EUROPEAN WORKSHOP ON INDUSTRIAL COMPUTER SYSTEMS
TECHNICAL COMMITTEE 7
(Safety, Reliability and Security)

Guidelines for the use of Programmable Logic Controllers in Safety-related Systems

Edited by

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EWICS TC 7 (European Workshop on Industrial Computer Systems, Technical Committee 7) is an international body of experts in the field of dependable industrial computer systems and focuses its interest on safety, reliability and security.

The Programmable Logic Controllers (PLC) Working Group was set up within EWICS TC7 in 1992. Throughout its life-span the Group attracted attention of more than twenty experts from ten countries. The members are from industry, universities and government institutions. The main industries represented include transportation, process control and atomic energy. Government agencies include regulatory, assessment and testing authorities.

The utilisation of PLCs in safety-related Systems (SrS) is receiving much favour amongst industry. The need for good engineering practices in this area is a vital tool for the industrial users not only in the European Community.

This guideline addresses important areas in the use of PLCs in SrS for hazardous processes, such as global requirements, specifications, procurement, hardware and software design, implementation, verification, validation, security, operations, maintenance, and documentation. References are provided to allow the reader to review issues in greater depth. The guideline is intended for persons knowledgeable in basic PLC characteristics.

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EWICS TC 7
Programmable Logic Controllers (PLC)
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Contents

Part I About the Guideline

I.1 Scope

The Programmable Logic Controller (PLC)-Subgroup of EWICS TC 7 has provided a guideline defining the proper use of Programmable Logic Controllers in Safety-related Systems (safety PLC) according to Safety Integrity Levels (SIL) 1-3 (typically in demand mode, de-energised to trip) as defined in dIEC 1508 [IEC 98] or according to requirements classes 1-6 as defined in DIN V 19250 [DIN 94] in a way that

- utilises existing and developing practices, guidelines and standards
- considers users, procurers, developers, engineering, and certifiers / assessors needs
- allows a path forward to guideline development for other programmable electronic controllers (e.g. DCSC = distributed control system controller, SLC = single loop control etc.)
- allows guideline users to implement computer technology to improve safety in their plant.

Higher safety integrity levels such as SIL 4 (IEC) or requirements classes 7/8 (DIN) typically require additional design considerations that are not provided in this guideline.

A PLC is a special purpose computer having a central processing unit (CPU), power supply, a programming panel and/or interface to a programming system, inputs, and outputs. A PLC should also provide the capability to support remote I/O, special purpose I/O, I/O housings, connection, cables, additional power supplies, communication boards etc.

At the advent of PLCs they offered relay ladder diagramming as their principal 'problem oriented' language to allow an easy migration from conventional electromechanical control equipment. PLCs offer additional programming features including:

- application specific languages
- textual and graphical languages conforming to IEC 1131, Part 3, Programming Languages [IEC 93]
- proprietary variants of the languages defined in IEC 1131

The following features are characteristic of PLCs and may be used as guidance when determining whether or not a given programmable device is a PLC.

- A PLC real-time response should match electromechanical relay operating speeds.
- Logic ground is isolated from PLC safety (enclosure) ground, hence single point ground is not required.
- Power supplies are provided with line noise rejection features (e.g. chokes, RC circuits, filters, isolation transformers with Faraday shields etc.), thus not requiring power line conditioning.
- PLCs have high electrical noise rejection threshold as compared to other programmable devices.
- Equipment is rated to 60° C.

I.2 Intended Audience

The PLC Guideline is intended for:

- Persons with an understanding of control systems and with experience with PLCs in non-safety-related control systems (as a minimum).
- Persons with experience using electrical and electronics technology in safety-related systems.
- Persons who have properly completed all steps in a safety life cycle (e.g. [AIChE 93], [ISA 96] or [IEC 98]) leading to the development of a safety PLC.
- Customers who require a PLC based safety system. The customer should have a safety management strategy in place. The customer is also referred to as the user or end-user.
- Suppliers of these safety PLC if they are charged with the task of commissioning the PLC system on behalf of the customers.

  Note: The two major roles filled by the suppliers are application developer and PLC equipment manufacturer . The equipment manufacturer is responsible for the PLC-based system hardware, system, and utility software.
  The application developer is typically responsible for the design, installation and start-up of the PLC-based system. The application software may fall to either the application developer or equipment manufacturer.

- Assessors of safety PLC System.
  Assessors are responsible for certifying that the safety PLC System functions per the safety requirement specification. The assessor could be:
  - regulatory body (government), e.g., (UK HSE, USA OSHA and EPA) or regulatory body (government)
  - independent agency (e.g. TÜV, FM) or independent agency
  - independent company
  - internal group of customer company
  - internal group of contracting company
  - same group as customer or supplier above

I.3 Structure of the Guideline

This guideline focuses primarily on the activities of the customer, supplier and assessor. The guideline is structured as follows:

Part I	About the Guideline
Part II	Safety Requirements
Part III	PLC Selection Guide for PLC systems
Part IV	PLC System Implementation
Part V	Plant Level Integration and Validation
Part VI	Certification/Assessment
Part VII	Commissioning and Use
Part VIII	Contractual and Other Issues

Table I.1 provides an overview of the relationship of the customer, supplier and assessor to the required safety PLC.

ACTIVITIES	REFERENCE PARTS Part #	CUSTOMER	SUPPLIER		CERTIFIER ASSESSOR
			APPLICATION DEVELOPER	EQUIPMENT Manufacturer	
Understanding the Guideline	I	*	*	*	*
PES Safety Requirement Specification	II	*	*	***	*
PLC Selection Considerations	III	*	*	*	***
PLC SrS Implementation	IV	*	**	*	*
Plant Level Integration	V	*	*	*	*
and Validation		*	*	**	**
Certification/ Assessment	VI	*	**	**	*
Commissioning and	VII	*	*	**	***
Use		*	**	***	***
Contractual Issues	VIII	*	*	*	*

Legend: *Primary Function

**Secondary Function (Ready resource if problem arises)

***General Information

Table I.1 Participants and Related Activities

I.4 How to use the Guideline

The typical use of the guideline is demonstrated by the following two examples and figure I.1.

Each example assumes Figure I.1 is the life cycle.

Example 1:

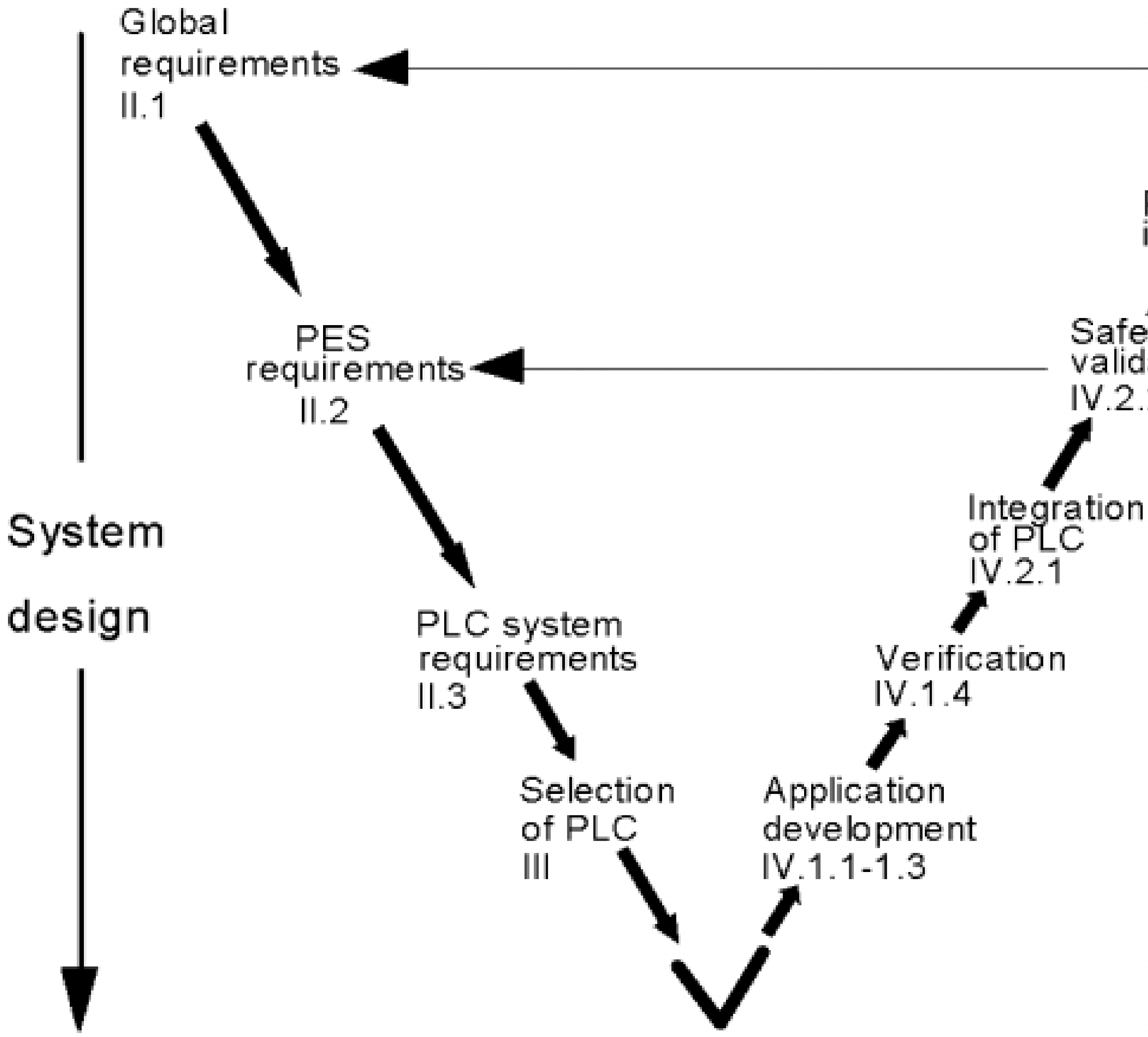
Chemical company A contracts engineering contractor B to commission a PLC system to protect personnel from a possible hazardous event in a chemical process. ”A” has a policy of using PLC supplier ”C’s” PLC world wide. ”B” sub-contracts the development of the application software to consultant ”D.” Assessment will be performed by company ”E.”

II.1	II.2	II.3	IV.1	IV.2	V.I	V.2
A/B	B	B/C(D)	B/D	B/E(D)	B/A(D)	E/A(B)

Example 2:

Motor car manufacturer P requires a PLC based safety system. It will procure the PLC from an external supplier Q (or R or S), but will perform all other development and integration functions itself:

II.1	II.2	II.3	III	IV.1	IV.2	V	VI
P	P	P	P/Q	P	P	P	P



Legend: ➡ Life Cycle Progression

➜ Information Resource Path

Figure I.1 - Example Life Cycle

I.5 Tailoring the Guideline

It is recommended that the guideline is carefully studied by the responsible project personal (customer, supplier) in order to ensure that the scope is fully understood. Then a judgement should be made as to how much of the guideline applies to the project in question. The result of these deliberations should have some contractual significance associated with them.

Documentation produced in accordance with this guideline is expected to be relevant to the need of all potential customers. However, if due regard is not taken of the particular project requirements, this documentation may be insufficient. The need to minimise both the cost and the bulk of information is well recognised. This can be achieved if a project's specific requirements are clearly identified.

I.6 Relevance of Guideline

The relevance of this guideline has been brought about because of the success the PLC has had in controlling processes. The natural flow of applications from control to safety requires the need for guidelines to ensure the correct use of PLCs in safety applications.

I.7 Conformance clause

In the statements which follow, the organisation will be understood to be the company, institution or other uniquely identifiable body which is claiming conformance to this guideline.

In order to claim conformance with this guideline the organisation must:

- Identify, within its procedures the existence of activities corresponding to each step or phase defined in this guideline.
- Identify the safety body or bodies who are charged with the responsibility for assuring that the steps in these guidelines are followed.

Part II Safety Requirements

II.1 Global requirements

A PLC should not be used in a safety related application without process hazards analysis (PHA). For guidance in developing a PHA, see reference [AIChE 93].

II.1.1 Plant

This should include all everything which can be affected by the Safety PLC System's operation and any other layers of protection needed to provide a safe unit of operation.

II.1.2 Environment

The environment in which this process operates should also be considered. This will certainly include the immediate area in which the plant is sited and the enclosing building, compound or vehicle. If failure of the process (not necessarily caused by failure of the PLC) is likely to have effects beyond the boundary of this enclosure the description should extend to the maximum expected geographical limits of such effects.

II.1.3 Modes of operation

The mode of operation of the process should be described. This should include the whole process, not just the interface with the PLC. Operator responsibility in the process should be made clear.

II.1.4 Control / safety system

The required behaviour of the safety systems should be described, both in normal process operation and in the presence of potential process safety hazards. The role of the specific Safety PLC System to be procured should be further identified.

II.1.5 Global hazard analysis

Constraints on the control systems are not to be considered without its environment. Hazard analysis of the plant including its control system identifies the constraints on the control system part (and on rest of equipment and process).

Techniques which may be used to assess process safety hazards include:

- Process Hazard Analysis (PHA)
- Checklists
- Fault Tree Analysis (FTA)
- Hazard and Operability Study (HAZOP)
- Failure Mode and Effect Analysis (FMEA)
- Event Tree Analysis (ETA)
- Quantitative Risk Assessment (QRA)

For guidance to these techniques see [Bish 90].

II.1.6 Validation planning

Safety validation planning is necessary to optimise the validation phase and to guarantee the feasibility of the validation.

The Safety Validation should describe:

- right formulation of the safety criteria (safe status)
- test pattern for the inputs
- required environment in which the test will be placed
- procedure to be used for validation of each safety function (the right method).

The Safety Validation should consider all phases of the EUC (equipment under control) operation. These are the start-up, steady state, shut down, maintenance, all enhancements and reasonably fore-seeable abnormal conditions.

At the development of the validation it should be considered that the main PLC safety validation methods are expected to be testing. Simulation and modelling methods and analysing may be used to support the validation process. It should be considered that the Safety Validation may have to be assessed by an independent person.

II.1.7 Procurement plan - standards and guidelines

At this point an overall procurement approach should be finalised. This will be influenced by several considerations.

First the activities to be carried out internally to the company should be identified, and specifications for tendering and contracting out the remaining work drawn up. At one extreme all requirement, specification, application software development, integration, installation testing, certification, and acceptance may be carried out internally, with only the PLC being bought externally. At the other extreme, the company may draw up a performance specification, and contract out all other aspects of the procurement. In reality the work is likely to be spread amongst several organisations or groups (both internal and external), so sequencing of activities and flow of information and responsibilities must also be considered. Flow of information could be a constraint if commercially sensitive. Use of language and its subsets may be a constraint.

The second task will be to identify aspects of company practice, including any standards or guidelines which will apply to the remainder of the procurement. The company may have an approved list of PLC hardware suppliers; it may have internal guidelines; it may demand certain international or national standards to be applied; it may simply always have used a particular PLC, and for ease of future support demand its continued use; it may have specific coding standards, or prefer particular languages to be used; the relevance of the IEC 1131 family of standards should be considered.

Decisions made at this point will influence and pervade all remaining activities in the procurement so it is important to consider this area properly.

II.2 Programmable Electronic System (PES) requirements

This chapter describes the requirements needed for the specific PES system to be commissioned. For details see reference [IEC 98].

II.2.1 Process behaviour and interface

All aspects of the process which are to be protected or monitored by the PES must be specified. This includes detailed behaviour of the process during normal operation, in the presence of (possibly multiple) failures and in any other operating mode such as maintenance or diagnostic operation. Interfaces, at physical, electrical and protocol levels between the process and the PES should be specified in detail.

II.2.2 Operator role and interface

All modes of communication between the operator and the PES should be defined. Indirect communication should also be considered (e.g. via the plant or the environment). The behaviour of the operator for correct operation of the plant should be defined, and as far as possible the impact of operator failure (and the consequent impact on plant safety) considered.

There is a need to consider Identification & Authentication as well as Access Control of the operator. Also the security log should record the operator actions.

II.2.3 Functionality of the PES

The expected functional behaviour of the PES should be specified to take account of both normal operation and operation with failures such that under any event or any combination of events so described, the system as a whole will remain in or move to a safe state.

II.2.4 Integration plan

Procedures for unit test and assessment, system integration, system test and assessment and final acceptance should be clearly documented including a detailed description of responsibilities (a transfer thereof at different stages) between customer, supplier and assessor.

II.2.5 Risk classification and risk reduction

Starting with the potential process danger one can identify a 'risk class' (applying the risk graph from relevant standards, e.g. [IEC 98], [DIN 94], [ISA 96]). This analysis leads to system integrity levels.

II.2.6 Performance

It is important that overall process timing characteristics are clearly documented and the timing and synchronisation of the PES meets timing needs.

Integrity levels [IEC 98] for both hardware and software components shall be identified both in normal system operation and in the presence of external failures to which the PES should respond.

Mechanisms for diagnosing problems and monitoring the operation of the PES shall be described.

II.2.7 Maintenance requirements

Mechanisms for maintenance and replacement of components and systems (including software) should be documented. The effect of invoking these on the whole plant should also be described.

II.2.8 Requirements Specification

II.2.8.1 General

Here, it should be stated clearly and in the appropriate detail, what the BPCS (Basic Process Control System) has to do with the plant or process. For example:

- generate electricity
  - adjust boiler control to meet load demand
- nylon press
  - packages nylon in a transportable bale

This is called a non safety related requirement specification which has to be distinguished from the safety related requirement specification e.g.:

- generate electricity in a safe way (very general)
  - under no circumstances blow up the boiler
  - do not open a burner fuel valve without having ventilated for at least 10 minutes
- operator interface eliminates injury to operator from press.

These functional requirements should be separated as described chapter IV.1.1.1.

II.2.8.2 Non safety related requirements specification

The following list of keywords should guide the user / customer to come to a complete specification. After analysis each feature mentioned must (at least) fall into one of the categories:

- mandatory
- optional
- not required
- not applicable

According to such a weighted list a BPCS and supplier should be chosen, keeping in mind, that ideal solutions are rare. There is no sense in requesting all (and having no money).

Keywords:

- size of data to be controlled
  - numbers and types of sensors
  - numbers and types of actuators
  - timing requirements
    interrupt processing
    processing on demand
- report system
  - time stamps

- ordering of (the sequence of) events
- system wide clock
- granularity and accuracy of system wide clock/ single clocks

- human machine interface (HMI)
  - interfaces for operators
    conventional (lamps, switches, mimics etc.)
    monitors, keyboards (alphanumeric or symbolic), mouse, trackball
    lightpen, touch-screen etc.
    access rights for operators: Which changes to the process control are required / to be allowed / to be hindered on-line?
    national language support for HMI
    uniform I/O to the user
  - engineering system (programming environment)
    conventional programming
    use of standard software modules
    management of change, on-line or only off-line
    graphical / textual input
    graphical / textual documentation
    communications between BPCS and engineering system
    use of standards
  - national language guidelines and documentation

II.2.8.3 Safety Requirements Specification

II.2.8.3.1 General

The Safety Requirements Specification should comprise the functional Safety Requirements Specification and the Safety Integrity Requirements Specification.

The Safety Requirements Specification should contain all the requirements necessary for the design phase to achieve functional safety of the PES. The Specification should encompass both function and safety properties.

To the extent required by the Safety Integrity Levels the Safety Requirements Specification should be expressed and structured in such a way that it is clear, precise, unequivocal, verifiable, testable, maintainable and feasible.

The Safety Requirements Specification should include modes of expression and descriptions which are understandable, and appropriate to the duties they have to perform, to personnel involved in the design, operation and maintenance of the PES.

II.2.8.3.2 Functional Safety Requirement Specification

The objective is to develop the PES function requirements Specification for the safety-related system necessary to implement the required safety functions. The safety functions may be required to put the EUC (Equipment Under Control) into a safe state (for safety-related protection systems) or to maintain a safe state (for safety-related continuous control systems).

The functional Safety Requirements Specification should specify:

a) the required safety functions in order to achieve functional safety;

b) whether the safety function is applicable to a safety-related protection system or a safety-related continuous control system;

c) the safety-related system that is to implement the safety functions;

d) throughput and response time performance;

e) system and operator interfaces;

f) any other safety relevant information which may have an influence on the safety-related system design.

g) all interfaces between the safety-related system and any other systems (either directly associated within, or outside, the EUC);

h) all relevant modes of operation of the EUC;

i) all required modes of behaviour of the safety-related system. In particular, failure behaviour and the required response of the safety-related system should be detailed;

j) the significance of all hardware/software interactions. In particular, where relevant, any constraints between the hardware and the software should be identified and documented;

k) those parts of the safety-related system, if any, that are required to perform non-safety functions;

l) all environmental conditions which are necessary to achieve functional safety;

m) the procedures for starting up and restarting the PES;

n) those requirements necessary to enable monitoring of the PES hardware to be undertaken;

o) requirements for periodic testing of the safety functions;

p) anticipated future requirements.

II.2.8.3.3 Safety integrity requirements specification

The objective is to develop the Safety Integrity Requirements Specification for each of the safety functions.

II.2.8.3.3.1 General

The Safety Integrity Level for the designated safety-related system function should be qualified to indicate whether the target failure measure for the specified Safety Integrity Level is applicable to safety-related protection systems or safety-related control systems.

The Safety Integrity Requirements Specification should include requirements to enable all safety functions to be tested.

Where the PES safety-related system is to implement both safety and non-safety functions then the hardware and software should be treated as safety-related unless it can be shown that there is adequate independence between the safety and non-safety functions. If the system is to be treated as safety-related then the guidelines in this text should be met.

Relaxation from this requirement should only be permissible if it can be shown that:

- the safety functions are independent
- the implementation is independent
- the failure of any non-safety-related functions does not affect the safety-related functions.

Where the PES is to implement safety functions of different Safety Integrity Levels then the PLC logic solver hardware and software should be treated as belonging to the highest Safety Integrity Level.

II.2.8.3.3.2 Requirements for safety integrity

The requirements for safety integrity, as they relate to "the control of errors" in the PES design, should be composed of requirements for:

- hardware integrity
- software integrity
- system integrity comprising
  - environment
  - operation
- data integrity and application (software) integrity checks.

The requirements for the above error clauses are discussed in [IEC 98] Part 2 and are typical for other standards also.

II.3 Safety PLC requirements

II.3.1 General

From the hazard analysis of the process as well as PES safety integrity level requirements the following constraints on the PLC have to be derived:

- What safety layer is the safety PLC in? I.e. what is the criticality of the safety PLC functioning, and what are the relations of the safety PLC to the other safety layers of the process? Important is also the question how to realise independence of safety layers.

  NOTE: According to [AIChE 93] safety layer means independent protection layer (IPL). This in turn is defined as: A system or subsystem specifically designed to reduce the likelihood or severity of the impact of an identified hazardous event by a large factor, i.e. at least by a 100 fold reduction in likelihood. An IPL must be independent of other protection layers associated with the identified hazardous event, as well as dependable and auditable.

- Explicit definition of the SIL of the safety PLC. Qualitative categorisation may be on scales like those of the [DIN 94] or [IEC 98] (these are correlated to certain applications; it is questionable whether this approach is applicable in all cases). Quantitative characterisation should include the failure rate or MTBF and availability.

Probability of Failure on Demand (PFD)	**Safety Integrity Level dIEC 1508**	**Requirement Class DIN 19250**
$\geq 10^{-1}$	-	1
$\geq 10^{-2}$ to $\leq 10^{-1}$	1	2 - 3
$\geq 10^{-3}$ to $\leq 10^{-2}$	2	4
$\geq 10^{-4}$ to $\leq 10^{-3}$	3	5 - 6
$\geq 10^{-5}$ to $\leq 10^{-4}$	4	7 - 8

Table II.1 Demand Mode of Operation Safety integrity level vs. Requirement Class

- All security issues including access only to authorised personnel, protection from outside environmental influences (e.g. lightning, poor grounding, static electricity, electrical noise, corrosive atmosphere), read only privileges from the safety system, write privileges only by authorised personnel with approval of management, etc., should be addressed.

The assessment should identify unacceptable risks. If these are encountered, then risk reduction measures, mitigation methods, allocation of safety functions should be taken. If these are not sufficient to achieve the desired risk reduction alternative solutions must be sought.

II.3.1.1 Control of failures and avoidance of failures

The measures to control failures are built-in features of the safety PLC while the measures to avoid failures are procedures done during the safety life-cycle [IEC 98 - Part 2].

It is not possible to list all the individual physical causes of failures in complex hardware and software. The reason for this can be found in essence in the following two points:

- it is not possible to conclude the effects of the failures from their physical causes
- the emphasis of the failures is switched from the random failures to the systematic failures when complex hardware and software is used.

It is not possible to list all the individual causes of systematic failures during the safety life cycle. The reason for this can be found in essence in the following two points:

- systematic failures have different effects in the different life cycle phases
- one measure avoids different systematic failures in dependence of the application.

A quantitative analysis for the avoidance of systematic failures is therefore difficult.

The failures in the safety PLC vary essentially according to the time of their origin:

- failures, which occur before the system installation (inclusive), (e.g. software: specification failures and program failures or in the hardware: manufacturing failures and incorrect selection of components)
- failures, which occur after the system installation (e.g. random failures in the hardware or failures caused by incorrect use).

In order to avoid such failures or control such failures when they occur one single measure is normally not sufficient. Indeed, a large number of measures are necessary to avoid or control the failures.

In the safety PLC Safety Requirements Specification an appropriate group of measures and techniques to be used for safety integrity as they relate to the control of failures and the avoidance of failures should be composed.

Safety PLC design architectures have been developed. Information on fault diagnostic coverage and off-line proof test interval is available in references [IEC 98], [AIChE 93], [ISA 96], and [ISA 97]. These references contain information on measures and techniques for integrity that are suitable for processing unit, memory, I/O units & interface, data paths, power supply, programme sequence, ventilation, clock and communication measures and techniques.

For the control of failures in systematic integrity there is information on measures and techniques for hardware, environmental and operational failures.

Measures and techniques for the avoidance of failures during the different phases of the PES safety life cycle (e.g. safety requirement specification development, design & development, operation & maintenance procedures, integration, validation, etc.) should be considered [IEC 98].

II.3.1.2 Classification of the safety PLC states

In describing the process of developing safety PLC System Requirements we consider a simple classification of the system into 5 states and consider the transitions between these classes of state as illustrated in figure II.1: PLC states and transitions

1) *OK states,* in which the system is operating normally. The transitions from *OK* states are:
   - *OK* which takes us to the *OK* state. This is the ”normal” operation of the system. The functional and non-functional requirements for these transitions should be developed following good engineering practices for the development and engineering of PLC systems

     It is important to plan for potential changes in the system and software requirements. Where possible, parameters should be identified which allow change to take place simply without disturbing the overall structure of the system.

     By attempting to ensure that most or all of the transitions of the system fall into this category we are following a fault avoidance strategy.
   - *Fault* which takes us to the *Undetected* state. Typically such a transition can arise for a number of different reasons which typically need some analyses which should be carried out during systems requirements analysis.
2) *Undetected,* in which the system is operating with an undetected error. There are three possible transitions from this class of states:
   - *Fail safe,* this transition takes the system from the *undetected* state to the *fail safe* state. These failures do not influence the safety of the system, but may interrupt the operation of the equipment under control in a safe way.
   - *Fault detection* this transition takes the system to the detected class of states. The detection mechanisms should be linked to the faults identified under the given classes of faults given above. The aim is to provide an adequate level of assurance that a particular fault will be discovered depending on the severity of the fault.
   - *Fail dangerous,* this transition takes the system directly from the *undetected* state to the *fail dangerous* state. Such failures constitute a major threat to the integrity of the system. In devising the safety requirements we must argue that the evidence from the development process should guarantee the absence of such transitions.
3) *Detected,* in which the system is operating and has detected an error. There are three transitions from this state:
   - *Recover* --- those faults which require (and possess) recovery actions should be identified. The required recovery action should be identified.
   - *Fail safe* --- the requirement to safely move from some particular fault condition to a particular safe state along some given trajectory should be captured
   - *Fail dangerous* --- arguments demonstrating the impossibility of such a transition should be added to the safety requirements analysis.
4) *Fail Dangerous,* in which the system has failed in a dangerous manner.
5) *Fail Safe,* in which the system has failed safely.

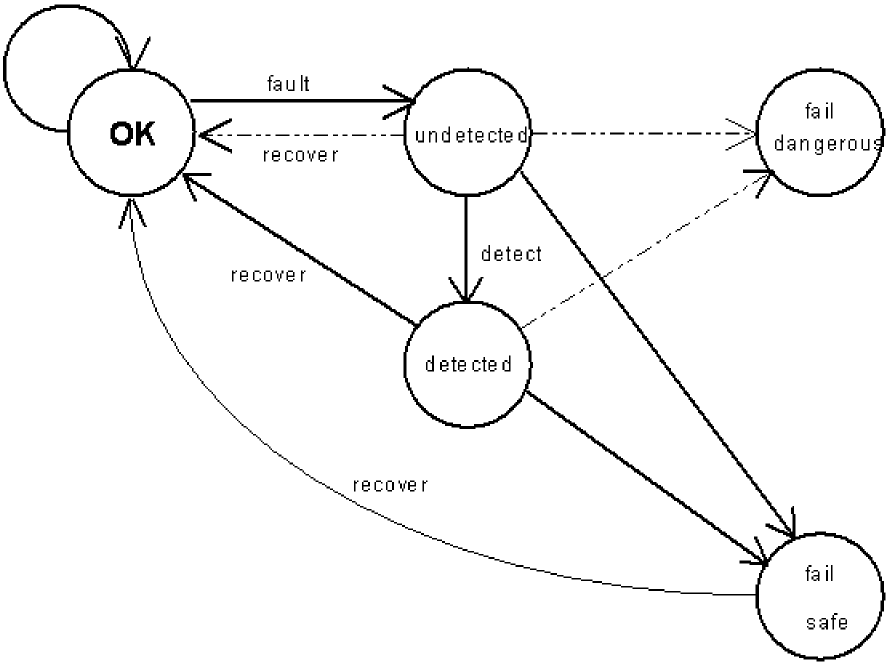


Figure II.1 PLC states and transitions

II.3.2 Software Design Specification

Critical to achieving correct normal operation is careful dialogue with the producer of the PLC system. Care should be taken to establish agreed, non-ambiguous nomenclature and to arrive at well-defined functional and non-functional requirements.

In constructing the software requirements one should consider the following classes of potential faults and attempt to identify distinct faults that can arise and give them a characterisation of the faults.

- Failure of some integrity property of the state of the system. This may either be an inconsistency arising from the internal variables of the intended software or on the input/output relation computed by the program.
- Failure to meet some progress or timing constraint. This will express a requirement that the software delivers certain responsiveness.
- Failure to obtain the format/range etc. of data from some hardware interface.
- Failure of the system software, kernel failure.
- Failure of compiler/assembler/translator from the coding language to the executed code.

It is important to plan for potential changes in the system and software requirements. Where possible parameters should be identified which allow changes to take place simply without disturbing the overall structure of the system.

II.3.2.1 Structure and function of PLC software

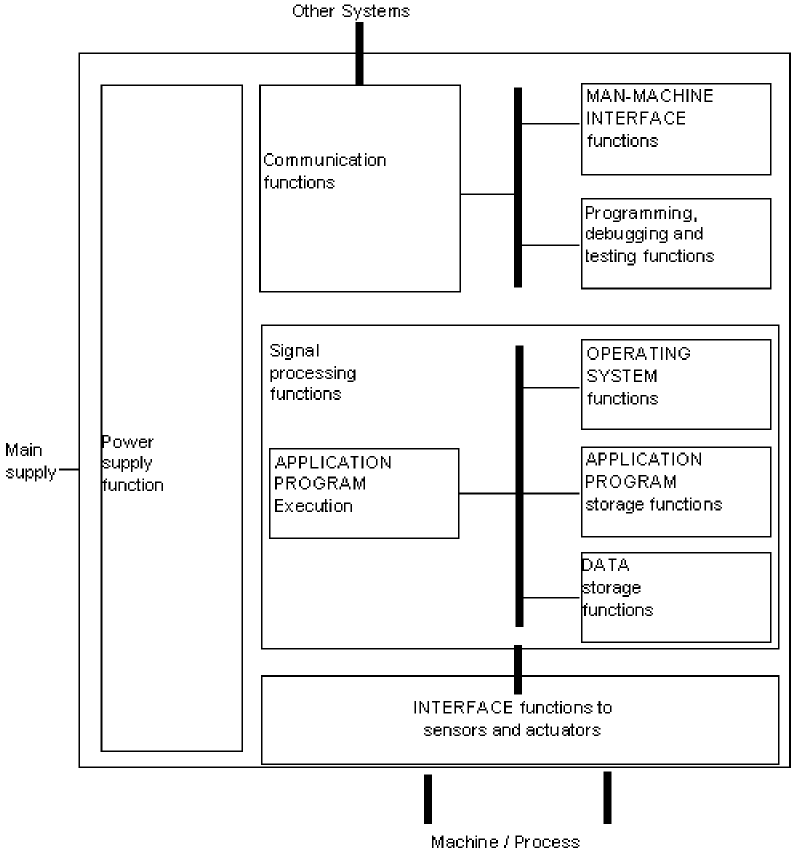

Other Systems
Communication functions
MAN-MACHINE INTERFACE functions
Programming, debugging and testing functions
Signal processing functions
OPERATING SYSTEM functions
APPLICATION PROGRAM Execution
APPLICATION PROGRAM storage functions
DATA storage functions
Main supply
Power supply function
INTERFACE functions to sensors and actuators
Machine / Process

Figure II.2 - Basic functional structure of a PLC system

The [IEC 92] standard identifies the following functions which can be found in typical Programmable Controllers:

- **Signal processing function** --- consisting of the application program storage, the data storage, the operating system or kernel, the execution of the application program. It processes signals obtained from sensors plus internal data storage to generate the signals to the actuators and the new state of the internal data storage.

- **Interface function to sensors and actuators** --- this involves the conversion of discrete, digital and analogue sensor data to the internal representation used by he programmable controller and vice versa for the actuators.

- **Communication function** --- this provides the support of interaction between the controller, sensor, actuator and the human operator.

- **Human-machine interface function** --- this provides the support of interaction between the controller and the human operator.

- **Programming, debugging, testing and documentation function** --- these provide for application program generation and loading, monitoring, testing and debugging as well as for application documentation and archiving.

- **Power supply function** --- provides the conversion and isolation of the PLC power supply from the mains.

All these functions may involve software in their provision. We have three different types of software here: system software (kernel, sensor interface, man-machine interface), application software (supplying the specific part of the signal processing function), and the support or development software (programming, debugging, testing, etc.). In this guideline we concentrate on the application software because this is the variable part of the software in a PLC.

II.3.2.2 Characteristics of PLC software

Though there is wide variation in the form of PLCs, there are a number of common features which influence their software development and, consequently, the evidence which can be used to argue for the safety of an application.

- Application specific languages --- Most PLCs are intended for a particular application area, and as a result, they use a programming notation which is close to engineering notation from the problem domain. The argument in favour of this approach is that the validation problem of moving from requirements to specification is reduced because familiar notation is used and that it may be that the specification is close to a system level design since the application specific language may be a design notation which is also used as a specification language. Examples of this is the schematic notation used in process control applications and the use of railway signalling notation in the programming of railway signalling interlocks.

- Limited variability --- In practice, many systems presume that the basic modules in any system will be drawn from some fixed set of pre-coded modules. Such limitation in the variability of a design can be seen as eliminating the need for module design, code and test. In addition, it may be that the range of possible configurations of the modules is limited to a few standard designs. Such an approach further reduces the complexity of system design.

- Kernels --- The kernel is the fixed software which is used by all applications on the PLC. Because the software is reused extensively, there is an economic justification for subjecting it to rigorous evaluation to ensure its safety. The design of such software can greatly influence the safety of systems; entire classes of potential software faults can be eliminated given suitably designed kernels. Also, if the kernel is large and ill-structured, it could pose insurmountable problems to the use of such a system in a safety context. In terms of the standard model of software development, a small, well designed kernel can simplify system testing greatly.

- Size --- PLCs can vary widely in size. Small systems can be readily configured with a minimal software engineering process. However, as size increases, the advantages of PLCs and the factors that allow a much simplified process to be used become weaker. For example, the development of a very large system in an application-specific language will loose the advantages of ready comprehension and verification, will have interfaces between subsystems and teams and begin to exhibit the characteristics and problems of conventional software.

To summarise, features of PLC software may impact on the standard design process in the areas shown in figure II.3.

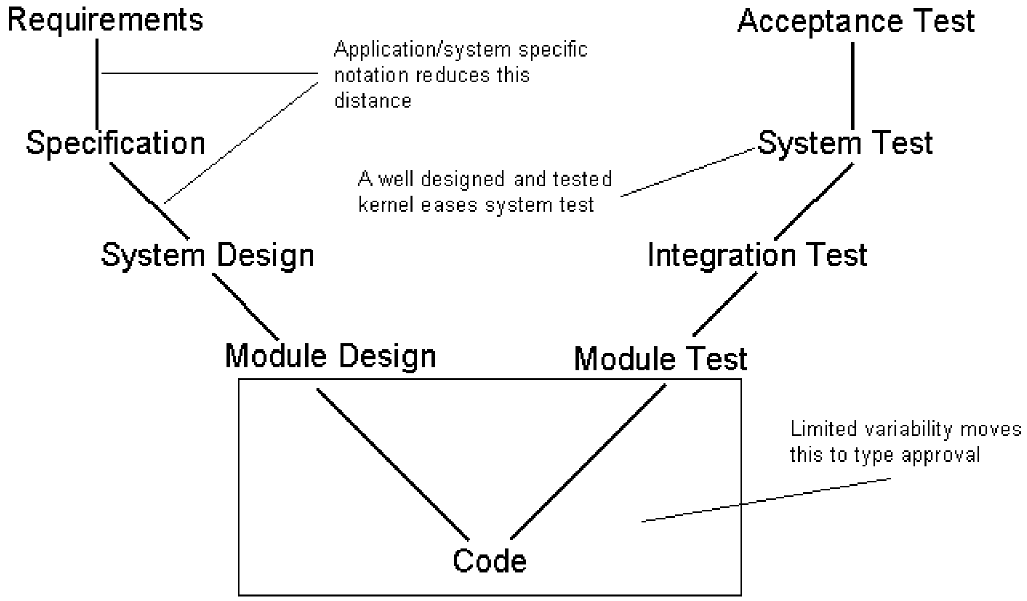

Requirements
Application/system specific notation reduces this distance
Acceptance Test
Specification
System Test
A well designed and tested kernel eases system test
System Design
Integration Test
Module Design
Module Test
Limited variability moves this to type approval
Code

Figure II.3 Standard design process

As the process moves down the left hand side of the diagram, three principal kinds of data are generated:

- Design justifications: arguments that the outcome of the process matches the specification given at the previous stage. These justifications are primarily deductive -- from some assumptions we generate the result by following a sequence of design rules.
- Testing criteria: these take the form of specific test/result data sets, quantitative constraints on performance and qualitative criteria on the behavior of the system. These provide the basis for inductive arguments that the system meets its requirements.
- Process conformance: evidence, in the forms of logs, training, choice of personnel, that the process is likely, on past experience, to generate product of the desired quality. This form of data argues that the process is in some way conforming -- correct procedure has been followed.

II.3.2.3 Partitioning of Software into Modules

Today’s PLC systems provide the software engineer with significant flexibility. This flexibility is an important attribute of the PLC system allowing custom applications to be efficiently developed. However, as is true with most software applications, the greater the flexibility the greater the complexity.

Software design concepts such as ”modular” and ”top-down” design have been used in the computer science fields for over twenty years. The application of these concepts, however, varies.

Support and maintenance of the control software is simplified when consistent formats and techniques are utilised. Troubleshooting interlock logic which is not implemented in a structured format is frustrating and tedious.

Developing a safety system which provides for ease of operation and maintenance requires that the control engineers, software engineers, production supervisors, and maintenance supervisors agree on:

- Design of the operator interface including overview displays, and troubleshooting/maintenance displays.
- Format of the safety program documentation.
- Partitioning of safety program into simple modules which can be reused throughout the safety PLC.

Agreement on a structured approach is imperative before any configuration of the software begins. This approach should provide the basis for a design specification document which defines the system development scope.

Typically, 80% of the configuration process can be partitioned into modules that are reusable throughout the PLC system. Examples include interlock logic, control valve tracking, timers, and flow totalizers. Once a module is developed and tested using simulation techniques, it can be reused with little risk. It is important that these modules be well documented so that they are easily understood by the person wishing to make use of the module. It is important to minimise the misapplication of modules.

The other 20% may represent custom logic which is unique for that area of the process. Through consistent formats, variable utilisation, and effective documentation within the logic, custom logic can be made easy to understand and maintain.

Through the use of a structured and modular architecture the software becomes easier to read, troubleshoot, modify and extend. Many ”war stories” exist with systems that were configured without using these techniques. The system may have been proven to function per the control specifications, but when it came time to troubleshoot a problem or to implement a modification, the task became nightmarish. It quickly becomes obvious that a structured approach is vital in these flexible yet complex PLC systems.

II.3.2.4 Execution Rates

Control devices with multiloop capability typically allow variable scan rates in order to minimise CPU loading. This allows the user to select the frequency at which the control algorithm is executed. The range of execution times normally runs from 0.1 to 60 seconds. While execution times of 0.2 to 0.3 second are adequate for most loops, applications such as compressor surge control may require scans less than 0.1 second. It is important for the user to recognise these applications and design for these requirements.

II.3.2.5 Event-Logging / Data-Historian Requirements

The ability to go back in time and trace a series of events and operator actions is an important feature required in most process situations. The following list represents the type of events that should generally be logged.

- Alarms:
  - Activated.
  - Cleared
- Operator requested changes to:
  - Set points
  - Modes
  - Outputs
- Operator messages:
  - System asks for operator input
  - Operator response
- Operator starts operation or sequence.
  - operator status message for each step.

The user needs to understand where this logging function takes place and how the messages are generated in order to interpret the data generated correctly. The message logging may not, depending on the system, provide messages in chronological order.

II.3.3 Hardware Design Specification

II.3.3.1 General

The hardware configuration of the safety PLC(s), is a direct result of the Safety Requirement Specification, see chapter II.1.6. But, there are some configuration independent hardware considerations and requirements. These are dealt with in the following chapter.

Please refer to the questionnaire in Appendix A-1 on page 66.

II.3.3.2 Keywords for hardware requirements

The following list of keywords should guide the user / customer to come to a complete specification. After analysis each feature mentioned must (at least) fall into one of the categories

- mandatory
- optional

- not required
- not applicable.

List of keywords:

- quality of the supplier
    - quality support system ; according to accepted standards DIN/ISO 900x, EN 2900x, large company standards
    - guaranteed supply of spare part
    - documentation, guidelines
    - training for users

- types of actuator/sensor signals
    - load / driving capability of/for these signals
    - binary
      TTL, 24 V DC (most common), NAMUR, 110 VAC, 220 VAC
      Load 50 mA, 1 A, 2 A, 4 A
    - relays (output only)
      Load, voltage, type
    - analog
      voltage -10..+10 V, 0..10 V, 0.. 24 V
      current 0..20 mA, 4..20 mA
      thermocouple, thermoresistor
      various mV
    - HART
    - sensor supply
    - Ex(i)
    - self testing facilities for I/O

- power supply
    - 110 VAC, 230 VAC
    - 24 VDC
    - redundancy
    - un-interruptible power supply (UPS)
    - battery back-up
    - buffering of supply within the units (most user standards expect uninterrupted operation for 5 ms-0 V-drop-out of 24 V, NAMUR expects 20 ms, see also IEC 550)

- grounding, shielding
    - shielded process cables necessary or not?
    - electrical safety (VDE 0100, IEC 950, 536, 529)
    - EMI / EMC
    - filtering / robustness of signal inputs
    - test voltages (e.g. 2,5 kV, 4 kV, 8 kV IEC 801)

- housing
    - distributed units / centralised units
    - wall-mounting / cabinets

        robust cabinets (transport, earthquake, according to standards, e.g. 1,5 mm at 2...9 Hz, 5 m/s^2 at 9...200 Hz)

- cooling

  no ventilators (often requested)
  if ventilators / air conditioners: redundancy / supervision
- floor plan
- cabling

- hardware redundancy
  - aim : availability or / and safety
  - redundancy of communication

    system property

    transparency to user / programmer
  - redundancy of processing units

    system property
    transparency to user / programmer
  - redundancy of I/O units

    system support

    flexibility of redundancy structures (none, 1 out of 2, 2 out of 2,...)
  - quality of redundancy

    system property or user responsibility

    transparency to user / programmer

    fault detection

    fault localisation

    error latency

    on-line repair

    self testing facilities

    fault isolation

    error confinement
- environment
  - temperature range (operation/transport, e.g. 5...40° C)
  - humidity-range (operation/transport, e.g. 5...85%)
  - temperature gradient (e.g. 10 K/h)
  - air pressure (e.g. min 70 kPa)
  - exposure to gas/dust
  - use of filters
  - exposure to radiation
  - vibration

Adherence to the required ambient conditions such as humidity, temperature, vibration, dirt, EMI etc. has to be checked for all elements. Especially the characteristics and requirements for the elements in the field have to be looked after.

The convenience and ergonomics of the installation place of data terminal devices and Human-machine-interface has to be checked, also the maintainability of all the equipment.

II.3.4 Security aspects

II.3.4.1 Data Access and Manipulation

In a safety PLC any change to any kind of software may result in a potentially hazardous condition. Therefore all software of a safety PLC should reside in a secure and controlled environment to maintain system integrity.

Software to be considered is the:

- Application Program
- Application Modules
- Compiler
- Operating Software
- Utility Software

Besides the software, hardware platforms involved during operation and development are important. This includes:

- Development Systems
- Application System
- Data Network
- Data Storage

Data access and manipulation may be requested for the following reasons:

- Engineering activities (create, modify, delete etc.)
- Implementation (copy, transfer)
- Operation of the process
- Maintenance (repair, preventive)

This may require multiple levels of security which may result in a combination of hardware and software design as well as security procedures.

A classification method for the levels of data access and manipulation is shown in Table II.2. These levels are normally password or keylock protected.

Access Mode	Description
Monitor	Data can be viewed; however, no changes can be made. Typical mode for remote console locations or backup systems in standby.
Operate	Normal operating mode allowing operator to manipulate set-points, modes, and outputs, as well as start and stop higher level sequences and systems.
Tune	Changes to loop tuning parameters, alarm set-points, overrides, and other register variables is allowed. User access to system parameters is not normally available. This mode is typically reserved for special situations such as loop tuning, troubleshooting, or some type of failure recovery mode.
Program	This mode may vary depending on the systems ability to support "on-line" and "off-line" programming functions. On-line programming (1) may allow changes to the BPCS to be made while the safety PLC is independently operating; it is not recommended for safety PLCs. Off-line programming (2) requires that all changes be made remote from the operating system memory. After the changes are completed, the new control program is swapped with the old program, resulting in varying degrees of disruption to the control system operation. The effects of (1) and (2) may be considered before use on an operating system.

Table II.2 Levels of Data Access and Manipulation

Access to the safety PLC data may be required by external devices such as process control systems, supervisory computers, management information systems, single-loop controllers, and miscellaneous peripheral devices. Care should be taken to ensure proper security to prevent corruption of PLC data. This is especially important during periods of maintenance and system modification.

Data can be corrupted by external influences such as electric and magnetic fields, capacitive coupling to electrical energy sources, different ground planes, and lightning. Wiring, raceways, and installation practices should follow the PLC supplier's installation and instructions. Where variances are required, PLC supplier concurrence should be obtained during the design stage. The installation scheme should be documented in such a way that maintenance and future modifications can be accomplished without compromising data security.

Changing the program in operating safety PLCs is not recommended/allowed. Where, because of system redundancy and the application, this option may be wished to be considered, the approval of the Hazards and Risk analysis team, must be obtained. The procedure for this activity has to be regulated according to the results of the safety PLC third party approval.

II.3.4.2 Separation

The safety PLC may be required to communicate with the Basic Process Control System. This places a separation demand on this communication link so that security of the safety PLC is not compromised by programming procedures from the BPCS. Separation can be accomplished by a number of methods. These include no connectivity, direct-wired connectivity, read/write communication, read only communications, configurable read-only communication, and memory mapping. No interconnectivity is frequently used in processes where there is no need for information transfer between the PLC and the BPCS. However, most PLCs require some degree of interconnectivity to the BPCS.

Direct wiring is an alternate communication method sometimes used between BPCS and PLCs. This is used when minimal information interchange is required (because of the impracticality of using this approach for large amounts of information interchange) or serial communications do not offer satisfactory speed and security.

Serial communications should only be used when the PLC application program cannot be altered by the read/write communications (e.g., ROM).

"Read-Only" means the PLC program can not be altered from the BPCS during normal process operation. This ensures that unintentional changes to the PLC program do not occur. "Read-Only" does allow commands (e.g., stop, run) to be transmitted from the BPCS to the PLC during normal operation.

A method that may be acceptable is called "Soft Read-Only". Here the BPCS and PLC offer software security (e.g., passwords, keylocks) to protect against inadvertent changes to the safety PLC. Consider this method for low-integrity PLCs and for higher integrity PLCs where supplemented by hardware "write" protect feature. PHA team approval is required.

An infrequently used separation concept found in some packaged safety systems integrates the BPCS and safety PLC logic into a single PLC. The BPCS program is partitioned from the safety PLC program to guarantee the integrity of the safety program and to minimise the potential for inadvertent changes to the PLC program while working on the BPCS program. This independence may be third party certified.

Note: This does not provide the same degree of separation as the previous techniques and may not be acceptable for the highest integrity level systems (SIL 4).

II.3.5 Documentation

The following is in accordance with [IEC 98].

II.3.5.1 Objectives

The objective of the requirements of documentation is to define it so as to make it possible to perform the following functions of the product

- design and develop
- produce
- install

- commission
- operate
- maintain
- decommission

In this text the term ‘document’ is normally understood as information and not as physical documents unless this is explicitly declared or understood in the context.

II.3.5.2 Requirements

- The documentation should
  a) describe exhaustively the installation, system or equipment and the use of it;
  b) be accurate and concise;
  c) be easy to understand;
  d) suit the purpose for which it is intended;
  e) be easy to handle and maintain
- The documents or set of information should have unique identities so it will be possible to reference the different parts.
- The documents or set of information should have document kind designations indicating the type of information.
- The documents or set of information should have titles/names indicating the scope of the content.
- The documents or set of information should have a revision index (version numbers) to make it possible to identify different versions of the document.
- The documents or set of information should be structured in document list or physical binders to make it possible to search for relevant information concerning an object or functions and their relations. It should be possible from at least one of the lists to identify the latest revision (version) of a document or set of information.

II.3.5.3 Execution

[IEC 98] part 1 Annex A provides description of the documents to be supplied:

- General

  Results from most of the activities during the design and the development phases are documents, which are used as inputs for activities that follow.

  Basic Document Kinds are: Specification, Description, Instruction, Plan, Diagram, List, Log, Report, Request
- Safety-Lifecycle document structure

  It is used to explain the chronological relation between the different documents, when they are produced (appendix A-3 of this document reflects this relation).

  There may be documents giving detailed additional information or information structured for a specific purpose like: Parts lists, Signal lists, Cable lists, Wiring tables and Loop diagrams.
- Delivery specific versus standard product documentation
- Documentation of computer system vs. application software
- Physical document structure
- List of documents

II.3.5.4 Additional Information in a Project Using Third Party Certified Safety PLC

Some of the additional information to consider in a chemical process project using a third party certified Safety PLC are discussed here.

The information (e.g. Safety Planning, Safety Functional Requirements, Safety Integrity Requirements, security operating procedures, technical security policies, etc.) previously discussed for Safety PLCs are still required in projects using third party certification Safety PLCs. The difference occurs in that self-certification is replaced by third party certification.

When this occurs, ensure appropriate information from the supplier and certifier of the Safety PLC is considered. It should include the regulation certification and its conditions of the hardware and system software. The application software needs separate information.

Important separate information may also include:

- Log, Dealings with the authorities
- Report, Hazard and Risk Analysis, All loops included in the PES
- Functional Safety Assessment Reports
- Test and Analysis Report, PLC Safety Validation (Factory Acceptance Test)
- Test and Analysis Report, Overall Safety System Validation (Site Acceptance Test)
- Instructions, Overall Safety System Operation
- Instructions, Overall Safety System Maintenance
- Modification Request, Overall Safety System
- Report, Overall System Modification/ Retrofit Impact Analysis
- Report, Overall System Maintenance
- Log, Overall System Modification / Retrofit

Part III Selection guide for a safety PLC system

III.1 General

The depth of the requirement specification will vary with the end-user technical culture and scope to be delivered. The end-user will need to make a contract with a supplier or manufacturer, called "vendor" hereafter. Many activities can be contracted with a vendor, but the final responsibility stays with the end-user (see also Part VIII). Therefore a detailed, qualified quotation should be asked for.

III.2 Potential vendor selection

After specifying the requirements (see Part II) possible vendors can be investigated. Key features to look for should be:

- availability of certification, check for application restrictions
- does the programming language meet your requirements, are there references for similar applications
- are your hardware requirements met
- is the operator interface adequate
- does the supplier guarantee maintenance / spare part over the intended life time of the system (e.g. for 15 years after having stopped selling the system, as required for German power plant control systems)
- is the system maintainability given during the whole life cycle, and is there a clear split in responsibility
- can the system be easily integrated into the environment

III.3 Evaluation of quotations

After receiving the quotations a detailed check against the requirement specification is necessary. All requirements which were not specifically answered or met in the quotation have to be re-asked.

The following list is a collection of experiences and recommendations:

- qualification of the application software is rather difficult for an end-user if he does not have his own experts. However at least the documentation of the top-layer should be understandable for any engineer.
- the cost of ownership should be taken in consideration and carefully calculated. Software changes and -maintenance have a very high impact.
- all people involved in the various life cycle phases (do not forget operators and maintenance people) should agree with the relevant product features.
- the operational quality and safety of the system is also influenced by the operator interface since this determines the subjective confidence level.
- the vendor must be able to perform the various training sessions with adequate training material.
- a good system documentation including as built is vital for a safe and reliable operation.
- spare part delivery, embedded software update service and software backup possibilities must be defined.
- the end-user may ask the organisation which has issued a certificate for this PLC system for their opinion on the product/services.
- the end-user should have only <u>one</u> contract for a PLC system. Any subcontractor of the vendor should be known to the end-user.

III.4 Safety aspects of PLC languages

This chapter aims at compiling some criteria for evaluating and selecting programming languages for safety-related PLCs. It is mainly based on previously published criteria for selecting general computer languages suitable for safety-critical systems.

III.4.1 Criteria for selecting programming languages

The following list of criteria should give some guidance to those who intend to evaluate a programming language for safety-related applications. The list has been compiled from various sources ([CGW 91], Chapter 3 "A Guideline for the Development of Critical Software" in [Redm 88], Chapter 1 "Guidelines to Design Computer Systems for Safety" in [Redm 89]. Most criteria listed in this section have been developed originally for the selection of general computer languages, while PLCs generally utilise limited variability application programming languages [IEC 98 Part 3]. However, much of the criteria is general enough to serve as a checklist for limited variability application programming languages found in PLCs as well as serving as a guide in those applications where a general computer language is being used. The list includes main criteria C1 to C9, auxiliary criteria supporting them, and comments (in parentheses).

C1: The language is fully defined (syntax and semantics).

- Semantics should be well and completely specified and easy to understand.
- There should be a rigorous implementation of both integer and floating point arithmetic within the language standard (as applicable).
- There should be procedures for checking that the operational program (i.e. the whole system) obeys the model of arithmetic when running on the target processor (as applicable).
- At least, the semantics of the language should be defined sufficiently for the translation process needed for static code analysis to be feasible.
- Language syntax should be completely and unambiguously defined.
- The language should be defined by an accepted standard.

C2: The use of a subset of a standard language or limited variability application programming language is recommended.

- This allows portability. It is also possible in this way to limit the techniques and instructions used to those which comply with the other criteria that can be analysed or proven correct, e.g. no interrupts, no global variables, no computed jumps, and, on a small application, no indirect addressing.
- A code of practice, designed to enforce a subset of the chosen language, is an essential element when implementing safety-critical software.

C3: The control flow is totally determined and restricted with respect to software safety.

- It can be shown that the program cannot jump to an arbitrary store location (i.e. the control flow is totally determined)
- The language contains a sufficiently large set of control structures. (There is no need to 'emulate' a control construct).
- Computed branching should be avoided.
- Arithmetical IFs should be avoided.

C4: The data flow is restricted with respect to software safety.

- There are language features which prevent an arbitrary store location being overwritten.
- Variables and their types should be explicitly declared.
- The means of data typing are strong enough to prevent misuse of variables.
- The type, range and precision of each variable and expression should be fixed.
- Types are checked across the module boundaries.
- Global variables should be avoided.

C5: There are mechanisms to facilitate recovery.

- There are mechanisms to facilitate recovery e.g. from malfunctions detected by software at runtime. (e.g. global exception handlers)

- Such mechanisms may in themselves introduce hazards if used unwisely. Exception mechanisms and handler should be utilised for exceptions only and not misused for influencing the program control flow.

C6: Language constructs help to guard against running out of memory.

- There are facilities in the language to guard against running out of memory at runtime (e.g. to prevent stack or heap overflow).
- Dynamic allocation of memory space can be a source of difficulty. it must not be used in safety critical applications.

C7: Appropriate notations of the language help preventing faults.

- Syntactic notations should be uniform; only one notion should be allowed for any one concept.
- Ease of reading of produced code is more important than ease of writing during programming.
- (In addition to the language constructs, an appropriate coding style should be defined and applied.)

Besides criteria applying to the language itself, some additional criteria about understanding the language, experience with the language and its development tools should also be considered.

C8: The language is sufficiently understood and enough experience is available.

- The designers and programmers will understand the programming language sufficiently to write safety-critical software.
- Do not underrate the importance of experience in the use of a given language or the advantage of a wide range of supporting tools. But, also, do not overrate it. It is unwise to stick to bad environments only because one owns it.

C9: The development tools support software safety.

- Translator, linkage editor and loader should be thoroughly tested prior to use; operational experience is considered very important.
- More recent guidelines like [IEC 98] even require verification of supporting tools.
- The problem of the reliability of high-level language compilers is a serious issue, as revealed by a special tool [WiDa 89].
- A very powerful method is the back-engineering of the specification out of a low level (assembly) listing or memory dumps. This method detects errors of the implementers and of the tool chain.
- The language provides facilities for separate compilation of modules.
- Language, compiler and linkage editor should together provide for detection of as many programming errors as possible during compilation and on-line execution.
- The run-time system which is part of any compiled program should fulfil the same set of safety-related requirements as the program itself.
- (For safety-related applications, some vendors offer restricted, pre-certified runtime systems, e.g. [Alsys 92].)
- There should be a support service for the development tools, including a formal fault- reporting and updating procedure.
- (Safety systems often have long lifetimes (5 to 30 years) so that obsolescence or planned replacement is an important consideration.)

There is a need to list security requirements for languages and to consider both the hardware and software design environment, and configuration control.

III.4.1.1 About the application of these criteria

Probably, there is no programming language which scores perfectly according to the above set of criteria. Published results for general computer programming languages demonstrate mixed results. For example, based on their set of criteria (a subset of the above criteria), the authors of [CGW 91] concluded: Structured assembly language may be acceptable in projects with limited risk. The use of C for safety-critical software must be very strongly deprecated.

A subset of ISO Pascal (SPADE Pascal) is suitable for safety-critical applications. ADA semantics are not completely defined; some ADA-subsets, like 'Safe ADA' and SPARK have been defined, which are more appropriate for safety-critical applications [Wich 89], [Alsys 92].

For limited variability application programming languages [IEC 93] available in PLCs the above issues only come into focus when verifying a PLC application software for adequacy.

III.5 Questions to ask potential suppliers

In Appendix A-2 on page 69 you will find a detailed list of questions that have to be considered when negotiating with potential suppliers.

Part IV PLC system implementation

IV.1 Application development

IV.1.1 Hardware design

A structured method of design is offered within this sub-section. The depth reached for given PLC equipment is dependent upon the intended application of the PLC. This applies equally to existing PLC products as it does to new designs.

It is expected that existing designs will have meaningful documentation. This must at minimum offer visibility of the design process, verification and validation activities and any actions taken from such activities.

Audit trails should exist through all designs which can easily demonstrate the quality of both the design process and that of the designed PLC product itself.

Typically, there are four phases of design for a hardware unit. The activities taking place within these four phases should be clearly identified within a quality plan which outlines all document related requirements for the design.

IV.1.1.1 Separation of non safety and safety system functions

Clearly, the realisation of the non safety (control) and the safety requirements should be separated in any way. There are several approaches to this:

(1) The non safety related control system is realised as a PLC and the safety requirements in additional safety layers, often built up with non-programmable electronics, or conventional means as relays etc.

(2) Same as (1) but the safety related control system is realised in a PLC. This results in safety software.

(3) Both process and safety requirements are realised by software (and some hardware) in the same PLC. All functions of the PLC will be treated as safety functions and the guidance provided herein for Safety PLCs will apply. Non-safety related software must be sufficiently separated.

Each approach has its conditions, disadvantages and merits. For Case (1) above, the PLC does not come under the guidelines provided herein. For Case (2) the Safety PLC must adhere to these guidelines. For Case (3) the PLC must adhere to these guidelines, and adequate independence of functions and inputs as well as common mode failure protection must be proven. Process Hazards Team approval is recommended prior to using Scheme 3 in high integrity applications.

Clearly, each approach (if realised in good technical manner) is admissible and is used in practice. For example, case (1) is more common in the German chemical industry and case (3) is found in many pre-certified packaged systems (compressors, turbine controls, etc.).

IV.1.1.2 Hardware design life cycle stages

Table IV.1 gives information on the different life cycle stages and the document output:

Activity	Document Output
Development of hardware requirements	Functional Specification
Decomposition of requirements (block level)	Phase 1 Design Specification
Design and analysis of circuits	Phase 2 Design Specification
Prototyping/Production Engineering	Phase 3 Design Specification
System Integration and Proving	Phase 4 Design Specification
Verification Activities, Quality (following each of the above)	Assurance Plan

Table IV.1 Hardware design activities

Suitable guidelines are provided within the following standards:

- dIEC 1508 Part 2 [IEC 98]
- MIL-HDBK 338 Volume 1 [MIL 84] Electronic Reliability Design Handbook, US DoD October 1984
- DIN V VDE 0801 [DIN 93] Principles for Computers in Safety - Related Systems

Each of the four phases of design is described as follows:

- Phase 1
  This is the preliminary design stage, where the key blocks or elements within a hardware item are defined:
  - Generation of block diagram
  - Translation of sub-system requirements and interface criteria
  - Detailed parameter definition
- Phase 2
  This is essentially the most detailed stage which will comprise the generation of circuit diagrams, design analysis, detailed calculations and test philosophies /procedures.
- Phase 3
  This is the prototype stage of the development. Prototypes are tested and aged prior to continuation of the development. Any prototype software that may be required is used at this stage for testing.
- Phase 4
  This is the stage at which the hardware documentation is collated, showing test results and final production information - prior to system integration.

IV.1.1.3 Reviews

Reviews follow each phase of the design. These cover Verification and Validation activities and should involve the user.

The product reviews objectives at all design phases are to verify the following:

- Consistency between requirements and the specification at each level
- Performance Criteria
- Completeness of Design (level)
- Numerical Factors
- Safety and Reliability
- Correctness of Design
- Traceability to previous levels/specifications
- Testability
- Maintainability
- Usability of product/documentation
- Software / Hardware Co-ordination
- Design for manufacture

IV.1.2 Software design

It is assumed that a "Software Design Specification" is available as a result of previous activities.

IV.1.2.1 Software design life cycle stages

Software design and development should be split into four phases with information as shown below:

Activity	Information output

Software Design	Software Design Specification Software Design Test Specification
Software Module Design	Software Module Design Specification Software Module Test Specification
Coding	Source Code and supporting documentation
Software Testing	Software Module Test Report Software Design Test Report Software Requirements Test Report

Table IV.2 Software design activities

Within each of the above phases, there are two additional information requirements recording the verification activities: Software Verification Planning and Software Verification Report (see IV.1.4 Verification of Module Design and Programming Phase).

Validation is dealt with in Chapter IV.2 and in part V.

IV.1.2.2 Software module design

IV.1.2.2.1 Objectives

The objective is to create PLC software of a defined integrity level from the software design specification. The module design will enable the implementation of software, which not only achieves the required integrity level, but which is also analysable, verifiable and maintainable.

IV.1.2.2.2 Requirements

The Software Design Specification should be available prior to the start of the module design process. If the Software Design Specification contains either safety-related functions and non-safety-related functions or safety-related functions of different integrity level, then the Software Module Design Specification should indicate how independence between these functions is achieved.

The software produced should be minimum in size and complexity.

In accordance with the required integrity level the module design method chosen should possess features that facilitate

i) Abstraction, modularity and other features which control complexity;

ii) The clear and precise expression of:

- Functionality;
- Information flow between components;
- Sequencing and time related information;
- Concurrence; and
- Data structures and properties

iii) Human comprehension; and

iv) Verification and validation

The module design method chosen should possess features that facilitate software maintenance. Such features include modularity, information hiding and encapsulation.

The module design should include self-monitoring of control flow and data movements. On failure detection appropriate actions should be taken.

If standard or previously developed software is to be used as part of the design then it should be clearly identified and documented. A separate report justifying the software's suitability in satisfying the Software Design Specification should be produced. Suitability should be based upon evidence of satisfactory operation in a similar application or having been subject to the same verification and validation procedure from the coding phase on, as would be expected for any newly developed software.

Wherever possible existing verified software modules (or function blocks) should be used in the design.

Each software module should be readable, understandable and testable.

Examples for representations of module design are function plan, decision table, state graph and those used in structured design.

IV.1.3 Programming

IV.1.3.1 Implementing PLC application programs

Many PLC application programs are implemented or programmed in one of two different ways. The first one, more applicable to smaller software application programs, is by writing a new program completely. The second is by configuring a set of predefined functional blocks, provided e.g. by the PLC vendor. Configuring means to select the appropriate blocks, to set the interconnections between them and to set the parameters within the blocks. For the selection of suitable PLC programming languages, the standard IEC 1131-3 offers some guidance by defining a set of five languages: Instruction List (IL), Structured Text (ST), Ladder Diagram (LD), Function Block Diagram (FBD) and Sequential Function Chart (SFC). Languages like IL, LD and FBD are in common use; ST is a high-level language similar to other general programming languages like C, Pascal and ADA. IL and ST are examples of textual languages, whereas LD, FBD and SFC are graphical 'languages'.

What also influences the programming style and language, is the size and complexity of the application program. Small scale applications typically are programmed by the user; large scale applications (e.g. in control) should be configured from standard function blocks as completely as possible. Only those functions for which no standard block is available, should be programmed. This minimises coding errors.

IV.1.3.2 Objectives

The objective is to implement software, which achieves the required integrity level, and which is also analysable, verifiable and maintainable. A sub-objective is to select a suitable set of coding tools, for the required integrity level, over the whole life cycle of the software which assists verification, validation, assessment and maintenance.

IV.1.3.3 Requirements

A suitable set of tools, including languages, (graphical) editors, compilers and configuration tools, should be selected for the required integrity level over the whole life cycle of the software. When applicable automatic testing tools and integrated development tools should be used.

The tools used for programming (e.g. compiler, configuration tools) either have a "Certificate of Validation" to a recognised national / international standard or an assessment report which details its fitness for purpose. The same applies for programming equipment wherever it is applied.

The PLC programming language selected should be completely and unambiguously defined or restricted to unambiguously defined features. When this requirement cannot be satisfied a justification for any alternative language detailing its fitness for purpose should be recorded in the Software Design Specification.

The language(s) chosen should meet the following requirements:

i) A programming language should be selected that relates to the characteristics of the application.

ii) The language chosen should contain features that facilitate the identification of programming errors.

iii) The language chosen should support features that match the design method.

A more detailed list of criteria for evaluating PLC languages is included in Chapter III.4.

Programming standards should be developed and used for the development of all software and should be reviewed by the assessor. The coding standard should specify good programming practice, proscribe unsafe language features and describe procedures for source code documentation. As a minimum the following information should be contained in the source code documentation: author, description; inputs and outputs; and configuration history.

IV.1.4 Verification of Module Design and Programming Phase

IV.1.4.1 Objective

The objective of this clause is to the extent required by the integrity level, to test and evaluate the products of a given phase to assure correctness and consistency with respect to the products and standards provided as inputs to these phases.

IV.1.4.2 General requirements for software verification

Software Verification Planning should be established, concurrently with the development, for each phase of the software life cycle and detailed in suitable and appropriate documentation.

Software Verification Planning should address all criteria, techniques and tools to be utilised in the verification process for that phase.

Software Verification Planning should describe the activities to be performed to ensure correctness and consistency with respect to the products and standards provided as input to that phase.

Software Verification Planning should address the following:

i) The selection of verification strategies and techniques;

ii) The selection and utilisation of the software test equipment;

iii) The selection and recording of verification activities;

iv) The evaluation of verification results gained from verification equipment directly and from tests; and

v) The evaluation of the reliability requirements.

In each development phase it should be shown that the functional, reliability, performance and safety requirements are met.

Verification shall be carried out by an independent party to the extent required by the integrity level. Function blocks made available by the PLC vendor, have been verified in advance on behalf of the vendor.

The results of each verification should be retained in a form that is auditable.

After each verification activity produce Software Verification results stating either that the software has passed the verification or the reasons for the failures. The Software Verification results should address the following:

vi) Items which do not conform to the Software Requirements Specification, Software Design Specification or Software Module Specifications;

vii) Items which do not conform to the design standards;

viii) Items which do not conform to the Quality Assurance Procedures; and

ix) Modules, data, structures and algorithms poorly adapted to the problem.

IV.1.4.3 Special requirements for verification in the software module design

After the Software Module Specification has been established and before the coding begins, verification should address the:

i) Adequacy of the Software Module Specification in fulfilling the Software Design Specification;

ii) Adequacy of the Software Module Test Specification in fulfilling the Software Design Specification;

iii) The decomposition of the Software Design Specification into software modules and the Software Module Specifications with reference to:

  - Feasibility of the performance required;
  - Testability for further verification;
  - Readability by the development and verification team; and
  - Maintainability to permit further evolution;

and should check for incompatibilities between:

iv) The Software Module Specification and the Software Design Specification;

v) The Software Module Specification and the Software Module Test Specification.

IV.1.4.4 Special requirements for verification in the programming phase

To the extent demanded by the integrity level, the programming should be verified to ensure conformance to the Software Module Specification, the Coding Standard and the Quality Assurance Procedures.

IV.1.5 Detailed recommendations for software module design and programming

This section refers mostly to separate books and standards. There, many useful techniques can be found on how to develop software in compliance with functional and safety requirements. Due to the large volume of such detailed recommendations, these are not duplicated here but referenced only. Most of these recommendations do not address specifically the configuration of pre-defined function blocks; instead they concentrate on general programming techniques.

The recommended programming paradigm with PLC limited variability application programming languages which is the combination of pre-defined function blocks, logical, arithmetical, timing, I/O, control functions etc., normally supplied with the PLC. These blocks are instanced and connected in textual or graphical form.

The figure below shows a simplified example of a program as block diagram:

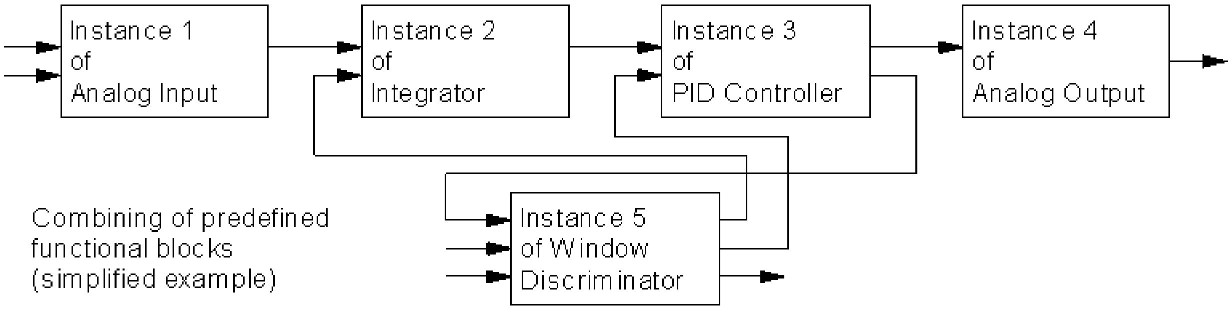

Instance 1 of Analog Input
Instance 2 of Integrator
Instance 3 of PID Controller
Instance 4 of Analog Output
Instance 5 of Window Discriminator
Combining of predefined functional blocks (simplified example)

Figure IV.1 Functional block diagram

The semantics of this "data flow" programming is that all instances of the functional blocks work simultaneously at "unlimited" speed, as if they were pieces of independent hardware. The execution of the blocks is sequential (one after another) in a given cycle. The "data flow" programming paradigm only hold

- if the overall execution speed of all relevant blocks is high enough and or the given cycle time is low compared to the time constants of the controlled process and
- if the blocks are executed in a "sensible" sequence.

Both conditions have to be carefully checked, which is relatively simple for the first one.

IV.1.5.1 Quality of software engineering practices

There are many good software engineering books and standards on how to develop high quality software. Recommendations in these publications are valid for software in general and mostly also applicable to PLC software with safety requirements.

A valuable resource with detailed recommendations are the three books on previous EWICS TC 7 guidelines. The first two TC 7 books, the Green Book ([Redm 88] and the Blue Book [Redm 89]) contain several guidelines on different aspects and stages of software and hardware development; the third one, the Red Book [Bish 90], is the associated techniques directory, where the techniques referenced are described in some detail. Relevant to quality assurance is: "A guideline on software quality assurance and measures" ([Redm 89], Ch. 4)

IV.1.5.2 Techniques for compliance with safety related requirements

In its relevant clause tables, detailed tables and its bibliography of techniques, the dIEC 1508 gives generic guidance on how to select the appropriate techniques and measures to achieve compliance with the proposed standard.

IEC 98, Part 3 provides guidance on software requirements for each SIL, including general techniques on good programming practices.

The HSE guideline volume 2 "General technical guidelines" [HSE 87] contains a set of checklists, where the purpose is "to provide a stimulus to critical appraisal of all aspects of the system rather than to lay down specific requirements". Four checklists are related to this part of the PLC guideline:

Checklist No. 11:	Software design
Checklist No. 12:	Software coding
Checklist No. 14:	Embedded software
Checklist No. 15:	Application programming

Section A of these checklists describes general aspects, Section B covers common cause failures in redundancy configurations and applies to redundant safety-related systems using diverse software.

In [Redm 88] there are two additional guidelines relevant to software module design and coding under safety requirements:
Chapter 1 is a guideline for the documentation of critical computer systems
Chapter 3 is a guideline for the development of critical software.

Also the [DEF 96] gives some detailed recommendations in its Part 2, Clause 30 "Design" and Clause 31 "Coding".

As there are many more standards and proposed standards relevant to this PLC Guideline, it is impossible to refer the reader to every relevant standard. Instead, the reader is referred to some surveys of these standards ([Bloo 92], [Rata 93], [Wall 92]).

IV.1.5.3 Use of existing software

Application software for PLCs normally uses libraries of pre-defined modules / blocks. Use of existing proven software is encouraged, but nevertheless it is important that the existing software fulfils the same functional and safety requirements as the newly written software. This is usually the case with the standard function blocks available for certified PLCs.

IV.2 Safety PLC system integration and validation

IV.2.1 Integration of PLC hardware and software

This activity would appear to correspond to the System Testing Phase in [IEC 98] document.

Objective

The objective of this activity is to integrate the verified application software with the target PLC hardware and to demonstrate that all the PLC System Requirements have been met.

Inputs

i) PLC System Requirements Specification derived in accordance with the guidelines of Part II, Section 3. This document includes functional and safety requirements.

ii) Plant Level Validation Plan produced in accordance with the guidelines of Part II, Section 1.6

iii) PLC Hardware Subsystem selected in accordance with the guidelines of Part III

iv) Verified PLC application software, developed in accordance with the guidelines of Part IV, Section 1: Application Development.

Activities

The integration procedure should proceed in accordance with System Integration Planning. This planning will contain information on the sequence and nature of the verification and validation activities which will take place when application software and target hardware are brought together. The System Integration Planning may also contain the criteria for completion of the integration procedure.

Verification activities should focus on demonstrating that the integrated hardware and software system satisfies the functional and safety requirements in the Requirements Specification produced in accordance with the guidelines in Part II, Section 2: PES Requirements.

Verification techniques may include testing on test beds with I/O simulation equipment, and ideally will allow the eventual operators of the system to test the software with simulated I/O.

Statistical testing may also be performed with simulated I/O if "typical" operational data is available.

It may be possible to verify the behaviour of the integrated hardware and software system through software modelling of an integrated set of system components.

As part of the integration activities evidence needs to be collected that system functional and safety requirements will be maintained during operation. To achieve this the following should be investigated:

i) the effects of failure of individual software and hardware modules on the maintenance of system requirements

ii) in multi-PLC systems, the effects of a single PLC failure on other PLCs and the effects of inter-PLC communication failures

iii) the implementation aspects of the PLCs being used and their configurations e.g. scan times, power-on & power-off behaviour

iv) PLC and system performance under load

v) safety aspects of software and hardware system architecture and their behaviour in the event of operation e.g. fault tolerance through redundancy, exception handlers, recovery blocks etc.

To achieve a demonstration of higher safety integrity levels the following techniques are available:

a) functional testing outside the specification to check for unintended events e.g. sabotage, operator errors etc.

b) functional testing based on partitioning of input data specifications, using boundary value analysis

c) dynamic coverage of system states provided by function test data through the use of state transition diagram models

d) statistical testing for robustness involving continuous operation test but with an additional significant amount of unexpected input conditions e.g. regular bad data as expected from faulty input device

e) working back from hazardous system states to determine dangerous input data sets with which to perform further functional testing.

Outputs

The information from the integration activities should form part of PLC System Integration Report. This report should summarise the conclusions drawn from the results of the integration activities as to the degree to which the integrated PLC system meets its function and safety requirements.

IV.2.2 Safety validation against PLC requirements

This section deals with the testing of the safety functions implemented by a PLC-based safety system after the integration and installation of the system.

Objectives are gaining of

- confidence in the availability of the safety functions under all specified conditions (assessor)
- experience with the implemented safety functions and procedures (vendor, operators)

Inputs to the activities are

- Specification of the safety functions
- Outcome of prior off-line-tests and type approvals
- Checkout procedure for the correctness of the installation
- Start-up and shut down procedures
- Run in procedures (if appropriate for controlled process)
- Manually executed complementary safety shut down procedure (if appropriate for controlled process)

Activities are

- Testing of the correctness of the installation
- Running in the controlled process (if applicable)
- Testing of all automatic safety related functions during run-in
- Start up of the controlled process
- Testing the safety functions with manual safety functions and with simulated dangerous conditions
- Shut down of the controlled process

Except for the first one all or some of these steps will have to be re-iterated according to the test plan.

Some processes require a run-in phase before final operation. This phase is distinguished form normal operation by:

- use of non dangerous material in chemical plants (e.g. water instead of gasoline)
- running a boiler at very low load (only one burner at lowest possible load) and blowing off the generated steam
- running at lowest speed and / or with no persons or dangerous material on board (transport systems)

The character of such run-in phases differs widely from process to process (and there are processes where no sensible run-in phase can be defined for). The run-in procedures and the tests to be carried out in this phase may be clearly defined. The main goal will be the testing of the plant - installation, pipes, vessels etc. - and of the basic process control functions - sensors, actors, man-machine interface, operating procedures - as well as the gaining of first experiences of the operators. This time is the biggest opportunity to test all safety functions in the integrated environment and monitor the process response.

The testing of some safety functions requires the process to be in a dangerous state. The test may demonstrate that the safety system would bring the process into a non-dangerous state by the appropriate action (e.g. shut down). Of course, in test steps like these, any "real danger" has to be avoided. This can often be done by taking these test steps in the run-in phase or by having complementary (manual) shut down facilities available.

An alternative way is to simulate a dangerous state of the process at the sensor level in order to test some of the safety functions.

The testing of the safety functions has to be planned and carried out very carefully.
At one hand the testing has to be complete in a specified sense (cover all functions) - at the other hand the on-line-testing of safety functions can be expensive and potentially dangerous. The reports of

previous off-line-tests and the type-approval of the safety PLC should be considered, as to not unnecessarily repeat test steps.

An important key to a later safe operation of the process is the involvement of plant operations and maintenance personnel during the on-line-testing phase to assure a clear understanding of all aspects of the process, the control system, and the Safety related System (PLC).

Outputs of the activities are

- Information of used tools and calibration data
- Information of the activities and of the conclusions
- Final Test information for the safety PLC.
- Skilled operators well acquainted with the system
- Well trained maintenance people

IV.2.3 Development of procedures

Operating procedures to safely operate and maintain the system may be written during design, development and implementation phases. For detailed requirements see Chapter VII, Commissioning and Use.

Part V Plant level integration and validation

V.1 Installation

The objective of this phase is to install the total safety-related PLC system. Installation should proceed according to Installation Planning.

The elements of the safety-related PLC system include:

- hardware cabinets
- monitors
- data busses (also to non-safety-related systems)
- configuring / programming devices (also for the non safety-related systems communicated to)
- printers
- sensors & transmitters
- actuators
- cabling
- uninterruptible power supplies
- power feed and fuses
- manual bypassing and resetting devices
- manual shutdown system
- testing possibilities, e.g. shut-off valves and their alarms
- system software
- application software
- documentation
- spares, back-up software.

The installation planning should identify:

- the phases of installation, i.e. the sequence in which the various elements are integrated;
- the criteria for declaring the safety-related PLC system, or parts thereof, ready for installation and for declaring installation phases complete;
- resolution of failures and incompatibilities;
- the kinds of checks (where, by whom, type etc.) to ensure the elements are ready for installation;
- the kinds of checks (e.g. pre-testing all loops, communications, data presentation, motor rotation, etc.) required to approve the installation phase complete prior to validation, assessment and commissioning.

Security measures should guarantee that code has not been modified.

Noticed failures or incompatibilities are to be reported. They could include:

- not reliable enough power supply;
- partitioning of connections to the safety-related process or I/O-cards could be better;
- not sound data transfer.

V.2 System Test

System test includes factory acceptance test (FAT) and field test. Evidence for sufficient coverage may be given, e.g. by statistical techniques.

System test is a major step in determining reliability behaviour of PLCs. Depending on the quality of the development process the coverage of the test may be high or low. High reliability PLCs require almost complete coverage of the test of the safety related functions in the PLC.

PLCs where extensive validation procedures have been performed need less stringent field tests. Of course, properties which are asserted by third party certification as intrinsic system functions (coverage of built in self tests) need not be re-tested for every individual installation.

As always, a good allocation of the given resources is the key to suitable reliability given a particular application: it may be wiser to invest in a "good" approved system base and having less effort (an re-development) in the field tests.

V.3 Safety validation against global requirements

V.3.1 Objectives

The objective of this life cycle phase is to test the integrated system to ensure compliance with the Requirements Specification at the intended safety level.

Testing should be the main validation activity, simulation and modelling may be used to supplement the validation process.

For the overall safety validation the following tests should be performed at system level:

- function tests
  - all sequences
  - all functions
  - all inputs
  - all outputs
- time behaviour tests
  - all operating conditions
  - all timing requirements
- interface tests all interfaces
  - all operational modes

V.3.2 Validation

The results of the validation should be in an auditable form, stating either that the PLC has passed the validation or the detailed reasons for its failure.

The Validation should identify all

- hardware and software used,
- the equipment used,
- equipment calibration,
- simulation models used,
- discrepancies found.

Information characteristics

'Test' is used here in its wider sense, e.g. as encompassing all kinds of verification and validation.

All information related to the assurance work on safety of PLCs for critical applications should include the following characteristics and aspects.

The main points should correspond to the main steps of the testing work. They should contain the following pattern:

- presentation of the test objective and test tools
- synopsis of safety principles of the test object
- detailed description of the tests
- summary of the work including final judgement

The **presentation** part should include an overview of the test object based on the requirements specification and functional analyses. The following information should be included:

a) presentation of the test object
   - purpose, application, function
   - general data and specification
   - safety concept of the whole system (hardware and software)
   - explanation of the structure and function of the hardware
   - explanation of the structure and function of the software

b) presentation of the test tools
   - applied test methods
   - applied test equipment

The **synopsis** of the safety principles of the test object is resulting from functional analyses and could be presented in form of a table for better readability. Based on this safety principle synopsis the fulfilling of specification requirements by the test object can be assessed.

In the **description** part, the test carried out should be listed and their results should be described in sufficient depth to ensure complete understanding. Tests that are available include:

for hardware:

a) functional analyses

b) detailed failure analyses (FMEA, FTA, Error Sequence Analysis, quantification etc.)

for software:

c) functional analyses (black-box, white-box, etc.)

d) detailed failure analyses (investigations regarding structure and dependence / independence of software modules)

The description part consists of all measurement configuration, tables and diagrams (e.g. fault trees, FMEA-tables, structograms, flow-charts, listing reviews, specific test results, wiring diagrams if necessary etc.) made in course of the whole testing work.

The **summary** of the work should give a short description of the whole test work. It should include:

e) functional safety principles of the test object

f) tests carried out

g) test conditions

h) applied test methods

i) final judgement in relation to the requirements.

Part VI Certification / Assessment

VI.1 Review of development

It is important that the user monitors the development to ensure that it is happening as defined in the contract. This activity should be scheduled to fit into the defined development phases. The development should have 'hold points' beyond which development should not proceed until the user is satisfied that the safety requirements as defined in the specification are being implemented correctly.

The types of checks will include:

- compliance with standards and guidelines specified in the contract
- system configuration
- V&V activities
- testing
- production of development documentation, as specified in the contract
- evidence of compliance with development procedures (i.e. signatures on procedures as they are completed)
- evidence of internal reviews
- inspection of the safety log (safety problems encountered, and how they are resolved)
- evidence of the software repair and re-test procedures

The purpose of the above activities is to ensure that safety is being implemented into the product as the development proceeds, so that if safety problems occur, they can be resolved as soon as they manifest themselves. If the above activities are not carried out, the problems might only be manifested during the FAT when it might be too late to resolve them satisfactorily, due to time scale pressures.

VI.2 Assessment of the safety PLC

VI.2.1 General

The assessment should:

- address expected behaviour in the case of (component) failure, fire or abnormal events
- explicitly address accepted failure modes
- cover acceptance criteria (quantitative and qualitative)
- review relation between safety layers and process: ESD, control system, procedures, mitigation systems
- cover how the supplier should verify the correctness of the safety PLCs; formal methods, qualitative / quantitative methods, FAT
- make acceptance criteria explicit
- verify integrity levels according to the required standards, e.g. IEC, DIN
- address maintainability: practical issues as ease, availability of spare parts, training of personnel, required personnel education level, maximum down time.

If necessary the assessment should cover any given evidence or calculations for:

- Probability of Failure on Demand (PFD) and/or
- mean time to failure.

With the application dependent approval it should be demonstrated that the hardware as well as the software system meet the requirements for a specific application. The approval normally concentrates on the application software and the integration of the whole system.

The assessment procedure is divided into the analytical approval and on-site approval.

VI.2.2 Analytical approval

During this phase a lot of questions concerning the system and its behavior in the presence of failures have to be verified. The following list is an extract of all these questions:

- Is a safety philosophy described for all safety functions ?
- Can each individual safety function be specified (e.g., logic diagram, flow diagram, state diagram etc.)?
- Which PLC system is the best one to meet the requirements ?
- Does the safety function include redundancy and / or diversity ?
- Is the safety system safe ?
- Does there exist a prescription of a safety philosophy or failure calculation in the application dependent standards ?
- What are the timing constraints for individual safety functions ?
- Is the application software separable into safety related and non-safety related parts ?
- Where in the application are non-fail-safe actuator operations considered ?
- Which control signals are static, which ones are dynamic ?
- What kind of strategies are applied to find passive failures ?
- Is the link / communication between BPCS and safety PLC secure ?

The following concrete steps are conducted during the analytical approval:

- inspection of the documentation with respect to completeness, validity and consistency
- verification of logic diagrams
- verification of the application software
  * The application software is verified with respect to the specifications and the logic diagrams which have to be pre-verified by the process engineer.
  * extraction of all safety critical parts (modules, subroutines) of the software
  * control flow and data flow analysis
  * verification of all specified functions
  * if possible simulation of all functions and time behavior under normal and erroneous conditions on a simulator (recommended, but not prescribed)
- verification of hardware design and installation documents.

VI.2.3 On-site approval

The **first step** in this phase is to control the physical installation of the PLC hardware and the application software on the target system. It is being validated whether both the hardware system as well as the application software are in accordance with the pre-validated information.
With respect to the hardware the following tests are conducted:

- test of the installation of the PLC system with respect to the aspects
  * field wiring, e.g. separate installation of redundant wiring
  * protective and functional earthing
  * noise and transient suppression measures:
    # separation of cables for inputs, outputs and power circuits
    # correct length of wiring
    # separation of the field wiring from internal I/O cabling and from bus lines
    # control of mechanical contacts which are in series with inductive loads

- test of compliance with the actual service and environmental conditions, e.g. temperature, shock and vibration, electromagnetic influence etc.

- loop checks (interaction between PLC and process periphery)
  * binary inputs
    checking binary and digital input signals to ensure that physical states of sensors comply with signal latches (memory elements) in the PLC
  * analog inputs
    checking analog input signals to ensure equivalence of physical value and data received by the PLC

* binary outputs
ability to switch; checking that no forced binary and digital outputs are set
* analog outputs
* supervised inputs and outputs: detection of opens and shorts

The **second step** is to test all system functions. During these tests the functional behavior of the system with respect to the specified functions is validated. All functions are being tested under operational conditions.

In a **third step** fault simulations are conducted based on a pre-defined list of failures. Generally the majority of failures can be located in I/O and other periphery. Therefore failures are simulated with respect to
* sensors, contacts and actuators
* inputs and outputs
* field wiring, e.g. exchanged connections
* interlocks

During failure simulations it may be validated that the system - in the case of failures - is being brought into a safe state. The kind of this state is depending on the application. It can be a de-energized state of all outputs or the shutdown of certain parts of the application.

In the **final step** it is being assessed whether all restrictions fixed in the type approval report (if a certified PLC is used) are fulfilled.

Part VII Commissioning and Use

VII.1 Operation and Maintenance

The objective is to properly operate and maintain the safety PLC.
Implementation of a safety PLC should include the initiation of a number of actions:

- implement procedures;
- follow maintenance schedules;
- maintain records;
- carry out of functional safety audits periodically;
- implement the Safety Management System.

The performance of the safety PLC should be compared on a regular basis with the design characteristics (e.g. failure and demand rates.)
Any deviation from the original assumptions should be assessed for their effect on the functional safety. Modification procedures should be initiated if the deviations increase the risk.

This section contains:

- Operating Procedures
- Maintenance Facility Planning
- Testing Frequency Requirements
- Plant Operations Training

VII.1.1 Operating Procedures

The development of all procedures related to safety PLC should involve participation of management, engineering, maintenance, operations, safety, and other groups as appropriate.

Also all operating procedures should be reviewed with operations personnel periodically.
This will allow to introduce any practical changes that are to be considered and incorporated into the procedures and uncover any undocumented changes that might have taken place. This review also serves as a training tool to reinforce the operators' and support personnel's knowledge of safety PLC operation.

During the development of safety PLC operating procedures, particular attention has to be paid to:

- Unit start-ups and shutdowns.
- Initial start-ups versus routine start-ups.
- Start-ups after maintenance.
- Switching to backup units.
- Starting or stopping equipment.
- Changing of personnel at shift change time.
- Preparing equipment for maintenance.
- Performing maintenance on operating equipment.
- Verifying the accuracy of input signals.
- Switching from one operating mode to another (e.g., manual to automatic and vice versa).
- Switching from one operating state to another (e.g., start-up to normal, or hold to normal).
- Making significant operating rate changes.
- Converting operation to an alternate product.
- Performing on-line tests.
- Performing on-line maintenance.
- Response to any pre-alarms on trip signals.

When these situations occur, additional instructions on the safety implications of the safety functions may be necessary and have to be described in the procedures.

VII.1.1.1 Critical Operations Procedures

Safety System Operating Procedures may have some instructions that are specific to a safety PLC and require a special procedure. Areas that should be covered by these procedures include:

- Bypassing criteria.
- On-line calibration.
- Response to safety alarms.

All these topics are described further in the following subtitles.

Procedures for operation of a safety PLC should emphasise the importance of the interlocks and how they provide the desired safety function. Training should be provided for *all* personnel to ensure adequate understanding of, and the reasons for, these interlocks.

The long-term integrity of the safety PLC systems still depends on the proper actions of human beings. Engineers design the systems. Operators monitor and direct the operation of the plant. Maintenance personnel maintain the integrity of the various components. It is, therefore, important that appropriate management and administrative procedures and controls be in place to ensure that the integrity of the safety PLC is maintained. The implementation and enforcement of these procedures demonstrate management's support and commitment to the safe operation of the plant.

Minimum procedural requirements have to be described for:

- Operating during normal and abnormal conditions of the plant.
- Making changes to safety PLC Systems.
- Maintaining the equipment and software.
- Testing of the systems.
- Training personnel on the use and maintenance of the systems.
- Providing adequate information for the systems.
- Maintaining information of the systems.
- Auditing the systems.
- Maintaining performance history on the systems.

The importance of having these procedures developed and in place prior to starting operation of the plant is also stressed.

VII.1.1.1.1 Bypassing criteria for safety PLC

Bypassing of safety PLC functions during operation of the process can have significant safety implications. It is recommended that each facility establish a policy concerning this action. The policy should be applied uniformly throughout the facility to ensure that movement of personnel among units does not result in different interpretations of the policy.

A policy is recommended that does not permit master bypasses (action that bypasses all trip initiators simultaneously) on a safety PLC. This will prevent loosing protection on all interlocks of a safety PLC while working on a specific one.

Bypasses on individual safety PLC trip initiators may be acceptable, provided that written procedures and proper authorisation are established defining how they may be used, e.g. monitoring of specific process conditions with other instruments while the bypass is being used.

The accepted bypassing method should be determined ahead of initial operation of the safety PLC, and special operating procedures should be established and be approved in writing by appropriate plant management prior to use of the bypass.

Usually it may be appropriate to establish a time limit for which a bypass may be in place and a means by which to prevent return to normal operation until the bypass has been removed.

The bypass procedures should include a cautionary note identifying improper ways that safety interlocks could be bypassed through some seemingly unrelated actions, such as:

- Elevating or suppressing zeros on transmitters.
- Adjusting spans on the transmitters.
- Adjusting transmitter purge rates.
- Providing hand jacks on automatic valves.
- Installing bypasses around automatic valves.
- Installing filters to reduce noise on instrument signals.
- Leaving span gas open to analysers.
- Defeating limit switches.

Bypass procedures should require special tagging on all safety PLC trip initiators that are in a bypass mode during operation of the plant. The tags should be visible and may include items such as:

- Identifies the function bypassed.
- When bypass initiated.
- Who approved the bypass.
- Personnel authorised to remove the tag.

The tags should not be removed until the system is returned to a normal operating mode. The time removed and the individual removing the tag should be noted in the operations logbook.

VII.1.1.1.2 On-line calibration of safety PLC

During normal operation of a unit, the need may arise for verifying the calibration or status of an input to the safety PLC. Procedures should be developed prior to initial operation of the unit, detailing the steps to be followed during this verification process.

Consideration should be given to the following points:

- if verification can be accomplished without disrupting normal operations.
- if the calibration can be accomplished while complying with bypass procedures.
- the time allotted to perform the calibration.
- how the calibration is to be done.
- who can authorise the work.

VII.1.1.1.3 Response to safety PLC Alarms

Pre-alarms may be an indication of impending safety PLC action if preventive action cannot be taken immediately. Safety system pre-alarms situations should be defined and procedures and training developed ahead of time to prevent confusion when these alarms occur.

Safety PLC alarms are directly followed by an action to force the equipment under control to a safe state. Operators have to be trained how to react to these conditions and what to do with the related or dependent systems to avoid additional developing hazards or equipment damage. Possible cascading of safety PLC actions may be considered in procedures and training.

VII.1.1.2 Abnormal Condition Procedures

Operators may need specific guidance on actions to be taken when addressing such situations as:

- Indicated loss of instrument power or air.
- Indicated loss of key utilities to the plant, such as cooling water, steam, and electricity.
- Loss of a feed-stock or some other key ingredient.
- A fire or chemical release especially with potential impact on the community.
- Failure of a pump seal.
- Pipe breakage.
- A phoned-in threat, or the occurrence of other acts of terrorism.
- Severe weather conditions.
- Blank screens during normal operation.
- An indication that the safety PLC has failed in a "stall" position (i.e., the program sequence has stopped in an unknown condition).

Whether or not the safety PLC is affected directly by the abnormal condition may not be the critical concern. The fact that out-of-the-ordinary conditions exist may require operators to respond in a different manner. However the safety PLC should automatically react in a safe way if necessary.

All identifiable abnormal situations should be defined ahead of time and appropriate response procedures should be developed.

Providing both the procedure and the training ahead of time may prevent a serious incident when an abnormal situation occurs.

VII.1.1.3 Turnover Procedures

When responsibility for plant facilities are transferred from one functional group to another, there is potential for compromising safety that might not otherwise be present. This is primarily due to change of personnel and the potential for loss of critical information. Procedures should be established describing those criteria that should be covered in the turnover operation.

These might include such things as:

- Transition information to be handed over.
- Special tagging of equipment to identify responsible functional group.
- Special requirements when checking out equipment.
- Special requirements for equipment start-up (e.g., any run-in requirements).
- Special conditioning (e.g., like seals in valves, pumps).
- Establishing initial conditions for control equipment.

The smooth transition of information between functional groups to prevent compromising safety can be accomplished with the establishment of checklists, with a sign-off procedure for both the group transferring the facility responsibility and the one receiving the responsibility.

A list of some items that might be included in a checklist for transferring a Safety PLC System from maintenance to operations after major maintenance work might include:

- Hardware components, whether different or exact replacements, used in maintenance activities have been verified as compatible with current system configuration.
- Field sensor calibrations have been verified against a master list of ranges for field instruments.
- Wiring and communication links from field to control room equipment have been verified and tested to ensure correct operation.
- Failure directions of all final elements worked on during the maintenance activities have been verified as correct.
- Operator displays modified or developed during the maintenance activities have been tested with operator actions.
- Software operating system upgrades made during maintenance have been tested to ensure safety controls still function as designed.
- New control applications have been tested to verify correct function.
- Operators have been trained on any new features and control applications implemented during maintenance.

Another area where turnover procedures are very important is at shift change time. Transfer of plant equipment and safety PLC status from those leaving the plant to those coming into the plant can be critical to plant safety. The lack of information or the transfer of incomplete information could potentially compromise safety. Procedures may consider information (e.g. checklists) of the status of critical equipment and the safety PLC between the two shifts involved and verbal review of the information at shift change time. This will ensure that the necessary information has been transferred in both a timely and understandable manner.

VII.1.1.4 Facility Change Procedures

Modifications can have significant impact on operating plant safety. Processes frequently undergo changes to improve efficiency and productivity, conserve energy, reduce waste materials, etc. These changes may be in the process itself or in the safety PLC and may create problems unless an adequate safety review of the proposed changes is performed.

Changes to a safety PLC function require a formal procedure to ensure that the safety function provided by the safety PLC is not compromised.

Additional considerations that should be reviewed include changes to the following:

- Trip initiator values.
- Logic within the control processor.
- Any valve actions.
- Sequencing.
- Type of hardware used for inputs, outputs, or other components.
- Addition/deletion of any trip initiators.
- Addition/deletion of any final-control elements.
- Type of control processor.

This concern also applies when software upgrades are made by equipment vendors. A revision to system software may impact a Safety PLC System in an unexpected manner. It is therefore important that software revisions and updates be controlled.

Examples when changes are required include:

- Suppliers no longer support the revision level of your spare parts
- Vendor initiated revision correcting defects in the utility and system software version you are using.

The review process should include proper approval(s) before implementation. Testing of the changes is mandatory prior to placing the modified system in operation. The testing required may include a full functional test as described in this chapter.

Information defining the changes, approval, and testing are all very important. A modified system should never be placed in operation unless the information has been completed and appropriate personnel have received instructions and training on the operation of the revised system.

The concept known in the chemical industry as "Management of Change" addresses these issues. Details of this concept are outlined in [AIChE 89]. The concept of managing change is also addressed in the [OSHA 92]. Both of these documents stress the importance of establishing a plant-wide review of all proposed changes before they are implemented.

VII.1.1.5 Safety Review Procedures

Process safety reviews address the overall process safety philosophy and cover such things as when a formal review should take place, of what the review should consist, who should perform the review, etc. The Safety PLC System is an integral part of those reviews, but there may be instances where the Safety PLC Systems themselves require separate and independent reviews. The makeup of the group performing such a review should include qualified process control, process, and hardware- and software-knowledgeable individuals with input from operations, maintenance, and safety personnel where appropriate. It may be desirable to involve personnel from other company locations in these safety reviews, if applicable, to provide fresh, unbiased input. There may also be a need to include the manufacturer of the equipment, or their representative, in the review process to ensure all considerations relating to the operation of the system are covered.

The complexity of some Safety PLC Systems makes them difficult to analyse in a simple manner. This may not be evident in the safety review technique being used for the process. There is a danger of looking at the safety-related system only as a “black box” controller (i.e., the variable being measured and the variable being controlled), and evaluating the effects of changes or modifications to these variables on the process safety. Especially with complex functions this may obscure side effects or intermediate conditions which may occur.

For this reason at least a simplified complete functional diagram should be available and it should belong to the controlled safety documents.

Procedures should be established for performing adequate reviews. Considerations that should be addressed include:

- Verification of wiring to input and output devices in the Safety PLC System.
- Analysis of control logic as it may impact other loops.
- Consequences if the Safety PLC System halts.
- Status of any redundant (backup) system in terms of how it is updated to current operating conditions.
- Methods of making hardware changes or replacements for faulty equipment and how they might impact safe operation.
- The policy concerning facility changes discussed previously.
- Consequences of loss of HMI.

This is not an exhaustive list, but one can see the need for adequate review covering all the identifiable situations that can occur as well as some that may be highly speculative.

VII.1.1.6 Security Procedures

The use of Safety PLC Systems also introduces security concerns in various ways as described in chapter II.3.4. Any unauthorised change to the safety relevant software may compromise the functionality and a potentially hazardous condition could result. Therefore, security methods and procedures are recommended to maintain the control logic integrity of the safety relevant systems. Security procedures should be implemented in the following areas:

- Engineering activities that modify, add, or delete software.
- Maintenance activities that diagnose, replace, or repair components or systems.
- Operations activities relating to changes in informational alarms, set-points of control loops, data reporting, and sequence of events.

- Vendor activities related to the upgrading of vendor- supplied operating systems and hardware modifications.

These procedures should address:

1. who is authorised to perform these activities,
2. what method will be used to prevent unauthorised access to the system
3. how authorised or approved activities will be implemented.

This may require multiple levels of security. Changes made by the operator or maintenance technician that have no adverse impact on process safety may not require special access to the system. Changes impacting software should require access through a key or password available only to supervisory personnel.

VII.1.2 Maintenance Facilities Planning

In the operational life of the plant the PLC will have to undergo three types of maintenance activities.

- Improvements of the process control, i.e. perfective maintenance
- Replacement of failed parts, i.e. repair
- Replacement/upgrading of operable parts which are considered liable to fail, i.e. preventive maintenance

It can be considered probable that all three types of maintenance activities will occur during the life time of the plant. The facilities for these activities have to be planned with two goals in mind

- to make these activities possible (no spare parts - no repair, see below)
- to carry out these activities with no decrements in safety

All activities with this type of changes to control parameters, PLC-software, PLC-hardware and plant hardware have to be considered as (perfective) maintenance activities. Hardware changes can and shall be controlled by procedures. The same applies to procedures for parameter and software changes. Besides that, the facilities for these changes have to be planned and implemented carefully (see subchapter "maintenance engineering workstations" below).

The character of repair is obvious. Nevertheless, the facilities have to be planned. They are

- good written procedures for all types of repairs to be expected
- skilled maintenance personal
- spare parts (see subchapter below)

These considerations and facilities are also needed for preventive maintenance. Above this, the preventive maintenance activities themselves need careful planning. The questions to be asked (and answered) are

- For which types of the parts used preventive maintenance is feasible?

For parts, that fail only statistically (even distribution over long time scales), there is no sense in preventive maintenance. This is true for the great majority of electronic parts.

- For which parts of the plant or PLC, that fall into this category (i.e. are subject to wear or ageing) is preventive maintenance sensible?

To answer this question one has to ask for every part:

- If the part fails, is that detrimental to the availability and / or the safety of the plant?

If the availability is at stake the answer to the question of planning preventive maintenance for that part will be found by economical reasons. And the answer will often be No, as preventive maintenance can be expensive. If safety is at stake, preventive maintenance will become mandatory. But, it may also be considered to reduce the safety criticality of that part by other means, e.g. redundancy.

If one decides or has to decide for the preventive maintenance of a certain part, the following questions have to be answered:

- Can the part be replaced by time schedule as repair criterion?
- Can the near end of the operational life be detected by tests?

And if so

- What is the procedure and the time schedule for the tests?
- Can the near end of the operational life be calculated by certain criteria?

These criteria could be operational hours, perhaps weighted by some further stress factors (temperature, speed, etc.), counting of switching on and off and the like. And if so

- Are the resources to calculate these criteria (sensors, software) planned?

After the planning of the range of preventive maintenance activities, the following questions have to be answered for each planned activity:

- Can the maintenance / test be carried out on-line?
- Is the activity potentially dangerous?

Often, the answer to the last question is yes. One has to be very careful not to give raise to more potential danger by preventive maintenance activities than that activity is assumed to avoid or reduce (see chapter on testing frequencies below).

The preventive maintenance activities that can not or should not be carried out on-line have to be planned in co-ordination with the planned down times of the plant.

VII.1.2.1 Maintenance and Engineering Work-Stations

Human Machine Interfaces (HMI) - or Engineering Workstations - exist for five types of activities:

- configuring and programming the safety PLC (functions)
- setting parameters (e.g. trip levels) for the safety PLC (functions)
- configuring and programming the non-safety PLC (functions)
- setting parameters (e.g. control loop coefficients) for the non-safety PLC (functions)
- surveillance and interaction for the (normal) plant operation

The criticality of the need for (re-) assessment and, hence, the level of access rights or authorisation increases from the last to the first named activity. Facilities have to be planned to ensure that none of these activities can be carried out without proper authorisation. Authorisation may only be given to individuals with the necessary level of familiarity with

- the process,
- the technical aspects of the control logic
- its impact on plant safety
- functional operation of the Safety PLC System
- the steps required to effect changes both during operation and during plant downtime

The topic can be handled as a security issue.

A good practise often (but not necessarily) used, is to have the work stations used to configure Safety PLC Systems and perform certain maintenance functions separate from the operator interfaces used in normal plant operation. They can be separate devices located in separate locations.

A security technique that limits access to engineering work-stations and / or to the tools for the activities named above should be in place. This may be accomplished by a key lock arrangement on the station, but may also include software password protection to further ensure proper authorisation. The use of passwords by themselves may provide a level of security, but it should be recognised that they may be easily compromised.

According to the very different character of the named activities several separate levels of security will have to be planned and implemented. Communication of a written policy on engineering work-station security should take place prior to plant start-up.

VII.1.2.2 Spare Parts

A key consideration in planning for maintenance of a Safety PLC System is the provision for spare parts. An important issue is that the spare parts have the same or compatible revision level as the original equipment. Also the vendor has to commit to deliver spare parts during the specified life cycle (e.g. 15 years). Components will fail and most likely at the most inopportune time. When this occurs, having the required replacement parts available and in working order will not only ensure rapid return to normal operation but also will provide a measure of safety.

To guarantee the having of spare parts on hand in time there are, basically, two strategies:

- having a store of spare parts at the plant
- having the PLC vendor’s commitment to deliver spare parts in time

The first alternative is contractually and logistically simpler.

Economical and technical reasons favour the second alternative. The technical reasons are that the necessary facilities for testing and storing spare parts are usually implemented by (large) suppliers of PLCs, but, can not normally be expected at the site of the user's plant. Without these facilities, having spare parts on hand does not necessarily guarantee that they are operational. The conditions under which the parts are stored may result in inoperable components when they are needed.

Topics addressed to achieve these requirements may include:

- Availability of spare components.
- Provision for the verification of operational status.
- Adequate storage facilities with special respect to
  temperature
  excessive humidity,
  dust and gases,
  potential for mechanical damage
  magnetic and electric fields,
  static electricity
- Provision for security of the spare parts to prevent their unauthorised use and hence undetected change of operational status.

As said, it may be desirable to store spare parts off-site at a vendor warehouse, for example. When this is done, the accessibility of parts on a 24 hours a day basis should be considered along with the other contractual issues.

VII.1.2.3 Third Party Maintenance

The trend toward the use of contract personnel for maintenance of Safety PLC System rather than in-house maintenance personnel, presents some additional considerations relative to the Safety PLC System. There are at least three methods by which this is implemented:

1) contracting with the supplier of the Safety PLC System for maintenance,
2) contracting with a third party service organisation for the maintenance, or less probable
3) contracting with individuals to perform the maintenance.

Considerations that should apply to the selection of a third party maintenance method or supplier include:

- Capability of the personnel relative to the system to be maintained.
- Availability of personnel in a timely manner.
- Will there be capability for maintaining the process technology with an external service organisation?
- Will the contract personnel be committed to meeting your needs?
- Stability of the contract organisation for long-term support.
- Are you willing to transfer critical safety system know-how to an external source?
- Confidentiality and security concerns.
- Contractual issues. For example, if the maintenance organisation chosen is not the supplier of the PLC, additional contracts or contract terms may be needed. The support by the supplier (spare parts, information etc.) the user is entitled to, may or will not necessarily be given to third parties.

There may be other concerns that should also be included in the evaluation of the most satisfactory method for providing the required maintenance. Those listed have been highlighted to precipitate planning prior to action.

VII.1.3 Testing Frequency Requirements

VII.1.3.1 Safety PLC System Testing

The frequency of testing required for Safety PLC Systems is dependent on the required SIL. If the SIL is minimal, the testing interval may allow longer periods between tests. If the SIL is higher (SIL 2…4), the testing will have to be done more frequently.

Another factor that can impact the testing frequency is the finding of faults or failures of any system components during a test. The number of failures may dictate more frequent testing or the lack of failures could allow longer intervals between tests. There should be balance, however, between the time taken for testing and the estimated time the equipment will be out of service due to failures. In no instance should the frequency of testing be less than that included in the risk assessment analysis performed on the plant.

This testing should be performed prior to initial operation of the Safety PLC System for all new installations. It should be repeated for all modifications prior to their initial operation. It should be repeated completely after all major turnarounds where work has been done that might impact any Safety PLC System components. For critical safety systems, a periodic repeat of this test may be required, even if known changes have not occurred. The frequency of testing of Safety PLC System components is typically defined in the overall plant risk assessment and shall be used.

The testing after minor maintenance or minor modifications to a Safety PLC System may not require the same level of testing that would be required for initial validation or after major modifications. Procedures should establish whether or not the Safety PLC System is still capable of meeting the safety requirements specifications by appropriate testing. Some sound engineering judgement will obviously be required in this area.

The internal diagnostics which are part of the vendor-supplied system, should not run at a frequency that could have an adverse impact on the sequencing time of the CPU, as it might affect plant safety. It should, however, operate at a frequency no less than that time included in the calculated availability for the equipment.

VII.1.3.1.1 Application Software Testing

This testing or reviewing of the program logic should be completed prior to installation of the system. It should be repeated after any changes are made to control logic or at any time an operating system upgrade is performed.

VII.1.3.1.2 Functional System Testing

This test should be performed prior to placing any Safety PLC System in operation for the first time. It should be repeated any time changes have been made to Safety PLC System logic or when physical changes have been made to arrangement of inputs or outputs. For minimal-risk safety systems, it should be repeated no less than every other year or during the scheduled major turnarounds, whichever is more frequent. For high-risk safety systems, it should be repeated as defined in the overall plant risk assessment, at least annually or at times of major maintenance, whichever is more frequent.

VII.1.4 Plant Operations Training with Installed Controls

If Safety PLC Systems are to perform properly, it is recommended that those who design, install, operate, and maintain the systems be properly trained. A plant management commitment to provide the training is recommended. Since this requires no small commitment of resources, adequate time and money should be allocated prior to the need. Those performing the design configuration may require training in the methods and procedures necessary to accomplish their work. Those who will maintain the equipment may require training in the necessary routine, breakdown and preventive maintenance techniques. Those who will operate the process using this equipment may require training in how to perform the functions required of an operator quickly and efficiently. All of these personnel should be able to perform their functions without compromising a safety function or creating a potentially unsafe condition.

A continuing training effort is just as important as the initial training on the installed system. Provision should be made for providing scheduled training updates for both operations and maintenance personnel to ensure they do not become "rusty" on the use and operation of the Safety PLC System. This should cover not only changes made to the system but also functions that may not be used on a regular basis.

A concept currently being considered in the chemical processing industry is that of certification of operators and maintenance personnel. In such a program, specified skills and abilities would be determined for each job or classification level; the individuals at these levels, or aspiring to them, would be tested to determine their adequacy. This would not be a one-time occurrence, but a scheduled and continuing procedure to ensure that those operating and maintaining e.g. the Safety PLC System equipment are, in fact, qualified to do so. A continuing training program will be a necessary part of such a certification program.

[OSHA 92] also addresses the requirements of training for personnel who have an impact on process safety. This regulation should be consulted in the development of any training programs to ensure those working with Safety PLC Systems meet the requirements.

One method that may be useful in training involves simulation of the safety PLC system

There are four basic operational conditions where specific training in the use of the Safety PLC System equipment is necessary:

- Normal conditions.
- Start-up conditions.
- Shutdown conditions.
- Abnormal conditions.

VII.1.4.1 Normal Conditions

During normal operation of the plant, there are functions that the operator may be required to perform on a regular basis to maintain control of the plant. These include monitoring of:

- Control loop status, automatic or manual.
- Set points.
- The status of any interlocks or safety-related systems.

Training should address the means of accomplishing each of these tasks and also include things to look for that might indicate deviate conditions. This may include:

- Responding to routine alarm messages.
- Identifying input variables that might be false or out of normal bounds.
- Determining inferred flows from control valve positions.
- Comparing the indicated pressure and temperature profiles to those expected.

Training should be specific to the operating plant and process, whenever possible, but generic training in use of equipment, diagnostic procedures, and the like should also be included. Again, it should be stressed that when changes are made, follow-up with training to cover the changes is recommended.

All operating procedures relating to process safety should be reviewed with operations personnel on a regularly scheduled basis. An annual review of these procedures should be considered a minimum.

VII.1.4.2 Start-up Conditions

In general, the most potentially hazardous time in any process is during start-up or shutdown. During training, emphasis should be placed on the transitional nature of these times and the increased potential for problems. Strict adherence to predefined procedures, operational sequences, use of start-up permissives, and perhaps, different variable-controlled levels should be covered in detail. Special requirements such as safety software initialisation and alarm suppression during start-up should also be addressed. The use of training simulators should be considered whenever practical. Areas where strict adherence to procedures/sequence of operation is required for safe operation should be defined and emphasis on why this is necessary should be communicated to operations personnel prior to initial start-up and on a regular basis afterwards to prevent any "forgetting" that might take place due to lack of use.

VII.1.4.3 Shutdown Conditions

In any training program, special emphasis should be given to the shutting down of plants or equipment. This may be especially true when the purpose of shutting down is for the performance of maintenance work. In addition to the normal process-related concerns, emphasis should include the preparation of equipment for direct personnel contact. There may also be special considerations related to the Safety PLC Systems themselves, such as updating to a new software release, testing of any system components, functional testing of any Safety PLC System, or any other work that can only be done when the plant is not in operation. If system re-initialisation is required prior to restart, it should also be covered.

After power-off and shutdown at least in the process industry the process should not be restored to normal operation without manual reset.

VII.1.4.4 Abnormal Conditions

There may be conditions that require advance training relating to abnormal situations in the plant. This might include potential emergency situations arising during the operation of the plant; preparation for on-line maintenance; operation without a backup system, such as reserve power, for some time period; or other similar situations. Operating personnel should be trained in the proper responses to these potential situations. The use of simulation training may prove helpful in this instance also.

VII.2 Modification and retrofit

The objective is to ensure that the target integrity level for the PLC system and external risk reduction facilities is appropriate during and after modification and retrofitting activities have taken place.

Prior to carrying out any modification or retrofit activity procedures should be documented.

The modification and retrofit phase should only be initiated by the issue or an authorised request. The reason for the request could arise from, for example:

- Existing risk reduction not adequate;
- Systematic fault experience;
- New or amended safety legislation;
- Modifications to the equipment under control or its use;
- Modification to the overall safety requirements.

An impact analysis should be carried out which should include an assessment of the impact of the proposed modification or retrofit activity on the functional safety of any safety-related system or external risk reduction facility. The assessment should include a hazard and risk analysis sufficient to determine the breadth and depth to which subsequent Safety Life cycle activities will need to be undertaken. The assessment should also consider the functional safety both during and after the modification and retrofitting activities have taken place.

The information obtained in the Modification/Retrofit Impact Analysis should be recorded.

Authorisation to carry out the required modification or retrofit activity should be dependent on the result of the impact analysis.

All modifications which have an impact on the functional safety of any safety-related system or external risk reduction facility should initiate a return to an appropriate phase of the Safety Life cycle. All subsequent phases should then be carried out in accordance with the procedures for the allocated Safety Integrity Levels for the safety PLC.

It may be necessary to implement a full hazard and risk analysis which may generate a need for different System Integrity Levels for the safety PLC system. All relevant documents should be revised, amended, reviewed, approved and be under the control of an appropriate document quality control scheme.

Information defining modification or retrofit activity, re-verification and revalidation shall be available.

A chronological record should be established and maintained which should record details of all modifications and retrofits.

VII.3 Decommissioning

The objective is to ensure that the target integrity level for the safety PLC is appropriate during and after the decommissioning process of the EUC.

Prior to implementing any decommissioning activity procedures should be documented.

An impact analysis should be carried out which should include an assessment of the impact of the proposed decommissioning process on the functional safety of any safety-related system or adjacent EUCs and the impact on their safety-related systems and external risk reduction facilities. The assessment should include a hazard and risk analysis sufficient to determine external risk reduction facility associated with the EUC. The impact analysis should also consider the breadth and depth that subsequent Safety Life cycle phases will need to be undertaken.

The results obtained in the impact analysis should be recorded.

Authorisation to carry out the required decommissioning should be dependent on the results of the impact analysis.

Prior to decommissioning taking place a plan should be prepared. This should include procedures for:

- the closing down of the PLC system;
- dismantling the PLC system.

If the decommissioning process has an impact on the functional safety of any safety PLC this should initiate a return to the appropriate phase of the Safety Lifecycle. All subsequent phases should then be carried out in accordance with the procedures specified for the allocated System Integrity Levels for the safety-related systems.

NOTE: 1) It may be necessary to implement a full hazard and risk analysis which may generate a need for different Safety Integrity Level for the PLC system and external risk reduction facility.

NOTE: 2) The functional safety requirements during the decommissioning phase may be different from those required during the operational phase.

A chronological record should be established and maintained which should record details of the decommissioning process.

Part VIII Contractual issues

VIII.1 Tender

The tender documents will normally include a full functional specification together with sections covering commercial matters. It is important to ensure that in a tender for the procurement of a safety related system that a section covering safety related matters is also included. Such issues include:

- a statement of the safety aspects to be met by safety related systems
  - an overview of the overall plant process safety strategy
  - where the asked for safety related systems fit into the overall plant process safety
  - the integrity level demanded by the asked for safety PLC arrived at by reference to the overall plant or process safety strategy and the statement on where the asked safety PLC fits into the overall strategy.
- a statement of the basis on which the purchaser will accept that the as supplied safety PLC meets the stated integrity levels
  - a statement on whether particular guidelines and/or standards are to be complied with
  - a statement on how the suppliers should demonstrate to the purchaser conformance to standards / guidelines
  - a statement as to whether or not an independent third party assessment will be required
  - a statement on access requirements by the purchaser or an independent third party assessor to proprietary information relating to the supplied products or to the process used, such as:
    - number and nature of project audits
    - any additional testing or validation & verification to be carried out by the purchaser or a third party
    - a statement on the extent to which the purchaser wishes to witness tests and inspections and monitor the process
    - a statement on the minimum acceptable level of documentation
    - a statement on the nature and timing of any hold points
- a statement on safety specific design requirements
  - have particular levels of probability of failure on demand, availability, spurious activation rate etc. to be met
  - is there a requirement to fail to a preferred state
  - is segregation between redundant safety channels a requirement
  - what is the full range of environmental conditions under which the equipment should function
- a statement of the basis on which the purchaser will accept that the as supplied safety PLC meets the safety specific design requirements
- a statement on the relationship between the purchaser, the supplier and any regulatory body or any internal or external safety body
  - statement identifying any regulatory body, internal or external safety body
  - statement specifying the communication routes and procedures between parties
  - statement specifying the contractual position in relation to this three-way relationship

In all the above the purchaser may choose to invite the supplier to propose statements for negotiation followed by mutual agreement. Where possible it is very desirable that the agreed statements are also endorsed by any internal or external safety body.

VIII.2 Liability

Discuss liability issues in an early stage of the development process. Later it may not be possible. Liability is best covered with a good specification and assessment guideline, especially when design responsibility is attributed explicitly to persons / organisations. Experience and field data after commissioning is also a way to show non-compliance to specification, but it takes a long time before significant data is available and damage may already have occurred.

Appendices

A-1 Hardware questionnaire

1. System level

1.1 General

Does a definitive requirement specification exist?

Does a system overview exist?

Does a quality plan exist?

Has the period of support for the system been specified?

Is training available for the operation of the system?

Are hardware reliability calculations (reliability used here in the generic sense) auditable ?

Has the type of technology been specified?

Are there any intrinsically safe requirements?

What are the maximum and minimum electrical loads?

What are the maximum and minimum loads with respect to throughput or communications terms?

Have communications distances been specified?

Have the electrical noise conditions been specified for communications links?

Have baud rates for the communications links been specified?

Have all modes of operation been specified?

Have maintenance spares been specified?

1.2 Fault tolerance, fault detection

Does a preliminary safety case exist?

> (A *Safety Case* - also referred to as a *safety argument* - is a documented, reasoned argument of why a system is believed to be sufficiently safe to be deployed under given circumstances. Supporting documentation will consist of all relevant information concerning the development, operational history and safety history of the system and can amount to a considerable volume. In industries where a license is required for the operation of equipment, a safety case must be prepared to demonstrate adequate safety to the assessor.)

Does the safety inherently possess self stimulation / testing facilities (e.g. for input and output circuitry?

Has the factory testing philosophy for the system been specified?

Has the philosophy for testing the system during commissioning been specified?

Has the on-line testing philosophy for the system been specified?

Is on-line repair a specified feature?

Has a differentiation been specified between different modes of failure within the reliability analysis ?

Have common mode failure points been specified to be kept to a minimum and identified wherever possible?

Has the level of fault tolerance been specified?

Is memory back-up specified?

Is non-volatile program/data storage media specified?

How is fault tolerance specified (hardware implemented fault tolerance / software implemented fault tolerance)?

Has the level of fault localisation been specified?

Have modes of operation in the presence of faults been specified?

1.3 Environmental constraints

Have EMI / EMC parameters been specified?

Have the operating, maximum and minimum temperatures been specified along with their rates of change?

Has the level of ventilation been specified?

Has the maximum tolerable audible noise been specified?

Have the withstanding levels of the ingress of fungus, solid particles, poisonous and corrosive gasses, liquids and mists been specified?

1.4 I / O, HMI

Have all electronic interfaces to / from the system been specified?

Have all human interfaces with the system been specified?

Have the specified limits for analog and digital signals been specified?

Has the resolution for analog signals been specified?

Are analog inputs and outputs tested on-line?

Are binary inputs and outputs tested on-line, e.g. short circuits ?

Have the output relay circuits been designed according to DIN 0116 (prEN 50156-1) ?

Have the sensor and actuator parameters been specified ?

Have human operator requirements been specified?

1.5 Power supply

Have the power supply requirements been specified?

Are un-interruptible power supplies (UPS) specified?

Is the monitoring of power supplies specified ?

Are redundant power supplies available?

How is the system's earthing to be implemented?

2. Electronic Module / Circuit level

2.1 General

Are fixed rather than variable components used in the design wherever possible?

Where redundancy is used, have considerations been made as to the possibility of common mode failures?

Has the use of limited life expectancy components been kept to a minimum e.g. potentiometers, tantalum bead capacitors, EEPROMS etc.?

2.2 Fault tolerance, fault detection

Does a component level fault tree exist?

Has a failure mode and effect analysis been carried out on each component within the module to assess Overt and Covert modes, and is the level required, i.e. Overt-safe, Overt-dangerous, Covert-safe, Covert-dangerous appropriate for the specified requirements?

Has thermal analysis been carried out for each component or component type i.e. junction to case coefficients, heat sinking requirements, dissipation, hot-spots etc.?

Has sneak circuit analysis (SCA) been carried out?

Has component level fault simulation been carried out?

Have the results of predictions been used to increase reliability by:

reduction of ambient temperature conditions;

reduction of internal temperature rises;

reduction of stresses by further de-rating;

utilisation of redundancy;

increases in quality levels for purchased components?

Has protective circuitry been utilised in the design of the module?

Has the scope of in-service testability been stated and proved through simulation?

2.3 Reliability

Has a reliability prediction been carried out?

Do reliability predictions meet specified criteria?

Does a reliability prediction exist, and have failure rates been apportioned according to the modes as identified above?

Are reliability data traceable to their respective sources ?

A-2 Questions to ask potential suppliers

1. General

1.1. Type of programmable controllers

1.2. Company selling the controllers

1.3. Engineering company developing the system

1.4. How many systems of this type have been installed ?

1.5. References:

1.5.1. Types of applications and start-up dates:

1.5.2. Are records of the service available?

1.6. Manufacturer quality assurance:

1.6.1. Has the manufacturer a certified quality assurance procedure?

1.6.2. Has any third party laboratory assessed or tested the system, hardware or software ? If so, how, what laboratory and are the results available ?

1.6.3. Has any authorised laboratory certified the system ? If so, what laboratory, according to what test program and for which use ?

1.6.4. Have any regulating authorities approved the system? If so, who and for what use ?

2. General presentation of the system

2.1. Methods or tools used for the development

2.2. Architecture:

2.2.1. Schematic diagram (please show clearly the various units of the system: CPU, I/O's, communications, redundancies, test or voting unit, etc...)

2.2.2. Justification of the architecture (based on the following criteria: safety, security, availability, maintainability, reliability, price, market, kind of application etc...)

2.2.3. Is the system designed, constructed and tested according to any guidelines or standards on safety critical programmable systems? If so, what are they ?

2.2.4. Are there other architectures proposed? If so, what are they ?

2.2.5. Functional description of each used unit (programmable controllers, redundancy controller, voter, bus, hardware test unit, etc...)

2.2.6. What is the type of connections between these units ?

2.2.7. Inputs / outputs

How many digital and analog inputs/outputs are allowed? How many are on one card?

How many are controlled together ? How many are tested ?

Are the connections between I/O and other elements duplicated ?

2.2.8 Central processing unit

Time to run a 1 Kbyte application program

Time to run a given test program

2.2.9. Memory

What is the size of the memory for the embedded software and application programs?

What type of memory is used ?

Is the program memory protected against overwriting ?

2.3. System specifics

2.3.1. Description and simplified flow-chart (scanning of I/O, application processing, diagnostics, switching to stand-by, etc...)

2.3.2. Output functioning modes

Functioning type (impulse or permanent)

Maximum response time to a change at the input ?

To what degree is the system claimed to be fail-safe ?

2.3.3. System (embedded) software

Has any software engineering method and tools been used for the development ?

What principles are used to ensure safety integrity of the embedded software ?

Are the manufacturer's software validation and verification procedures and results available ?

Release number of embedded software in the past six months and the past 2 years ?

2.3.4. Other information

2.4. Application software development and maintenance

2.4.1. Description of the programming device

Is it specific? With colour screen ? What type of keyboard ?

Withstanding disturbances (temperature, humidity, vibration and shock, EMC etc.)

Is the device connectable on-line to the programmable controller or to a local area network ?

Must the device be connected for programming ?

May the programming access be locked by hardware or software key ?

2.4.2. Programming aid

2.4.2.1. Software characteristics

Release number of programming device software, in the past six months and the past two years

Describe the software assistance that you furnish

Description of the used languages

In case of programming relying on a sequential function chart structure, is there a real simultaneity of the sequence processing (rule No. 4 of the IEC 848 standard on the synchronous sequential function chart) ?

Do macro-instructions of function blocks exist ? Are they defined by the manufacturer ? (In this case, describe them.) Can the user define them ?

Sub-routines: Do they exist ? Number of levels ? Addressing modes ? May they be parameterised ?

Is self-documentation of logic functions available within the system ?

2.4.2.2. Application program

What method and tools are used to ensure safety integrity of the application software ?

What third party do you recommend for assessment or certification ?

Describe the structuring principles provided

May the executable code be produced by software engineering products ? Specify them.

2.4.3. Assistance to the modification and the maintenance of the application

2.4.3.1. Is there a trace of any software modification ?

2.4.3.2. Simulation

Looping the outputs on the inputs

Other means and possibilities (procedure)

2.4.3.3. Program execution mode:

What are the different modes (line by line, stage by stage, by program cycle, etc...) ?

Can we switch from one to the other ?

2.4.3.4. On-line modifications:

Possibilities for changes: cards, I/O circuits, bypassing, program parameters etc.

Are they performed on the source programs or directly on the program in memory? What is the procedure ?

Is there a possibility to lock the program area ?

2.4.3.5. Input / Output forcing

Possible inhibition of the inputs and outputs: procedure

Is the software forcing maintained during only one cycle or until a new intervention ?

What are the possibilities of hardware forcing of the inputs and outputs ?

2.4.3.6. Dynamic visualisation

What are the visualised elements (timing, counters, process state, relay schemes, active transition or states of a sequential function chart, functional boxes, etc...) ?

What are the parameters which can be modified on the screen ?

What is the refresh period (fixed or expressed in controller cycle number) ?

2.4.3.7. Printing and updating of the application documentation

What are the procedures to edit, update and print the application program and diagrams ?

Can the documentation be done graphically or only literally ? Are comments and cross references printed ?

Is there an automatic indexation of the version at each modification ? How is it done? How many versions are automatically stored ?

Is there an indication of the modified lines and the reasons of the modifications ?

2.4.3.8. Assistance tools for the maintenance of the application

What are the means and the provided functions ?

Is there saving of the information provided by the assistance to the maintenance on temporary power break ? Are they accessible ?

2.5 Physical characteristics of the used programmable logic controllers

2.5.1. Intrinsic characteristics

Is there an integrated forced ventilation ?

Do the connectors enable withdrawing the cards without disconnecting the lines ?

2.5.2. Environment constraints

Storage conditions: humidity, temperature, corrosion, static electricity

Resistance to vibration (standard) ?

Operating conditions

- Environment temperature
- Humidity
- EMC
- Protection index (IP xx) of the programmable controller under operation
- Does the hardware conform to the requirement for a hazardous area utilisation ? Indicate the certificate references and the concerned hardware configuration.
- Has the hardware been subjected to tests in conformity with the GUIDAP protocol or according to dIEC 1508 ?

2.5.3. General characteristics of the power to be supplied to the installation

Voltages: - Tolerances:

Frequencies: - Tolerances:

Power:

Starting current:

Isolation transformer necessity ?

Admissible micro failure duration (e.g., PLC power ride-through capability)

3. **Safety characteristics and detailed description of the operating units**

3.1.Digital and analog Inputs

3.1.1. Schematic and electrical diagram of the input system

3.1.2. Description of the normal operation

3.1.3. Stated reliability

3.1.4. Fault detection

Types of faults detected ?

What is the method of detection ?

Specifically what happens when an analog input goes far over scale, e.g. in a range of 20 mA to 22 ... 30 mA or short-circuited field loop ?

Are there different configurations and methods for pronounced and slow data flow changes ?

How is the result of fault localisation displayed ?

3.1.5. Period and duration of the tests

3.1.6. Maintenance procedure

3.1.7. Action taken in response to fault detection

How are the faults managed by

- the safety system (redundancy - switching to stand-by mode...) ?
- the user ?

Procedure for communicating fault information to the user and other parts of the system:

Justification of action taken according to criteria of:

- safety:
- availability:

Restart procedure:

3.2. Processing unit:

3.2.1. Schematic diagram of the processing unit

3.2.2. Description of normal operation

3.2.3. Stated reliability

3.2.4. Fault detection

Types of faults detected ?

Detection method ?

How is the result of fault localisation displayed?

3.2.5. Period and duration of tests

3.2.6. Maintenance procedure

3.2.7. Action taken in response to fault detection (description of data path)

How are the faults managed by

- the safety system
- the user:

Justification of the action by criteria of

- safety
- availability

Restart procedure

3.3. Power supplies

3.3.1. Schematic and electrical diagram of power supplies partition and fusing (main and auxiliary)

3.3.2. Description of normal operation

3.3.3. Stated reliability

3.3.4. Fault detection

Types of faults detected

- main power supply
- auxiliary power supply

How is detection performed ?

How is the result of fault localisation displayed ?

3.3.5. Period and duration of tests

3.3.6. Maintenance procedure

3.3.7. Action taken in response to fault detection

How are the faults managed by

- the safety system
- the user

Procedure for communicating fault information to the user and other parts of the system

Justification of action by criteria of

- safety
- availability

Restart procedure

3.4. Test system:

3.4.1. Schematic and electrical diagram of the hardware part of the test systems

3.4.2. Description of normal operation

3.4.3. Stated reliability

3.4.4. Fault detection

Types of faults detected

How is detection performed

Are tests performed during safety responses ?

How is the result of fault localisation displayed ?

3.4.5. Period and duration of the tests

3.4.6. Maintenance procedure

Are there specifications and procedures for the system tests ?

3.4.7. Action taken in response to fault detection (description of data path)

How are the faults managed by

- the safety system
- the user

Procedure for communicating the information on faults to the user and to other parts of the system

Justification of the action according to criteria of

- safety
- availability

Restart procedure

3.5. Outputs

3.5.1. Schematic and electrical diagram of the output system

3.5.2. Description of normal operation

3.5.3. Stated reliability

3.5.4. Fault detection

Types of faults detected ?

How is the detection made ?

How is the result of the fault localisation displayed ?

3.5.5. Period and duration of the tests

3.5.6. Maintenance procedure

3.5.7. Action in response to fault detection (description of the data path)

How are the faults managed by

- the safety system (redundancies, switching to stand-by mode...)

- the user

Procedure for communicating information on faults to other parts of the system

Justification of action by criteria of

- safety
- availability

Restart procedure

3.6. Communication system

3.6.1. Schematic diagram of the communication system

3.6.2. Description of normal operation

Protocol types ?

Systems that can be connected

Means for setting up

How specifically is redundant communication to other computers set up ?

3.6.3. Interoperability: which systems (particularly from other suppliers) are able to communicate in the same network ?

3.6.4. Stated reliability

3.6.5. Fault detection

Types of faults detected

Detection method

How is the result of fault localisation displayed ?

3.6.6. Period and duration of tests

3.6.7. Maintenance procedure

3.6.8. Special precautions to set up the medium (impedance adaptation, cable path, etc...)?

3.6.7. Action taken in response to fault detection (description of data path)

How are the faults managed by

- the safety system
- the user

Justification of the action by criteria of

- safety
- availability

Restart procedure

A-3 Safety life cycle related information

Life cycle phase	**Information**
Concept	Overall System Concept
Overall System Definition	Overall System Concept
Hazard and Risk Analysis	Hazard and Risk Management
Overall Safety Requirements	Specification; Overall Safety Requirements - comprising Overall Safety Functions & Overall Safety Integrity.
Safety Requirements Allocation	Safety Requirements Allocation
Overall Operation and Maintenance Planning	Overall Operation and Maintenance
Overall Validation Planning	Overall Safety Validation
Overall Installation and Commissioning Planning	Overall Installation Overall Commissioning
Realisation	Realisation of E/E/PES safety-related systems
Overall Installation and Commissioning	Overall Installation Overall Commissioning
Overall Safety Validation	Overall Safety Validation
Overall Operation and Maintenance	Overall Operation and Maintenance
Overall Modification and Retrofit	Overall Modification Overall Modification/Retrofit Impact Analysis Overall Modification/Retrofit
Decommissioning	Overall Decommissioning Impact Analysis Overall Decommissioning
Concerning all Phases	Safety Verification Functional Safety Assessment

A-4 Abbreviations

AIChE	American Institute of Chemical Engineers
AS	Automation System
BPCS	Basic Process Control System
CCPS	AIChE, Center for Chemical Process Safety
CFC	Continuos Function Chart
DCSC	Distributed Control System Controller
DIN	Deutsches Institut für Normung
DoD	Department of Defence
E/E/PES	Electrical / Electronic / Programmable Electronic System
EWICS	European Workshop on Industrial Computer Systems
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
EN	European Norm
ESD	Emergency Shutdown
ETA	Event Tree Analysis
EUC	Equipment Under Control
FAT	Factory Acceptance Test
FBD	Function Block Diagram
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability study
HDBK	Handbook
HMI	Human Machine Interface
HSE	Health and Safety Executive (UK)
IEC	International Electrotechnical Commission
IL	Instruction List
ITSEC	Information Technology Security Evaluation Criteria
LD	Ladder Diagram
MTBF	Mean operating Time Between Failures
MTTR	Mean Time To Restoration
NAMUR	Normenausschuß für Meß- und Regelungstechnik
NEMA	National Electrical Manufacturers Association (USA)

OSHA	Occupational Safety and Health Administration, US
PES	Programmable Electronic System
PEC	Programmable Electronic Controller
PHA	Process Hazard Analysis
PFD	Probability of Failure (of Safety Action) on Demand
PLC	Programmable Logic Controller
QRA	Quantitative Risk Assessment
SCA	Sneak Circuit Analysis
SFC	Sequential Function Chart
SIL	Safety Integrity Level
SLC	Single Loop Controller
SrS	Safety-related System
SRS	Safety Requirements Specification
ST	Structured Text
TC 7	EWICS Technical Committee 7 on Reliability, Safety and Security
TÜV	Technischer Überwachungsverein
VDE	Verein Deutscher Elektrotechniker
VDI	Verein Deutscher Ingenieure
WG	Working Group

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