

ENGINEERING  
TOMORROW



Safety Manual

# PLUS+1<sup>®</sup> Safety Controllers

## SC0XX-1XX Safety Controller Family



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**Revision history***Table of revisions*

<b>Date</b>	<b>Changed</b>	<b>Rev</b>
June 2019	User application software development requirements, first bullet updated	0501
December 2018	Updated user application software development requirements	0404
August 2018	Corrected typo	0403
August 2018	Corrected title	0402
July 2018	Updated IEC 61508 to IEC 61508 : 2010 Parts 1-7 and IEC 62061:2005+ A1:2012+ A2:2015 functional safety standards	0401
April 2017	Recommended diagnostics update; User application software development requirements update	0301
March 2015	FMEDA analysis; User application software development requirements; and added tables for control of outputs	BA
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## Introduction

### This safety manual

This safety manual provides information necessary to design, implement, verify and maintain a safety critical function utilizing the PLUS+1® SC0XX-1XX Controller Family. This manual provides necessary requirements for meeting the IEC 61508 : 2010 Parts 1-7 and IEC 62061:2005+ A1:2012+ A2:2015 functional safety standards:

**⚠ Warning**

**Read manual completely before programming your application.**

### Certified SIL 2 Capable

The SC0XX-1XX Controller Family is certified SIL 2 Capable when deployed with the certified SIL 2 Capable OS that is embedded in their respective SC0XX-1XX HWD files.

The SC0XX-0XX Controller Family is designed for meeting the needs of SIL 2 applications where the OEM certifies at the machine level. The SC0XX-0XX Controller Family is not certified SIL 2 Capable as a component regardless of the HWD files with which it is deployed. The table below summarizes this information (the HWD filenames are representative, but not actual).

In all cases, the OEM/customer is responsible for the safety integrity requirement, implementation, and validation of their application.

Controller Family	HWD for the Primary Processor	HWD for the Secondary Processor	Component-Level SIL 2 Capable	Machine-Level SIL 2 Capable
SC0XX-1XX	SC0XX-1XX_HWD_Primary*	SC0XX-1XX_HWD_Secondary*	Yes	Yes
SC0XX-1XX	SC0XX-0XX_HWD_Primary	SC0XX-0XX_HWD_Secondary	No	Yes
SC0XX-0XX	SC0XX-1XX_HWD_Primary*	SC0XX-1XX_HWD_Secondary*	No	Yes
SC0XX-0XX	SC0XX-0XX_HWD_Primary	SC0XX-0XX_HWD_Secondary	No	Yes

\*These HWD files incorporate the certified SIL 2 Capable OS with Safety Diagnostic Functions.

### Comprehensive information

#### Manual

Title	Type	Identification number
PLUS+1® SC0XX-1XX Controller Family	Technical Information	L1415500
PLUS+1® GUIDE Software User Manual	Operation Manual	10100824
How to Install PLUS+1® GUIDE Upgrades	Operation Manual	11078040

#### User information

SC Controller model	Document number		
	Primary processor reference manual	Secondary processor reference manual	Data Sheet
SC050-120/122	70156324	70156321	L1410421
SC024-120/122	70156499	70156500	L1410171
SC024-110/112	70156496	70156498	L1410890
SC050-13H	70153891	70153903	L1407546

## Introduction

### **Latest version of technical literature**

Comprehensive technical literature is online at [www.danfoss.com](http://www.danfoss.com)

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### **PLUS+1° SC Controller support**

Contact information is online at: <http://powersolutions.danfoss.com/products/PLUS-1-GUIDE/PLUS-1-support-and-training/>

## Component description and failure rates

### Processors and subsystems

The PLUS+1® SC0XX-1XX Controller has two processors, the primary and the secondary processor, which communicate asynchronously with each other. The PLUS+1® SC0XX-1XX Controller has six main subsystems, each of which was analyzed individually. The configuration of a specific controller deployment is a function of the user application software.

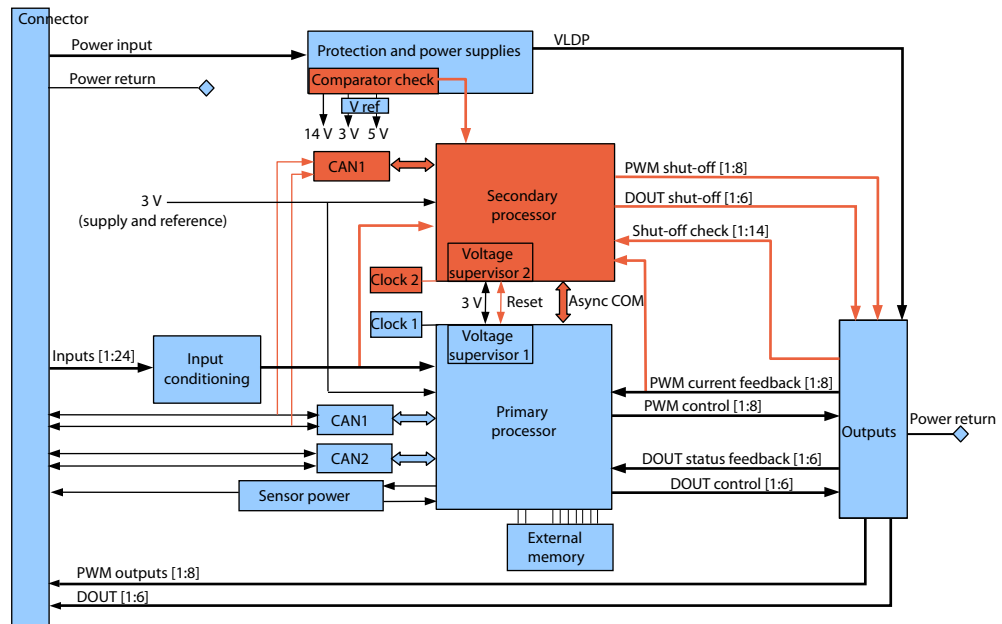
#### Analyzed subsystems

Subsystem	Description
Common Logic	Electrical components and circuitry typically involved with all applications regardless of the input-output channel configuration
DIN/AIN/FreqIN	Digital analog and frequency input pins
CrntIn (current)	Current input pins
ResIN	Resistance input pins
DOUT	Digital output pins
CrntOUT (current)	Current output pins

### FMEDA analysis

The FMEDA analysis results include the elements shown in the following diagram (components and inputs/outputs are color coded, blue for the primary processor and red for the secondary processor).

PLUS+1® SC0XX-1XX Controller—Parts included in the FMEDA



The PLUS+1® SC0XX-1XX Controller is classified as a Type B<sup>1</sup> high demand mode component with HFT = 0 per IEC 61508.

The PLUS+1® SC0XX-1XX Controller is certified to provide a 1oo1D architecture in accordance with IEC 61508. This allows the conclusion that a CAT2 architecture can be implemented in accordance with ISO 13849 or ISO 25119. For example this can be accomplished by using the primary processor as main controller for the Safety Function and the secondary processor as diagnostic element (intelligent watch dog, TE-Test Equipment) to observe the correct function of the primary processor and to independently de-energize (safe-state) all corresponding safety-related outputs.

<sup>1</sup> Type B component: “Complex” element (using microcontrollers or programmable logic); for details see 7.4.4.1.3 of IEC 61508.

## Component description and failure rates

Detailed analysis, review and documentation for compliance to ISO 13849 or ISO 25119 must be done by the designer or integrator of the safety related system.

### Failure categories description

In order to judge the failure behavior of the PLUS+1® SC0XX-1XX Controller, the following definitions for the failure of the component apply.

#### Definitions for failure of the component

Failure category <sup>(1)</sup>	Definition
Fail-Safe State	State where the safety output is de-energized.
Fail Safe	State where the safety output is de-energized.
Fail Detected	Failure that is detected by the PLUS+1® SC Controller and causes the output signal to go to the predefined fail safe state.
Fail Dangerous	Failure that deviates the measured input state or the actual output by more than the safety accuracy (2% of span) and that leaves the output within the active range.
Fail Dangerous Undetected	Failure that is dangerous and that is not being diagnosed by automatic diagnostics or expected user logic.
Fail Dangerous Detected	Failure that is dangerous but is detected by automatic diagnostics or is expected to be detected by user logic.
Fail High <sup>(2)(3)</sup>	Failure that causes a safety input signal to go to a value that is clearly above the normal range and can therefore be reliably detected by the user application software.
Fail Low <sup>(2)(3)</sup>	Failure that causes a safety input signal to go to a value that is clearly below the normal range and can therefore be reliably detected by the user application software.
No Effect	Failure of a component that is part of the safety function but that has no effect on the safety function.
Annunciation Detected	Failure that does not directly impact safety but does impact the ability to detect a future fault (such as a fault in a diagnostic circuit) and that is detected by internal diagnostics.
Annunciation Undetected	Failure that does not directly impact safety but does impact the ability to detect a future fault (such as a fault in a diagnostic circuit) that is not detected by internal diagnostics.
$\lambda_{SD}$	Failure rate of all safe detected failures
$\lambda_{SU}$	Failure rate of all safe undetected failures
$\lambda_{DD}$	Failure rate of all dangerous detected failures
$\lambda_{DU}$	Failure rate of all dangerous undetected failures
$\lambda_D$	Failure rate of all dangerous failures, detected and undetected
$A_D$	Failure rate of all annunciation detected failures
$A_U$	Failure rate of all annunciation undetected failures
FIT	Failure In Time ( $1 \times 10^{-9}$ failures per hour)

<sup>(1)</sup> The failure categories listed above, expand upon the categories listed in IEC 61508, which are only safe and dangerous, both detected and undetected. In IEC 61508, the No Effect failures cannot contribute to the failure rate of the safety function. Therefore, they are not used for the Safe Failure Fraction calculation.

<sup>(2)</sup> Depending on the application, a Fail High or a Fail Low failure can either be safe or dangerous and may be detected or undetected depending on the user software application program.

<sup>(3)</sup> Consequently, during a Safety Integrity Level (SIL) verification assessment, the Fail High and Fail Low failure categories need to be classified as safe or dangerous, and as detected or undetected.

## Component description and failure rates

### Failure rates

The results of the FMEDA analysis for the PLUS+1® SC0XX-1XX Controller are presented in the following table.

#### Failure rates (FIT)

Controller Subsystem	$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$
Common Logic	2451	16	2556	263
DIN/AIN/FreqIN	0	11	0	22
CrntIn (current)	0	5	0	5
ResIN	0	11	0	11
DOUT	73	38	28	1
CrntOUT (current)	143	1	36	10

### Recommended diagnostics

The PLUS+1® SC0XX-1XX Controller can be implemented with diagnostics to detect many dangerous failures and other failures that would result in the controller operating in a degraded mode. The machine integrator is responsible for the safety and compliance to relevant standards. See [Safety critical function](#) on page 9 for design considerations and diagnostic recommendations.

## Design considerations

### Safety critical function

The PLUS+1® SC0XX-1XX Controller can perform a wide variety of control functions. If these control functions of the primary processor are safety critical, then additional safety reliability can be achieved by configuring the secondary processor to monitor the sensor inputs, perform diagnostics, and act to bring the machine to a safe state if safe operating parameters are violated. The recommended configuration is to use the secondary processor to monitor the control function of the primary processor.

### Recommended diagnostics

The following table lists recommended diagnostics. These diagnostics are implemented in the user application software that would be loaded into the PLUS+1® SC0XX-1XX Controller.

**⚠ Warning**

**If these diagnostics are not implemented, then all dangerous failures should be treated as dangerous undetected failures.**

### Diagnostics

Function	Failure mode	Condition	Action	Continuous or Start-up
Sensor power	Short to battery	Analog reading at or near maximum	Stop reading inputs powered by sensor power.	Continuous
Sensor power	Short to ground	Analog reading at or near zero	Stop reading inputs powered by sensor power.	Continuous
Sensor power	Out of range	Analog reading different than expected	Can compensate inputs for new voltage if possible	Continuous
Analog input	At Max	Analog reading at or near max	Stop using this input	Continuous
Analog input	At zero volts	Analog reading at or near zero	Stop using this input	Continuous
Current driver	Load shorted	Duty cycle at least 50% less than expected for known load	Information only or turn off output	Continuous
Current driver	Load shorted	Status signal indicates short circuit	Turn off output immediately	Continuous
Current driver	Open load	Duty cycle at least 50% less than expected for known load	Information only or turn off output	Start-up
Current driver	Load shorted	The output current decays too slowly after the output is disabled	Turn off output immediately	Continuous
Current driver	Incorrect load	Coil resistance is greatly different than expected	Do not use that output	Continuous
Digital input	Load shorted	Status signal indicates short circuit or open load	Application dependent	Continuous
Digital input	Open load	Status signal indicates short circuit or open load	Application dependent	Continuous
Battery Power	Dangerously High	Battery voltage reading above 36V	Turn off all outputs and ignore inputs	Continuous
Battery Power	Dangerously Low	Battery voltage reading below 7V	Turn off all PWM outputs	Continuous
Frequency input	Open	Analog reading is at or near middle voltage	Ignore frequency input	Continuous
Frequency input	No signal	Analog value doesn't change for longer than the maximum period	Ignore frequency input	Continuous
CAN	Bus off	CAN bus status signal indicates bus off	Turn off outputs that rely on CAN information	Continuous

## Design considerations

### Diagnostics (continued)

Function	Failure mode	Condition	Action	Continuous or Start-up
CAN	Time out	An expected message hasn't been received in the expected time	Turn off outputs that rely on that message	Continuous
CAN	Failed transition	Application requests message transmission while pending flag is active	Application dependent	Continuous
Configuration	Invalid configuration	Status signal indicates input or output is configured in an invalid way.	Make change to application software	Start-up

### User application software development requirements

#### Warning

The application programmer must apply these software development requirements when developing their safety-related system to insure the most robust safety integrity of the system architecture.

#### Warning

The system must be designed with de-energized as the safe state to assure system safety function.

- The CAN bus must not be used for safety critical functions unless a sufficient safety protocol like SAE J1939-76 or EN 50325-5 (CANopen Safety) is deployed for CAN bus communication.
- All changes made to the configuration through the service tool must be verified by the user to ensure that they function as expected in the safety controller.
- Appropriate action must be taken to put the system into a safe state when an output to output-feedback mismatch error is identified by the application.
- The user application software must include plausibility checks on frequency input data to detect possible failures in frequency input calculations.
- EEPROM data must include software part number and the user application software should check that this matches with the application.
- The user application software must include plausibility checks on all safety relevant inputs.
- If data is shared between the primary and secondary processors through the internal UART, time monitoring must be used to ensure that messages are being sent within the expected time period.
- The user application software must take appropriate action to put the system into a safe state when a current feedback reading mismatch is reported.
- If the user application allows it, the current output must periodically be set to zero to allow the zero offset to be recalculated.
- For optimal performance, the output current should be set to zero after large temperature changes (> 25° C (77° F)) to allow the zero offset to be re-calculated
- If the checksum on the EEPROM fails, the user application software must shutdown outputs (de-energize) depending on the EEPROM data or use default data if that can be done safely.
- Redundant channels must be utilized to provide reliability where there is concern about channel reliability based on PFH.
- Signal comparisons must be implemented by the user application software to compare signals between primary and secondary processors for safety related signals. Function blocks from the Safety Library can help with this task.
- Wiring of the control must be done in compliance with the Danfoss wiring guidelines addressed in *PLUS+1° SC0XX-1XX Controller Family Technical Information, L1415500*.
- The user application software must implement strategies to mitigate against the effects of corrupted RAM. For example, include shadow copies of safety critical data and checksums of data.
- Internal UART communication implemented by user application software must have as a minimum control mechanism of a heartbeat with sequence signal.
- In all cases, the sensor power supply must be monitored and taken into a ratiometric calculation for the analog inputs.

## Design considerations

- The user application software must implement shutdown of safety critical outputs either by the primary or the secondary processor or by both processors based on user application software safety requirements.
- The user application software must be tested for proper function including fault insertion testing. For more details, see [Appendix A](#) on page 18.
- The user application software must be tested for proper response to:
  - Highest frequency input conditions.
  - Highest frequency output conditions.
  - Highest CAN traffic load conditions on the corresponding used CAN buses.
- The user application software must verify that the process time set by function OSExecTimeout (GUIDE API) or by PC\_OS\_SET\_ExecTimeOut (C Open API) can meet the process safety time.
- The checksum failure treatment can be set with function OS.ChecksumFailureTreatment (GUIDE API) or by PC\_OS\_SET\_ChecksumFailureTreatment (C Open API) allowing the user application software to override memory corruption faults and to continue operation instead of turning off all outputs. The user application software must not override faults, since doing so could result in an unsafe condition.
- The user application software must verify that either the primary or the secondary processors or both processors are capable of disabling the safety related outputs.
- The user application software must use the frequency values and the count value of the Quad encoder inputs to validate functionality.
- The user application software must verify that the current output overload status returns to zero after commanding zero current output.
- A Functional Safety Assessment must be conducted before designing any safety related system using the PLUS+1® SC0XX-1XX Controller.
- When a high-inductance valve is switched off, false alarms may occur inside the safety layer because the decay of the PWM output current is too slow. This safety monitoring of PWM outputs can be disabled to improve compatibility with high-inductance valves. This is done by setting DisableCurrent-DecayRateMonitoring whereby it now becomes the responsibility of the application to monitor the output current for unintended short (overcurrent) conditions. When such a condition is detected, the application must immediately disable (turn off) the output. By default, DisableCurrent-DecayRateMonitoring is not set and the monitoring is done by the kernel.
- When a high-inductance valve is switched off, false alarms may occur inside the safety layer because the decay of the digital output current is too slow. This safety monitoring of digital outputs can be disabled to improve compatibility with high-inductance valves. This is done by setting DisableOutputSafetyMonitoring whereby it now becomes the responsibility of the application to monitor the output current for unintended short (overcurrent) conditions. When such a condition is detected, the application must immediately disable (turn off) the output. By default, DisableOutputSafetyMonitoring is not set and the monitoring is done by the kernel.

## Control of DOUT

DOUT Status	Description	Recovery
BIT 3	Over temperature/open load	<ol style="list-style-type: none"> <li>1. The primary application must first command the output to the off-state.</li> <li>2. The BTS chip temperature must return to its valid range.</li> <li>3. The kernel then clears status bit 3.</li> </ol>
BIT 6	Safety layer failure	<ol style="list-style-type: none"> <li>1. The controller must be reset by performing a power cycle.</li> </ol>
BIT 7	Safety FET disabled by secondary	<ol style="list-style-type: none"> <li>1. The Safety FET must be off for 250 ms.</li> <li>2. The primary application must command the output to the off-state.</li> <li>3. The secondary application can then re-enable the output.</li> </ol>
BIT 8	Hardware supply power out of range	<ol style="list-style-type: none"> <li>1. The primary application must command ALL outputs to the off-state.</li> <li>2. The supply voltage must return to its valid range.</li> <li>3. The kernel then clears status bit 8.</li> </ol>

## Design considerations

### Control of PWMOUT/DOUT

PWMOUT/DOUT Status	Description	Recovery
BIT 4	Overload	<ol style="list-style-type: none"> <li>1. The kernel will automatically disable the output.</li> <li>2. The primary application must set the output to the off-state for a minimum of 250 ms.</li> <li>3. The kernel then clears status bit 4 and re-enables the output.</li> </ol>
BIT 5	Incorrect selected output mode	<ol style="list-style-type: none"> <li>1. The primary application must select a valid output mode.</li> <li>2. The kernel then clears status bit 5.</li> </ol>
BIT 6	Safety layer failure	<ol style="list-style-type: none"> <li>1. The controller must be reset by performing a power cycle.</li> </ol>
BIT 7	Safety FET disabled by secondary	<ol style="list-style-type: none"> <li>1. The Safety FET must be off for 250 ms.</li> <li>2. The primary application must command the output to the off-state.</li> <li>3. The secondary application can then re-enable the output.</li> </ol>
BIT 8	Hardware supply power out of range	<ol style="list-style-type: none"> <li>1. The primary application must command ALL outputs to the off-state.</li> <li>2. The supply voltage must return to its valid range.</li> <li>3. The kernel then clears status bit 8.</li> </ol>

### Environmental limits

The designer or integrator of a safety critical function must verify that the safety controller is rated for use within the expected environmental limits of the target application. Refer to [User information](#) on page 4, for environmental limits.

### Application limits

The designer or integrator of a safety critical function must check that the safety controller is rated for use within the expected application limits. Refer to the *PLUS+1° SC0XX-1XX Controller Technical Information, L1415500*, for safety controller limits.

### Design verification

Refer to [Failure rates](#) on page 8 for a summary of failure rates for the PLUS+1° SC0XX-1XX Controller.

The achieved Safety Integrity Level (SIL) of an entire Safety Critical Function design must be verified by the designer or integrator via a calculation of PFH considering the I/O required, demand mode, any implemented diagnostics, safety time, and architecture.

The failure rate data listed the FMEDA report is only valid for the useful lifetime of a PLUS+1° SC0XX-1XX Controller. The failure rates will increase sometime after this useful lifetime period. Reliability calculations based on the data listed in the FMEDA report for mission times beyond the lifetime may yield results that are too optimistic, in other words, the calculated Safety Integrity Level will not be achieved.

### SIL capability

#### Systematic capability

The systematic capability of the PLUS+1° SC0XX-1XX Controller Family is SC 2 per IEC 61508.

#### Random capability

Refer to [Failure rates](#) on page 8 for a summary of failure rates for the PLUS+1° SC0XX-1XX Controller Family.

For each user application, the failure rates for the particular configuration should be determined and compared to the allowable failure rate for a given SIL target.

## Design considerations

### Connection to sensors and actuators

The connection of the PLUS+1® SC0XX-1XX Controller to the required sensors and actuators must be performed in accordance with the *PLUS+1® SC0XX-1XX Controller Family Technical Information, L1415500*.

### Requirements

- The system's response time must be less than the process safety time defined by the user application.
- The worst-case response time for a change of value of an analog input or contact signal (measured at the terminals) through the complete system to the completion of change of state of the analog output or contact output (measured at the terminals) will be a maximum of 10 ms plus the user application software programmed ExecTimeOut, as measured to the standard outputs. This worst case time must be determined for the worst-case loading of the safety controller. See [User information](#) on page 4.
- The diagnostic self-checks other than the RAM diagnostic self-test and CRC on Flash application must be performed based on demand every loop time, the delay time from the onset of a failure to the time at which the outputs reach the safe state will be a maximum of 10 ms plus the user application software program parameter, ExecTimeOut.
- The time interval of RAM diagnostic self-check for the platform is a maximum of 1 hour. The time interval RAM test is reported to the user application software.
- The CRC flash check time for the user application software is a maximum of 1 hour and is reported to the user application software.

#### *Diagnostics and response times*

Description	Worst case time	Additional information
Diagnostics and Response Times	1 hour	Depends on total size of RAM
Flash CRC error detect from onset to safe state	1 hour	Depends on total size of Flash memory
Change of input to output	10 ms	Not including ExecTimeOut
Diagnostic error detection time from onset to safe state	10 ms	Diagnostics are based on demand during execution loop

- The maximum delay time from the onset of a failure to the time at which the outputs reach the safe state is the diagnostic time interval plus 10 ms.
- All safety related system components, including the PLUS+1® SC Controller, must be operational before machine operation.
- Personnel must verify that the PLUS+1® SC Controller is suitable for use in safety applications by confirming the PLUS+1® SC Controller's nameplate is properly marked.
- Personnel performing testing on the PLUS+1® SC Controller must be competent to perform such testing. Functional Safety Training is provided by Danfoss Power Solutions, and details can be found on the Danfoss Power Solutions website at: <http://powersolutions.danfoss.com/solutions/Functional-safety/>.
- Results from the functional tests and diagnostics must be recorded and reviewed periodically.

## Installation and operation considerations

### Installation

The PLUS+1° SC Controller must be installed per standard practices outlined in the *PLUS+1° SC0XX-1XX Controller Family Technical Information, L1415500*. The environment must be checked to verify that environmental conditions do not exceed the ratings. Instructions on installation of latest version of the safety controller HWD file are found in *How to Install PLUS+1° GUIDE Upgrades Operation Manual, 11078040*.

### Physical location and placement

The PLUS+1° SC Controller must be mounted in accordance with the *PLUS+1° SC0XX-1XX Controller Family Technical Information, L1415500*, in a low vibration environment. If excessive vibration is expected, special precautions must be taken to ensure the integrity of electrical connections or the vibration should be reduced using appropriate damping mounts.

### Repair and replacement

The PLUS+1° SC0XX-1XX Controllers are not repairable and no maintenance of them is required.

### Useful life

The useful life of the PLUS+1° SC0XX-1XX Controller is 30 years. No proof tests are required.

### Software/hardware version numbers

See document for the relevant PLUS+1° SC0XX-1XX Controller, listed under *User information* on page 4.

### Security considerations

The PLUS+1° SC Controller does not use data that the user can configure externally, for example, by the PLUS+1 Service Tool. The user application software may contain data that is configured externally. If this is the case, then suitable security should be provided. The *PLUS+1° GUIDE Software User Manual, 10100824* provides a description of how to handle parameters in a safe way.

### Danfoss Power Solutions notification

Any failures that are detected and that compromise functional safety should be immediately reported to Danfoss Power Solutions. Any change suggestions for future improvements or new features can be forwarded to Danfoss Power Solutions:

Contact information is online at: <http://powersolutions.danfoss.com/products/PLUS-1-GUIDE/PLUS-1-support-and-training/>

## Using the FMEDA results

### PFH calculation or PFD<sub>AVG</sub> calculation

An average Probability of Failure per Hour (PFH) or an average Probability of Failure on Demand (PFD<sub>AVG</sub>), depending on the operating mode, must be determined for each Safety Critical Function. The total will include the failure rate of all sensors and actuators that are required to perform the function as well as the elements of the PLUS+1<sup>®</sup> SC0XX-1XX Controller that are utilized.

Since the elements of the controller subsystem vary based on the Safety Critical Function implemented, the contribution for the PLUS+1<sup>®</sup> SC0XX-1XX Controller needs to be determined for each application.

To demonstrate how to calculate the contribution of the PLUS+1<sup>®</sup> SC0XX-1XX Controller Family, consider the example of a steering function that is safety critical. The steering function relies on a Steer Command that is transmitted by a joystick utilizing a single ResIN – Resistance Mode Input. The controller processes the input and controls the movement of the machine through a dual path control subsystem utilizing four CrntOUT outputs.

This safety critical function would have an overall failure rate that is the sum of controller subsystems used which are:

- (1) Common Logic
- (1) ResIN
- (4) CrntOUT (current)

In a machine application, the safety critical function could be operating in high demand. In a high demand function, only the dangerous undetected failures are included when calculating the PFH. To be considered a high demand application, the diagnostics must be executed 10 times faster than the process safety time. Care must be taken when modeling a function as high demand. It is recommended that the designer or integrator review the requirements with Danfoss Power Solutions to help avoid understating PFH.

### Example application, failure rate analysis

The following table is for an example application. Consider for this example, the function is a high demand system.

*Failure rate analysis for the example function*

Controller Subsystem	Quantity	$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	Total $\lambda_D$
Common Logic	1	2451	16	2556	263	2819
DIN/AIN/FreqIN	0	0	11	0	22	22
CrntIn (current)	0	0	5	0	5	5
ResIN	1	0	11	0	11	11
DOUT	0	73	38	28	1	29
CrntOUT (current)	4	143	1	36	10	46
Example Total (Sum of Quantity multiplied by Column Value)		3023	31	2700	314	3014

The implementation of the recommended diagnostics (Section 3.1) affects the system failure rate. For example, if all recommended diagnostics are implemented, only the undetected failures ( $\lambda_{DU}$ ) contribute to the failure rate, which is 314 FITS or  $3.14 \times 10^{-7}$  failures per hour. This results in a SFF of 94.8%, which is a SIL2 compliant system.

If none of the recommended diagnostics are implemented, then all failures ( $\lambda_{SD}$ ,  $\lambda_{DU}$ ,  $\lambda_{DD}$ ) are treated as undetected failures. In this example, the failure rate would then be 3014 FITS or  $3.014 \times 10^{-6}$  failures per hour, which does not meet the SIL2 requirement, but does meet the SIL1 requirements.

## Abbreviations and definitions

### Abbreviations

#### Abbreviations

Abbreviation	Definition
<b>EUC</b>	Equipment under control.
<b>FMEDA</b>	Failure modes, effects and diagnostic analysis.
<b>HFT</b>	Hardware fault tolerance.
<b>PFH</b>	Probability of failure per hour.
<b>PFD<sub>AVG</sub></b>	Average probability of failure on demand.
<b>SFF</b>	Safe failure fraction, summarizes the fraction of failures which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action.
<b>SIF</b>	Safety instrumented function.
<b>SIL</b>	Safety integrity level.
<b>SRS</b>	Safety related system, implementation of one or more safety critical functions. An SRS is composed of any combination of sensor(s), control module(s), and actuator(s).
<b>DIN/AIN/FreqIN</b>	Digital analog and frequency input pins.
<b>CrntIn (current)</b>	Current input pins.
<b>ResIN</b>	Resistance input pins.
<b>DOUT</b>	Digital output pins.
<b>CrntOUT (current)</b>	Current output pins.
<b>OS</b>	Operating system.

### Definitions

#### Definitions

Term	Definition
Continuous Demand Mode	Mode where the safety function retains the equipment under control in a safe state as part of its normal operation.
High Demand Mode	Mode where the safety function is only performed on demand, in order to transfer the EUC into a specified safe state, and where the frequency of demands is greater than one per year.
Low Demand Mode	Mode where the safety function is only performed on demand, in order to transfer the EUC into a specified safe state, and where the frequency of demands is not greater than one per year. NOTE: The E/E/PE safety-related system that performs the safety function normally has no influence on the EUC or EUC control system until a demand arises. However, if the E/E/PE safety-related system fails in such a way that it is unable to carry out the safety function, then it may cause the EUC to move to a safe state (see 7.4.6 of IEC 61508).
Safety	Freedom from unacceptable risk of harm.
Functional Safety	The ability of a system to carry out the actions necessary to achieve or to maintain a defined safe state for the equipment, machinery, plant, and apparatus under control of the system.
Basic Safety	The equipment must be designed and manufactured such that it protects against risk of damage to persons by electrical shock and other hazards and against resulting fire and explosion. The protection must be effective under all conditions of the nominal operation and under single fault conditions.
Safety Assessment	The investigation to arrive at a judgment, <i>based on evidence</i> of the safety achieved by safety-related systems.
Safety Critical Function	A set of equipment intended to reduce the risk due to a specific hazard.
Process Safety Time	The period of time between a failure occurring in the control system (with the potential to give rise to a hazardous event) and the occurrence of the hazardous event if the safety function is not performed.
Type A Component	<i>Non-Complex</i> element (using discrete elements); for details see 7.4.4.1.2 of IEC 61508.

## Abbreviations and definitions

*Definitions (continued)*

<b>Term</b>	<b>Definition</b>
Type B Component	<i>Complex</i> element (using micro controllers or programmable logic); for details see 7.4.4.1.3 of IEC 61508.
Common Logic	Electrical components and circuitry typically involved with all applications regardless of the input-output channel configuration.

## Appendix A

The following topics are details as they appear in the *PLUS+1° GUIDE User Manual*, **10100824** regarding risk reduction, software safety validation, and testing the application for proper function including fault insertion testing. These same precautions must be taken when using PLUS+1° C Open.

### Risk reduction

It is important to design, test and secure applications developed with the PLUS+1° GUIDE software to reduce the risk of personal injury and equipment damage.

The applications that you create with the PLUS+1° GUIDE software typically control heavy, powerful, and mobile off-road equipment such as tractors, cranes, and harvesters. Under normal operating conditions, using this type of machinery always involves the risk of personal injury and equipment damage. Abnormal operating conditions greatly increase the risk of personal injury and equipment damage.

The PLUS+1° GUIDE software has no automatic protections against these risks. The tool has no protection against the risks that result from bugs in the tool software, errors in the tool manual, or incompatibilities between software versions of the tool.

#### **Warning**

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You must design and test your application to reduce these risks. Secure your application against unauthorized changes in its operating parameters to reduce these risks.

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### Design

You have the responsibility when you design a PLUS+1° GUIDE application to include the fault checking and the error handling needed to reduce risks in normal and abnormal operating conditions. The following are some items to consider when developing fault checking and error handling for your application:

- How the machine is normally used.
- Possible operator errors and their consequences.
- Industry safety standards and legal requirements.
- Input and output failures and their consequences. These failures can include:
  - Joystick, sensor, and other inputs suddenly going to  $\pm 100\%$  or to  $0\%$ .
  - Outputs that control machinery direction, speed, and force suddenly changing direction or going to  $\pm 100\%$  or to  $0\%$ . Decide how likely each failure is. The more likely a failure, the more you need to protect against the consequences of the failure.
- The sequence of events and consequences of a fault or error.
- The sequence of events and consequences of an emergency stop.

### Test

You have the responsibility once you have created an application to test the application. You should download your application to hardware and test its operation under both normal and abnormal operating conditions. You should make sure that:

- Individual inputs produce expected outputs.
- Fault handling and error checking work as designed.

---

You must repeat your tests whenever you make configuration, calibration, or software changes to your application.

---

### Secure

- You have the responsibility to secure your application against unauthorized changes.
- You should always use the PLUS+1° GUIDE program's Tool Key feature (or a parameter PIN feature for PLUS+1° C Open) to restrict access to your application's operating parameters.

## Appendix A

- Without Tool Key or PIN protection, there is an increased risk that unauthorized personnel could use the PLUS+1<sup>®</sup> Service Tool program to change your application’s operating parameters
- Tool Key/PIN protection reduces the risk that unauthorized personnel could use the PLUS+1<sup>®</sup> Service Tool program to change your application’s operating parameters.

**Warning**

Changes in your application’s operating parameters could cause unexpected machinery movement that result in personnel injury and equipment damage.

### Prerequisites

The **Statements: Yes, No, Partial** in the table below appear in the **Fulfill** columns in the tables on the following pages.

The statements in this table are only from a PLUS+1<sup>®</sup> tool perspective.

The overall responsible person for checking the fulfillment of the requirement in IEC 61508 and ISO 13849-1 must investigate which additional measures that needs to be taken for each individual requirement before it is completely fulfilled.

Statement	Description
<b>Yes</b>	This requirement is automatically fulfilled by using PLUS+1 <sup>®</sup> tools.
<b>Yes*</b>	Full conformance with this requirement demands that the software application designer considers the measures described in the column “detailed description.”
<b>No</b>	This requirement is not fulfilled by using PLUS+1 <sup>®</sup> tools.
<b>Partially</b>	Indicate that the PLUS+1 <sup>®</sup> tools do not cover all the requirements in an <b>Annex B</b> table that is referenced from a certain technique and measure described in an <b>Annex A</b> table, or only covers certain of the requirements within the sub chapter.
<b>Partially*</b>	The additional measures, beyond those described in the column “Detailed description,” that has to be performed for claiming full conformance with this requirement will vary from case to case. The application designer will be responsible for this work.
<b>N/A</b>	Not applicable for support tools.

### Requirements for Support Tools and Programming Languages

#### 7.4.4—Requirements for Support Tools and Programming Languages

Subclause	PLUS+1 GUIDE Tools	
	Fulfill <sup>(1)</sup>	Detailed description
1. A software on-line support tool shall be considered to be a software element of the safety related system.	N/A	Not applicable since PLUS+1 <sup>®</sup> GUIDE and PLUS+1 <sup>®</sup> Service Tool are certified as off-line support tools. Documented by the certificate.
2. Software off-line support tools shall be selected as a coherent part of the software development activities.	Yes	Selecting tools is covered by using PLUS+1 <sup>®</sup> GUIDE and PLUS+1 <sup>®</sup> Service Tool.
3. The selection of the off-line support tools shall be justified.	Yes	PLUS+1 <sup>®</sup> GUIDE and PLUS+1 <sup>®</sup> Service Tool are certified as off-line support tools in accordance to IEC61508.
4. All off-line support tools in classes T2 and T3 shall have a specification or product documentation which clearly defines the behavior of the tool and any instructions or constraints on its use. See 7.1.2 for software development lifecycle requirements, and 3.2.11 of IEC 61508-4 for categories of software off-line support tool.	Yes	PLUS+1 <sup>®</sup> GUIDE and PLUS+1 <sup>®</sup> Service Tool User Manuals defines the behavior of the tools. Fully covered and documented by the certificate.

Appendix A

7.4.4—Requirements for Support Tools and Programming Languages (continued)

Subclause	PLUS+1 GUIDE Tools	
	Fulfill <sup>1)</sup>	Detailed description
5. An assessment shall be carried out for offline support tools in classes T2 and T3 to determine the level of reliance placed on the tools, and the potential failure mechanisms of the tools that may affect the executable software. Where such failure mechanisms are identified, appropriate mitigation measures shall be taken.	Yes	PLUS+1° GUIDE and PLUS+1° Service Tool are certified as off-line support tools in accordance to IEC61508. Fully covered and documented by the certificate.
6. For each tool in class T3, evidence shall be available that the tool conforms to its specification or documentation. Evidence may be based on a suitable combination of history of successful use in similar environments and for similar applications (within the organization or other organizations), and of tool validation as specified in 7.4.4.7.	Yes	PLUS+1° GUIDE is certified as off-line support tool in accordance to IEC61508. Fully covered and documented by the certificate.
7. The results of tool validation shall be documented covering the following results: A) A chronological record of the validation activities; B) The version of the tool product manual being used; C) The tool functions being validated; D) Tools and equipment used; E) The results of the validation activity; the documented results of validation shall state either that the software has passed the validation or the reasons for its failure; F) Test cases and their results for subsequent analysis; G) Discrepancies between expected and actual results.	Yes	PLUS+1° GUIDE and PLUS+1° Service Tool are certified as off-line support tools in accordance to IEC61508. Fully covered and documented by the certificate.
8. Where the conformance evidence of 7.4.4.6 is unavailable, there shall be effective measures to control failures of the executable safety related system that result from faults that are attributable to the tool.	—	Not applied since 7.4.4.6 is fulfilled.
9. The compatibility of the tools of an integrated toolset shall be verified.	Yes	PLUS+1° GUIDE and PLUS+1° Service Tool are certified as off-line support tools in accordance to IEC61508. Fully covered and documented by the certificate.
10. To the extent required by the safety integrity level, the software or design representation (including a programming language) selected shall: A) Have a translator which has been assessed for fitness for purpose including, where appropriate, assessment against the international or national standards; B) Use only defined language features; C) Match the characteristics of the application; D) Contain features that facilitate the detection of design or programming mistakes; E) Support features that match the design method.	N/A	PLUS+1° GUIDE is certified as off-line support tools in accordance to IEC61508 (A). Dependency view support detection of design and programming mistakes (D). PLUS+1° GUIDE provides features to match the characteristics of control applications and control flow designs (C and E).
11. Where 7.4.4.10 cannot be fully satisfied, the fitness for purpose of the language, and any additional measures which address any identified shortcomings of the language shall be justified.	—	Not applied since 7.4.4.10 is fulfilled.
12. Programming languages for the development of all safety-related software shall be used according to a suitable programming language coding standard.	Yes*	PLUS+1 Development Guidelines.
13. A programming language coding standard shall specify good programming practice, proscribe unsafe language features (for example, undefined language features, unstructured designs, etc.), promote code understandability, facilitate verification and testing, and specify procedures for source code documentation. Where practicable, the following information shall be contained in the source code: A) Legal entity (for example company, author(s), etc.); B) Description; C) Inputs and outputs; D) Configuration management history.	Yes*	PLUS+1 Development Guidelines.
14. Where automatic code generation or similar automatic translation takes place, the suitability of the automatic translator for safety-related system development shall be assessed at the point in the development lifecycle where development support tools are selected.	Yes	PLUS+1° GUIDE is certified as off-line support tool in accordance to IEC61508. Fully covered and documented by the certificate.

## Appendix A

### 7.4.4—Requirements for Support Tools and Programming Languages (continued)

Subclause	PLUS+1 GUIDE Tools	
	Fulfill <sup>1)</sup>	Detailed description
15. Where off-line support tools of classes T2 and T3 generate items in the configuration baseline, configuration management shall ensure that information on the tools is recorded in the configuration baseline. This includes in particular: A) The identification of the tool and its version; B) The identification of the configuration baseline items for which the tool version has been used; C) The way the tool was used (including the tool parameters, options and scripts selected) for each configuration baseline item.	Yes	Version control support of the project file (P1x) contains the information to fulfill this clause.
16. Configuration management shall ensure that for tools in classes T2 and T3, only qualified versions are used.	Yes	For certified hardware there is the possibility to compile as safety related software. That will require qualified PLUS+1° GUIDE and PLUS+1° Service Tool.
17. Configuration management shall ensure that only tools compatible with each other and with the safety-related system are used.	Yes	For complete Danfoss systems this is fully covered and documented by the certificate. For systems containing non-Danfoss parts the system integrator needs to document the compatibility.
18. Each new version of off-line support tool shall be qualified. This qualification may rely on evidence provided for an earlier version if sufficient evidence is provided that: A) The functional differences (if any) will not affect tool compatibility with the rest of the toolset; and B) The new version is unlikely to contain significant new, unknown faults.	Yes	PLUS+1° GUIDE and PLUS+1° Service Tool are certified as off-line support tools in accordance to IEC61508. Fully covered and documented by the certificate.
19. Depending on the nature of the software development, responsibility for conformance with 7.4.4 can rest with multiple parties. The division of responsibility shall be documented during safety planning (see Clause 6 of IEC 61508-1).	Yes*	The user of the PLUS+1 GUIDE software tool and the software tool itself share the responsibility for support tools and programming languages. (See clauses 7.4.4.1–7.4.4.18.)

<sup>1)</sup> See the table [Prerequisites](#) on page 19 for more information about the items in this column.

## Software Safety Validation

### 7.7.2—Software Safety Validation

Subclause	PLUS+1° tools	
	Fulfill <sup>1)</sup>	Detailed description
1. If the compliance with the requirements for safety related software has already been established in the safety validation planning for the E/E/PE safety-related system (see 7.7 of IEC 61508-2), then the validation need not be repeated.	N/A	---
2. The validation activities shall be carried out as specified in the validation plan for software aspects of system safety.	N/A	---
3. Depending on the nature of the software development, responsibility for conformance with 7.7 can rest with multiple parties. The division of responsibility shall be documented during safety planning (see clause 6 of IEC 61508-1).	Partially	The user of the PLUS+1° GUIDE software tool and the software tool itself share the responsibility for software design and development. (See clauses 7.7.2.1–7.7.2.9.)
4. The results of validating the software aspects of system safety shall be documented.	Yes*	Test tool feature built in but the software application designer has the responsibility to utilize these features.

Appendix A

7.7.2—Software Safety Validation (continued)

Subclause	PLUS+1° tools	
	Fulfill <sup>1)</sup>	Detailed description
5. For each safety function, software safety validation shall document the following results: A) A chronological record of the validation activities that will permit the sequence of activities to be retraced; B) The version of the validation plan for software aspects of system safety (see 7.3) being used; C) The safety function being validated (by test or analysis), together with reference to the validation plan for software aspects of system safety; D) Tools and equipment used together with calibration data; E) The results of the validation activity; F) Discrepancies between expected and actual results.	Partially*	Version control support enables the use of external configuration/test management systems (A). Test tool built in that enables validation by testing (B–F).
6. When discrepancies occur between expected and actual results, the analysis made and the decisions taken on whether to continue the validation, or to issue a change request and return to an earlier part of the development lifecycle, shall be documented as part of the results of validating the software aspects of system safety.	N/A	---
7. The validation of safety-related software aspects of system safety shall meet the following requirements: A) Testing shall be the main validation method for software; analysis, animation and modeling may be used to supplement the validation activities; B) The software shall be exercised by simulation of: 1) Input signals present during normal operation; 2) Anticipated occurrences; 3) Undesired conditions requiring system action. C) The supplier and/or developer (or the multiple parties responsible for compliance) shall make available the documented results of the validation of software aspects of system safety and all pertinent documentation to the system developer to enable his product to meet the requirements of IEC 61508-1 and IEC 61508-2.	Partially*	PLUS+1° Service Tool provides sufficient means to support testing of safety-related software (A and B). Test tool further enhances the ability to test safety-related software (A and B). Subsection C is dependent on the organization where the system is developed. The tools have no explicit support for this step.
8. Software tools shall meet the requirements of 7.4.4.	Yes	See 7.4.4. <i>Requirements for Support Tools and Programming Languages</i> on page 19.
9. The results of the validation of safety-related software aspects of system safety shall meet the following requirements: A) The tests shall show that all of the specified requirements for safety-related software (see 7.2) are correctly met and the software does not perform unintended functions; B) Test cases and their results shall be documented for subsequent analysis and independent assessment (see clause 8 of IEC 61508-1) as required by the safety integrity level; C) The documented results of validating the software aspects of system safety shall state either (1) That the software has passed the validation or (2) The reasons for not passing the validation.	Yes*	Test tool provides sufficient means to support this requirement.

<sup>1)</sup> See the table *Prerequisites* on page 19 for more information about the items in this column.







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