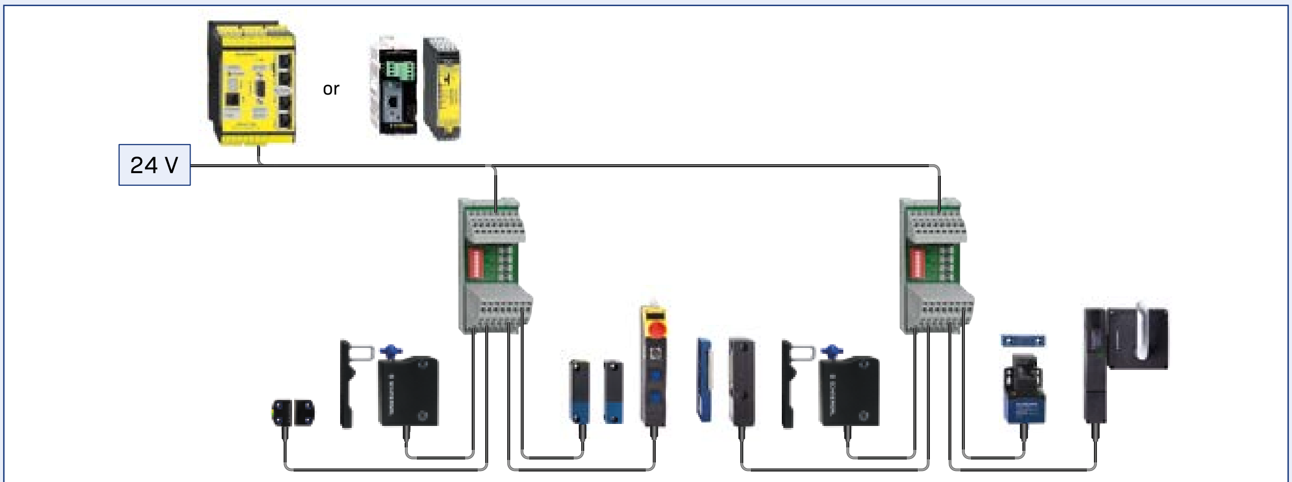

Figure 6: Example wiring, SD with PDM control cabinet distributor

4. SD IN PRACTICE – COMPARISON WITH PARALLEL WIRING

To illustrate the differences between a system with parallel wiring and an installation with SD components, let us consider an example system. This fictitious system, comprising two partial machines, has the following protective devices:

- Two control panels with emergency-stops (e.g. BDF200)
- Two doors with solenoid interlocks with locking function
- 1x four maintenance hatches (four per machine, monitored by safety sensors)

The safety considerations are neglected at this point, as series circuitry to PL e is possible when SD components are used. As such, in terms of the safety values, the components are at least equivalent to those in parallel wiring.

This yields the following number of safety switchgear devices:

- 2 x BDF200
- 2 x AZM300
- 8 x RSS36

All safety switchgear devices are located in a safety circuit.

4.1. INSTALLATION EFFORT

A key benefit of series circuitry is the reduced number of secure inputs required in the safety logic, as well as the one-off connection of the chain to the supply voltage, etc. at its input. We can make an initial estimate of the effort needed by comparing the number of contacts or connection points that need to be wired. The number of corresponding connections is listed in Table 3 to Table 6.

Unsurprisingly, the parallel wiring variant has the most contacts that need to be connected. In addition, two secure digital inputs of the safety logic are assigned to each device, giving a total of 24. Only two secure inputs are ever assigned on variants with SD bus, irrespective of the total number of connections required.

PARALLEL WIRING VARIANT

Device	Number of contacts, device	Number of contacts, logic	Number of devices	Total number of contacts/ connections
BDF200	16	16	2	64 (= 2 x (16 + 16))
AZM300	1 (M12 8-pole)	8	2	18 (= 2 x (1 + 8))
RSS36	1 (M12 8-pole)	8	8	72 (= 8 x (1 + 8))
Total				154

Table 3: Parallel wiring variant

SERIES CIRCUIT VARIANT, SD BUS WITH Y ADAPTERS

Device	Number of connections, device	Number of contacts, logic	Number of connections, installation	Number of devices	Total number of contacts/
BDF200	1 (M12 8-pole)	-	1 (M12 8-pole)	2	4
AZM300	1 (M12 8-pole)	-	1 (M12 8-pole)	2	4
RSS36	1 (M12 8-pole)	-	1 (M12 8-pole)	8	16
CSS-Y-8P	-	-	2 (M12 8-pole)	12	24
Total [1]		2			50

[1] In a series circuit, 2 secure contacts in the safety logic are occupied by the safety chain

Table 4: Series circuit variant, SD bus with Y adapters

SERIES CIRCUIT VARIANT, SD BUS WITH PFB-SD

Device	Number of connections, device	Number of contacts, logic	Number of connections, installation	Number of devices	Total number of contacts/
BDF200	1 (M12 8-pole)	-	1 (M12 8-pole)	2	4
AZM300	1 (M12 8-pole)	-	1 (M12 8-pole)	2	4
RSS36	1 (M12 8-pole)	-	1 (M12 8-pole)	8	16
PFB-SD-4M12-SD	-	-	4 (M12 8-pole)	3	12
Total		2	6		44

Table 5: Series circuit variant, SD bus with PFB-SD

VARIANTE REIHENSCHALTUNG SD-BUS MIT PDM-SD

Device	Number of connections, device	Number of contacts, logic	Number of connections, installation	Number of devices	Total number of contacts/
BDF200	1 (M12 8-pole)	-	8	2	18
AZM300	1 (M12 8-pole)	-	8	2	18
RSS36	1 (M12 8-pole)	-	8	8	72
PDM-SD-4CC-SD	-	-	10	3	30
Total		2	3		143

Table 6: Series circuit variant, SD bus with PDM-SD

Neglected at this point is the difference (in cost) between pre-assembled M12 connecting lines and other solutions. The spectrum ranges from rolled goods pre-assembled in house to cable harnesses assembled externally, making a blanket statement difficult to produce.

4.2. DIAGNOSTICS AND MAINTENANCE

This aspect can be divided into two separate tasks:
1. Error identification
2. Troubleshooting

Error identification in parallel wiring is possible to the extent that a response from the safety outputs of every connected safety switchgear device can be individually assigned and detected immediately. Detailed information about the cause of the response is not initially available. To the extent that the device has appropriate display mechanisms, e.g. LEDs or diagnostics outputs, detailed diagnostics can be carried out. This requires, inter alia, access to the device being used, which, depending on the installation situation, may be difficult in the case of safety sensors.

When using SD, diagnostics information is considerably more detailed. Both the individual status of the safety outputs of all connected device and more detailed diagnostics data are available, see the diagnostics data of the RSS36 in Table 7 as an example. These detailed diagnostics data enable faster and more adequate responses to faults, thereby reducing downtime.

When using the SD system, troubleshooting is facilitated in particular by the fact that field wiring uses M12 connectors and connected devices can be easily replaced. In series circuits, damaged cable connections can also be replaced more easily in the field (Y distributor and PFB fieldbox version) than with parallel wiring or a PDM control cabinet distributor.

A particularly interesting aspect in the context of Industry 4.0 is the connection of the SD system via fieldbus and PLC or directly via OPC UA to systems for management of service and maintenance. With the detailed information from the SD system, it is possible to take measures for predictive maintenance and, if necessary, to schedule and carry out maintenance and repair work in a more targeted manner. This applies in particular to the identification of the source of the error, spare parts procurement and estimation of the downtime.

Bit no.	Call byte	Response byte	Diagnostics error warning	Fault messages
Bit 0:	Solenoid on, irrespective of operating or quiescent current principle	Safety output switched on	Error at output Y1	Error at output Y1
Bit 1:	---	Actuator detected	Error at output Y2	Error at output Y2
Bit 2:	---	---	Cross-fault Y1/Y2	Cross-fault Y1/Y2
Bit 3:	---	---	Excess temperature	Excess temperature
Bit 4:	---	Input status X1 and X2	---	Incorrect or defective actuator
Bit 5:	---	Actuator in limit range	Internal device error	Internal device error
Bit 6:	---	Error warning	Communication error between fieldbus gateway and safety sensors	---
Bit 7:	Error acknowledgement	Error (release path de-energised)	---	---

Table 7: RSS36 diagnostics data

4.3. COMPONENT COSTS

When comparing the overall costs of parallel wiring and series circuitry with SD, the following cost items must be taken into consideration:
1. Costs of safety switchgear devices
2. Costs of installation components
3. Costs of safety logic

There is no difference between the costs of Schmersal safety switchgear devices with and without SD interface.
This means that the cost of an AZM300 with a conventional diagnostics interface (signalling output) does not differ from that of the corresponding version with SD interface (also applies to all other products).

The costs for installation components, on the other hand, are far from negligible. On the one hand, there is the comparison of the cabling in parallel circuitry with the assembled M12 connecting cables when an SD is used. Additional installation components are the Y adapters (one per safety switchgear device) or PFB fieldbox (one for every four switchgear devices) or PDM passive distributor (one for every four switchgear devices).

The use of SD (Y adapter and PFB) has a positive effect by reducing the cable lengths required, as wiring is implemented in series instead of star configuration from the direction of the control cabinet.

Another influencing factor on the costs is the fieldbus gateway. In parallel wiring, this gateway is usually provided via a corresponding module in the safety controller, and the costs are dependent on the manufacturer. If a separate SD universal fieldbus gateway is used, the costs will clearly be higher. If, however, Schmersal type PSC1 safety logic with fieldbus interface is used, there is always an integrated fieldbus gateway, which means no additional costs. In that case, there is no difference in price between the parallel wiring version and SD.

The costs for pure safety logic are primarily defined by the number of channels used. Here, two contacts are required for each safety circuit when using SD. In parallel wiring, two contacts are required for each safety switchgear device. The difference is thus greater as the number of devices increases.

5. CONCLUSION

If we weigh up the benefits and drawbacks of the different installation systems, certain scenarios crystallise in which one or the other system exhibits its benefits.

If multiple safety switchgear devices are used, which act on a just few safety functions (ideally one), the Schmersal SD system is the better solution. The enhanced diagnostics data make maintenance and repair work easier to carry out, wiring is quicker to implement and the safety switchgear devices are no more expensive than comparable devices without SD interface.

The SD system is physically limited by the maximum line length of 200 m, the maximum number of 31 slaves and the voltage drop along the series circuit.

The voltage drop is of greater significance in long lines in particular, and with devices with increased power consumption, such as solenoid interlocks. The voltage drop can be countered by creating additional feed-in points for the power supply (passive PFB fieldbox or passive distributor module). Ultimately, Ohm's law is the limiting factor.

By contrast, if only a small number of switchgear devices are used, or only a few such devices per safety circuit, parallel wiring is the better solution. Here, the benefits of series circuitry do not tend to outweigh the initial outlay required to use the SD system. Even if connectivity to a functional PLC or via OPC UA is not required, the other systems discussed can better show their advantages rather than the SD system.

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About the Schmersal Group:
The Schmersal Group is an international market and expertise leader in the challenging field of machine safety. With the world's most comprehensive range of safety switchgear products, the Schmersal Group develops safety systems and solutions for special requirements in a variety of user industries. Schmersal's tec.nicum business division offers a comprehensive service portfolio to complement the range of solutions offered by Schmersal. Founded in 1945, the company is represented by seven manufacturing sites on three continents with its own companies and sales partners in more than 60 countries.

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