framatome

HARDLINE

Non-programmed safety I&C platform dedicated to nuclear safety

Principles

For more than 50 years, Framatome has been providing digital and non-programmed safety I&C systems on various types of reactors all over the world.

Hardline platform is our latest generation of non-programmed (Hardwired) safety platform, designed specifically to implement category A, B or C (IEC 61226) & class 1E nuclear safety or safety-related I&C functions.

Hardline is the result of the evolution of previous non-programmed Framatome technologies, and is based on modern components, architecture, and nuclear safety design processes.

All the safety functions are based on hardwired technology, without programmable components such as processors or FPGAs, making them immune to software Common Cause Failure (CCF) and Cybersecurity threats.

Spinline technology is one of our digital (programmed) safety platforms for cat. A & class 1E applications.

Multibloc

Amp-ops, discrete components

France
- EDF 900MW units (34)
- EDF 1300MW units (20)
- EDF 1450MW units (4)
- CEA research reactors

International
- China (4)
- South Korea (2)
- South Africa (2)

Modumat / BUX

Analog modules

France
- EDF 1300MW units (20)

International
- China (37)

Dynamic Logic (ULS)

Failsafe dynamic signals (Transformers)

France
- EDF 1300MW units (20)

Silimog

Analog

France
- EDF 900MW units (34)
- CEA research reactors

Designed with flexibility and safety in mind, Hardline meets the demanding functional and safety requirements for non-programmed safety I&C systems employed in modern nuclear power plants (NPPs).

This makes Hardline ideally suited for new build NPPs or refurbishment of safety I&C systems in existing NPPs for a variety of safety I&C applications including:

- Diverse Reactor Protection System (DRPS)
- Actuator Priority Logic System (PLS)
- Backup or post-accident systems (PAMS/SAMS)
- Main Reactor Protection System (RPS)
- Diverse I&C for Diesel generators

Hardline can easily be adapted to multiple NPP designs, including PWRs, VVERs, BWRs reactors, research reactors and small modular reactors (SMR).

A modern, robust and standardised technology

Main applications

Hardline technology can be used for several applications.

Diverse Reactor Protection System

Most Reactor Protection Systems in modern NPPs are based on programmed microprocessors that are potentially subject to software Common Cause Failure. A Diverse Protection System is an I&C system needed when a deviation from normal operation occurs at the same time as a failure of the main Protection System. That means it can detect the event, initiate automatic mitigation (trip and ESFAS) and inform the operator. It can also allow the operator to handle the monitoring and manual operations necessary in post-accident management.

The Diverse Protection System proposed by Framatome is based on Hardline non-programmed technology, thus immune to software CCF.

Priority Logic System

The actuators of a NPP can be controlled by several separate I&C systems due to the large number of protection functions that need them. In order to manage the potentially conflicting instructions sent from several control systems, the Priority Logic System gathers all these instructions and controls the actuators according to a pre-established priority order. Framatome proposes dedicated non-programmed Priority Logic System, based on Hardline technology.

Diesel Generator (EDG, BDG) I&C

Emergency diesel generators are started when the NPP unit is disconnected from the grid, and may be supplemented by backup diesels in case of failure. These diesel generators safeguard the power supply to vital elements, such as the reactor cooling system, so that a controlled reactor shutdown can be guaranteed. Hardline can be used to provide the safety I&C systems commanding this diesel power, and guaranteeing its correct operation when needed.

Post-Accident Monitoring System (PAMS) and Severe Accident Management System (SAMS)

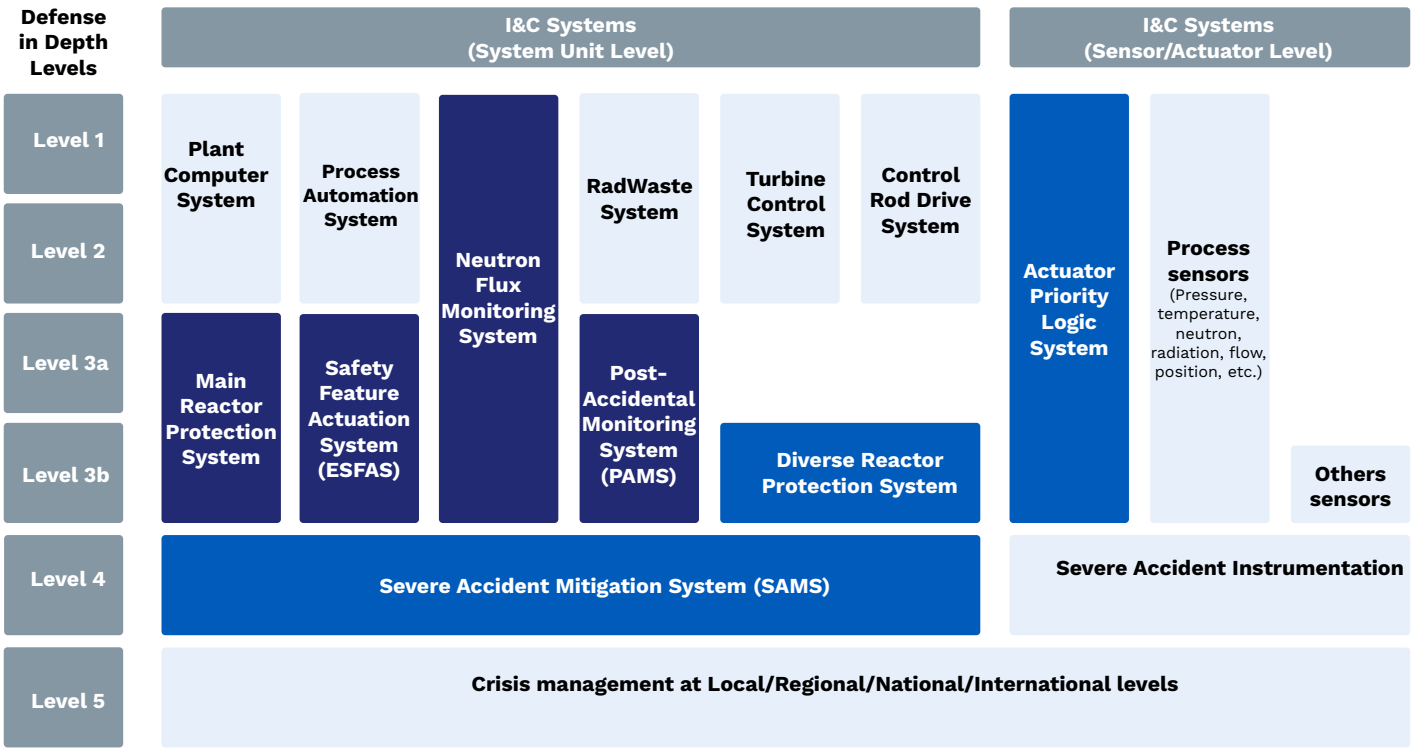
During and after an accident, the reactor's key parameters must still be monitored as the situation develops. A dedicated Post-Accident Monitoring System (PAMS) can be implemented to fulfil this task.

When the accident worsens and the main (and diverse) protection systems are unable to operate, the Severe Accident Management System (SAMS) will trigger additional mitigating actions to terminate core damage and maintain containment integrity.

The requirements for these two systems vary according to plant design, local regulations and the site's characteristics, but Hardline's design and functionalities guarantee its compliance with the most stringent PAMS & SAMS requirements.

Main Reactor Protection System (retrofit & research reactors)

Some of the older NPPs still operate with their OEM analog main RPS. As they modernize their safety systems, in whole or in part, to extend their operating license, overcome obsolescence issues or match new safety requirements, the use of Hardline technology will allow them to benefit from a modern technology without having to adapt and license a digital programmed technology. Similarly, new or modernized research reactors that prefer non-programmed technology can benefit from Hardline's easy system design to implement their main Protection System.



Possible uses of Hardline and Spinline within defense lines

Hardline | **Spinline / TELEPERM XS / Tricon**

Architecture

Designed for adaptability and safety, Hardline modular features ease the implementation of varied safety functions and architectures.

Redundancy

Hardline components and their distributed capabilities are convenient to build up to 4-fold redundant systems.
This allows sharing thresholds, results and sensors signals between redundancies with proper isolation. Results are collated in each redundancy and combined into actuation logic to generate output orders.

Geographical and electrical separation

Inter equipment exchanges are hardwired, using electrical isolators at both ends for high isolation and geographical separation within the plant.

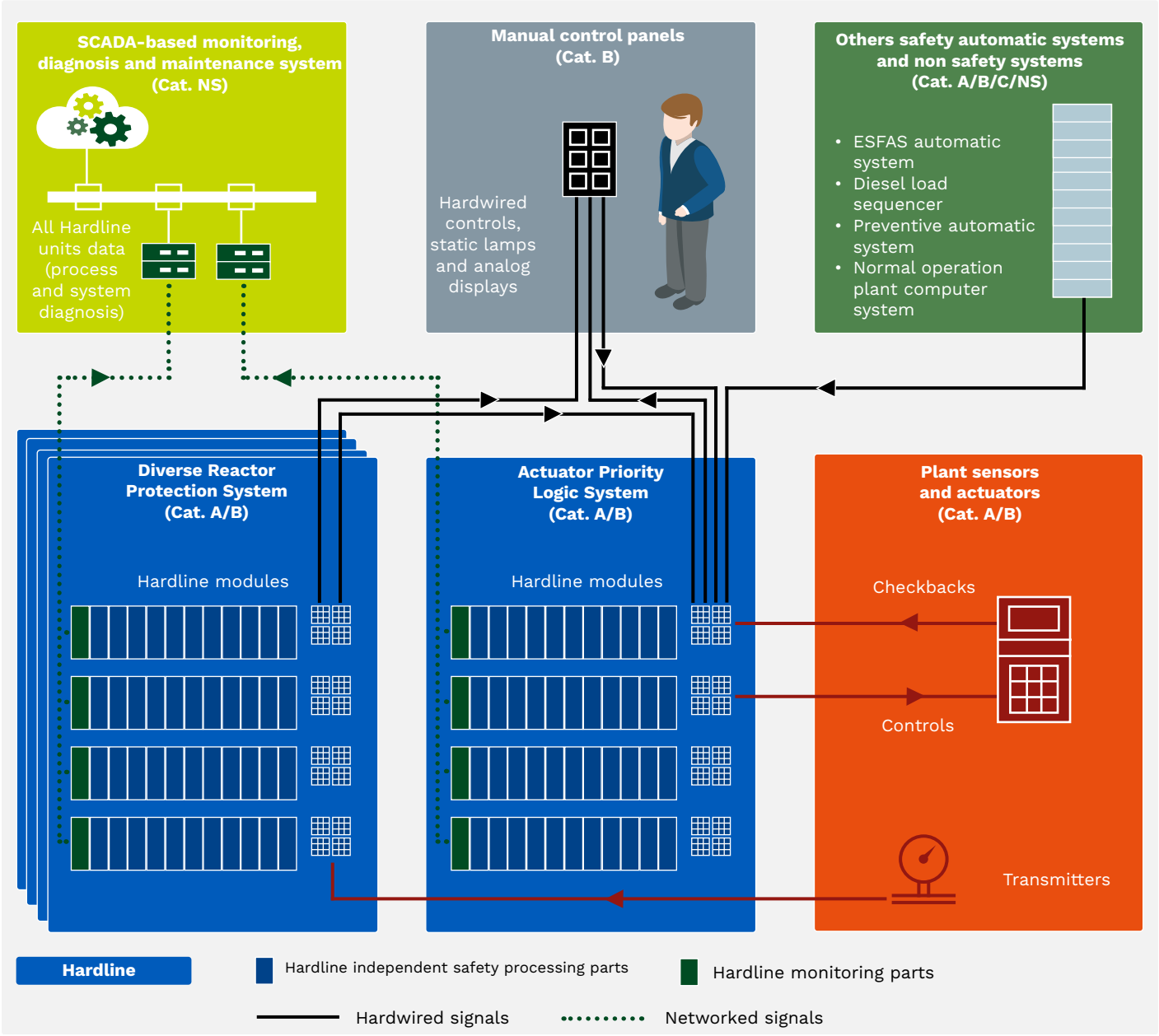
Separation of modules (safety, monitoring, and communication)

Hardline safety functions are performed by non-programmed safety modules separated from monitoring and communication modules.

Hardline monitoring and communication modules are physically separated from safety modules. Separation and isolation functionalities are provided with the use of non-programmed discrete electronic components.

These properties ensure that the communication elements of Hardline can never prevent non-programmed safety modules from performing their safety function correctly.

Hardline communication parts are made of devices that act as observers only. Their isolation guarantees they cannot interfere with the safety functions.



Typical example of Hardline systems architecture

Main technical features

Hardline is a modern and standardized technology, dedicated to safety classified I&C systems.

Modern technology

Hardline is a modern hardwired-based, non-programmed safety I&C platform with state of the art electronic features providing:

- High functional possibilities with analog thresholds and binary fail-safe logical functions
- High degree of safety and availability with fault detection capabilities
- Flexibility, scalability and possibility of evolution,
- Improvement in operation and maintenance (supervision and automatic diagnosis)

Dedicated to safety classified I&C systems

Hardline is composed of specially-designed hardware components suitable to develop safety classified I&C systems:

- Cabinets and units designed to withstand harsh conditions (e.g. temperature, EMI, vibrations, earthquake) as defined in relevant standards
- A full range of non-programmed modules performing binary and analog functions and actuator control,
- Communication gateway device with standard Modbus TCP link allowing integrated monitoring capabilities and interface to the outside world

These components have been designed according to high-level system features in order to easily fulfill customer and regulator's requirements.

Hardline is the result of 50 years of experience in the use of safety analog technologies

Standardized components

Hardline hardware components are standardized (i.e. modular and scalable):

- Modular: Hardline can be delivered either as units to be integrated into existing cabinets (especially in case of refurbishment) or as whole new cabinets. The content of the units and cabinets is adapted to fit system requirements
- Scalable : Hardline can fit any size of I&C systems, ranging from simple ones such as one equipment with few modules without redundancy to complex ones such as an integrated 4-fold redundant diverse protection system with more than 200 modules per redundancy, voting, local and remote testing units
- The Hardline racks and cabinets are standard and can be configured to their specific contents after production (“delayed differentiation”). This allows for shorter delivery dates and adaptation late in the design phase
- The internal cabling of the cabinets is not complex thanks to an optimized cabling system

Large number of functionality

Binary and Analog input:
- Sensor conditioners
- EMC filters
- Test mode switches

Analog processing:
- Adjustable high & low thresholds with hysteresis
- Signal selectors

Output:
- Inhibition for tests
- Output relays
- Signal isolators

Binary:
- Voter (1oo2, 2oo2, 2oo3, 2oo4...)
- Relay-based logic circuits (OR, AND, NOT...)
- Actuator control logics
- Time delay controls
- Signal selectors

Monitoring:
- Analog and binary isolated digital converters
- Communication gateways

Test:
- Test panels for automatic tester
- Communication gateways

Hardware components

Hardline is a modern and standardized technology, dedicated to safety classified I&C systems.

Safety modes

Isolation and separation function is realized with non-programmed electronic components that ensure electrical isolation, functional separation and independence between safety functions and communication modules.

Only one-way data exchange is permitted from safety modules to communication modules. Isolation and separation function is designed and qualified according to IEC 62808 ensuring that no failure can be propagated from the communication parts to safety modules.

Isolation and separation function is integrated in safety modules, and is safety qualified.

Communication modules

Hardline communication modules provide one-way communication features with other I&C digital systems. As shown in Figure 4, the monitoring communication module C.11 COM 1 allows monitoring up to 11 safety modules. It is associated with Hardline Gateway allowing unidirectional communication from up to 22 units to an upper-level monitoring and diagnosis system.

Local HMI

Local HMI on the front panel of a Hardline cabinet is provided with a standard set of keys, push-button, LEDs to manage test mode and allow troubleshooting. Dedicated local HMI can be customized upon request.

List of main safety modules

Module ID	Function	Input/Output signals
A. THR	Adjustable high or low thresholds	Input: 0(4)..20mA / Outputs: dry contacts
A. ISO	Analog isolators	Input: 0(4)..20mA / Outputs: 0(4)..20mA
A. THC	Thermocouple type K conditioners with external compensation (0..1300°C)	Inputs: 0..60mV / Outputs: 4..20mA
A. RTD	PT100 conditioners (0..400°C)	Inputs: 100..247mV / Outputs: 4..20mA
B. REL 1 B. REL 2	SPDT relays with NO and/or NC contacts	Input coils: $24V_{DC}$ Output contacts: dry contacts
B. SEQ	TON, TOFF and TPULSE adjustable time delays and latch functions	Inputs: $24V_{DC}$ / Output: dry contacts
B.PRIO	Priority control logic	Inputs: $24V_{DC}$ / Outputs: : $24V_{DC}$
B. TST	Test switching features	Input and output signals: 0(4)..20mA or $24V_{DC}$ Test switch command: $24V_{DC}$ coil
P.DC/DC	$24V_{DC}$ isolated DC-DC converter	Input & output: $24V_{DC}$

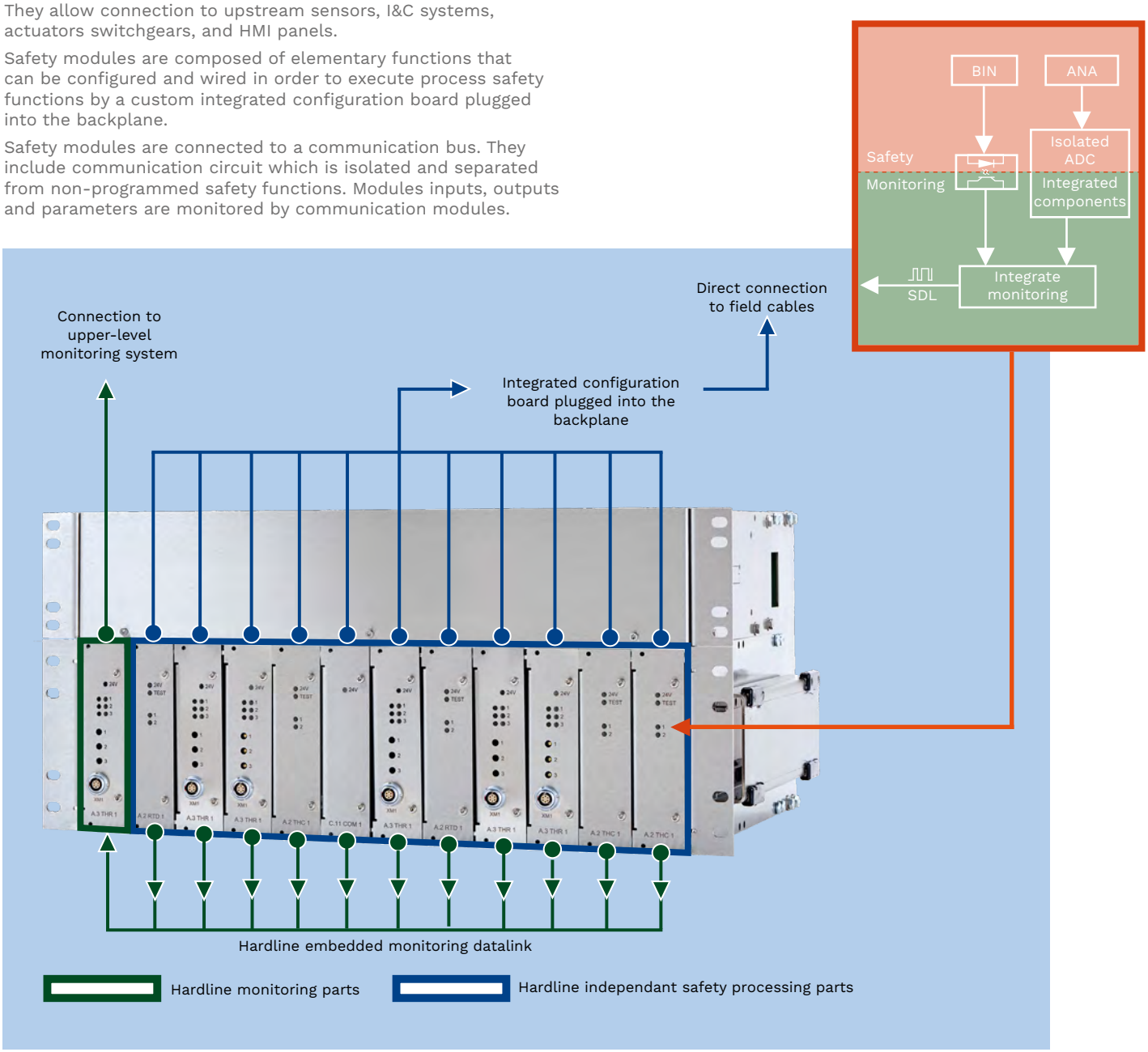
Hardline modules

Units

Safety is assured by a set of connected safety modules. They allow connection to upstream sensors, I&C systems, actuators switchgears, and HMI panels.

Safety modules are composed of elementary functions that can be configured and wired in order to execute process safety functions by a custom integrated configuration board plugged into the backplane.

Safety modules are connected to a communication bus. They include communication circuit which is isolated and separated from non-programmed safety functions. Modules inputs, outputs and parameters are monitored by communication modules.



Hardline rack implementing a Hardline unit

Hardware components

Hardline is a modern and standardized technology, dedicated to safety classified I&C systems.

Cabinets

Hardline modules can be installed in racks inside Framatome standard cabinets. One-sided cabinets can be used as well as deeper two-sided cabinets in order to densify the amount of installed modules per cabinet.

The cabinets can contain up to 6 Hardline 19” racks.

Cabinets are provided with protection index up to IP31 and seismic withstanding capabilities. When high requirements for room ambient temperature (60°C) are imposed, possibilities exist to set up an optimized fan-based air-flow system.

Hardline racks and cabinets are standards and can be configured to their specific contents after production (“delayed differentiation”). This allows for shorter delivery dates and adaptation late in the design phase.

Maintenance personnel have immediate and easy access to any element of the system inside the cabinets.

Hardline standard cabinets characteristics:

Height	≤ 2100 mm
Width - without side panels	≤ 1000 mm
Width - group of 4 cabinets with sidepanels	≤ 4100 mm
Depth - without rear panels and doors	≤ 495 mm
Front space required for doors opening (WxD)	≤ 1000 x 600 mm
Weight	250kg

A flexible and modular technology

Monitoring

State-of-the-art monitoring and HMI, similar to those provided by digital systems

Diagnosis and surveillance

Each safety module has a one-way serial datalink to provide essential signals to communication module. The communication module has a one-way serial datalink to the Hardline Gateway which communicates with an external diagnosis unit.

Hardline is provided with software solutions for PC-based external monitoring systems featuring:

- Gateway capabilities to interface with higher level plant control systems
- Alarm management possibilities
- User interface for troubleshooting

These monitoring features allow the display of information regarding both the status of components health and the safety functions values and parameters.

Examples of modules and rack monitoring interface

Standards / technical specifications

Hardline has been developed in accordance with the following rules and standards.

Safety requirements

International	IAEA GSR part 2	Leadership and Management for safety (2016)
	IAEA SSG-30	Safety classification of structures, systems and components in nuclear power plants (2014)
	IAEA SSR-2/1	Safety of nuclear power plants: design
	IAEA SSG-2	Deterministic safety analysis for nuclear power plants
	IAEA SSG-39	Design of instrumentation and control systems for nuclear power plants
	IEC 60671	Nuclear power plants - Instrumentation and control systems important to safety - Surveillance testing
	IEC/IEEE 60780-323	Nuclear power plants - Electrical equipment of the safety system - Qualification
	IEC 60812	Analysis technique for system reliability: procedure for failure mode and effect analysis
	IEC 60709	Nuclear power plants - Instrumentation and control systems important to safety - Separation
	IEC 60068-2 series	Environmental testing
	IEC/IEEE 60980-344	Nuclear Facilities - Equipment Important to Safety - Seismic Qualification
	IEC 60987	Hardware design requirements for computer based systems
	IEC 61000-4 series	Electromagnetic compatibility
	IEC 61226	Nuclear power plants - I&C systems important to safety - Classification of I&C functions
	IEC 61513	Nuclear power plants - I&C systems important to safety - General requirements for systems
	IEC 62003 ed2:2020	Nuclear power plants - Instrumentation, control and electrical power systems - Requirements for electromagnetic compatibility testing
	IEC 62138	Nuclear power plants – Instrumentation and control systems important to safety – Software aspects for computer-based systems performing category B or C functions
	IEC 62566	Development of HDL-programmed integrated circuits for systems performing category B & C functions
	IEC 62566-2	Nuclear power plants – Instrumentation and control important to safety – Development of HDL-programmed integrated circuits – Part 2: HDL-programmed integrated circuits for systems performing category B or C functions
	IEC 62808	Nuclear power plants - Instrumentation and control systems important to safety - Design and qualification of isolation devices
USA	10 CFR 50	General design criteria for nuclear power plants (appendix A)
	NUREG 800, chap.7	Standard review plan for the review of safety analysis reports for nuclear power plants
	IEEE 338	Standard for criteria for the periodic surveillance testing of nuclear power generating station safety systems
	IEEE 379	Standard application of the single-failure criterion to nuclear power generating station safety systems
	IEEE 603	Standard for criteria for safety systems for nuclear power generating stations
Europe	RCC-E	Design and construction rules for electrical and I&C systems and equipment
	RFS	French ASN - Fundamental safety rules for nuclear reactors
	CRT	Technical rules file
	EN 55011 (A Class)	Industrial, scientific and medical (ISM) radio frequency equipment - Radio disturbance characteristics - Limits and methods of measurement
	EN 61000-6-2	Electromagnetic compatibility - Generic immunity standard
	EN 61000-6-4	Electromagnetic compatibility - Generic emission standard
	TS 61000-6-5	Immunity for power station and substation environments

Qualification

Hardline has been qualified according to the following tests.

All hardware components and systems from Framatome have been designed, implemented and qualified in compliance with European nuclear standards, International Atomic Energy Agency (IAEA) 50-C-QA code for quality assurance, IEC 61513 and associated IEC nuclear-specific standards and the European code RCC-E, which prescribes requirements for qualification of electrical equipment used in nuclear power plants.

The Hardline system qualification package is built on a combination of tests and analyses:

- Qualified species are defined to cover full capabilities of the technology, in most demanding configurations. They endure qualification testing in certified laboratories to build a set of reference tested levels and approved configurations
- Installed systems qualification is argued based on analyses of custom cabinet setups compared with reference qualified configurations

Electrical and manufacturing tests

Reference tests are performed on the first-of-a-kind electronic board, unit and cabinet. They allow operators to check the electrical and functional characteristics and the quality of manufacturing through:

- Visual and mechanical inspection
- Electrical tests
- Functional features tests

Aging tests

Aging tests are performed on qualified species before environmental and seimic tests. They simulate the effects of the lifetime of the equipment. They consist of:

- Repeated unplugging and plugging of connector
- Mechanical vibrations
- Fast temperature variations
- Dry heat
- Damp Heat
- Cold
- Prolonged operating test

Functional operating limits

- Slow & sudden voltage variation tests
- Frequency variations tests
- Thermal variation tests
- Humidity withstand tests
- EMC tests are described in a separate paragraph

Environmental tests are performed on qualified species.

EMC Qualification tests

Based on experience of nuclear environment, Framatome has defined a standard compliance process. EMC tests are performed on each item belonging to the Hardline products family. EMC tests are performed on qualified species.

Seismic qualification tests

Seismic tests are performed on qualified species with the use of covering test spectrum. Applied seismic levels are defined strong enough to encompass the stresses that equipment can suffer in most areas of the world.

Qualified environmental conditions

Operating room ambient temperature (cabinet-level)	+1 to +45°C (more than 45°C for some specific cases)
Recommended average room ambient temperature	+23°C
Relative humidity	95% at +40°C
EMC robustness according to IEC/EN 62003	Level III with standard external cabling Level IV with reinforced EMC external cabling
Seismic and large airplane crash resistance	Vertical & Horizontal ZPA 12 m/s^2 Zero Period Acceleration (ZPA) is applied on cabinet anchoring structure. Tested spectrum is available in Framatome documentation.

Customer benefits

Hardline is the latest non-programmed I&C technology, dedicated to nuclear safety.

Safety oriented

Hardline hardware components have been designed to implement safety I&C systems. They include appropriate features to defend (i.e. detect and act) against failures which may occur inside the system, caused from inside or outside the I&C system. Its fail-safe oriented features are given hereafter:

- Analog modules use 4-20mA electrical ranges. In case of detected hardware internal failure, output is set to 0 or +22mA so signal receivers do not display wrong information
- Logical algorithm can be performed with the use of Hardline fail-safe configurations that set the module binary outputs to safe state in case of detected hardware failure
- Voting modules allow detection of non-unanimity allowing operators to continuously detect spurious activation as well as failure on demand in case of real activation

Not subject to software common cause failure and cyber security threats

Hardline technology is hardwired-based and does not require any software. This guarantees that there is no risk of software common cause failure (CCF) with the other plant safety digital systems, but also that the Hardline technology is immune to cybersecurity threats.

Dependability

Hardline is aimed at building highly dependable I&C systems.

- Safe: no normal or abnormal operation or failure of the system can lead to an unsafe state
- Available: the system always fulfills its functions

The dependability of NPP I&C systems is strongly oriented towards safety and is ruled by the “single failure” criteria:

- One single failure shall not prevent the system from being safe and available
- Two simultaneous and independent failures shall not lead to an unsafe state

Easier licensing

Similarly, the absence of software ensures a straighforward licensing phase with the regulator.

Self-diagnostic and periodic tests

Hardline modules are continuously checked by self-monitoring features during operation.

Self-tests can detect and signal instantaneously most module hardware failures.

All signals are continuously monitored and signal status is automatically transmitted toward the monitoring system: this early fault detection limits the maintenance needs.

Hardline safety systems can be designed with periodic testing capabilities usable either off-line or during on-line operation. Periodic tests can simulate the plant inputs conditions, which shall lead to protective actuation. They are suitable to detect those potential failures which could prevent the safety system from initiating appropriate actions when needed.

Hardware reliability

Hardline electronic boards have been designed to meet safety class 1 (IEC 61226) requirements.

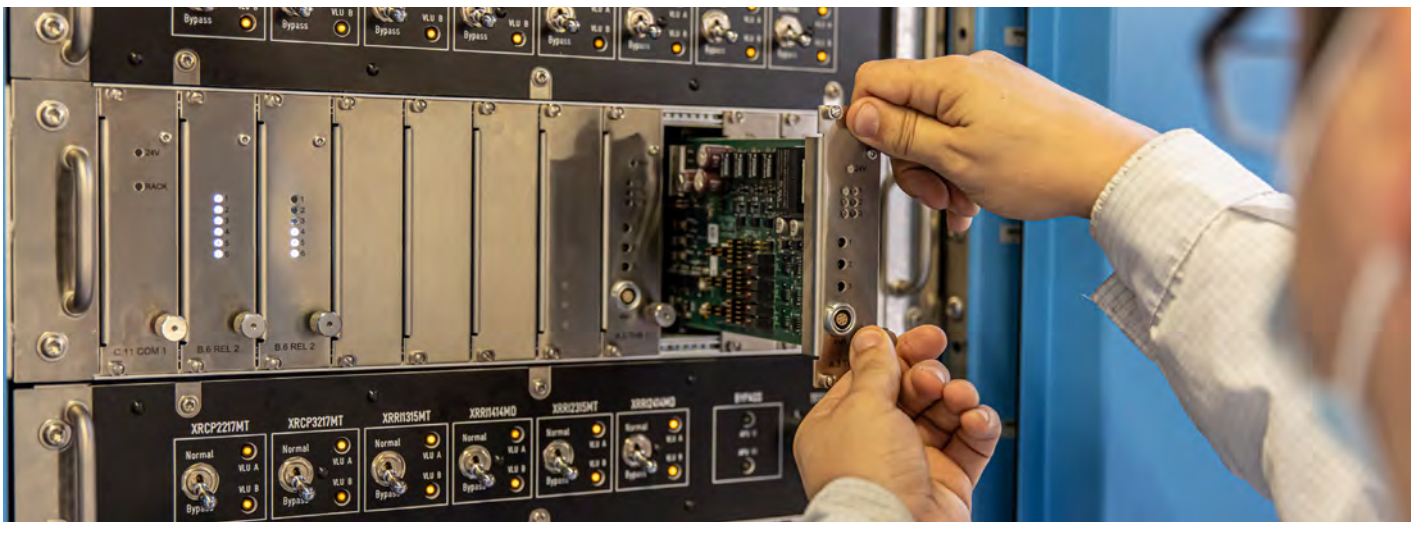
Failure Mode and Effect Analysis (FMEA) is available for each electronic board and is used to establish failure rate estimates for system reliability. These estimates help assess the fulfillment of the safety objectives by the system hardware architecture and the time interval needed between periodic tests.

Cabinets and units implementing technology are designed, manufactured and validated to meet Safety Class 1 requirements. They undergo comprehensive environmental qualification type tests such as earthquake and EMC tests.

Hardware maintainability

In order to help the customers meet their safety and availability objectives, Hardline has been designed with failure avoidance, failure detection and repair features:

- Reliability is achieved by using proven designs implemented with high quality and qualified hardware components
- Failure detection achieves 100% coverage with local and remote signaling and with periodic testing procedures
- Easy access to hardware components and cabling within the cabinets
- Spare parts policy for on-site quick repairs



Experience and references

Hardline is the result of 50 years of experience in the use of safety analog and non-programmed technologies.

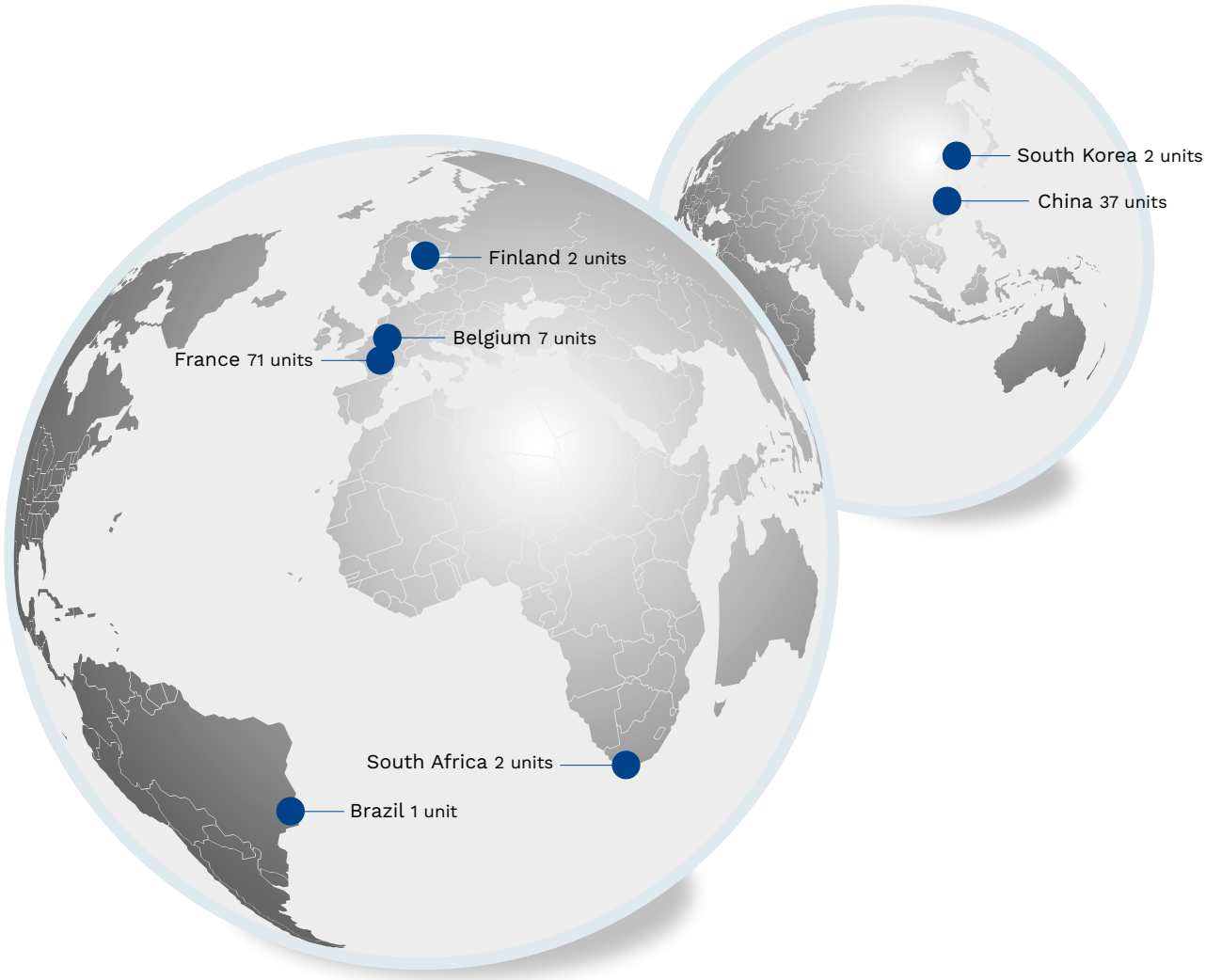
For more than 50 years, Framatome has been designing, manufacturing, and is still maintaining non-safety and safety I&C systems developed using non software-based technologies.

We supplied Multibloc for nuclear instrumentation and Silimog for logic functions for 34 EDF three-loop 900MW PWRs built between 1978 and 1987. All of them are still in operation today.

In the frame of the refurbishment project of the 1300MW 20-unit French fleet started in 2012, the ULS dynamic logic system has been upgraded according to new functional requirements from the operator. Framatome has implemented new electronic functions in the existing non-programmed I&C systems originally developed in the 80s.

For the Loviisa modernisation project started in 2014, Framatome has renewed electronic functions in order to deliver non-programmed systems to the Loviisa NPP.

Two non-programmed I&C safety systems were delivered allowing the operator to increase the safety of the plant. The first one allows prioritization of safety manual commands over non-safety automatic commands. The second one implements additional diversity for critical protection functions and provides access to the operator to diverse trip and ESFAS manual commands.



Selected Framatome references for non-programmed safety technologies

Framatome is an international leader in nuclear energy recognized for its innovative solutions and value added technologies for the global nuclear fleet. With worldwide expertise and a proven track record for reliability and performance, the company designs, services and installs components, fuel, and instrumentation and control systems for nuclear power plants. Its more than 15,000 employees work every day to help Framatome's customers supply ever cleaner, safer and more economical low-carbon energy.

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Framatome
Tour AREVA. 1 Place Jean Millier
92400 Courbevoie, France

ic@framatome.com
www.framatome.com