Safety relays: Advantages of fail-safe semiconductor outputs

Abstract

In order to protect people and the environment, in all industrial applications in the manufacturing and process industries, machines and plants must meet the fundamental safety requirements and thus comply with the EU Directives – in particular the Machinery Directive. In addition to design solutions, automation systems and components are also expected to perform safety-related tasks. This means that the life and health of people and the physical integrity of capital goods and the environment depend on the proper operation of these systems and components, that is "functional safety".

In very many cases, safety relays are used for this purpose. Conventional safety relays use relays as the switching element to shutdown in dangerous situations. They certainly have the advantage of electrical isolation between the switching device and the load to be switched, but they also have the great disadvantage of being subject to wear, and consequently have a limited service life. Safety relays with fail-safe semiconductor outputs are an alternative. Their advantages are described below.

A White Paper from: Siemens

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Introduction

Both machine manufacturers and operators must ensure the maximum possible safety for personnel and machines. Machine control systems must be designed and implemented so as to prevent the development of hazardous situations. If these requirements cannot be fulfilled by adequate machine design, further measures must be taken. For example by using safety relays and their associated sensor technology. Faults in the evaluation device or externally connected sensors or actuators must not lead to loss of the safety function. In addition, the objectives are to avoid restricting industrial production, the use of machines or manufacture of products more than absolutely necessary.

What is really safe?

Safety defines a state in which the risk of damage is reduced to a tolerable level, or which can be regarded as risk-free. This definition consequently applies to the functional safety of persons, machines and the environment.

Challenges facing the implementation

The growing trend toward flexible production plants in order to be able to adapt the production to different products quickly and easily, and produce customized products in small batches is giving rise to new machine safety requirements.

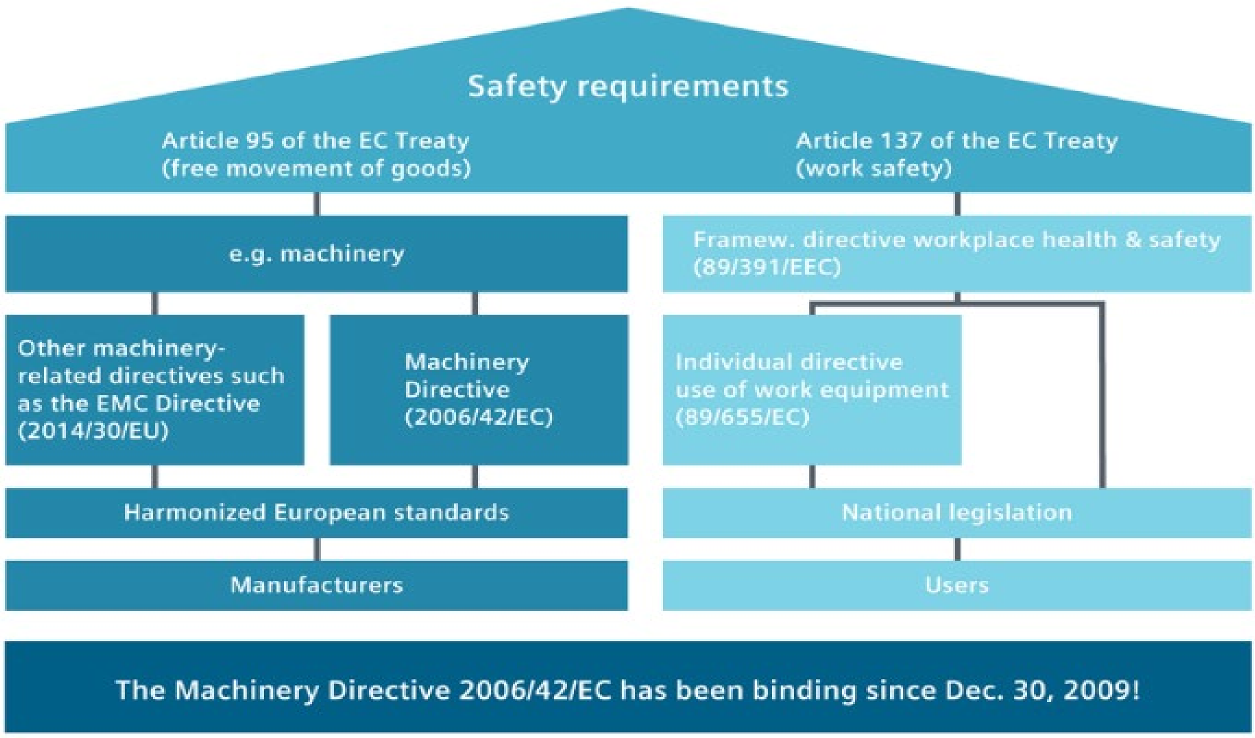
This means that it is no longer possible to simply isolate the operator from the working area. Nowadays, machine manufacturers apply safety solutions which enable the operator to work safely and efficiently in the working area. The following always applies: The safety engineering must be absolutely comprehensive.

Regulations and standards

Internationally harmonized standards are intended to ensure equal protection of people and the environment in all countries.
Apart from that, many countries have laws which mandate the fulfillment of safety aspects, such as the European Machinery Directive (2006/42/EC).
This obligation can often be fulfilled by applying the standards.

In particular, the following standards must be applied to factory automation:

- IEC 62061
- EN ISO 13849-1



European Machinery Directive

The IEC 62061 standard

The IEC 62061 standard "Safety of machines – Functional safety of electrical, electronic and programmable electronic control systems" defines comprehensive requirements. Furthermore, it issues recommendations for the design, integration and validation of safety related electric, electronic, as well as programmable electronic control systems (SRECS) for machines. For the first time, the standard covers the entire safety chain, from the sensor to the actuator. The "Safety Integrity Level", or "SIL" for short, is defined as the application parameter for this standard.

The standard does not specify performance capacity requirements for non-electric – e.g. hydraulic and pneumatic – safety-related control elements for machines.

The EN ISO 13849-1 standard

The EN ISO 13849-1 standard "Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design" superseded EN 954-1 at the end of 2011. It takes into consideration the complete safety chain with all the devices involved in their performance. EN ISO 13849-1 also involves a quantitative analysis of the safety functions. The standard describes how to determine the "Performance Level", "PL" for short, for safety-related parts of control systems on the basis of architectures specified for the intended service life.
When several safety-related parts are combined to form a complete system, the standard explains how to determine the resulting PL. It can be applied to safety-related parts of control systems (SRP/CS) and all types of machines, irrespective of the technology and energy used, e.g. electrical, hydraulic, pneumatic or mechanical.

Design of a safety function

A safety function describes the reaction of a machine/plant when a specific event occurs
(e.g. opening a protective door or actuating an emergency stop). The safety function(s) is/are executed by a safety-related control system. This usually comprises three subsystems: detection, evaluation and reaction.

Detection

A safety demand is detected, e.g.: emergency stop
or a sensor monitoring a hazardous area (light array, laser scanner, etc.) is actuated.

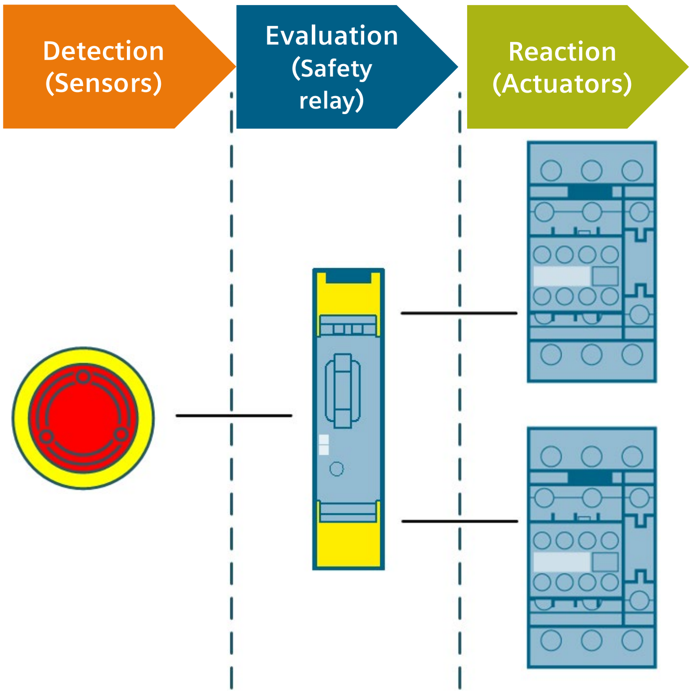
Evaluation

A safety demand is detected, and the reaction is reliably initiated, e.g. the enabling circuits are shut down, the correct function of sensors and actuators is monitored, and a reaction to the detected faults is initiated.

Reaction

The cause of the hazard is shut down, e.g.: contactors or fail-safe motor starters.

A typical safety function – comprising emergency stop, safety relay and two contactors – is illustrated below:



Typical safety function

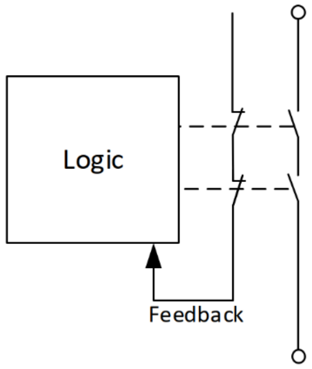
In the above safety application, if the frequency of its actuation is considered there are generally a very low number of switching cycles, because the emergency stop is only actuated in hazardous situations.
However this is not the case with, for example, a protective door which has to be opened to insert parts. In this case, there is a considerable number of switching cycles, which leads to wear on the switching contacts in the safety relay and on the contactors. For the contactors, this can be counteracted by appropriate over-dimensioning. Apart from that, replacing the contactors is often not a problem because they are inexpensive and easy to wire. However, this is not the case with more complex safety relays. After replacing the safety relay, the entire safety function – including the fault detection measures – also has to be checked for correct functioning. This requires a considerable amount of time and money. On the other hand, the correct functioning of the contactors is relatively easy to check.
As safety relays with fail-safe semiconductor outputs do not need to be replaced because they are not subject to wear, they are particularly suitable for applications with a high number of switching cycles.

Differences between different types of outputs in safety relays

Relay outputs

Safety relays are devices which generally meet the safety requirements by initiating a safe state by the upstream sensors switching off the actuators.
The safety relays with relay outputs are usually used for this purpose.

Many things have to be considered when choosing the right safety relay for a specific application, including factors such as operating speed, sensitivity and expandability. Although the operating principles of the relay outputs are primarily suitable for electrically insulating the control circuit from the main circuit, they are also frequently used where semiconductor outputs would be more suitable, for example with high frequency of operation or low loads.



Relay output

A standard relay uses a wire coil and the mechanical movement of the metal contacts it induces to switch the load off and on.

Why is a standard electromechanical relay regarded as unsafe?

The metal contacts may weld after multiple switch cycles or in the event of faults. If this happens and the operator, for example, actuates the emergency stop button, the machine would continue to run. This would create a hazardous state for the operator. The safety standards therefore specify the use of relays and contactor relays with force-guided contacts instead of simple relays or contactor relays.

Relays with force-guided contacts

The most important characteristic of the force-guided operation of the contact is that all contacts have to have a rigid mechanical connection to one other. Only in this way can the positions of all other contacts be inferred from testing the switching of one contact.

It is necessary to take further design measures in order to ensure the force-guided operation, even if other types of fault occur. One of these faults in particular is the breakage of a contact spring. Therefore all contacts are embedded in contact chambers, which prevent parts of the contact spring causing a short circuit if a spring breaks in the relay. Breakage of the armature tappet would also result in the loss of force-guided operation. This is countered by over-dimensioning the armature tappet.

Additional safety measures

The use of two mutually monitoring safety relays in series in the switching device ensures a safe switch off and prevents reclosing of the load. In this way, faults with a common cause can usually be excluded.

Application

Relays are mainly used for switching high electrical powers with a low control power when electrical insulation is required between the controlling circuit and the circuit to be switched. Another advantage is the low switching contact resistance when the contact is in a closed state, which has a particularly positive effect with high loads.

Disadvantages of relay outputs

Because of their disadvantages, electromechanical relays are being replaced by electronic semiconductors in many applications. In comparison with semiconductor switches, relays have the above-mentioned advantages, which means that they cannot be substituted in every case.

Some advantages and disadvantages of the electromechanical relay are explained in the following:

Wear caused by arcing

When relays are used, arcing causes a significant deterioration of the contact characteristics. Each time the relay contacts open or close under load, an electric arc may form between the relay contacts which, in the end, leads to the contacts welding or failing on account of the accumulation of surface damage caused by the destructive arcing energy.
In this respect, the wear caused by switching DC voltage loads is greater than with AC voltage loads, because the arcs last longer. With AC voltage, the arc breaks down at the latest when the voltage crosses zero.
The relay is therefore the factor determining the length of the service life of safety relays. The maximum number of switching cycles that the relay can reach depends on the load switched. The safety relay must be replaced when it reaches this number of switching cycles, because otherwise hazardous failures may occur. The service life therefore depends on the switching load and the switching frequency.
Here is an example:

- Service life: 1 million switch cycles
- 1000 cycles per day, 200 days per year = 200 000 cycles per year
- Service life: 5 years

After that there is a **HAZARDOUS SITUATION**

➔ **Replace after 5 years**

The safety relay must therefore be replaced after 5 years to avoid hazardous situations arising.

High reaction and release times

The reaction time of relays lies in the order of milliseconds in comparison to that of the microseconds or less of semiconductor switching elements. Especially the higher release times can have a significant effect on the total reaction time of fail-safe applications.

Lower switching frequency

Resulting from the above-mentioned high reaction and release times, relays also have a lower switching frequency in comparison to semiconductors.
Another aspect leading to a lower switching frequency is the rise in the temperature of the relay during the switch-on and switch-off processes. This restricts the number of times which, depending on the load, the relay can be switched per hour.

Minimum contact load required

There must be a minimum load on the contacts to ensure that the relay outputs switch reliably. In order to pass through the oxidation layer, this usually requires a voltage of between 12 V and 17 V at a minimum current of 5 mA to 10 mA. Whereas the voltage is not usually a problem, the necessity of the minimum current can lead to problems if the relay has to switch signals which affect the electronic inputs of automation components. These inputs often only need low currents in the low, single-digit mA range.
This can have a noticeable negative effect, especially with those fail-safe applications in which, for example, shutdown signals for electronic inputs (e.g. of safe frequency converters) are to be switched with relays. This effect is reinforced with dual-channel connections. Oxidation of the contacts can increase the occurrence of discrepancy errors, which will restrict the availability.

Mechanical sensitivity

Relays are also sensitive to mechanical influences. Vibrations can lead to short-term opening of the contacts, which in turn can result in actuators switching off, and the application having to be restarted. Especially in safety engineering where signals are frequently switched in dual channels, discrepancy errors can occur which, as already mentioned, restrict availability.

Advantages of relay outputs

Despite the stated disadvantages, relay outputs also offer certain advantages.

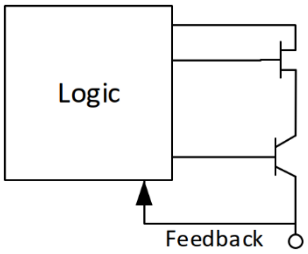
Electrical isolation

One of the most important advantages of relay outputs is the electrical isolation between the contacts and the control. This means that other types of voltage can be switched than that which the safety relay itself possesses.
It is also possible to switch different signals between the individual contacts.

Switching of the most diverse types of signal

Relays are also suitable for switching the most diverse types of signals, from the lowest signals to high frequency and even high powers. They also have little tendency toward crosstalk.

Semiconductor outputs



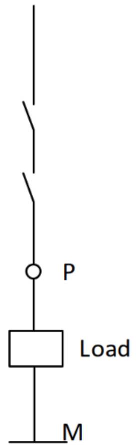
Electronic output

Semiconductor outputs are usually implemented with transistors or FET. They thus offer a function similar to that of an electromechanical relay, however they do not have any movable mechanical components, which increases their long-term reliability. They are wear-free, have a very long life, are mechanically insensitive, and are suitable for high switching frequencies and switch cycles.

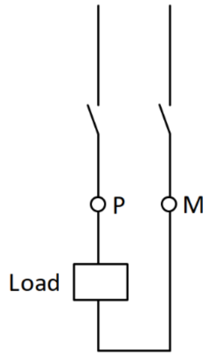
What makes semiconductor outputs safe?
As with relay outputs, a single semiconductor output with a transistor is not adequate from the safety point of view. Here again, measures must be taken to ensure functional safety.
Therefore the principle of redundancy also applies here, this means that there are two switching elements per output. This gives two possible interconnections:

- pp switching: Both switching elements lie in the supply to the load.
- pm switching: The load lies between the two switching elements. Here, the supply and ground are connected.

Furthermore, measures have to be taken to detect faults in the switching elements so that safe switch-off is ensured in the event of faults.
In so doing, on the one hand, the states at the outputs are read back to check their plausibility against the control state and, on the other hand, to dynamize the control signals. This means that in the switched-on state the control signal is briefly switched off (dark test) and during the read-back whether the output signal really follows the control signal is checked.
Similarly, in the switched-off state, the output is briefly switched on (light test) and whether the output signal behaves correspondingly is checked.
In so doing it must be ensured that the loads are not switched off during the dark test and, even more importantly, that they are not switched on during the light test, and so cause a hazardous state.



pp switching



pm switching

Application

Semiconductor outputs are mainly used to switch DC loads, which use the same voltage supply as the switching device as there is no electrical isolation. So not only higher loads, such as contactors and solenoid valves, can be fail-safe switched but also low loads, such as fail-safe frequency converters.

Advantages of semiconductor outputs

The use of semiconductor outputs offers the following advantages in comparison to relay outputs:

Higher numbers of switch cycles

No mechanical wear and no arcing allow a very large number of switch cycles. This gives the safety relays a long service life, and consequently they do not have to be replaced before the end of their service life, which usually lies between 10 and 20 years.

Short switching times and high switching frequency

The switch on and off times for semiconductor outputs are well below 1 ms. This leads to very short switch-off reaction times, and also allows a very fast switch-on and a high speed operating sequence, for example in applications with acknowledgment buttons or two-hand operation. Especially with acknowledgment buttons, there is often fast operation by the user, for example with manual tracking or setup.

No contact bounce

Another advantage of electronic semiconductor outputs is that, in contrast to mechanical contacts, contact bounce cannot occur. Especially in safety applications, which frequently have dual channels, contact bounce can lead to discrepancy errors and thus to availability problems.

No minimum contact load

The switching of electronic semiconductors does not require a minimum contact load to achieve reliable switching. Semiconductor outputs function reliably even with extremely low load currents, such as those of electronic inputs in automation components.

Mechanically insensitive

As electronic semiconductor outputs do not have electromechanical components, they are insensitive to influences such as vibrations or impacts. This allows use under harsh environmental conditions as well as on vehicles.

Electromagnetic behavior

The ruggedness of the electromagnetic behavior is another advantage. So magnetic fields do not create interference which can be generated by the coil drive in relays. This also avoids the emission of interference caused by the arcing on the switching contacts.

Noise level

In comparison to relays, switching with semiconductors is noiseless, which is certainly an advantage in some applications, such as elevators.

Reservations regarding semiconductor outputs

Users have some reservations regarding fail-safe semiconductor outputs, and they continue to use devices with relay outputs. However, most of these reservations can be rebutted.

No electrical isolation

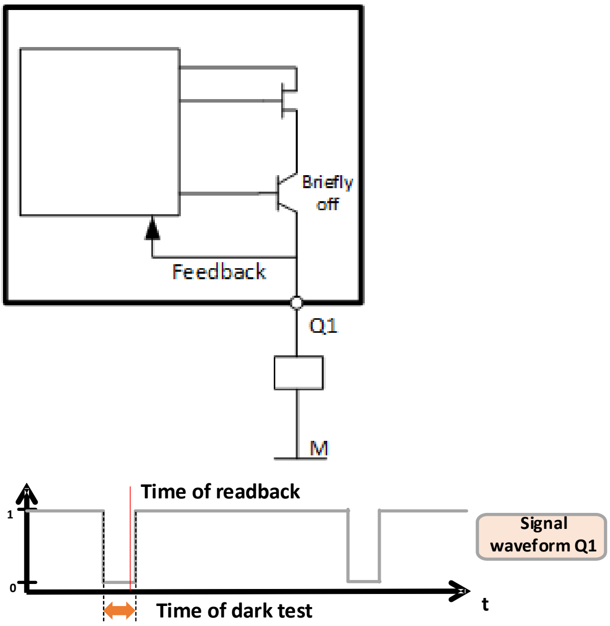
With semiconductor outputs there is no electrical isolation between control circuit and load circuit. This means that the load switched is supplied by the same power supply as the switching device. However, as nowadays the control supply voltage is 24 V DC, this is frequently not a problem.

Higher contact resistance

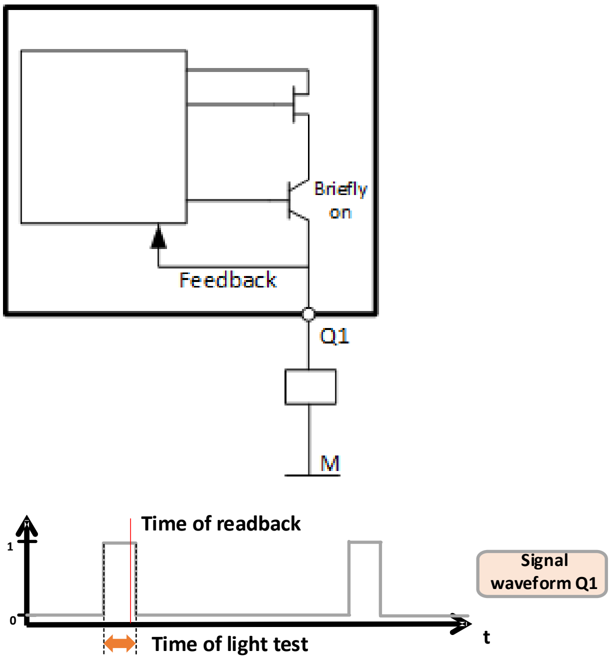
The switching elements of the semiconductor outputs often have a higher contact resistance than relay contacts. This results in a larger voltage drop, so that a lower voltage is available for the switching and, as a result of the losses, a higher temperature rise occurs at the switching element itself.
This is usually not noticeable in practice as inexpensive switching elements with low resistance are now available. So the safety relays with semiconductor outputs do usually not differ from those with relay outputs in respect of ambient temperatures during operation.

Capacitive and inductive loads

Due to the light and dark tests needed to detect faults, problems may occur with capacitive or inductive loads.
That is the capacity of the load can feed back in the dark test. This means that the readback signal does not fall to the expected extent, and the safety relay then switches to the safe state.



Inductive loads cause similar behavior in the light test. In this case, as a result of the counter-induction, the signal does not rise to the extent that the device expects, which also leads to a transition to the safe state.



However, as a rule the safety relays are designed so that they can be operated problem-free with normal loads. Furthermore, with software parameterizable safety relays, the behavior of the light and dark tests can be adapted to the switched load.

Conclusion

	Relay	*Semiconductor output*
Wear (especially with DC)	High	No wear
Reaction time	High	Low
Mechanical sensitivity	Sensitive to vibration and shock	Not sensitive
Electrical isolation	Present	Not present
Contact bounce	Present	Not present

To sum up, it can be said that fail-safe semiconductor outputs in safety relays offer many advantages in comparison to conventional relay outputs. However, there are still many possible uses for relay outputs.

Relay outputs are still the best choice when electrical isolation from the load is required or different types of signals have to be switched.

Safe semiconductor outputs show their strengths at high numbers of switch cycles and by their freedom from wear, with the consequent advantages in respect of minimum contact load and bounce.

With its 3SK family of safety relays, SIEMENS offers reliable devices for both application areas, because it offers versions with electronic semiconductor outputs as well as versions with relay outputs. Consequently, the user can find the devices which are perfectly suitable for his application.

Complying flexibly with basic safety requirements with 3SK

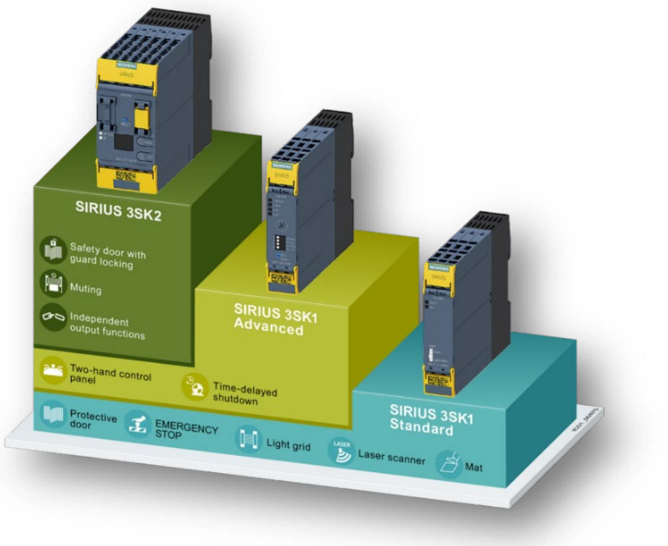
To meet the requirements listed above, Siemens has brought the comprehensive 3SK switchgear family onto the market for monitoring emergency stops, protective doors, two-hand operation, light barriers, light arrays and so on.

The device family has the following divisions:

- 3SK1 Standard for basic applications
- 3SK1 Advanced for flexible and demanding applications
- 3SK2 Safety Functions with easy graphic parameter assignment

Both 3SK1 series are available in versions with relays or semiconductor outputs.

The modular design of the **3SK1 Advanced** allows flexible expansion of the safety application by increasing the number of inputs and outputs with innovative device connectors. This enables the easy addition of further sensors, such as extra door monitors or enabling contacts.



The clearly structured 3SK portfolio of devices reduces the number of versions, supports the solution-optimized selection of components, and so reduces the spare parts inventory.

Another highlight is the seamless integration of the devices into the main circuit by means of 3RM1 fail-safe motor starters, which are also connected to the 3SK configuration by device connectors. Both direct and reversing starters can be used. In this way, the advantages of hybrid switching technology can also be used in conjunction with safety applications.

SIRIUS 3SK2 safety relays are primarily used in safety applications, in which the functional scope of the 3SK1 devices is no longer sufficient, such as in the implementation of independent shutdown functions or integration via optional fieldbus interfaces into higher-level control systems for diagnostics.

3SK2 basic units also offer:

- Up to six fail-safe, independent enabling circuits
- Flexibility through software parameter assignment
- Powerful semiconductor outputs
- Convenient diagnostics using diagnostics display and configuration software
- Communication via PROFIBUS/PROFINET through optional communication modules

No matter whether EMERGENCY STOP, protective door monitoring, light array, laser scanner or the protection of presses or punches – with SIRIUS safety relays, all safety applications can be optimally implemented in narrow overall width both technically and commercially.

Further information

Siemens keeps you up to date.

You will find detailed information about our safety relays with 3SK semiconductor outputs on the website:
www.siemens.com/safety-relays

Here is the link to our range of SIRIUS safety products:
www.siemens.com/safety-sirius

You will find all-embracing information about universal safety engineering from Siemens here:
www.siemens.com/safety-integrated

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