

Contents

| | |
|--|-----------|
| 1 Introduction..... | 9 |
| 1.1 Subject of the Book | 10 |
| 1.2 The IEC 61131 standard | 12 |
| 1.2.1 Goals and benefits of the standard | 12 |
| Manufacturers (PLC hardware and software) | 13 |
| Customers | 13 |
| 1.2.2 History and components | 14 |
| 1.3 The OrganisationPLCopen | 16 |
| 1.3.1 Aims..... | 16 |
| 1.3.2 Committees and fields of activity | 17 |
| 1.3.3 Results..... | 18 |
| Certification | 18 |
| Exchange format for user programs | 19 |
| | |
| 2 Building Blocks of IEC 61131-3..... | 21 |
| 2.1 Introduction to the New Standard..... | 21 |
| 2.1.1 Structure of the building blocks..... | 22 |
| Declaration of variables..... | 22 |
| Code part of a POU..... | 23 |
| 2.1.2 Introductory example written in IL..... | 25 |
| 2.1.3 PLC assignment | 27 |
| 2.2 The Program Organisation Unit (POU) | 30 |
| 2.3 Elements of a POU | 32 |
| 2.3.1 Example | 33 |
| 2.3.2 Declaration part..... | 34 |
| Types of variables in POU's..... | 35 |
| Characteristics of the POU interface | 36 |
| The formal parameters and return values of a POU | 37 |
| External and internal access to POU variables..... | 37 |
| 2.3.3 Code part..... | 39 |
| 2.4 The Function Block | 41 |
| 2.4.1 Instances of function blocks | 41 |
| What is an "instance"?..... | 41 |
| Instance means "structure"..... | 43 |

| | |
|---|-----------|
| Instance means “memory” | 45 |
| Relationship between FB instances and data blocks | 46 |
| 2.4.2 Re-usable and object-oriented FBs | 47 |
| 2.4.3 Types of variables in FBs | 48 |
| 2.5 The Function | 48 |
| 2.5.1 Types of variables in functions and the function value | 49 |
| 2.5.2 Execution control with EN and ENO..... | 50 |
| 2.6 The Program | 52 |
| 2.7 Calling Functions and Function Blocks | 53 |
| 2.7.1 Mutual calls of POU..... | 53 |
| 2.7.2 Recursive calls are forbidden..... | 54 |
| 2.7.3 Calling with formal parameters | 56 |
| 2.7.4 Calls with input parameters omitted or in a different order | 59 |
| 2.7.5 FB instances as actual FB parameters..... | 60 |
| Example of an indirect FB call | 62 |
| FB instance names as actual parameters of functions. | 63 |
| Function values as actual parameters. | 63 |
| 2.8 Summary of POU Features | 64 |
| 3 Variables, Data Types and Common Elements..... | 65 |
| 3.1 Simple Language Elements..... | 65 |
| 3.1.1 Reserved keywords | 67 |
| 3.2 Literals and Identifiers | 68 |
| 3.2.1 Literals | 68 |
| 3.2.2 Identifiers | 70 |
| 3.3 Meanings of Data Types and Variables | 71 |
| 3.3.1 From direct PLC addresses via symbols to variables | 72 |
| 3.3.2 The data type determines the properties of variables..... | 73 |
| 3.3.3 Type-specific use of variables | 74 |
| 3.3.4 Automatic mapping of variables onto the PLC..... | 75 |
| 3.4 Data Types | 75 |
| 3.4.1 Elementary data types..... | 76 |
| 3.4.2 Derived data types (type definition) | 77 |
| Additional properties for elementary data types..... | 78 |
| Arrays..... | 80 |
| Data structures. | 81 |
| Initial values in type definitions. | 83 |
| 3.4.3 Generic data types..... | 84 |
| 3.5 Variables | 85 |
| 3.5.1 Inputs, outputs and flags as special variables | 86 |
| 3.5.2 Multi-element variables: arrays and structures | 88 |
| 3.5.3 Assignment of initial values at the start of a program | 90 |
| 3.5.4 Attributes of variable types..... | 91 |
| 3.5.5 Graphical representation of variable declarations..... | 93 |

| | |
|---|-----------|
| 4 The New Programming Languages of IEC 61131-3 | 95 |
| 4.1 Instruction List IL | 96 |
| 4.1.1 Instruction in IL | 96 |
| 4.1.2 The universal accumulator (Current Result)..... | 97 |
| 4.1.3 Operators..... | 100 |
| Negation of the operand..... | 100 |
| Nesting levels by parenthesis..... | 100 |
| Conditional execution of operators..... | 101 |
| 4.1.4 Using functions and function blocks | 104 |
| Calling a function..... | 104 |
| Calling a function block..... | 106 |
| 4.1.5 IL example: Mountain railway..... | 107 |
| 4.2 Structured Text ST..... | 111 |
| 4.2.1 ST statements | 111 |
| 4.2.2 Expression: Partial statement in ST | 113 |
| Operands..... | 113 |
| Operators..... | 113 |
| Function as operator..... | 115 |
| 4.2.3 Statement: Assignment | 116 |
| 4.2.4 Statement: Call of function blocks..... | 118 |
| 4.2.5 Statement: RETURN | 118 |
| 4.2.6 Statement: Selection and Multi- selection | 119 |
| Selection..... | 119 |
| Multi- selection..... | 120 |
| 4.2.7 Statement: Iteration..... | 122 |
| WHILE and REPEAT statements..... | 122 |
| FOR statement..... | 123 |
| EXIT statement..... | 125 |
| 4.2.8 Example: Stereo cassette recorder | 125 |
| 4.3 Function Block Diagram FBD | 128 |
| 4.3.1 Networks, graphical elements and connections of LD and FBD..... | 128 |
| Network label..... | 128 |
| Network comment..... | 129 |
| Network graphic..... | 129 |
| 4.3.2 Network architecture in FBD..... | 131 |
| 4.3.3 Graphical objects in FBD | 133 |
| Connections..... | 134 |
| Execution control (jumps)..... | 134 |
| Call of functions and function blocks..... | 135 |
| 4.3.4 Programming methods in FBD | 136 |
| Network evaluation..... | 136 |
| Feedback variable..... | 137 |
| 4.3.5 Example: Stereo cassette recorder | 137 |
| Comments on the networks of Example 4.24 and Example 4.31..... | 140 |

| | |
|--|------------|
| 4.4 Ladder Diagram LD | 141 |
| 4.4.1 Networks, graphical elements and connections (LD) | 141 |
| 4.4.2 Network architecture in LD | 141 |
| 4.4.3 Graphical objects in LD | 142 |
| Connections. | 142 |
| Contacts and coils. | 143 |
| Execution control. | 147 |
| Call of functions and function blocks. | 148 |
| 4.4.4 Programming methods in LD | 149 |
| Network evaluation. | 149 |
| Feedback variable. | 151 |
| 4.4.5 Example in Ladder Diagram: Mountain railway | 153 |
| Comments on the mountain railway networks | 156 |
| 4.5 The American way of Ladder programming | 159 |
| 4.5.1 Network Layout | 159 |
| 4.5.2 Module addresses and memory areas | 161 |
| 4.5.3 Configuration | 163 |
| 4.6 Sequential Function Chart SFC | 164 |
| 4.6.1 Step / Transition combination | 165 |
| 4.6.2 Step - transition sequence | 167 |
| 4.6.3 Detailed description of steps and transitions | 172 |
| Step. | 172 |
| Transition. | 174 |
| 4.6.4 Step execution using action blocks and actions | 179 |
| 4.6.5 Detailed description of actions and action blocks | 181 |
| Actions. | 181 |
| Action block | 182 |
| 4.6.6 Relationship between step, transition, action and action block | 185 |
| 4.6.7 Action qualifiers and execution control | 189 |
| Qualifier. | 189 |
| Sequential control. | 195 |
| 4.6.8 Example: “Dino Park” | 196 |
| Comments on the network for the dinosaur park | 200 |
| 5 Standardised PLC Functionality | 201 |
| 5.1 Standard Functions | 202 |
| 5.1.1 Overloaded and extensible functions | 206 |
| Overloaded functions | 206 |
| Extensible functions | 208 |

| | |
|---|------------|
| 5.1.1 Examples..... | 209 |
| Type conversion functions..... | 210 |
| Numerical functions..... | 211 |
| Arithmetic functions..... | 211 |
| Bit-shift functions..... | 212 |
| Bitwise Boolean functions..... | 212 |
| Selection functions..... | 213 |
| Comparison functions..... | 214 |
| Character string functions..... | 215 |
| Functions for time data types..... | 215 |
| Functions for enumerated data types..... | 216 |
| 5.2 Standard Function Blocks..... | 217 |
| 5.2.2 Examples..... | 218 |
| Bistable element (flipflop)..... | 220 |
| Edge detection..... | 221 |
| Counter..... | 223 |
| Timer..... | 224 |
| 6 State-of-the-Art PLC Configuration..... | 227 |
| 6.1 Structuring Projects with Configuration Elements..... | 227 |
| 6.2 Elements of a Real-World PLC Configuration..... | 228 |
| 6.3 Configuration Elements..... | 230 |
| 6.3.1 Definitions..... | 230 |
| 6.3.2 The CONFIGURATION..... | 231 |
| 6.3.3 The RESOURCE..... | 232 |
| 6.3.4 The TASK with run-time program..... | 233 |
| 6.3.5 ACCESS declarations..... | 236 |
| 6.4 Configuration Example..... | 237 |
| 6.5 Communication between Configurations and POU's..... | 240 |
| 7 Innovative PLC Programming Systems..... | 243 |
| 7.1 Requirements of Innovative Programming Tools..... | 243 |
| 7.2 Technological Change..... | 244 |
| 7.2.1 Processor performance..... | 244 |
| 7.2.2 Full-graphics display and printout..... | 244 |
| 7.2.3 Operating systems..... | 244 |
| 7.2.4 Uniform user interfaces..... | 245 |
| 7.3 Decompilation (Reverse Documentation)..... | 245 |
| 7.3.1 No decompilation..... | 246 |
| 7.3.2 Decompilation with symbols and comments..... | 246 |
| 7.3.3 Decompilation including graphics..... | 246 |
| 7.3.4 Sources stored in the PLC..... | 247 |
| 7.4 Language Compatibility..... | 247 |

| | |
|--|------------|
| 7.4.1 Cross-compilation | 248 |
| The motivation for cross-compilation | 248 |
| Different approaches in graphical and textual languages | 249 |
| Differences in languages affect cross-compilation..... | 250 |
| Restrictions in LD/ FBD..... | 251 |
| Restrictions in IL/ ST..... | 251 |
| Cross-compilation IL / ST..... | 251 |
| Full cross-compilation only with additional information | 252 |
| Quality criteria for cross-compilation..... | 253 |
| 7.4.2 Language independence..... | 254 |
| 7.5 Documentation..... | 255 |
| 7.5.1 Cross-reference list | 255 |
| 7.5.2 Allocation list (wiring list)..... | 256 |
| 7.5.3 Comments | 257 |
| 7.6 Project Manager..... | 257 |
| 7.7 Test & Commissioning Functions..... | 261 |
| 7.7.1 Program transfer | 261 |
| 7.7.2 Online modification of a program | 262 |
| 7.7.3 Remote control: Starting and stopping the PLC | 263 |
| 7.7.4 Variable and program status | 263 |
| 7.7.5 Forcing..... | 267 |
| 7.7.6 Program test..... | 268 |
| 7.7.7 Testing Sequential Function Chart programs | 269 |
| 7.8 Data Blocks and Recipes | 269 |
| 7.9 FB Interconnection | 273 |
| 7.9.1 Data exchange and co-ordination of blocks in distributed systems | 273 |
| 7.9.2 Macro techniques in FB interconnection | 275 |
| 7.10 Diagnostics, Error Detection and Error Handling..... | 276 |
| Error concept of IEC 61131-3..... | 277 |
| Extended error handling model (beyond IEC)..... | 277 |
| 7.11 Hardware-Dependence..... | 279 |
| 7.12 Readiness for New Functionality..... | 279 |
| 7.12.1 Exchange of programs and data..... | 280 |
| 7.12.2 Extension with additional software packages | 281 |
| 8 Main Advantages of IEC 61131-3..... | 283 |
| 8.1 Convenience and Security with Variables and Data Types | 283 |
| 8.2 Blocks with Extended Capabilities | 284 |
| 8.3 PLC Configuration with Run-Time Behaviour..... | 285 |
| 8.4 Uniform Programming Languages | 286 |
| 8.5 Structured PLC Programs | 286 |
| 8.6 Trend towards Open PLC Programming Systems | 286 |
| 8.7 Conclusion | 288 |

| | |
|---|------------|
| 9 Programming by Configuring with IEC 61499 | 289 |
| 9.1 Programming by FB Interconnection with IEC 61131-3..... | 289 |
| 9.2 IEC 61499 – The Programming Standard for Distributed PLC Systems..... | 290 |
| 9.2.1 System model..... | 291 |
| 9.2.2 Device model..... | 291 |
| 9.2.3 Resource model..... | 292 |
| 9.2.4 Application model..... | 293 |
| 9.2.5 Function block model..... | 294 |
| Composite function blocks..... | 296 |
| 9.2.6 Creating an application..... | 298 |
| 9.3 Overview of the Parts of IEC 61499..... | 298 |
| 10 Contents of CD-ROM | 299 |
| 10.1 IEC Programming Systems STEP 7 and OpenPCS..... | 299 |
| Demo versions of STEP 7 (Siemens) and OpenPCS (infoteam)..... | 299 |
| IL examples..... | 300 |
| 10.2 Buyer's Guide for IEC 61131-3 PLC Programming Systems..... | 300 |
| A Standard Functions | 301 |
| A.1 Type Conversion Functions..... | 302 |
| A.2 Numerical Functions..... | 303 |
| A.3 Arithmetic Functions..... | 304 |
| A.4 Bit-Shift Functions..... | 305 |
| A.5 Bitwise Boolean Functions..... | 306 |
| A.6 Selection Functions for Max., Min. and Limit..... | 307 |
| A.7 Selection Functions for Binary Selection and Multiplexers..... | 308 |
| A.8 Comparison Functions..... | 310 |
| A.9 Character String Functions..... | 311 |
| A.10 Functions for Time Data Types..... | 313 |
| A.11 Functions for Enumerated Data Types..... | 314 |
| B Standard Function Blocks | 315 |
| B.1 Bistable Elements (Flip-Flops)..... | 316 |
| B.2 Edge Detection..... | 317 |
| B.3 Counters..... | 318 |
| B.4 Timers..... | 320 |
| C IL Examples | 323 |
| C.1 Example of a FUNCTION..... | 323 |
| C.2 Example of a FUNCTION_BLOCK..... | 325 |
| C.3 Example of a PROGRAM..... | 327 |
| D Standard Data Types | 331 |
| E Causes of Error | 333 |

| | |
|--|------------|
| F Implementation-Dependent Parameters | 335 |
| G IL Syntax Example | 339 |
| G.1 Syntax Diagrams for IL..... | 340 |
| G.2 IL Example from Syntax Diagrams..... | 347 |
| H Reserved Keywords and Delimiters | 349 |
| H.1 Reserved Keywords..... | 349 |
| H.2 Delimiters..... | 353 |
| I Planned Amendments to the Standard | 357 |
| J Glossary | 359 |
| K Bibliography | 365 |
| L Index | 369 |
| Author Biographies | 375 |
| Karl-Heinz John | 375 |
| Michael Tiegelkamp | 375 |