OOP with S7-SCL implemented to plastic welding machines

Thesis

TO ACHIEVE THE ACADEMIC DEGREE OF

Master in Mechatronics

BY

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Santiago de Queretaro, Qro., Mexico, February 2017

Declaration of authorship

I hereby declare that the following thesis submitted was made by my own and all sources are acknowledged as references.

This thesis has not been previously published or presented to another examination before.

Querétaro, February 2017 Hilario Salomón Galván Guzmán

Acknowledgements

I would like to show my gratitude to my thesis advisor Prof. Jörg Wollert of the FH-Aachen. He was always willing to help me and steering me in the right direction to make a good master thesis. I thank the directive of the company WIDOS for giving me the opportunity to develop this project. Dr. Kai Dombrowski and colleagues were always in the best disposition to help me.

I would also like to acknowledge Conacyt and CIDESI in Mexico for give me the support and resources to study in the FH-Aachen.

I want to thank God for my life and blessings. I express my gratitude to my parents for their love and trust in me. I thank my cousins in UK and Mexico for their support. I thank my girlfriend and her family for their disposition to help. And lastly to all my Mexican and German friends for their support and friendship.

Abstract

Many programmable logic controller (PLCs) are available in today's market. The international norm IEC 61131-3 is a standard for PLCs software development and usage. Nevertheless, Siemens, a major manufacturer of PLCs applies the norm IEC 61131-3 in its programming software only partly and is not able to do object oriented programming (OOP). The goal of this master thesis is to find out a strategy to transfer OOP code from CoDeSys V3.5 to Siemens TIA Portal V13 applying the norm IEC 61131-3:2013. The master project was carried out at Wilhelm Dömmer und Söhne (WIDOS), which develops a re-engineering project for their machines. In this thesis a new strategy was developed to overcome this problem. Firstly, Model Bases System Engineering (MBSE) was used for an object oriented design of the project in SysML. Secondly, the model was applied with CoDeSys, a programming software able to do OOP that fulfils the norm IEC 61131-3. Finally, the transfer strategy was applied using the Siemens PLC S7-1200 programmed in Structured Control Language (SCL) . The result is a package of transfer rules to reuse programming modules converting code from CoDeSys to Siemens TIA Portal.

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List of Abbreviations

CAN	Controlled Area Network
CNC	Computer Numeric Control
CoDeSys	Controller Development System
FB	Function Block
FBD	Function block diagram
FC	Function
HMI	Human Machine Interface
HSC	High Speed Counters
IEC	International Electrotechnical Commission
LD	Ladder diagram
MBSE	Model-based Systems Engineering
OB	Organization Block
OOP	Object Oriented Programming
PLC	Programmable Logic Controller
POU	Program Organization Unit
PRG	Program (In CoDeSys)
PROFINET	Process Field Network
SB	Signal Board
SCL	Structured Control Language
ST	Structured Text
STL	Statement List
SysML	System Modelling Language
TIA Portal	Totally Integrated Automation Portal
UDT	User Data Types

1 Introduction

After the industrial revolution, the amount of factories or manufacturing plants have been rapidly increasing. With this, the development in technology and machinery has also been promptly rising.

Modern factories, have automated systems to manufacture different products. In order to make a new system, it is important to make an analysis and design. To achieve this, the Model Based System Engineering (MBSE) was created. MBSE is an approach to realising successful systems. These models can be designed with SysML, a graphical modelling language for systems development.

Today, Programmable Logic Controllers (PLC) are used to reproduce system models of many factories. PLCs are able to control automated system in real time, for example production lines of a car assembly.

Nowadays, there are different types and brands of PLCs. Every company that has manufacturing plants has its own PLC preferences. Consequently, the International Electrotechnical Commission (IEC) created the norm IEC 61131. The object of the norm is the regularizations of the PLCs in every possible aspects like programming, communication, security, etc.

The third section of the norm deals with the software architecture, programming model and programming languages. The newest version of this section is from 2013 and includes the Object Oriented Programming (OOP). The application of the norm allows to build more complex and larger programming systems required today.

Siemens, a major PLC manufacturer, has its own software product to program their PLCs called *TIA Portal*. This software applies the norm in a specific way that includes the programming languages accepted by the norm but totally excludes the OOP, among other things. In contrast, the company 3S completely implements the norm in its software product after the version CoDeSys V3. This software has become now the standard software for PLC programming also involving OOP.

1.1 Problem statement

WIDOS, is a German company that manufactures equipment used in the construction of ditches. The principal products that the company manufactures are plastic welding machines.

In order to be more competitive, WIDOS develops a project to re-engineer their CNC method. Apart of this project, there is the master thesis performed by Tilmann Glücks in collaboration with the FH-Aachen [Glu16]. This master project consisted in two parts:

1. Making a reverse-engineering analysis of the WIDOS WI-CNC welding machine. Taking this analysis as a base, for a new object oriented design modelled in SysML.
2. Realising the model design with CoDeSys, a PLC programming system by using object oriented patterns and coding strategies.

Notwithstanding, the company has clients that request equipment controlled by Siemens PLCs. Due to this demand, there is a third step in the project:

3. Finding out translation rules to convert OOP in Structured Text (ST) language to TIA Portal in Structured Control Language (SCL).

1.2 Objective

The aim of this master thesis is to create a method to transfer code from CoDeSys V3.5 to Siemens TIA Portal V13. During the code transfer, the qualities and information of the original program should not be lost. The result is a strategy to convert object oriented CoDeSys code in ST to Siemens SCL by the usage of defined translation rules. Main scope of this rules is the adaptation of OOP to Siemens implementing the IEC norm. To prove the functionality of the method, the program was tested in the prototype machine *WI-CNC* of the WIDOS company.

The goal of the translation rules is to reuse programming structure and code. Achieving this, the company rises the efficiency of manufacturing process by reducing programming times.

2 State of the art

2.1 WIDOS WI-CNC

The machine WI-CNC of the company WIDOS is a trench welding machine for plastic tubes. It is made to operate in the construction site, for example, in the construction of pipe lines for sewage systems.

The name WI-CNC is because of the CNC (Computer Numeric Control) precision of the machine. The welding process for plastic tubes requires of a high precision. The tubes must be perfect aligned and without irregularities for a good welding quality.

The operation principle of the machine is shown in the Figure 2-1.

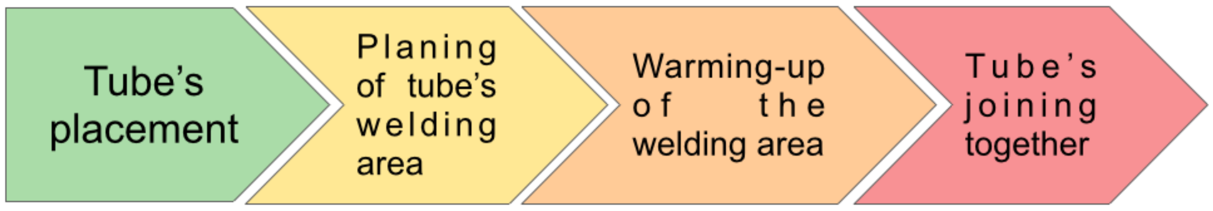

Tube's placement
Planing of tube's welding area
Warming-up of the welding area
Tube's joining together

Figure 2-1: Operation principle of the WI-CNC machine

1. The first step is about placing and fastening the tubes to weld in the machine.
2. The second step is to prepare the tube's area to be welded. Both tubes must be precisely aligned without irregularities.
3. Third step is the warming-up of the tube's welding area.
4. Fourth and last step is pressing both tubes to each other to join them together.

2.1.1 The WIDOS WI-CNC welding machine and their parts

The plastic welding machine WI-CNC and its principal parts are shown in Figure 2-2. It is important to know relevant parts of the machine for the better understanding of the program.

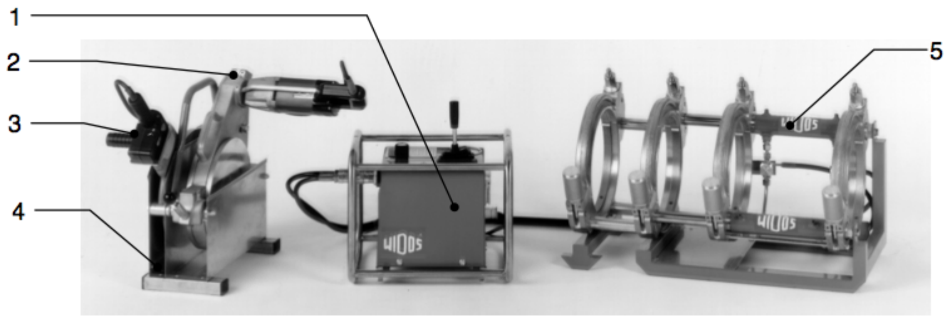


Figure 2-2: The composition of the WI-CNC machine [WID12]

1. Hydraulic control unit
2. Planner
3. Heating element
4. Placement case
5. Base machine with hydraulic actuators

The *hydraulic control unit* is the most important component of the WI-CNC, consists in sensors and actuators for the welding process. It comprise:

- Electro-valves: for the movement of the base machine.
- Pressure sensors: to measure the pressure in the input and output of the hydraulic control unit.
- Hydraulic pump: it generates oil pressure for the operation of the hydraulic control unit. It is controller with a frequency regulator controlled by an analogue voltage signal.

To the hydraulic control unit are all other components connected through the physical interface shown in Figure 2-3. The number 12 indicates the socket connector for the heating element, which is controlled with a CAN/230 V board. Number 16 show a 230 V socket to connect the planner. Numbers 13 and 14 are input and outputs coupling plugs, respectively. Through these connectors flow the oil to the base machine. Number 10 indicates the connector for the linear encoder in the base machine.

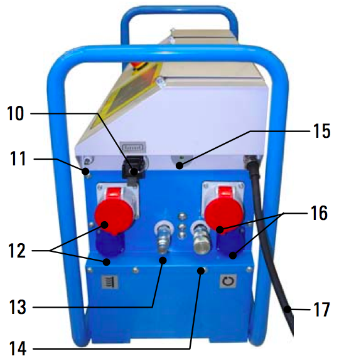


Figure 2-3: Hydraulic control unit [WID15b]

The *planner* is used for planing the contact surface of the tubes. That is to remove the oxidation and align the tubes in parallel. The functionality is similar to a grinder for shaping metal materials. This element is activated by a button in the device. Figure 2-4.

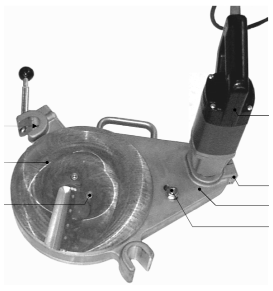


Figure 2-4: Planner [WID15b]

The *heating element* is for warming up the welding area of the tubes. Every material has a different welding temperature and welding time. For this reason, it is important to have a control over this device, a minor difference in the temperature can affect the welding process. The *heating element* has a controller inside. The set point for the controller is realised by an analogue input provided by the PLC. Figure 2-5.

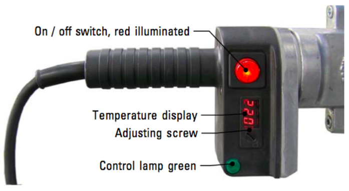


Figure 2-5: Heating element [WID15b]

The *base machine.* This device is used to hold and move the tubes for the welding process. One tube is fixed on the base machine and manually fastened. The another tube is mounted in the hydraulic moving sled. Both parts can be adjusted by a manual alignment system. Lastly a linear encoder is able to measure the exact position of the tubes. Figure 2-6.

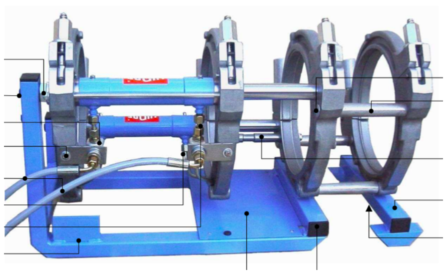


Figure 2-6: Base machine [WID15b]

2.1.2 WIDOS WI-CNC hardware control

The panel PC *smart9 T070B* of the company epis is used for automation and visualisation. The system is consists by a touch screen TFT of 7" and a micro-controller board with an operation system (OS) WinCE 6.0 R3. The Figure 2-7 shows the panel PC.

The OS Windows Embedded CE or WicCE is the operating system of Windows targeted to enterprise specific tools such as industrial controllers and consumer electronics devices. The latest release of the OS was the WinCE 6.0 R3.

Figure 2-7: Panel PC Smart 9

The CPU processor ARM11 of the smart9 has the following characteristics.

Clock frequency	532 MHz
Nand-Flash	256 MB
RAM	128 MB DDR2
EEPROM	32 kByte
Slot for micro-SD Card	MicroSDHC max 32 GB

2.1.3 Connection interfaces

The panel PC smart9 has different connection interfaces for the control of hardware:

- 24 V digital I/Os
- Ethernet
- RS232
- RS248
- USB
- CAN

2.1.3.1 CAN bus

The WI-CNC uses the CAN interface to control external hardware.

The Controlled Area Network (CAN) is a serial communication protocol, that is primary used in the automotive industry. Because of its real time behaviour, it is also used in the automation industry.

The smart9 panel PC allows up to 64 participants in the CAN bus, according to the CANopen protocol. All the different sensor and actuators are connected to the panel PC through the CAN interface with an specific identification.

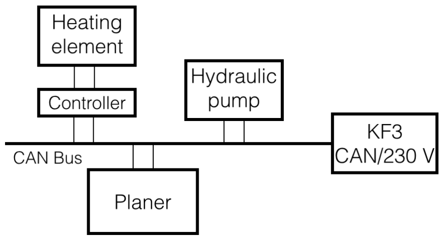
The WI-CNC has two peripheral boards.

1. The board *KF3* [WID15a] is a 230 V I/O interface for components like the heating element, the planner and the hydraulic pump. The heating element has an extra

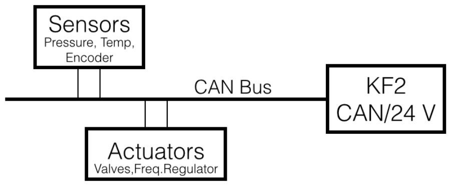
control for the temperature regulation. The board communicates the 230 V I/O elements with the CAN interface of the panel PC. The Figure 2-8a shows the CAN bus connection of these elements.

2. The board *KF2* [WID15a] is an 24 V I/O interface for the elements that require 24 V for their operation like pressure sensors and valves. Additionally is there connected the linear encoder, which operates with 5 V. This bus communication is shown in Figure 2-8b.

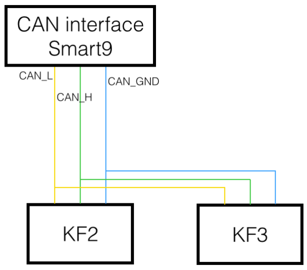
Both CAN boards are connected to the CAN interface of the Smart9 (Figure 2-8c).



(a) CAN bus of the 230 V board



(b) CAN bus of the 24 V board



(c) CAN bus connection to the Smart9

Figure 2-8: CAN bus connection of the WI-CNC

2.2 Siemens S7-1200

The Siemens S7-1200 1214C (DC/DC/DC) is the PLC used along the project. This PLC was selected because it is the most complete and cheaper Siemens PLC with an architecture of the new generation. This PLC is programmed with the TIA Portal and the older versions S7-200/300 do not have this software and its features.

The processes are handled by the PLC in order to control the I/Os of the machine. The PLC and its description is shown in the Figure 2-9. All the details about the PLC can be found in the S7-1200 System Manual [Sie16] in the Siemens web page.

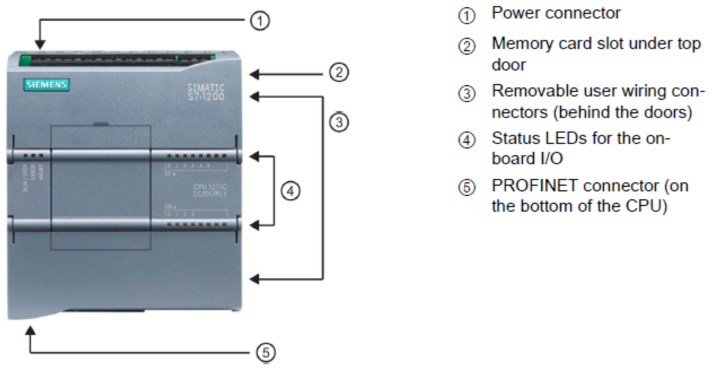

① Power connector
② Memory card slot under top door
③ Removable user wiring connectors (behind the doors)
④ Status LEDs for the on-board I/O
⑤ PROFINET connector (on the bottom of the CPU)

Figure 2-9: Physical description of the S7-1200 PLC [Sie16]

2.2.1 Connection interfaces

2.2.1.1 Digital I/O

The PLC S7-1200 has 14 digital input ports at the top of the PLC and 10 digital outputs at the bottom. The rated voltage of the I/Os is 24 V. The PLC has status LEDs to visualise the behaviour of the I/Os. These LEDs are indicated with the number four in the Figure2-9.

The I/Os are used to control the actuators of the machine. This PLC does not need a CAN/24 V board to interact with the components of the machine, instead the components are directly connected to the PLC.

The digital inputs can be used as High Speed Counters (HSC), there are up to 6 available in this PLC. The pins Ia0[1] to Ia5 are able to count up to 100 kHz pulses and the inputs Ia6 to Ib5 can read pulses up to 30 kHz. In this project it is essential to use the HSC in order to read the linear encoder signals.

2.2.1.2 Analogue I/O

The PLC has two analogue inputs on board. The full scale range is from 0 to 10 V with a resolution of 10 bits. The data word range is from 0 to 27648.

This inputs are used to read analogue signals like the pressure or temperature sensors. The outputs give analogue signals used to regulate the pressure allowance of the pro-

[1]This is an Input of the port A, pin 0

portional valve and the frequency regulator for the hydraulic pump.

2.2.1.3 Signal Board

The S7-1200 family provides a variety of plug-in boards for expanding the capabilities with additional I/Os. For this project, the Signal Board (SB) 1221 was chosen, shown in Figure 2-10. This SB has the particularity to have four digital inputs, the ones that can be used as HSC. They are two times faster than the HSC on board being able to read signals at a speed of 200 kHz at 5 V, which is perfect for the linear encoder used in the WI-CNC welding machine. This linear encoder sends a 5 V pulse every 0,1 mm of displacement.

Figure 2-10: SB 1221 DI 4x5 200 kHz

2.2.2 HMI

The Human Machine Interface (HMI) used for the project is the KTP700 PN shown in Figure 2-11. It is a 7” touch screen with 8 additional buttons at the bottom of it. The HMI is connected via PROFINET with the PLC and can interact with the variables of the program loaded in the PLC program. The touch screen is programmed with TIA Portal and it can be programmed simultaneously in the same project of the CPU.

Figure 2-11: HMI KTP 700

In comparison with the Smart9, this HMI is decentralised from the CPU connected via PROFINET with the PLC.

2.2.3 I/O PROFINET Module

The SIMATIC ET 200SP is a decentralised peripheral system able to distribute I/O processing signals to a central controller via PROFINET. The SIMATIC ET 200SP is installed on a mounting rail and generally comprises three parts: [AG17]

1. An interface module, which communicates with all the controllers that behave according to the PROFINET standard IEC 61158,
2. Up to 64 I/O modules, which are plugged into passive base units in any combination
3. A server module, which completes the structure of the SIMATIC ET 200SP.

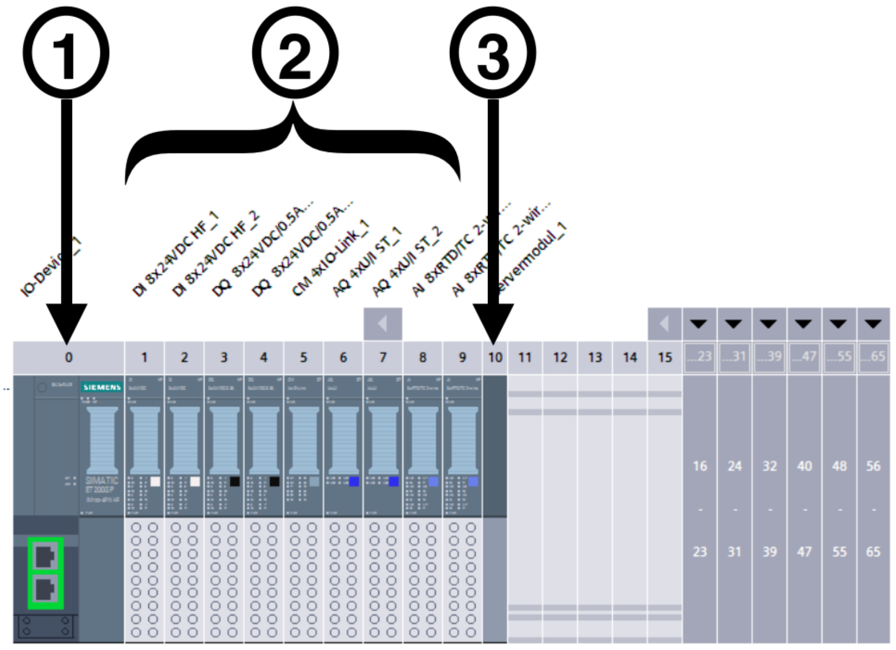


Figure 2-12: Composition of the SIMATIC ET 200SP

The configuration for the project includes one SIMATIC ET 200 SP with I/O modules. Two of this modules are very important for the development of the project, which are analogue modules for the processing signals of sensors and actuators.

The first module is an analogue output module AQ 4xU/I ST. It has four outputs and can be configured as follow:

- Current output
  - ±20 mA, resolution 16 bits including sign
  - 0 to 20 mA, resolution 15 bits
  - 4 to 20 mA, resolution 14 bits
- Voltage output
  - ± 10 V, resolution 16 bits including sign
  - ± 5 V, resolution 15 bits including sign
  - 0 to 10 V, resolution 15 bits
  - 1 to 5 V, resolution 13 bits

The second is the analogue input module AI 8xRTD/TC 2-wire HF specially selected for the analogue signals of the machine like the pressure and temperature sensors. This module is made by Siemens specially for industrial sensors and has the following specifications:

- Resolution: Up to 16 bits including sign
- Voltage measurement (perfect for the pressure sensors)
- Resistor measurement
- Thermal resistor (RTD)
- Thermocouple (TC)

Every module can be easily mounted and dismounted as seen in the Figure 2-13.

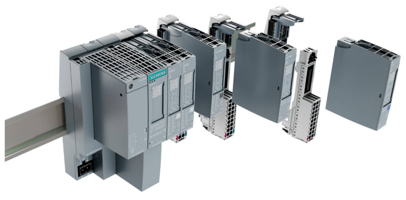


Figure 2-13: PROFINET module ET 200SP breakout [AG17]

2.3 PLC Software

2.3.1 Normative IEC 61131-3

The normative IEC 61131-3 of the International Electrotechnical Commission (IEC) is a specification for PLC programming, not as a rigid set of rules. PLC manufacturers choose if they want to conform the standard or not. [JT10]

The IEC 61131-3 recognises five programming languages in the latest version of 2013: two graphical, two textual and one graphical-textual PLC programming languages: [CEN13]

- Ladder diagram (LD), graphical
- Function block diagram (FBD), graphical
- Structured text (ST), textual
- Instruction List (IL), textual
- Sequential Function Chart (SFC), graphical-textual

The norm not only describes the PLC programming languages themselves, but also offers comprehensive concepts and guidelines for creating PLC projects.

The latest actualization of the norm includes the concept of OOP. That means that new elements of OOP are comprehended like: classes, interfaces and methods. The norm details all this elements and proposes rules to use them. For example, how to declare a new element, how and when can the element be called, what kind of variables can have the element, etc.

The norm proposes a list of configuration elements, POUs, section variables, data types and variable names that a PLC system project should comply with, in order to follow the standard. The norm also details the declaration and use of these elements.

After the introduction and the proposed programming languages, the norm begins to detail how a PLC system should be done. The norm defines an architecture model composed of three parts.

1. Software model
2. Communication model
3. Programming model

2.3.1.1 Software model

The architecture software model of the norm is shown in the Figure 2-14. The diagram includes elements that are programmable during the application of the languages, which are in the norm defined. These elements are: *programs, function blocks, classes, functions* and *elements of configuration* like: *configurations, resources, tasks* and instance specific initializations.

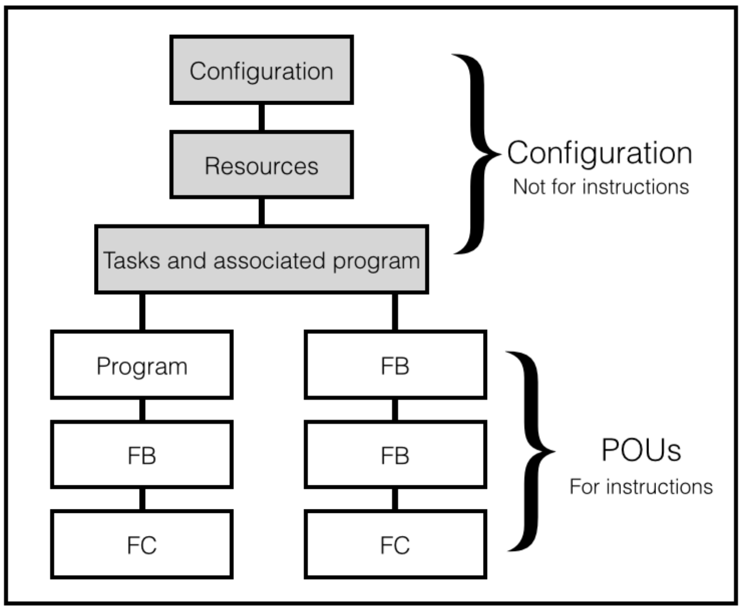


Figure 2-14: Software model according to the IEC 61131-3

Function blocks are a superset of classes and interfaces, that means that classes and interfaces are inside the concept of FB. Nevertheless, the norm declares these three elements individually. In the same way, methods are detailed separately from functions even when methods are a subset of FCs.

The principal elements of the configuration are the following ones:

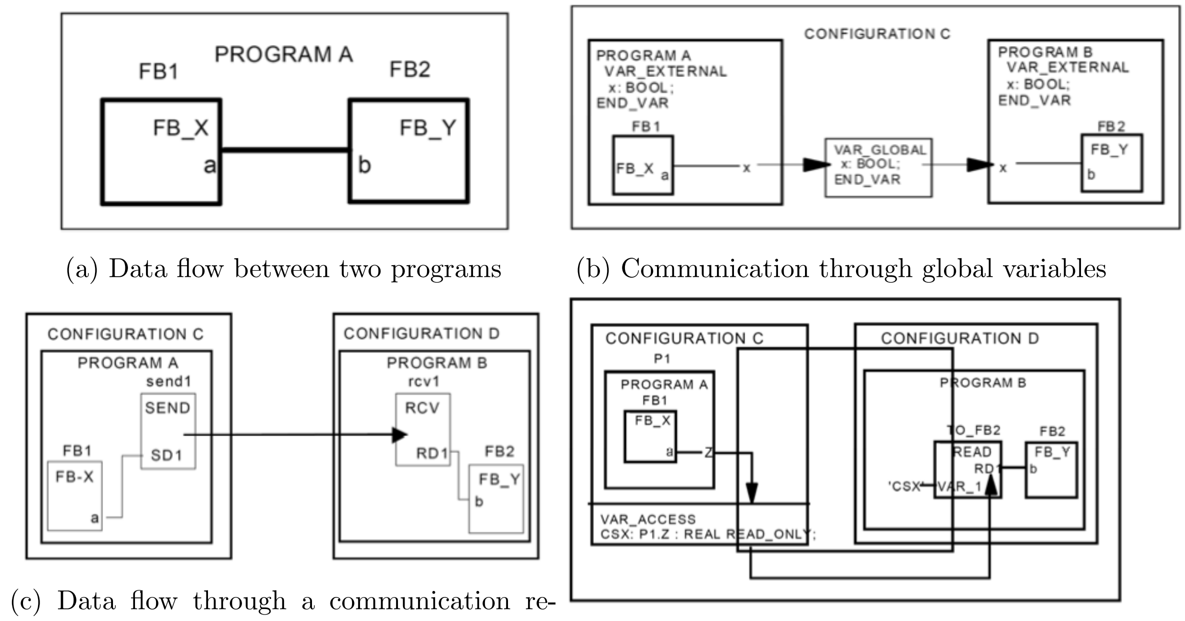
- A *resource* is defined in the IEC 61131-1 as a signal processing function. A resource is an element of the PLC, for example a HMI and its signals. It processes the signals of the sensors and actuators that are implicated in the PLC.
- A *configuration* is a language element that has one or more *resources.* These resources can have one or more *programs.* These programs are under the control of null or more *tasks.*

- A *program* can have null or more instances of *function blocks* or any other language elements that in this norm are mentioned.
- A *task* has the ability to activate *programs* or instances of FB e.g. cyclic activities.

2.3.1.2 Communication model

This section details a standard way to exchange values between variables and software elements. The value's exchange can be made in any of the following ways:

- The data flow can be made inside of a program. The data flows between the output of a programming element to the input of another. Figure 2-15a.
- The values of variables are able to go from one program to another only if both of them are in the same configuration. The data exchange is done through global variables. Figure 2-15b.
- Data can flow between different configurations if there is a communication resource making a connection between the elements. Figure 2-15c.
- It is possible to make a communication between SPS and not-SPS systems between an access path. Figure 2-15d.



(a) Data flow between two programs

(b) Communication through global variables

(c) Data flow through a communication resource

(d) Communication through access path

Figure 2-15: Communication model [CEN13]

2.3.1.3 Programming model

The programming model are the rules to call and use POUs in the for the programming structure.

1. Programs must be declared. Inside them, standard or UDT data, functions, FB and classes can be used.

2. A program can be performed in different configurations. In it, elements can be used like global variables, resources, tasks and access paths.

3. Function blocks-type can be declared. Inside them, standard or UDT data, functions or other function blocks can be used. In addition, object oriented FB and classes must be defined in order to use methods and interfaces.

4. Functions can be declared. Inside them, standard or UDT (user defined type) data, standard or user defined functions can be used.

5. Data types must be declared.

2.3.2 CoDeSys

CoDeSys is a software developed by the German company *3S-Smart Software Solutions* and is a global established system platform for industrial applications. From the third version, CoDeSys implements the Norm IEC 61131-3:2013 even including OOP.

CoDeSys is a complete, integrated development environment (IDE) able to support the most common industrial CPU architectures. It can be ported to almost all operating systems or to devices without operating system. The integrated CAN/CANopen-support provides a genuine added value for embedded applications [Sol17].

Due to the before mentioned advantages, CoDeSys was chosen for the development of the first part of the project. A framework application was built in CoDeSys based on the design made in SysML. With this, the second part of the project was carried out.

From the listed programming languages in the norm, structured text (ST) was chosen for the project. ST is the standard language for PLC programming systems. In contrast with IL, ST offers more structured possibilities being better for complex programming systems.

2.3.3 Siemens TIA Portal

The Totally Integrated Automation Portal v13 (TIA Portal) is the software product of Siemens to program their PLCs. However, TIA Portal is not as flexible as CoDeSys and it cannot build embedded systems.

Siemens documents all the parts of the norm that TIA Portal fulfils. Most of them correspond to the old version of 2003 and does not include the OOP concepts of the latest version. This information can be downloaded from the Siemens web page [Sie13].

TIA Portal includes all programming languages of the norm in its own version. The Table 1 shows a comparison between the programming languages of Siemens and their corresponding language of the norm.

Siemens		Norm IEC 61131-3
Instruction List	AWL/STL	AWL/IL
Ladder Logic	KOP/LAD	KOP/LD
Function Block Diagram	FUP/FBD	FUP/FBD
Structured Control Language	SCL	ST
S7-GRAPG		AS/SFC

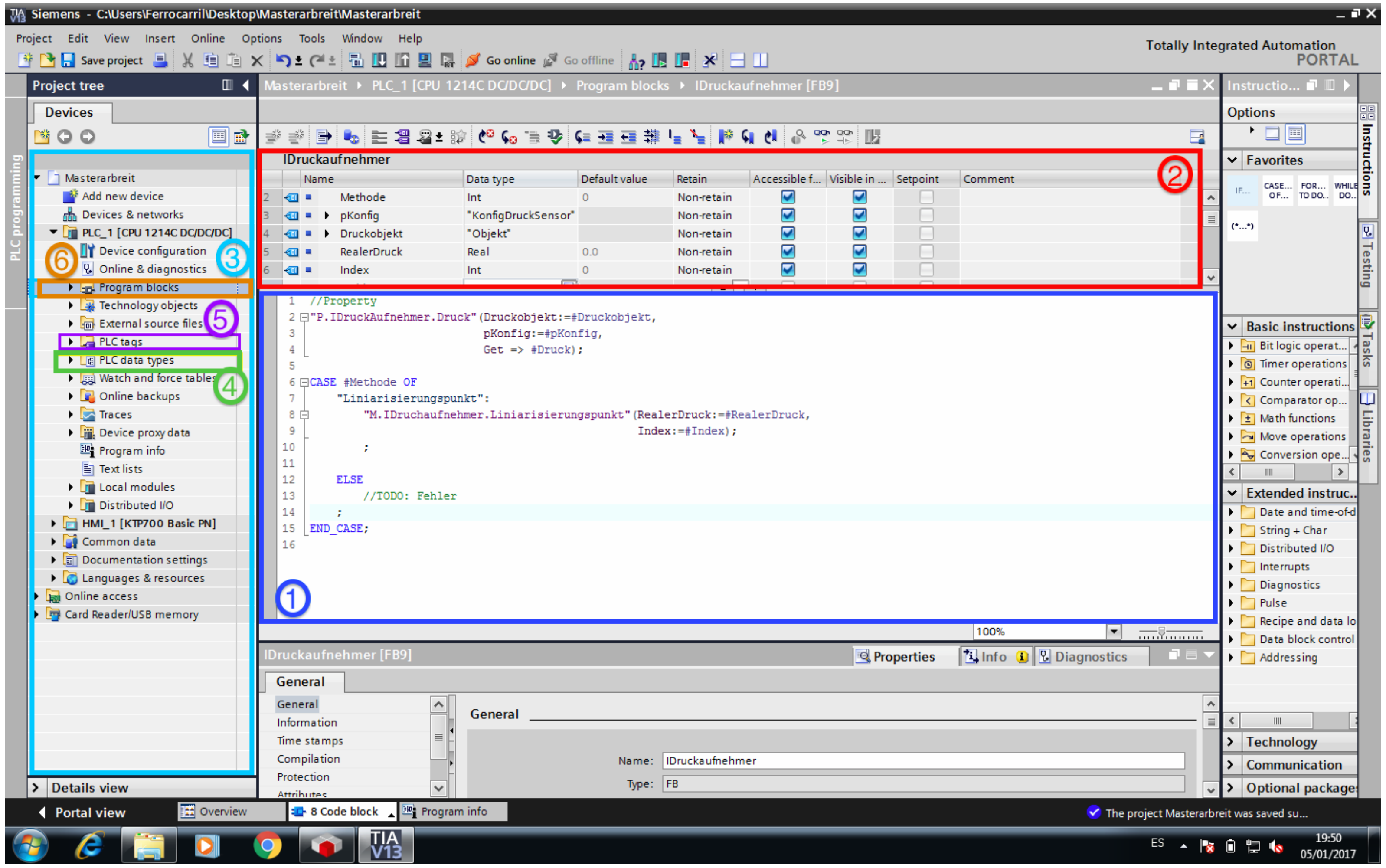
Table 1: Siemens corresponding programming languages according to the norm IEC 61131-3

2.3.4 TIA Portal and CoDeSys small comparative

This subsection shows a comparative of both software systems. Not a syntax or programming comparative, but a parallel visualisation of the working areas.

The Figure 2-16 shows the working area of TIA Portal and the Figure 2-17 the one for CoDeSys. Nevertheless, they both have similarities as well and are listed here.

1. **Work area or body**: this is the area for the code. Here are the instructions written and the functions are called.
2. **Declaration area**: here is where the variables of the current POU in the working area are declared. Free written in CoDeSys and in blank spaces to fill in Siemens.
3. **Project tree**: in this section are shown the resources, tasks, programming blocks and all kind of POUs.
4. **Number constants**: These are constant lists created by the user. This constants serve as index for the switch cases.
5. **POU**: here are listed all POUs like FB, FC or interfaces. Also, UDTs and global variables.



IDruckaufnehmer

	Name	Data type	Default value	Retain	Accessible f...	Visible in ...	Setpoint	Comment
2	Methode	Int	0	Non-retain	✓	✓	☐	
3	pKonfig	"KonfigDruckSensor"		Non-retain	✓	✓	☐	
4	Druckobjekt	"Objekt"		Non-retain	✓	✓	☐	
5	RealerDruck	Real	0.0	Non-retain	✓	✓	☐	
6	Index	Int	0	Non-retain	✓	✓	☐	

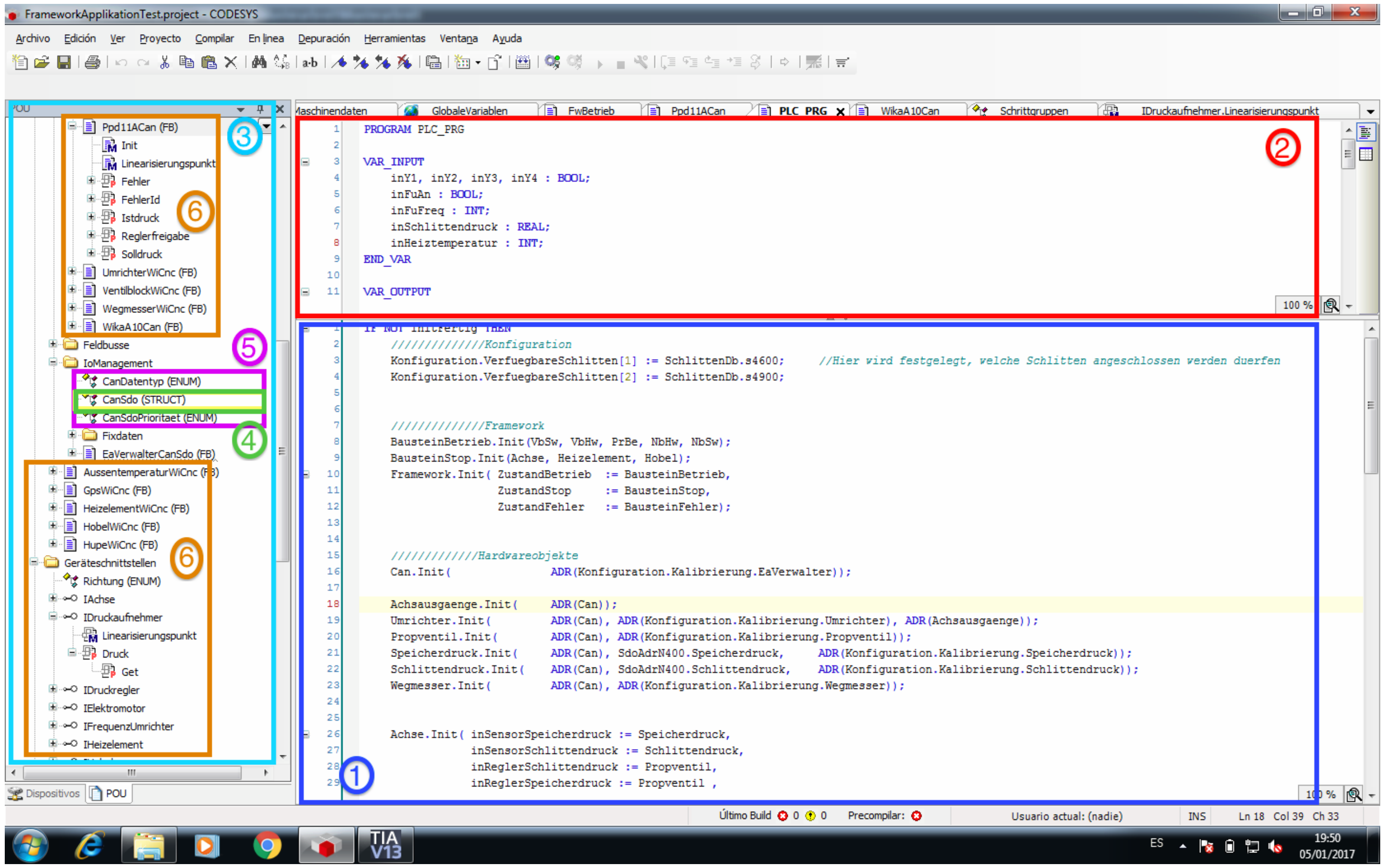
```
//Property
"P.IDruckAufnehmer.Druck"(Druckobjekt:=#Druckobjekt,
                          pKonfig:=#pKonfig,
                          Get => #Druck);

CASE #Methode OF
    "Liniarisierungspunkt":
        "M.IDruchaufnehmer.Liniarisierungspunkt"(RealerDruck:=#RealerDruck,
                                                 Index:=#Index);
        ;

    ELSE
        //TODO: Fehler
    ;
END_CASE;
```

General

Name: IDruckaufnehmer

Type: FB

Figure 2-16: TIA Portal - Working area



```
PROGRAM PLC_PRG

VAR_INPUT
    inY1, inY2, inY3, inY4 : BOOL;
    inFuAn : BOOL;
    inFuFreq : INT;
    inSchlittendruck : REAL;
    inHeiztemperatur : INT;
END_VAR

VAR_OUTPUT
```

```
IF NOT Initfertig THEN
    //////////////Konfiguration
    Konfiguration.VerfuegbareSchlitten[1] := SchlittenDb.s4600;     //Hier wird festgelegt, welche Schlitten angeschlossen werden duerfen
    Konfiguration.VerfuegbareSchlitten[2] := SchlittenDb.s4900;


    //////////////Framework
    BausteinBetrieb.Init(VbSw, VbHw, PrBe, NbHw, NbSw);
    BausteinStop.Init(Achse, Heizelement, Hobel);
    Framework.Init( ZustandBetrieb  := BausteinBetrieb,
                    ZustandStop     := BausteinStop,
                    ZustandFehler   := BausteinFehler);


    /////////////Hardwareobjekte
    Can.Init(               ADR(Konfiguration.Kalibrierung.EaVerwalter));

    Achsausgaenge.Init(     ADR(Can));
    Umrichter.Init(         ADR(Can), ADR(Konfiguration.Kalibrierung.Umrichter), ADR(Achsausgaenge));
    Propventil.Init(        ADR(Can), ADR(Konfiguration.Kalibrierung.Propventil));
    Speicherdruck.Init(     ADR(Can), SdoAdrN400.Speicherdruck,     ADR(Konfiguration.Kalibrierung.Speicherdruck));
    Schlittendruck.Init(    ADR(Can), SdoAdrN400.Schlittendruck,    ADR(Konfiguration.Kalibrierung.Schlittendruck));
    Wegmesser.Init(         ADR(Can), ADR(Konfiguration.Kalibrierung.Wegmesser));


    Achse.Init( inSensorSpeicherdruck := Speicherdruck,
                inSensorSchlittendruck := Schlittendruck,
                inReglerSchlittendruck := Propventil,
                inReglerSpeicherdruck := Propventil ,
```

Figure 2-17: CoDeSys - Working area

2.4 Model Based System Engineering

2.4.1 A brief history of Model Based System Engineering

Graphical modelling languages for software development have been evolving since the beginning of the computer sciences. These types of languages are useful for visualizing concepts. Three graphical languages are reviewed: 1) entity- relationship (E-R) diagrams; 2) the unified modeling language (UML); and 3) the systems modeling language (SysML) [DM13].

These languages are listed in chronological order as follow.

1. *Entity-Relationship (E-R) diagrams*:The E-R diagrams are data modelling approach introduced by Chen [Che76]. E-R is a modelling notation for high level data, it integrates the object oriented modelling.

2. *Unified Modelling Language (UML)*: This language is the standard for software development and can be used in systems engineering. It is a graphical language that provides semantics and notation for object oriented problem solving.

   The UML includes the use case diagram, class diagram, package diagram, sequence diagram, and state transition diagrams.

   UML includes classes. A class become object when it is instantiated and has attributes and methods. [Hol07]

3. Systems Modelling Language (SysML): This is a graphical modelling language that extends UML for use in model- based systems engineering (MBSE). It provides tools for systems engineering to design systems that include hardware, software, data, parametric, personnel, procedures, and facilities.

   Figure 2-18 illustrates the types of diagrams used by SysML; there are three primary types of diagrams at the highest level of the hierarchy: behaviour, structure, and requirements. The requirements diagram is new and not part of UML. At the next level down, SysML makes specialized modifications to UML activity diagrams, and it has made significant modifications to UML class diagrams, as extended by UML composite structures, to create what are called “block diagrams”. A completely new type of diagram called “the parametric diagram” has been introduced, which shows mathematical relationships among the pieces of the system being designed and more specifically combines mathematical formulas for analysis of critical system parameters. [DM13]

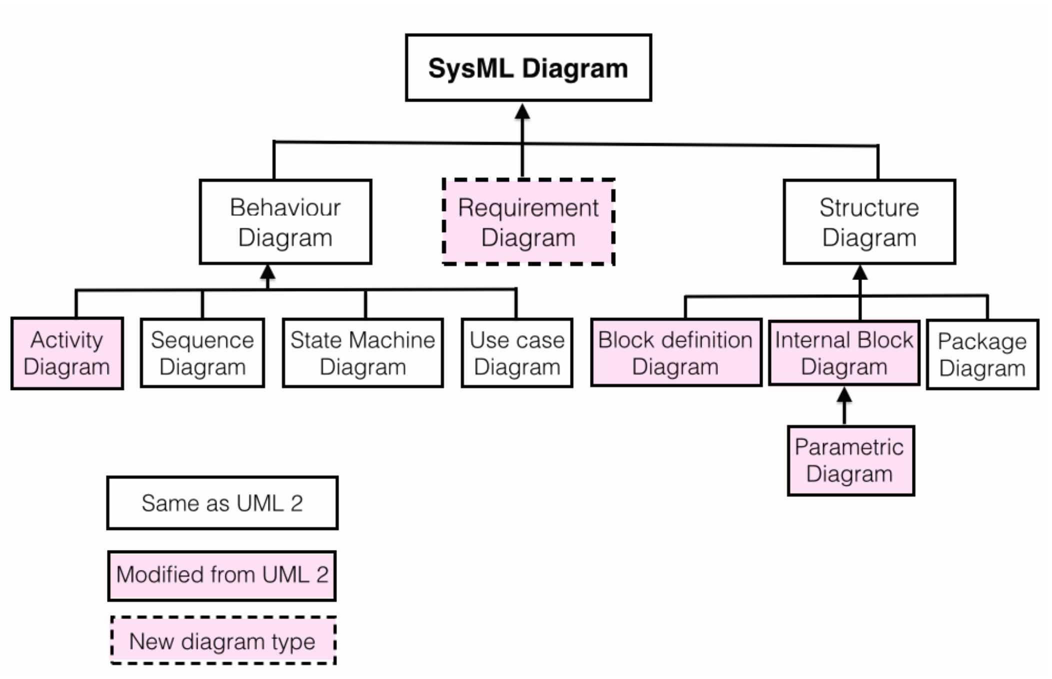


Figure 2-18: SysML artifact hierarchy and relationship to UML. [DM13]

The MBSE involves the concept that a system is a “whole” consisting of interacting parts, which was expressed by von Bertalanffy in 1967.

2.4.2 Composition of MBSE

A MBSE is compound of block definition diagrams, which are made of two basic elements: *blocks* and *relationships*. Both of them may have more detailed syntax that can be used to add more information about them. The *Blocks* describe the types of things that exist in a system, whereas *relationships* describe what the relationships are between the *blocks*. [HP13a]

The *blocks* can have features like ‘Operations’ or ‘Properties’, later explained in Chapter 3. *Blocks* have normally only properties, but can also contain operations. An example is shown in the Figure 2-19.

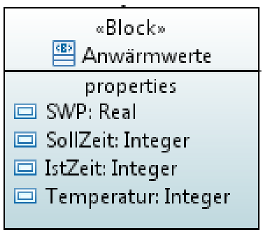


Figure 2-19: Example Block 'Anwärme' [Glu16]

A block can have different *stereotypes*. A common *stereotype* used in this project is the *interface*. An *Interface* is a block stereotyped ≪interface≫ which usually only contains *operations* but no *properties*. The operations represent the service provided by a *block* that has the *interface* as a service required by a *block*. An example of an *Interface* is shown in Figure 2-20.

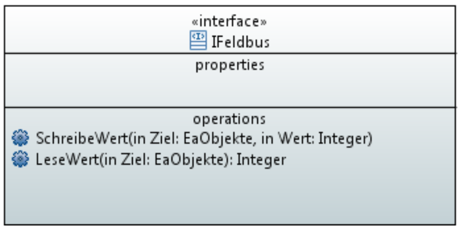

«interface»
IFeldbus
properties
operations
SchreibeWert(in Ziel: EaObjekte, in Wert: Integer)
LeseWert(in Ziel: EaObjekte): Integer

Figure 2-20: Example of Interface 'IFeldbus' [Glu16]

Firstly, a *block* can contain at the same time one or more *blocks* inside of it, which are called *internal block diagrams*.

Secondly, there is the *relationship* and there are three main types. These *relationships* are illustrated in the Figure 2-21 and described below.

- 'Association': which defines a simple *relationship* between one or more *blocks*. This kind of *relationship* is represented by a line ending with a rhomboid at the end.
- 'Generalization': which shows a 'has types' *relationships* that is used to show the heritage in *blocks*. Are represented with a line ending in an arrow.
- 'Dependency': it is used to show only that one *block* depends on another *block*, one change in one block is going to have an impact in the other one. It is represented with a dashed line.

These are the most important concepts to know for understanding this project.

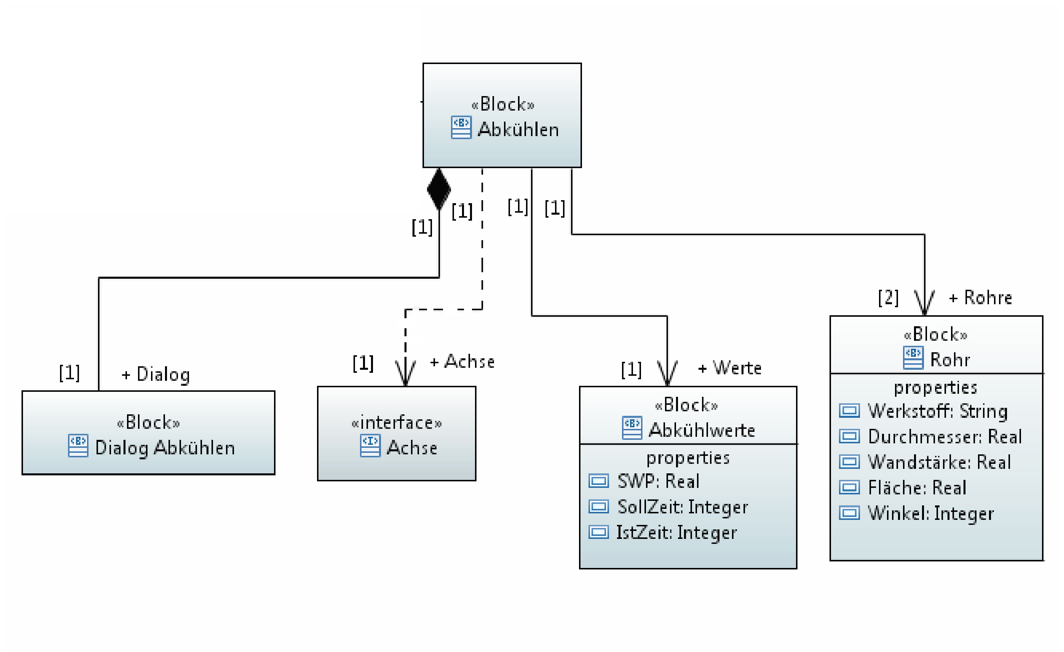


Figure 2-21: Example showing the relationships lines [Glu16]

2.4.3 SysML

Systems Modelling Language (SysML) is a description language used for the model-based systems engineering (MBSE). The book *SysML for system engineering* explains the importance of the system engineering:

'The fundamental reason, therefore, why we need a system engineering is: that is very easy for things to go wrong, resulting in disasters or failures.' [HP13b]

With failure it refers to a system where the project never reached delivery and where time and money were wasted because time or cost overran and the term disaster refers to a system where people were hurt or the environment was damaged as a result of the system failure.

For this important reason, the first step of the project consisted in make an analysis for the project and afterwards a design in SysML. As a building needs from an architecture design to be made, an engineering project needs also a design.

This description language provides tools to make a complete design of a system. Not only of the software or some parts of the machine, but all the parts that conform the project as a "whole".

3 Analysis and translation rules

3.1 Data type

A data type is a classification for variables, which are used in a program. A type classifies the variables according to the type of its value.

In the programming world exists different types of data. For example, *integer, real, string, etc.* All qualified data types are listed in the Chapter 6 *Data types* of the norm IEC 61131-3 [CEN13].

Siemens fulfils this point of the norm and supports all data types listed in it. The only difference is that in CoDeSys is possible to write the data types freely, while Siemens has blank spaces to fill with the variable names and types.

The data types listed in the norm IEC 61131-3 are available in both programming software.

3.1.1 User Data Types

A user data type (UDT) is a data type defined by the user. The user can name the data type with any name. An UDT can have one or more different data types in it and even other UDTs. An UDT can be used for the declaration of any variable in the program.

3.1.1.1 UDTs in CoDeSys

The declaration of a new UDT in CoDeSys must be between `TYPE` and `END_TYPE` as the norm declares in the section 6.4.4.

The following code is an example of UDT to describe a WIDOS machine.

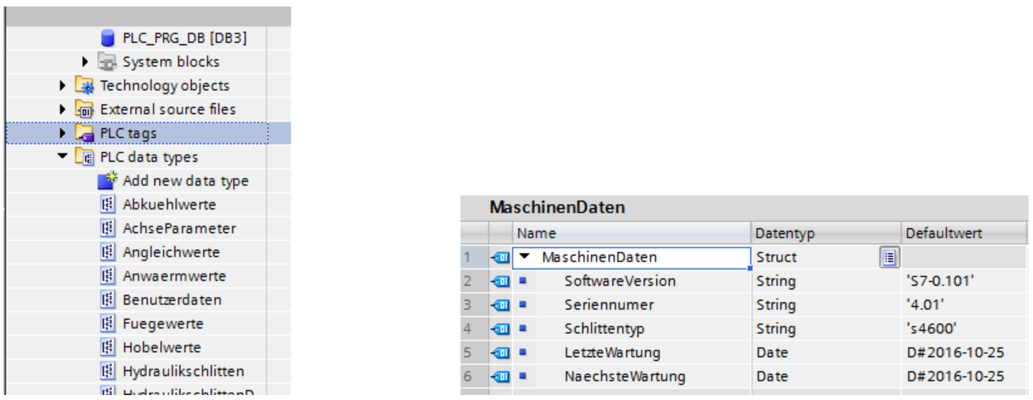
Listing 3.1: UDT Machinendaten CoDeSys

```
TYPE Maschinendaten :
STRUCT
  SoftwareVersion : STRING;
  Seriennumer : STRING;
  Schlittentyp : STRING;
  LetzteWartung : DATE;
  NaechsteWartung : DATE;
```

```
END_STRUCT
END_TYPE
```

3.1.1.2 Siemens transference of UDTs

In Siemens there is a section called PLC Data Types which is the equivalent of the UDT. This option can be found in the project tree and can be seen in the Figure 3-1a. An example of an UDT declaration is show in the Figure 3-1b. This kind of data types are reachable from every POU as well.



PLC_PRG_DB [DB3]
System blocks
Technology objects
External source files
PLC tags
PLC data types
Add new data type
Abkuehlwerte
AchseParameter
Angleichwerte
Anwaermwerte
Benutzerdaten
Fuegewerte
Hobelwerte
Hydraulikschlitten

MaschinenDaten

	Name	Datentyp	Defaultwert
1	MaschinenDaten	Struct	
2	SoftwareVersion	String	'S7-0.101'
3	Seriennumer	String	'4.01'
4	Schlittentyp	String	's4600'
5	LetzteWartung	Date	D#2016-10-25
6	NaechsteWartung	Date	D#2016-10-25

(a) UDT declaration window (b) UDT fillable spaces

Figure 3-1: UDT declarations in Siemens

Rule: The UDTs of CoDeSys are the PLC Data types in Siemens

3.1.2 Variable sections

Every POU begins with the variables declaration. According to the type of POU depend the variable sections that a POU can have.

3.1.2.1 Variable sections in CoDeSys

In CoDeSys a variable section is defined by `VAR_ ...  END_VAR`. The different variable sections and their descriptions are listed in the norm in the section 6.5.2. The Table 2 shows the different variable sections and a short descriptions according to the norm IEC 61131-3.

Keyword	**Usage of the variable**.
`VAR`	In the element (FB, FC, etc.)
`VAR_INPUT`	Provided from outside , cannot be changed inside the element.
`VAR_OUTPUT`	From the element to an external element.
`VAR_IN_OUT`	Provided from an external element, it can be changed and exported to another element.
`VAR_EXTERNAL`	Supplied from the configuration through `VAR_GLOBAL`.
`VAR_GLOBAL`	Global variables declaration.
`VAR_ACCES`	Access path declaration.
`VAR_TEMP`	Temporary store for variables in FB, methods and programs.
`VAR_CONFIG`	Specific instance initialisation and allocation.
`(END_VAR )`	Closes the variable sections before listed.

Table 2: Variable sections supported by the norm IEC 61131-3

3.1.2.2 Siemens transference of variable sections

Siemens has variable sections depending on the POU. A list of the variable sections and the POU are shown in the Table 3. These are the variable sections available in TIA Portal.

- The *IN, OUT, IN_OUT* and *TEMP* variable sections need no translation from CoDeSys to Siemens.
- The `VAR` section of CoDeSys can be taken as the *Static* variable section of Siemens.
- The variable section `VAR_GLOBAL` can be transferred to Siemens as a Data Base POU.
- The configuration and the physical allocations are made in a different way in Siemens. This configurations is made in the *configuration* section of the project tree. Physical allocations are set in *PLC tags* also in the project tree.
- `VAR_ACCESS` and `VAR_EXTERNAL` are not available in Siemens.

OB	Input	**FB**	Input
	Temp		Output
	Constant		InOut
			Static
			Temp
			Constant
FC	Input	**DB**	Static
	Output		
	InOut		
	Temp		
	Constant		

Table 3: POU and its variable types available in TIA Portal

3.2 Configuration

A *configuration* according to the norm IEC 61131-3 section 6.8 is made out of *resources*, *tasks* (defined in a *resource*), global variables, access paths and specified instance initialisations.

The *configuration* is the Hardware used in the project. CoDeSys has two different *resources*: the PLC and the HMI.

The *configuration* in Siemens is not a language element. Even though, a project in Siemens has a *configuration*. It is represented in Figure 4-2. The *configuration* of the project is composed of two resources as well, a PLC and an HMI. Besides, the PLC has an I/O device.

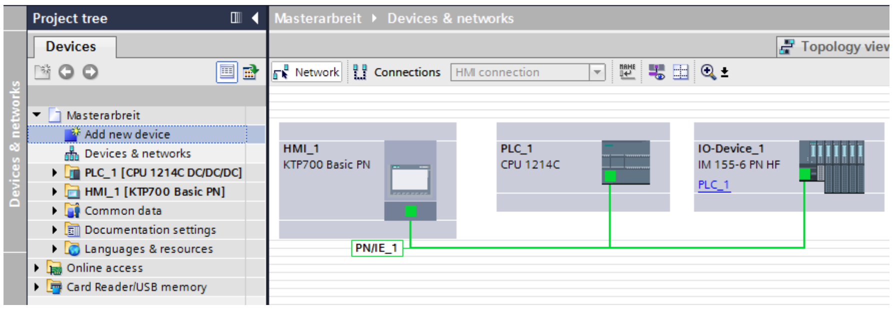


Figure 3-2: Siemens configuration

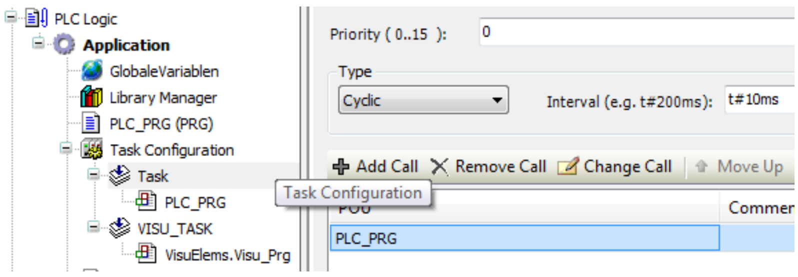
A *configuration* in Siemens can be made adding *resources*, which are devices.

3.2.1 Tasks

A *task* according to the section 6.8.2 of the norm 61131-3:2013 is defined as an execution control element. A very common *task* used is the cyclic function. It makes a *program* or FB execute again and again until the PLC is stopped.

3.2.1.1 Tasks in CoDeSys

An example *task* in CoDeSys is shown in the Figure 3-3. This *task* executes the *program* *"PLC_PRG"* in a cyclic way.



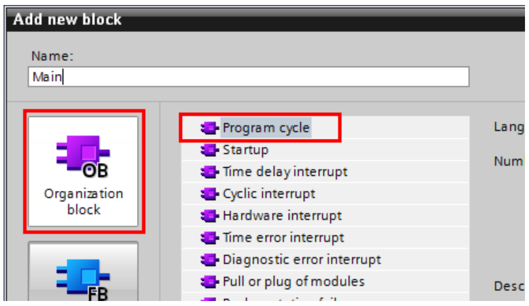
Priority (0..15): 0
Type
Cyclic
Interval (e.g. t#200ms): t#10ms
PLC_PRG

Figure 3-3: Cyclic task in CoDeSys

This task can execute others POUs, normally *programs*. It is used in this project to execute the main program that contains all the instructions and functions of the PLC. One or more calls can be added to this *task*.

3.2.1.2 Siemens transference of Tasks

In Siemens there are no *tasks* as a program element. But there is another element that can make the function of a task. TIA Portal has a POU called Organization Block (OB). This OB has the same function as a Task described in the norm. The figure 3-4 shows how to create a new OB with the cyclic function as in CoDeSys.



Name:
Main

Figure 3-4: Cyclic task in TIA Portal with an organization block

Rule: The cyclic tasks in CoDeSys can be taken as the organization blocks in TIA Portal with a "Program cycle" function.

An OB can contain one or more function blocks in it. The OB is going to execute the functions in a cyclic way. For example, to add the *PLC_PRG* as in the CoDeSys example, it is needed to call the function block as in Listing 3.2. That leads to have a close result of the *task* in the previous CoDeSys example.

Listing 3.2: Assignment of PLC_PRG in an OB

```
"PLC_PRG_DB"();
```

Rule: To assign a program (FB) to a task (OB) in TIA Portal is only needed to add the desired function block in the working area.

3.3 Program organisation unit (POU)

The norm IEC 61131-3 in the section 6.6 defines that a program organisation unit (POU) has the purpose of modularisation and structuring a well-defined program. A POU has a defined interface with inputs and outputs and can call more POUs or be called from other POUs.

The POUs listed in the norm are: functions, function blocks, classes and programs. Function blocks and classes are allowed to have methods [CEN13]. CoDeSys, contain all of them, but TIA Portal has only functions and function blocks.

A POU is composed by two parts: a declaration part and body. That is a common point in both instances as seen before in the comparative of CoDeSys and TIA Portal.

3.3.1 Program

A program is defined in IEC 61131-1 as a logical assembly of all the programming language elements and constructs necessary for the intended signal processing required for the control of a machine or process by a programmable controller system [CEN04]. In other words a program is used for the structure of the main program that controls the process.

A program is similar to a FB with the difference that a program can only be called inside of resources, while a FB only inside programs or another FB.

3.3.1.1 Programs in CoDeSys

A program in CoDeSys must be declared between the keywords `PROGRAM` and `END_PROGRAM` in the declaration part. For example:

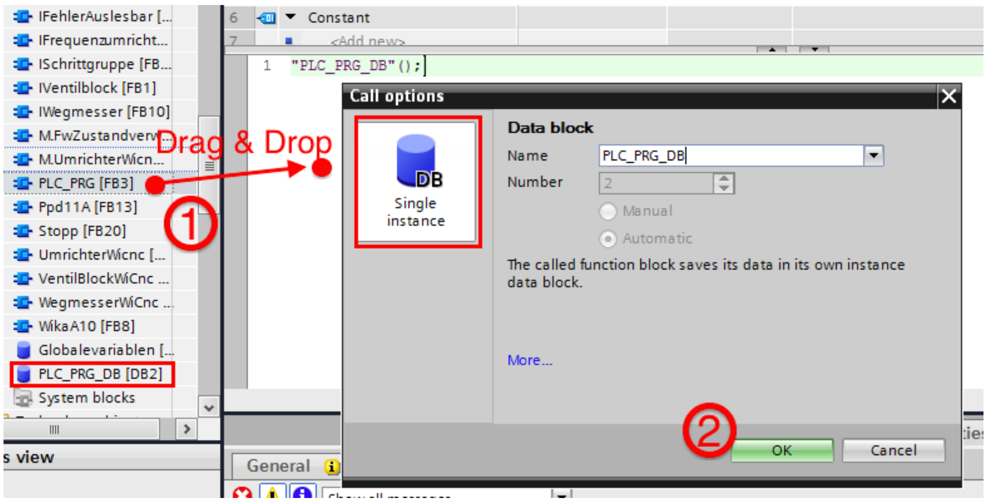
```
PROGRAM PLC_PRG

VAR ... END_VAR

END_PROGRAM
```

As seen in Figure 3-3 the program is instantiated inside a task, which is inside a resource, which is the PLC.

3.3.1.2 Siemens transference of Programs

As said before, there are no POU programs in TIA Portal. But it was also said that a program is similar to a FB. Taking this as an advantage, the FBs will be used as programs.

The FB used to represent a program must have the characteristic to be a single-instance FB. That means that every program must have its own Data base (DB). The Figure 3-5 shows how to make a single-instance FB.



```
"PLC_PRG_DB"();
```

Data block
Name: PLC_PRG_DB
Number: 2
Manual
[✓ Automatic]

The called function block saves its data in its own instance data block.

More...

Figure 3-5: How to make a assign a program to a task in TIA Portal

Doing this, is possible to reach data of elements that the program contains like variables in the FB that the program contains. For example:

```
#Value := "PLC_PRG_DB".Axis.PressureSensorA.Pressure;
```

As the norm declares, programs must be instantiated inside a *task* which is an OB.

Rule: A program can be represented in TIA Portal as a single-instance FB, which is instantiated inside an OB (task).

It is important to notice that the usage of a FB in an OB (task) is only possible with single-instance FB. If a single-instance FB is always a program, then it is not possible to add normal FB to a task. Therefore, the software model is limited, forcing to add a program first and then a FB. The software model is now modified as shown in Figure 3-6.

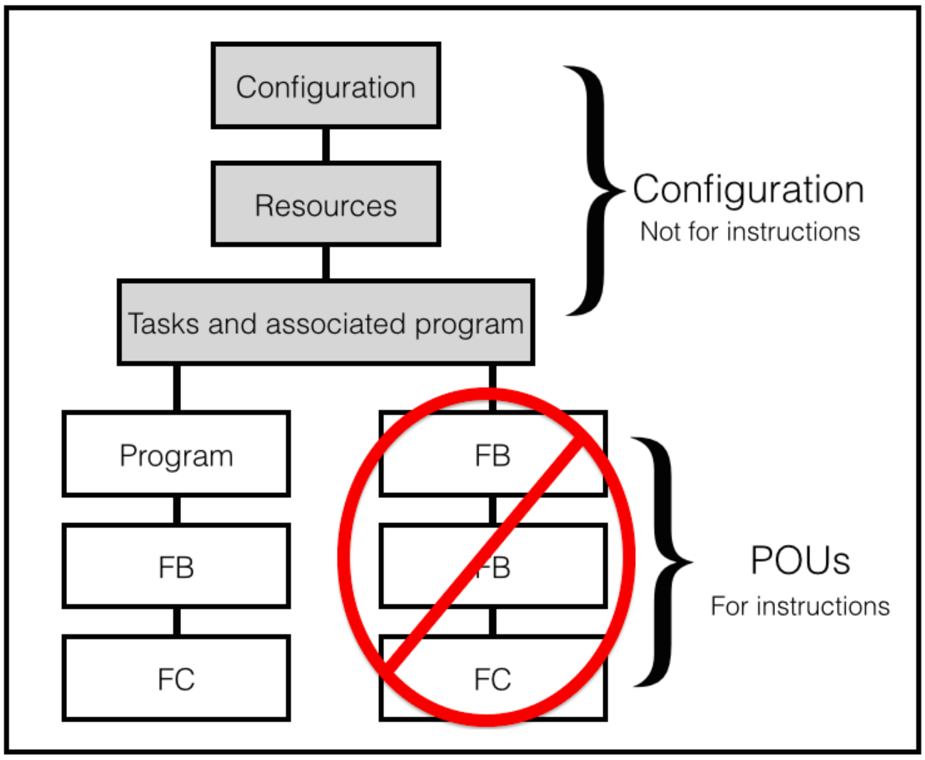


Figure 3-6: Modified software model

3.3.2 Function blocks

A function block (FB) is a POU listed in the norm IEC 61131-3. The concept of FB is composed by the following definitions:

- A Function block-type (FB-type) is:
  - The definition of a data structure, composed by inputs, outputs and internal variables.
  - An amount of operations that will be executed when an instance of the function block-type is called.
- A Function block-instance (FB-instance):
  - Is a multi-applicable function of a FB-type.
  - Every instance must have a corresponding identifier (name). Besides of a data structure of inputs, outputs and intern variables.

3.3.2.1 Function blocks in CoDeSys

A function block in CoDeSys must be declared in the declaration part by the keyword `FUNCTION_BLOCK` . For example:

```
FUNCTION_BLOCK WikaA10

VAR_INPUT ... END_VAR
VAR_OUTPUT ... END_VAR
VAR ... END_VAR
...
```

That is a Function block-type of a pressure sensor called *WikaA10*. That means, a structure of a program with variables and instructions but not yet instantiated.

This FB-type can be instantiate in the following way:

```
VAR
PressureSensorA : WikaA10;
END_VAR
...
```

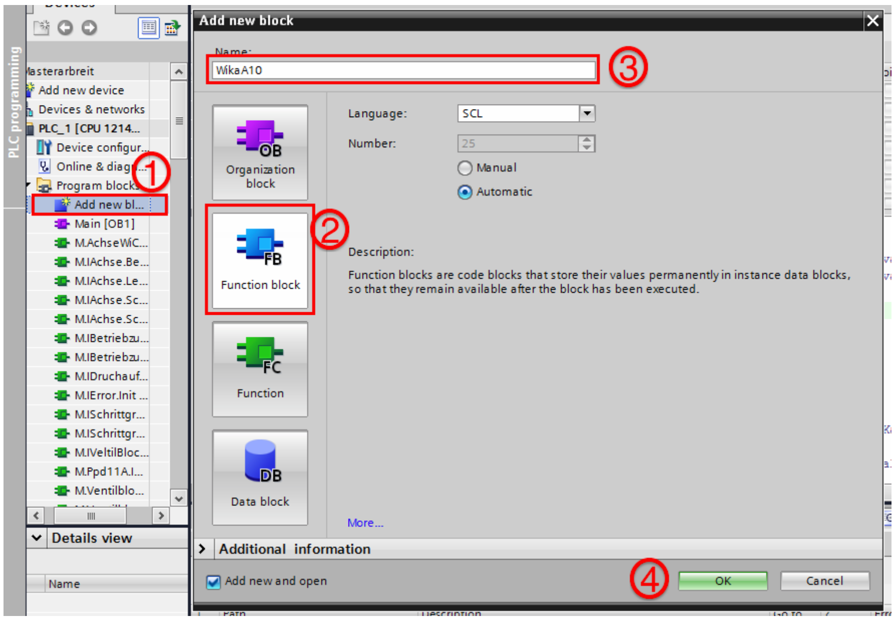
PressureSensorA is a FB-instance of the FB-type WikaA10. This FB-instance has its own variable values and can execute operations.

In the OOP environment, the FB-instance is the object created from the class FB-type. In this example, PressureSensorA is an object of the class WikaA10.

3.3.2.2 Siemens transference of function blocks

A function block is an official programming element in TIA Portal. It can be added in a program, or be called from another FB. It can have single-instances and multi-instances.

The steps to create a new FB in TIA Portal are shown in Figure 3-7.



Name: WikaA10

Language: SCL

Number: 25

( ) Manual

(●) Automatic

Description:

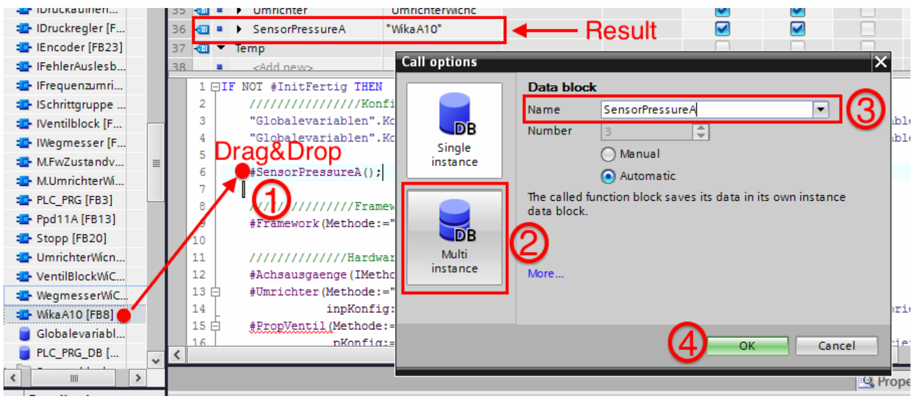
Function blocks are code blocks that store their values permanently in instance data blocks, so that they remain available after the block has been executed.

[✓] Add new and open

Figure 3-7: Steps to create a new FB-type in TIA Portal

A new FB has been created, but it is not yet a FB-type, that means that this FB is not able to make instances. To transform this FB into a FB-type it is necessary to turn the FB into a multi-instance FB. The steps to this are shown in the Figure 3-8.

Ruel: A FB-type of CoDeSys is a multi-instance FB in Siemens



36	SensorPressureA	"WikaA10"
37	Temp	
38	<Add new>	

```
IF NOT #InitFertig THEN
    ///////////////Konfi
    "Globalevariablen".Kc
    "Globalevariablen".Kc
    #SensorPressureA();

    //////////////Framew
    #Framework(Methode:="

    /////////////Hardwar
    #Achsausgaenge(IMethc
    #Umrichter(Methode:="
                  inpKonfig:
    #PropVentil(Methode:=
                  pKonfig:=
```

Call options

Data block

Name: SensorPressureA

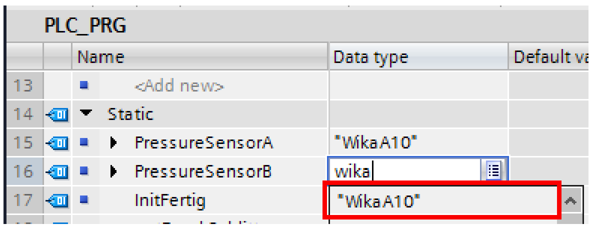
Number: 3

( ) Manual
(•) Automatic

The called function block saves its data in its own instance data block.

Figure 3-8: Steps to instantiate a FB-type

Doing this process, the FB-type automatically creates a FB-instance, pointed in the Figure 3-8 as *Result*. More instances can be created now that the FB-type exists. This process is just as easy as in CoDeSys. Every new instance is a new variable, this variable must be created in the variable section *static* and then select as data type the name of the FB-type. An example is shown in the Figure 3-9.


PLC_PRG

	Name	Data type	Default va
13	<Add new>		
14	Static		
15	PressureSensorA	"WikaA10"	
16	PressureSensorB	wika	
17	InitFertig	"WikaA10"	

Figure 3-9: Creation of new instances in TIA Portal

The variables *SensorPressureA* and *SensorPressureB* are FB-instances of the FB-type *WikaA10*. In OOP terms it can be said that SensorPressureA and SensorPressureB are objects of the class WikaA10.

Rule: the process to create a FB-instance is the same in TIA Portal and in CoDeSys. That is, through the creation of a new variable selecting as data type the wished FB-type. This variable must be created in the section variable "static".

3.3.3 Classes

The norm IEC 61131-3:2003 was extended to add the concept of OOP. With this new concept the function blocks can be defined to serve as classes.

It is important to clarify that a class has a different meaning in IT programming languages like C#, Java or UML. The Table 4 makes an explanation of these meanings.

IT programming language		**PLC programming languages of the norm**	
Class	(=Type of a class)	Type	of a Function block or a class
Object	(= instance of a class)	Instance	of a Function block or a class

Table 4: Comparative of classes between IT-OOP and PLC-OOP

A FB-type can be taken as a class. Both can implement interfaces and methods. Can be said that a FB can be extended to become a class. The Figure 3-10 explains the relationship between classes and FB.

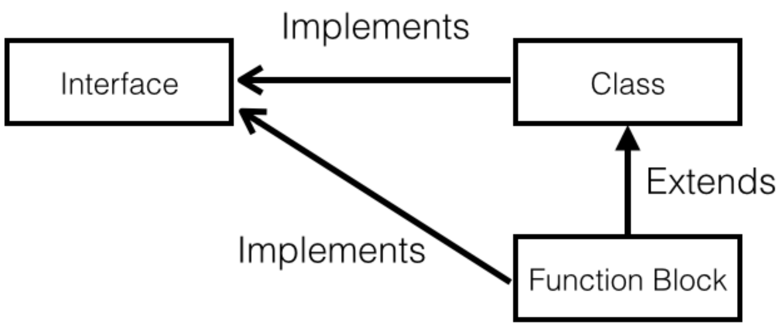


Figure 3-10: Relationship between FB and classes

A class is used to make different objects from the same type. That makes big codes easier to program, modify and understand.

3.3.3.1 Classes in CoDeSys

A class in CoDeSys can be declared by the keyword `CLASS`. But it can be a FB-type as explained in the last chapter. If it is done with FB then the transference to Siemens is easier.

An example of a class usage inside a FB-type is shown below.

Listing 3.3: MachineAxis Class

```
FUNCTION_BLOCK AchseWiCnc

```

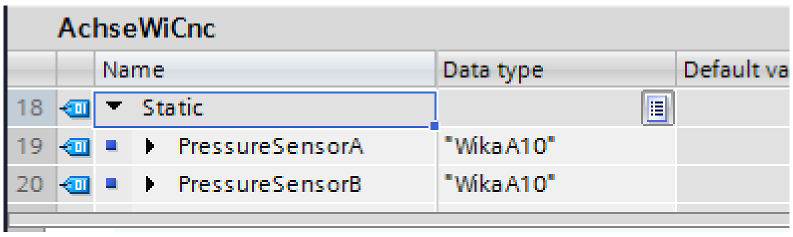
```
VAR
PressureSensorA : WikaA10;
PressureSensorB : WikaA10;
...
END_VAR
```

This is a new class for the axis of a WIDOS machine that uses two sensors of the same type. In this way two instances of the same type are called, each one with its own variable values.

3.3.3.2 Siemens transference of Classes

Classes are not a programming element in the TIA Portal. Therefore, the usage of classes in Siemens is exactly the same of a FB-type. If there is some case that a class is used in CoDeSys, the translation to Siemens would be done as if it were a FB-type.

To make the translation of the CoDeSys example of above, the result would be as shown in Figure 3-11. Which is the same result like the FB-type example.



AchseWiCnc

	Name	Data type	Default va
18	▼ Static		
19	▶ PressureSensorA	"WikaA10"	
20	▶ PressureSensorB	"WikaA10"	

Figure 3-11: Example of classes in TIA Portal

Rule: Classes in CoDeSys are transferred to TIA Portal as FB-types.

3.3.4 Methods of a class

A method is a language element. The concept of method was taken from the OOP. One or more methods can be defined in a class or FB-type. A method is used to execute operations. It can only be executed by an instance of a class or a FB.

A method must have three elements that together are called signature. There are:

- Name of the method

- Result type
- Variables declared with name and type. That means, input, output or in-out variables.

`VAR` variables are always taken as temporary variables. That means they are not saved in the PLC memory and are only available when the method is called. The values of the variables are reset every time that the method is called.

A method contains code instructions to be executed when is called. It returns a result value according to the input parameters and the result type.

3.3.4.1 Methods in CoDeSys

A method in CoDeSys is a language element, which can be added to any class or FB by selecting the desired element and then add method. A method is declared by the keyword `METHOD` followed by the name of the method. For example a method called *Init* would be declared as follow:

```
METHOD Init
VAR_IN .. END_VAR
VAR_OUT .. END_VAR
VAR .. END_VAR
```

3.3.4.2 Siemens transference of methods

A method is not a programming element available in the TIA Portal. But the characteristics of a method are so similar to the characteristics of a function (FC).

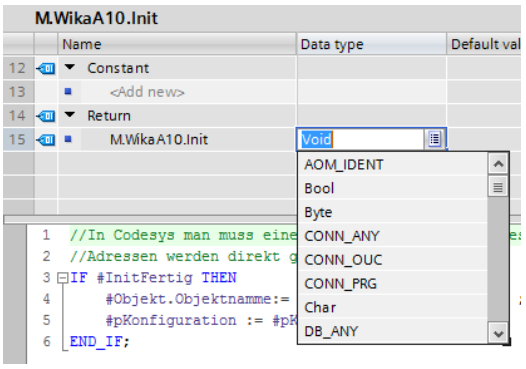
A signature of a method made in TIA Portal is the following:

- The name must begin with a “M.”, then the name of the class followed by a dot and finally the name of the method.

  e.g. M.WikaA10.Init

- The result type is the return value type. It can be set in the declaration part of the POU as shown in the Figure 3-12.

- As seen in the Table 3 a FC allows the same variable types as an OOP method. Temporary variables in TIA Portal work in the same way as in CoDeSys.



M.WikaA10.Init

	Name	Data type	Default val
12	Constant		
13	<Add new>		
14	Return		
15	M.WikaA10.Init	Void	

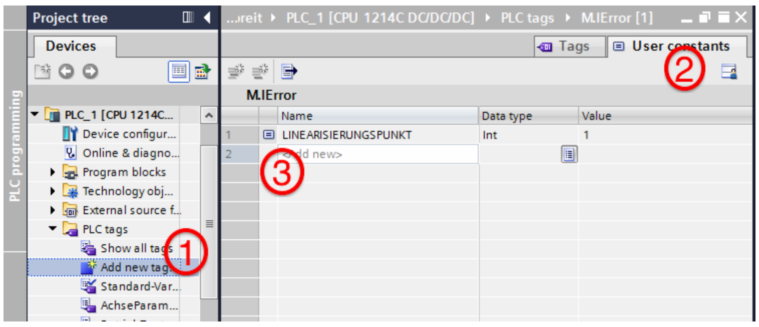
```
//In Codesys man muss eine
//Adressen werden direkt g
IF #InitFertig THEN
    #Objekt.Objektname:=
    #pKonfiguration := #pK
END_IF;
```

Figure 3-12: Return-value-type of a Method (FB) in TIA Portal

The method can have any code, input variables, output variables or temporary variables.

To add a method to a FB it must be called in the body of the FB-type. To call only the desired method, all methods must be in a switch case. That leads to have an extra variable in the FB-type, which is going to serve as the selector of the switch case. It is also needed constants for the index of the switch case. For the creation of an index a table of constant is created.

The steps to create a table of constants is shown in Figure 3-13. Firstly, click in *Add new tag table* in the project tree. Secondly, click in *User constants* and lastly, write the desired constants always with capital letters. The value of the constants is not important but it can not be null in order to avoid default initialisations in the switch case.



M.IError

	Name	Data type	Value
1	LINEARISIERUNGSPUNKT	Int	1
2	<Add new>		

Figure 3-13: Steps to create a table of constants

The rules to implement a method in a FB-type with TIA Portal are the following ones:

- The name must begin with the letter “M”, then the name of the FB-type that the method belongs to and finally the name of the method. In between of every word a dot must be written.

  e.g. M.WikaA10.Linearisierungspunkt

- Methods must be added to the FB-type inside a switch case.
- The FB-type must add a new variable called “Method” of type integer. This variable is used as the selector for the switch case.
- The inputs and outputs of the method must be declared as input and outputs in the FB-type.
- A tag table of user constants must be created in order to serve as the index of the switch case. (This table is important because its values can be reached from any POU in the project)

3.3.5 Interfaces

As defined in section 6.6.6 of the norm, an interface is a language element related to OOP. It contains prototyped methods to be implement by an object or instance. An interface do not have instructions, which is the main difference from the classes.

There are two ways to use an interfaces:

- In a class declaration:
  A class implements an interface. The interface declares which methods must the class implement .
- As variable type:
  Variables that have an interface as data type are instances of the interface. That means that the variable can use the elements of the interface like methods and variables.

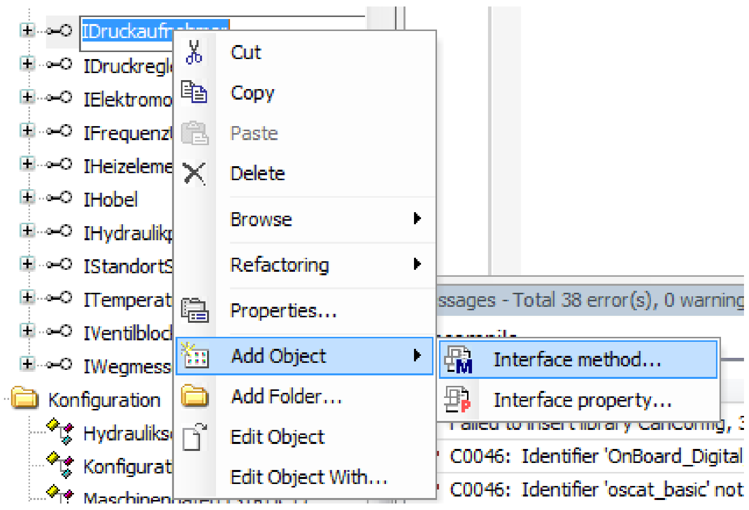
An interface can contain methods and properties. A method is an action to be implemented by an instance of the interface. A property is a state of the instance. Properties are not mentioned in the norm IEC 61131-3:2013, even though they are still methods but with specific functions.

To give an illustration, an interface can be seen as a toolbox. The toolbox has tools, which are the methods and properties. A method is a tool that makes an action, for example a screwdriver or a hammer. On the other hand are the properties, these are tools that inform a state of the instance, for example a measuring tape or a level bubble.

An interface or toolbox is useless until someone uses it, because a toolbox can not be used by itself. When an interface is instantiated, then it is no more useless.

3.3.5.1 Interfaces in CoDeSys

An interface is a language element available in the software. To it can be added methods and properties in an easy way as shown in Figure 3-14.



ssages - Total 38 error(s), 0 warning

C0046: Identifier 'OnBoard_Digital

C0046: Identifier 'oscat_basic' not

Figure 3-14: How to add methods and properties to an interface in CoDeSys

To implement an interface in a class or FB is needed to write the keyword `IMPLEMENTS`, for example:

```
PROGRAM_BLOCK WikaA10Can IMPLEMENTS IDruckaufnehemer
VAR ... END_VAR
...
```

The name of an interface must begin with an “I” followed by the name of the interface. *Druckaufnehemer* is the German name for pressure sensor. Since WikaA10 is a FB for a *pressure sensor*, it can implement the interface *IDruckaunehemer* to add its methods.

The other usage of an interface is as a variable type. To do this in CoDeSys it is as easy as to declare a variable. In the next example *PressureSensorA* is an instance of the interface *IDruckaufnehmer*.

```
VAR
PressureSensorA : IDruckaufnehmer;
....
END_VAR
```

3.3.5.2 Siemens transference of Interfaces

Siemens has no POU for interfaces. But an interface is similar to a class and a class is similar to a FB. Interfaces are transferred to Siemens as Function Blocks (interface-FB).

An interface-FB, starts its name with an "I". This element may not have instructions even when it has a body. An interface-FB can have one or more instances, for this reason a FB that serves as an interface must be turned into a multi-instance FB.

The methods and properties are called in the body of the interface-FB. That leads the interface-FB to have inputs and outputs. These input and output variables are the same variables of the methods and properties. Besides, a variable named "Method" must be added to select the method to be called. This is going to be detailed in the next sections.

An interface-FB calls methods and properties in its body. The interface *IDruckaufnehmer* has one property and one method, therefore the interface-FB body results in the following way:

```
//Property
"P.IDruckAufnehmer.Druck"(Druckobjekt:=#Druckobjekt,
                    pKonfig:=#pKonfig,
                    Get => #Druck);

//Method
CASE #Methode OF
   "Liniarisierungspunkt":
        "M.IDruchaufnehmer.Liniarisierungspunkt"(RealerDruck:=#RealerDruck,
                                            Index:=#Index);
        ;
END_CASE;
```

Rule: An interface is transferred to TIA Portal as a multi-instance FB without instructions.

3.3.6 Method of an interface

A method of an interface is in fact a prototype of a method. According to the norm, a prototype-method has input, output and in-output variables, besides of the result type of the method. Nevertheless, it does not have algorithm (code) or temporary variables. That means that the method is not implemented.

3.3.6.1 Method of an interface in CoDeSys

A prototype-method is called in CoDeSys "Interface method" as seen in Figure 3-14. The declaration of a method is with the keyword `METHOD` followed by the name of the method. An interface method has only declaration part but no body. It has a body to write code only when is implemented in a class or FB.

For example, the FB WikaA10 is a pressure sensor that implements the interface "IDruck-aufnehemer". The interface has a method and a property: "Linearisierungspunkt" and "Druck" respectively. The structure of the FB is shown in Figure 3-15.

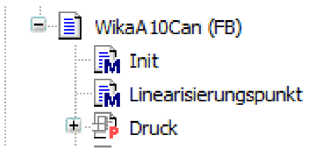


Figure 3-15: FB-WikaA10 and it methods

The prototype-method "Linearisierungspunkt" has the next configuration:

```
METHOD Linearisierungspunkt
VAR_INPUT
  RealerDruck : REAL;
  Index : INT;
END_VAR
```

Since the interface is already implemented in a FB, Linearisierungspunkt is no more a prototype-method but a method of a class. That means that it has body to write code and allows to declare temporary variables.

The method can be called from any POU in the following way.

```
WikaA10Can.Linearisierungspunkt(RealerDruck:=RealPressure,
                                    Index:=In_index)
```

First, the name of the FB that implements must be written followed by a dot. After that, the name of the method to be called. And finally, between parenthesis the input or output values must be filled. The calling of a method is the same either if it is implemented to a FB or used as a variable type.

3.3.6.2 Siemens transference of methods of an interface

This element is not available in TIA Portal and there is no way to make a prototype-method. A method of an interface is the same as a method of class. In other words, a method in TIA Portal will always be implemented, that means that it will always have code.

The rules to implement a method in an interface with TIA Portal are the following ones:

- The name must begin with the letter "M", then the name of the interface that the method belongs to and finally the name of the method. In between of every word a dot must be written.

  e.g. M.IDruckaufnehmer.Linearisierungspunkt

- Methods must be added to the interface inside a switch case.
- The interface must add a new variable called "Method" of type integer. This variable is used as the selector for the switch case.
- The inputs and outputs of the method must be declared as input and outputs in the interface-FB.
- A tag table of user constants must be created in order to serve as the index of the switch case. (This table is important because its values can be reached from any POU in the project)

To call a method in Siemens is in the following way:

```
#Achse(Parameter := "SPEICHERDRUCK",
        Methode := "LESEPARAMETERREAL",
        Wert => #outDruckSpeicher);
```

Where *Parameter* is an input value, *Wert* is an output value and *Methode* is name of the method.

3.3.7 Properties

Properties are not declared in the IEC 61131-3 but they are methods with specific functions. These can be added to an interface and afterwards to a FB.

Properties define parameters and states of a FB. A property has two different methods: one for writing and another for reading. These methods are also called *setters* (to write) and *getters* (to read).

A property has a result value, but may not have code, not even in the implementation. The methods set and get are the ones that may have code but only in the implementation.

3.3.7.1 Properties in CoDeSys

A property is also a programming element available in CoDeSys. To add a property inside an interface it is necessary to click over the interface and add property. It automatically add the methods *set* and *get*. This process is shown in Figure 3-16.

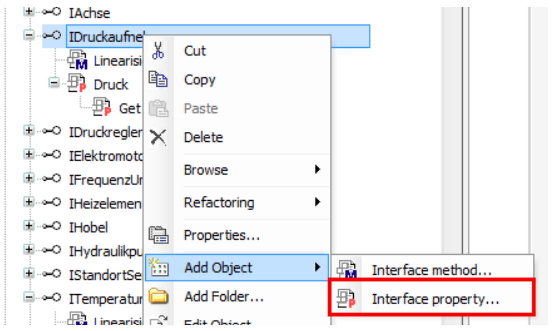
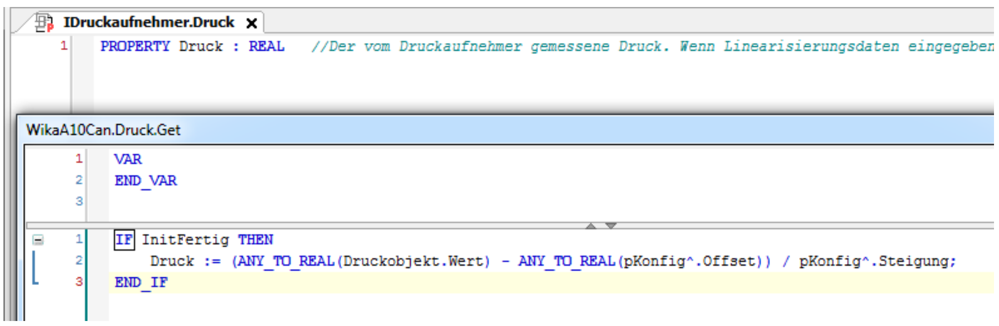


Figure 3-16: How to add properties in CoDeSys

A property has a result value just as a method. This value is set or gotten according to the function. For example, the interface IDruckaufnehmer has a property called *Druck*[2]. The property informs the state of a sensor. The PLC READS the signal of the sensor, which means a *get* method is used. The property may be *real* because the pressure value can have decimal point.

This interface is implemented to the FB WikaA10Can. The FB automatically imports the property. This example is shown in the Figure 3-17. In the upper part is the interface that only shows the name and data type of the property. The lower part shows the get method implemented in the FB WikaA10Can.



```
PROPERTY Druck : REAL   //Der vom Druckaufnehmer gemessene Druck. Wenn Linearisierungsdaten eingegeben
```

```
VAR
END_VAR

IF InitFertig THEN
    Druck := (ANY_TO_REAL(Druckobjekt.Wert) - ANY_TO_REAL(pKonfig^.Offset)) / pKonfig^.Steigung;
END_IF
```

Figure 3-17: Not-implemented vs implemented property

The way to get the value of a property is the following.

```
Pressure := SensorSchlittendruck.Druck;
```

Where SensorSchlittendruck is a variable of type IDruckAufnehmer, that means, SensorSchilttendruck is an instance of the interface.

3.3.7.2 Siemens transference of properties

A property is not an element in TIA Portal. Since a property is a function, properties are going to be transferred to TIA Portal as property-FC. In contrast with the methods, a property does not make actions, but only informs states. Therefore, it is not necessary to make a switch case, properties are only going to be called inside the interface-FB.

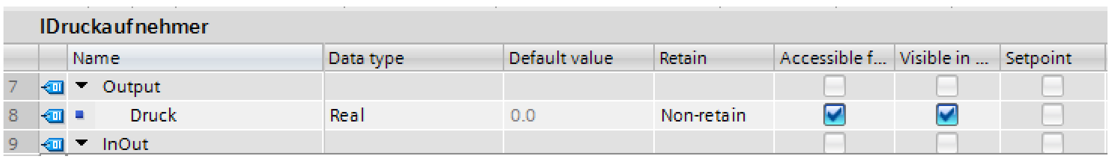
To add the set and get methods, a property is going to have an input value called *set* and/or an output value called *get*. The value of the property is saved in an in/output

[2]German word for Pressure

variable in the interface-FB. The name of the property follows the same principle as the method but instead of "M" a "P" is written.

For example, to make the CoDeSys example of above, a new FC is made with the name *M.IDruckaufnehmer.Druck*. This FC has an output value called *Get*. The code is written because prototype-methods cannot be done in TIA Portal. The next step is to call the property inside the interface-FB. A variable with the name of the property (Druck) is in the interface-FB created and this variable saves the FC-value *Get*.

The next code is in the interface-FB IDruckAufnehmer, the one that contains the property Druck.


IDruckaufnehmer

	Name	Data type	Default value	Retain	Accessible f...	Visible in ...	Setpoint
7	Output				☐	☐	☐
8	Druck	Real	0.0	Non-retain	✓	✓	☐
9	InOut				☐	☐	☐

```
//Property
"P.IDruckAufnehmer.Druck"(Druckobjekt:=#Druckobjekt,
                          pKonfig:=#pKonfig,
                          Get => #Druck);
```

Therefore, the rules to make a property in TIA Portal are the following.

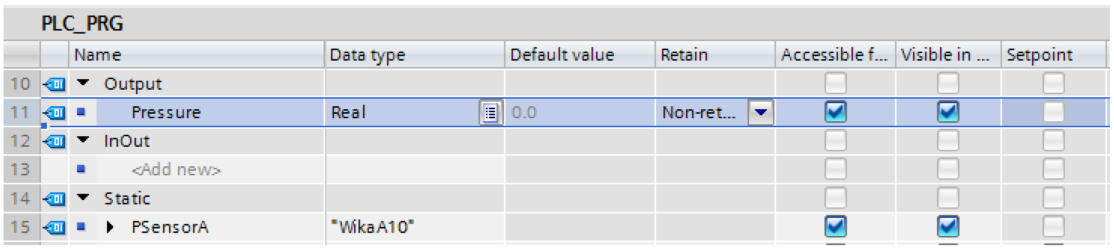
- A property is transferred to TIA Portal as a FC.
- The name of a property-FC starts with "P.", then the name of the interface followed by a dot and at the end the name of the property.

  e.g. P.TempSensor.Temperature

- A property is not a prototype but a FC with operations.
- A property has an input variable called *set* in case that the property has a set method.
- A property has an output variable called *get* in case that the property has a get method.
- The interface-FC calls the properties inside the body, without switch case.

- The interface has an in/output variable for the result of the property. This variable must have the same name as the property.

As a result, to call a property when needed is in the following way.



PLC_PRG

	Name	Data type	Default value	Retain	Accessible f...	Visible in ...	Setpoint
10	▼ Output				☐	☐	☐
11	Pressure	Real	0.0	Non-ret...	✓	✓	☐
12	▼ InOut				☐	☐	☐
13	<Add new>				☐	☐	☐
14	▼ Static				☐	☐	☐
15	▶ PSensorA	"WikaA10"			✓	✓	☐

```
#Pressure := #PSensorA.IDruckaufnehmer.Druck;
```

Where PSensorA is an instance of a FB-type WikaA10. This FB implements the interface IDruckAufnehmer, which has a property called *Druck*.

4 WIDOS application

As explained before, the development prototype WI-CNC is a plastic welding machine designed and manufactured in Germany by WIDOS company. The first part of the project, as it was explained in the state of the art, consisted in an application developed in CoDeSys for the WI-CNC machine. This application was translated to Siemens using the translation rules detailed in the last chapter. This chapter explains the translation process from CoDeSys to TIA Portal.

This translation is applied to the same WI-CNC machine. However, the control hardware is different. The application in CoDeSys sends and receives signals thorough CAN bus, while TIA Portal operates through the I/O ports of the PLC. Besides of the hardware configuration, the results in the programming should be the same.

It must be said that to make a clear explanation, this sections does not analyse every single part of the program, but only key parts. Nevertheless, the whole project can be found in the folder named *"MasterArbeit"* as a TIA Portal V.13 file.

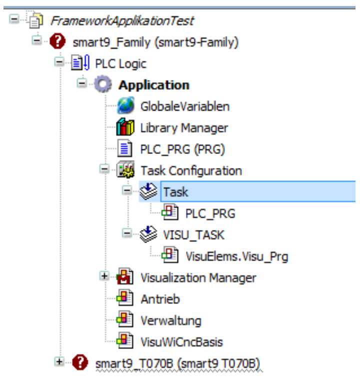
The structure model for the implementation is the following.

1. Configuration elements
   (a) Hardware configuration and resources
   (b) Task and associated program
2. UDT declaration
3. POU elements
   (a) FB-types and classes
   (b) Interfaces
   (c) Methods of a FB-type or class
   (d) Methods and properties of interfaces
4. Instructions

4.1 Configuration elements

4.1.1 Configuration is CoDeSys

A configuration is composed by resources and tasks. The resources of the project are one PLC and one HMI. The PLC has a cyclic task, this cyclic task instantiate the main program PLC_PRG. This configuration is shown in the Figure 4-1.

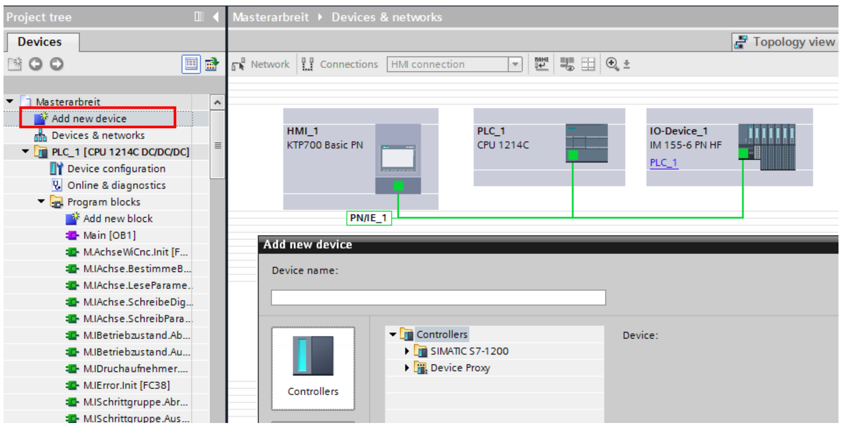


```
FrameworkApplikationTest
  smart9_Family (smart9-Family)
    PLC Logic
      Application
        GlobaleVariablen
        Library Manager
        PLC_PRG (PRG)
        Task Configuration
          Task
            PLC_PRG
          VISU_TASK
            VisuElems.Visu_Prg
        Visualization Manager
        Antrieb
        Verwaltung
        VisuWiCncBasis
    smart9_T070B (smart9 T070B)
```

Figure 4-1: CoDeSys configuration

4.1.2 Siemens configuration

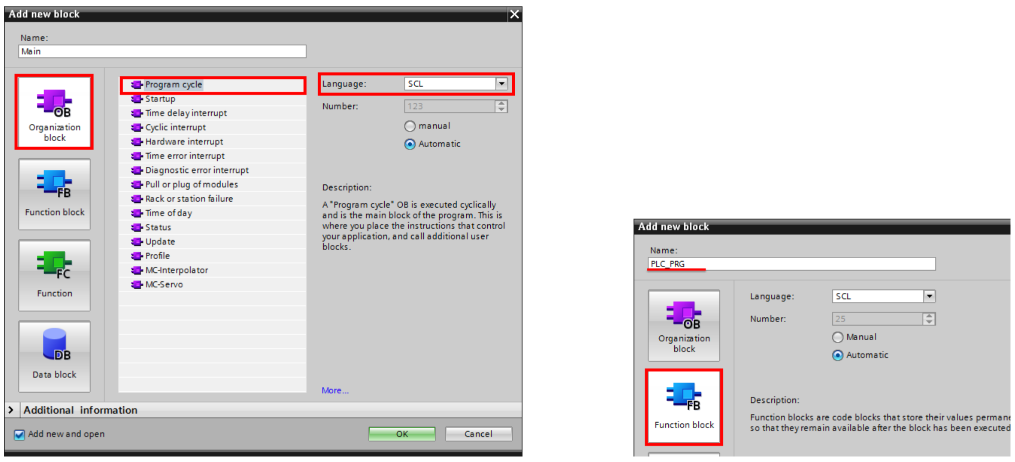
The hardware configuration is made in TIA Portal adding devices (resources) to the project. The hardware configuration is shown in the Figure 4-2.



```
Masterarbreit
  Add new device
  Devices & networks
  PLC_1 [CPU 1214C DC/DC/DC]
    Device configuration
    Online & diagnostics
    Program blocks
      Add new block
      Main [OB1]
      M.AchseWiCnc.Init [F...
      M.IAchse.BestimmeB...
      M.IAchse.LeseParame...
      M.IAchse.SchreibeDig...
      M.IAchse.SchreibPara...
      M.IBetriebzustand.Ab...
      M.IBetriebzustand.Au...
      M.IDruchaufnehmer....
      M.IError.Init [FC38]
      M.ISchrittgruppe.Abr...
      M.ISchrittgruppe.Aus...
```

Figure 4-2: Siemens hardware configuration

A cyclic task is transferred to TIA Portal as an OB with a cyclic program. A program of CoDeSys is a single-instance FB in TIA Portal. The Figure 4-3 shows the steps to create this two elements.



Name: Main
Language: SCL
Number: 123
( ) manual [✓ Automatic]
Description:
A "Program cycle" OB is executed cyclically and is the main block of the program. This is where you place the instructions that control your application, and call additional user blocks.
[✓] Add new and open

Name: PLC_PRG
Language: SCL
Number: 25
( ) Manual [✓ Automatic]
Description:
Function blocks are code blocks that store their values permane
so that they remain available after the block has been executed

(a) Creation of a cyclic task (b) Creation of a program - PLC_PRG (FB)

Figure 4-3: Basic blocks to start an OOP program in TIA Portal

The PLC_PRG program is added as a single-instance FB in the OB as shown below. Doing this, the configuration of the project in TIA Portal is done.

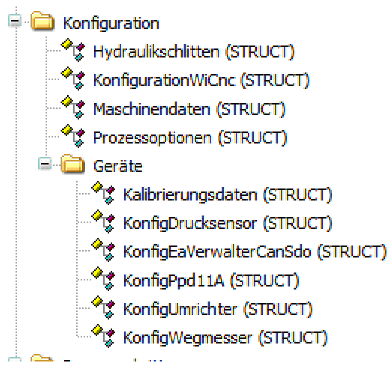
Listing 4.1: OB Main

```
"PLC_PRG_DB"();
```

4.2 UDT declaration

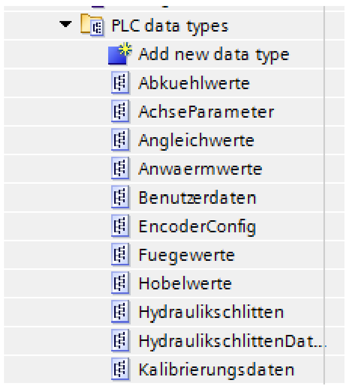
To do the UDT transference it is only necessary to identify the UDTs created in CoDeSys. Every UDT of CoDeSys is a PLC data type in TIA Portal.

CoDeSys allows the creation of folders in order to structure the programming elements. It is important to look for every UDT in every single folder. Siemens in contrast, has every PLC data type (UDT) in a single folder in the project tree. UDTs of both software are shown in Figure 4-4.



Konfiguration
Hydraulikschlitten (STRUCT)
KonfigurationWiCnc (STRUCT)
Maschinendaten (STRUCT)
Prozessoptionen (STRUCT)
Geräte
Kalibrierungsdaten (STRUCT)
KonfigDrucksensor (STRUCT)
KonfigEaVerwalterCanSdo (STRUCT)
KonfigPpd11A (STRUCT)
KonfigUmrichter (STRUCT)
KonfigWegmesser (STRUCT)

(a) UDTs in Codesys



PLC data types
Add new data type
Abkuehlwerte
AchseParameter
Angleichwerte
Anwaermwerte
Benutzerdaten
EncoderConfig
Fuegewerte
Hobelwerte
Hydraulikschlitten
HydraulikschlittenDat...
Kalibrierungsdaten

(b) PLC types (UDTs) in TIA Portal

Figure 4-4: UDTs represented in CoDeSys and TIA Portal

4.3 POU elements

4.3.1 FB-type

The next step is the creation of FB-types, the ones that create the instances (objects) of the machine. There are many different classes in the project like hardware classes, state classes, operation classes, etc. In order to give a clear explanation, only the axis classes were taken as example. The process principle is the same for any other class.

The axis classes are a group of FB-types oriented to the hardware of the machine. These classes are the responsible of the machine movement. The axis is supported by some elements. These elements are described in the Table 5.

Name	**Class name**	**Description**
Machine Axis	AchseWicnc	It is the main controller of the machine. This class effectuate every machine movement.
Valves	VentilblockWICnc	These valves are the ones that make possible the movement of the hydraulic actuators in the base machine.
Frequency converter	UmrichterWicnc	This converter controls the hydraulic pump that generates the oil pressure for the movement of the machine.
Linear Encoder	WegmesserWicnc	It measures the movement of the base machine.
Pressure Sensor	WikaA10Can	This is a pressure sensor. The sensor measures the pressure in the base machine.
Proportional Valve	Ppd11ACan	This valve is used to control the oil pressure in the machine.

Table 5: Axis classes and descriptions

4.3.1.1 FB-types in CoDeSys

The project is made of FB-types, there are no declared classes. In the Figure 4-5 is shown the folder axis classes[3].

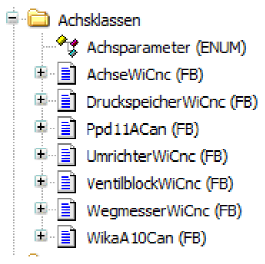

Achsklassen
Achsparameter (ENUM)
AchseWiCnc (FB)
DruckspeicherWiCnc (FB)
Ppd11ACan (FB)
UmrichterWiCnc (FB)
VentilblockWiCnc (FB)
WegmesserWiCnc (FB)
WikaA10Can (FB)

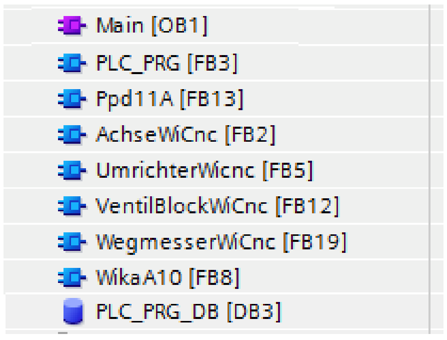
Figure 4-5: Axis classes in CoDeSys

[3]In German Achsklassen

4.3.1.2 FB-types in TIA Portal

Now that the FB-types are recognised, the next step is the translation to TIA Portal. As the rule says, a FB-type is in TIA Portal a multi-instance FB.

A new FB is created for very FB in CoDeSys and then they are turned into multi-instance FB. The result is shown in Figure 4-6. After this step, the FB-type declaration is finished.



Main [OB1]
PLC_PRG [FB3]
Ppd11A [FB13]
AchseWiCnc [FB2]
UmrichterWicnc [FB5]
VentilBlockWiCnc [FB12]
WegmesserWiCnc [FB19]
WikaA10 [FB8]
PLC_PRG_DB [DB3]

Figure 4-6: POUs declared after the classes declaration

4.3.2 Interfaces

This step affronts the problem that interfaces are in CoDeSys only prototypes without code, but in TIA Portal this concept does not exist. Due to that fact, this step is not as easy as go to the interface section in CoDeSys and transfer them to TIA Portal.

This section includes an explanation about how to go directly to the FB and see which interfaces are there implemented. Eventually, the interfaces are to TIA Portal transferred.

4.3.2.1 Interfaces in CoDeSys

For this topic explanation, the interfaces implemented in the FB Ppd11A are taken as example. The Figure 4-7 shows the elements of FB Ppd11ACan.

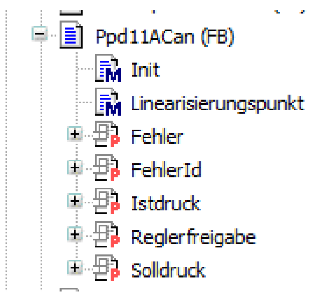


Figure 4-7: Elements of the FB Ppd11ACan

Those are all the methods and properties that the FB has. It is necessary to differentiate the methods of the FB from the methods of the interface. To do this, it is important to identify the interfaces implemented in the FB. The next code shows the declaration part of the FB Ppd11ACan.

```
FUNCTION_BLOCK Ppd11ACan IMPLEMENTS IFehlerAuslesbar, IDruckregler
```

The FB implements two interfaces: IFehlerAuslesbar and IDruckregler[4]. The next step is to look for the interfaces in the project and see which methods belong to which interfaces. The Figure 4-8 shows these two interfaces.

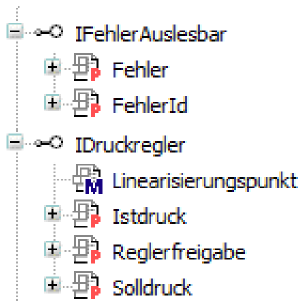


Figure 4-8: Elements of the interfaces IFehlerAuslesbar and IDruckregler

With this analysis, it could be figured out that only *init* method belongs to the FB and the transference can now be done.

[4]German words for Error readable and Pressure regulator, respectively

4.3.2.2 Interfaces in TIA Portal

The interfaces found after the previous analysis are: IFehlerAuslesbar and IDruckregler. Each interface is transferred to TIA Portal as a multi-instance FB. The result is shown in Figure 4-9.

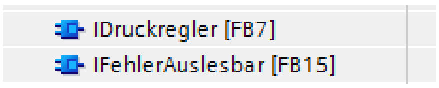

IDruckregler [FB7]
IFehlerAuslesbar [FB15]

Figure 4-9: Interfaces IFehlerAuslesbar and IDruckregler

4.3.3 Methods of a FB-types

In this section, the *init* method of the FB Ppd11A is explained. The process is the same for any other FB-type method. Nevertheless, this method is present in many FB-types.

The *Init* method is a function called just after the start of the PLC. This method set the initial values and configuration of the objects.

4.3.3.1 Methods of FB-types in CoDeSys

The init method is declared in CoDeSys as following.

```
METHOD Init
VAR_INPUT
  pEaAnbindung : POINTER TO EaVerwalterCanSdo;
  pKonfiguration : POINTER TO KonfigPpd11A;
END_VAR
```

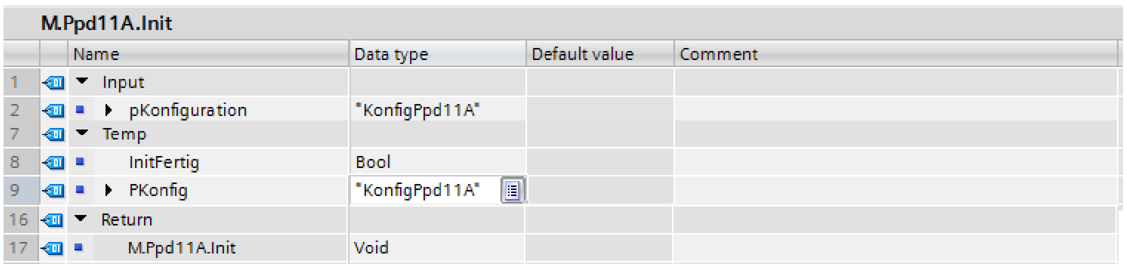
```
IF NOT InitFertig THEN
  pEaVerwalter := pEaAnbindung;
  pKonfig := pKonfiguration;

  pEaVerwalter^.InitialisiereSdo(ADR(Propventil),
     Knotenadressen.Kleinspannung, SdoAdrN400.Proportionalventil,
     CanDatentyp.Us16, CanSdoPrioritaet.Hoch, FALSE);

  InitFertig := TRUE;
END_IF
```

4.3.3.2 Methods of FB-types in TIA Portal

The first step according to the translation rules is to create the method functions. A method is transferred to TIA Portal as a FC with a specific name. The result is the following.

M.Ppd11A.Init (FC)

The method has no return value in the CoDeSys example, that means that the return value is *void*. Variables and code may now be included, the result is shown below.



M.Ppd11A.Init

	Name	Data type	Default value	Comment
1	▼ Input			
2	▶ pKonfiguration	"KonfigPpd11A"		
7	▼ Temp			
8	InitFertig	Bool		
9	▶ PKonfig	"KonfigPpd11A"		
16	▼ Return			
17	M.Ppd11A.Init	Void		

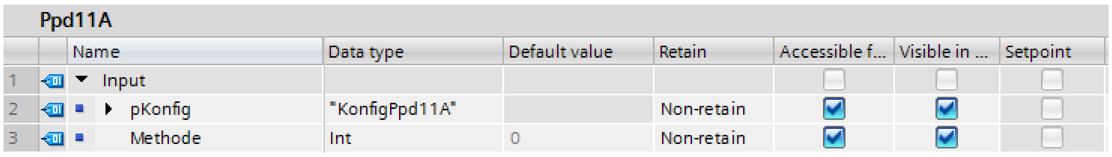
```
IF NOT #InitFertig THEN
   #PKonfig:=#pKonfiguration;

   #InitFertig := TRUE;
END_IF;
```

Note: it is important to pay special attention in the code related to the configuration. The code in CoDeSys has a CAN initialisation, which is not necessary in TIA Portal. The I/Os configuration is performed in the PLC tags section.

The next step is to add the method inside the FB-type. The rule says that a method is called inside a switch case. For the switch case, the following elements are created.

- An input variable called *Method* for the switch case selector in the FB-type.
- A constant tag table for the index of the switch case.

When the method is called, it request input/output variables. In this example, PKonfig is requested by the method-FC. This must be also added in the FB-type. The result in the FB-type is the following.



Ppd11A

	Name	Data type	Default value	Retain	Accessible f...	Visible in ...	Setpoint
1	▼ Input				☐	☐	☐
2	▶ pKonfig	"KonfigPpd11A"		Non-retain	✓	✓	☐
3	Methode	Int	0	Non-retain	✓	✓	☐

```
//Method
CASE #Methode OF
   "INIT":
      "M.Ppd11A.Init"(#pKonfig);
END_CASE;
```

Note: Inside the switch case can be added more methods.

This method is finished and it can be called by any instance of the FB Ppd11A.

4.3.4 Methods and properties of Interfaces

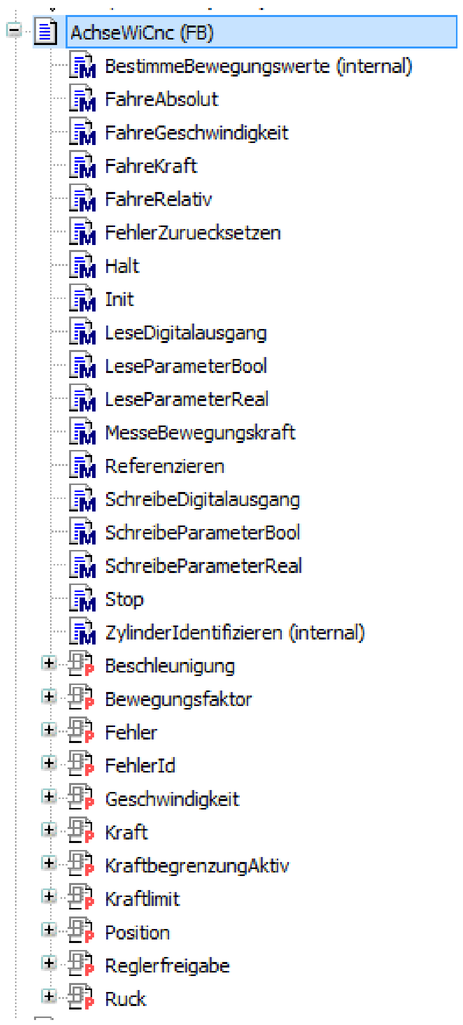
The interfaces were already made, but they are empty. This section is about how to fill the interfaces with methods and properties.

Methods and properties of an interface are only prototypes and do not have code. Since TIA Portal is not able to create these kind of functions, an implemented interface is analysed. In other words, these elements are attached to a FB-type by the implementation of an interface.

The elements analysed in this section are the properties and methods of the interface IAchse. This is the interface of the machine axis, responsible of the machine movement.

4.3.4.1 Methods and properties of an interface in CoDeSys

The interface IAchse is implemented to the FB-type AchseWinc. The structure of the FB in CoDeSys is shown in Figure 4-10.



AchseWiCnc (FB)
BestimmeBewegungswerte (internal)
FahreAbsolut
FahreGeschwindigkeit
FahreKraft
FahreRelativ
FehlerZuruecksetzen
Halt
Init
LeseDigitalausgang
LeseParameterBool
LeseParameterReal
MesseBewegungskraft
Referenzieren
SchreibeDigitalausgang
SchreibeParameterBool
SchreibeParameterReal
Stop
ZylinderIdentifizieren (internal)
Beschleunigung
Bewegungsfaktor
Fehler
FehlerId
Geschwindigkeit
Kraft
KraftbegrenzungAktiv
Kraftlimit
Position
Reglerfreigabe
Ruck

Figure 4-10: Structure of FB WiCnc

4.3.4.2 Methods and properties of an interface in TIA Portal

The process to make a method or property of an interface is similar to the process to make methods for a FB-type, but the implementation is different. For this reason, the creation of the methods is not again explained, but the implementation in the interface.

After the creation of all methods-FC and properties-FC, they must be added inside the body of the interface. Applying the translation rules, the result of the interface-FB is the following below.

Listing 4.2: IAchse

```
//Properties
"P.IAchse.Position"(#Position);
"P.IAchse.Geschwindigkeit"(#Geschwindigkeit);
"P.IAchse.Beschleunigung"(#Beschleunigung);
"P.IAchse.Regelfreigebe"(#ReglerFreigabe);

//Methods
CASE #Methode OF
   "LESEPARAMETERREAL":
      "M.IAchse.LeseParameterReal"(Parameter := #Parameter,
                                   Wert => #Wert);
      ;
   "BESTIMMEBEWEGUNSWERTE":
      "M.IAchse.BestimmeBewegungswerte"();
      ;
   "SCHREIBEDIGITALAUSGANG":
      "M.IAchse.SchreibeDigitalausgang"(Ausgang:=#Parameter,
                                       Wert:=#ReglerFreigabe);
      ;
   "SCHREIBEPARAMETERREAL":
      "M.IAchse.SchreibParameterReal"(Parameter:=#Parameter,
                                     SollFrequenz:=#SollFrequenz,
                                     SollDruck:=#SollDruck);
      ;
END_CASE;
```

Note: these are not all the methods and properties, but the ones used in the application project.

The same process applies for any other interface.

4.4 Code

Now, every OOP element is translated to TIA Portal. That means, instructions and process of the machine can now be written. The syntax is the same, since the programming languages are the same, but with different name.

The principle of variable declaration is also the same.

5 Evaluation of the project

5.1 Results and observations

The main purpose about finding out transfer rules to convert code from CoDeSys V3.5 to TIA Portal V13 was successfully. It was hardly at the begging to find the exact behaviour and definition of every CoDeSys element. However, the norm was very helpful with this problem. The norm IEC 61131-3 explains in detail every element of a PLC programming language including OOP elements. Based in the IEC norm and comparing results with CoDeSys, the translation rules were successfully written.

5.1.1 Result of configuration translation

This topic was a little challenging, the configuration is in both systems pretty different; although, a translation way was found. The norm declares that a configuration is composed by resources and tasks, which means, a configuration is the hardware configuration composed by devices. A hardware configuration can be made in TIA Portal adding devices, like HMI or decentralised modules.

Another challenge was faced in the application, the hardware configuration in the WI-CNC machines is composed by a panel PC communicated through CAN interface with the machine. This configuration was completely changed due to the I/O ports of the PLC. This change in the configuration also modifies the code instructions related with the hardware communication. Nevertheless, a transfer rule could be found in every case .

Therefore, a translation of configuration is successfully achieved only after a hardware analysis.

5.1.2 Result of Program translation

A ‘program’ was a programming element not available in TIA Portal. However, a successfully translation could be found. After reading the concept and specifications detailed in the norm, it was found out that the realisation of programs in TIA Portal is possible.

Rules about the translation of programs could be found, but not only that, also about the association of programs in tasks. With these achievements, the properly translation of programs and its association were finished.

5.1.3 Result of FB translation

The FB translation was one of the most accurate and perfect translation. Both FB-types and FB-instance were already in TIA Portal, but named after another name. After reading the concept in the IEC norm, it was found out that FB-types are multi-instances FBs and FB-instances are variables of type multi-instance FBs.

This element is also one of the most important ones in the project. The programming structure of CoDeSys uses only FB and does not make class declarations. Therefore, the successfully translation of this element was an important achievement for the project.

5.1.4 Result of functions

By functions' are involved methods of a class, methods of an interface and properties. This translation was achieved though lot of conditions in the implementation. In spite that all methods are as simply FC to TIA Portal translated, the association of these to classes or interfaces was complicated.

These functions needed of extra elements in order to find a proper translation. For example, extra declaration of variables, constants and switch cases. However, after all those extra elements and conditions a successfully approach for a proper translation was achieved. Notwithstanding, it could be worthy to invest more time in the improvement of this translation.

5.2 Results and evaluation of the WI-CNC application

The result of the application is the translation of the application framework of the WI-CNC made in CoDeSys by Tilmann Glücks. The translation in TIA Portal was able to reproduce all OOP elements of the CoDeSys programming structure. The PLC was also programmed in order to effectuate common tasks like the movement of the base machine and the correctly lecture of pressure sensors and encoder.

This effectiveness of the translation rules makes programming modules and structure reusable. With this, the programming timing is reduced, which means that the development timing of a machine is also reduced. This helps WIDOS to deliver their products quicker.

The translation rules make possible the representation of OOP elements in Siemens. This is an advantage, because OOD and modern system models like MBSE can be applied also in Siemens, not only that, but also OOP makes complex programming easier to develop and comprehend.

The application of the translation rules in WIDOS saves much money due to the following advantages:

- Avoiding the needing to hire external Siemens programmers.
- Avoiding the needing to write a whole new program only for Siemens.
- Avoiding to make a new programming design.
- Saving programming timing.
- It can deliver their products faster, no mater the PLC required by the client.

5.3 Summary

The Table 6 shows a summary of the elements that could be successfully translated or not in the period of time established for the master project.

Element	**Translation**	**Remarks**
Configuration	Successfully	The configuration is different but the result is the same.
Resources	Successfully	Each system has its own resources but the result is the same.
Tasks	Successfully	–
Program	Successfully	–
Function Blocks	Successfully	–
Classes	Not successfully	Classes cannot be declared but FB-types which are able to do the same operations.
Interfaces	Successfully	Not as prototypes but as implemented interfaces.
Methods of classes or FBs	Successfully	–
Prototype methods	Not successfully	Only implemented methods, that does not limit the translation-ability of the code.
Properties	Successfully	But only implemented properties
UDTs	Successfully	–

Table 6: Summary of the project

6 Future prospects

The norm IEC 61131-3 is large and deals with many other aspects of PLC programming systems. This master thesis details the most important ones so roughly. Nevertheless, a whole translation of the norm IEC 61131-3 can be done to be applied in TIA Portal. Documenting which specifications are able to be translated or not.

Talking about the translation of OOP elements, some of them can be improved and some others no. For example, FBs are very good translated and have no needing of improvement. On the other hand, elements like methods and properties of interfaces can be improved, making cleaner programming structures.

Another future prospect is the creation of a software able to recognise elements of a CoDeSys framework and make an automatic translation to TIA Portal. It may begin not by giving an already TIA Portal project file but a help file to make a translation easier and quicker.

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[WID12] WIDOS. *Betriebsanleitung WIDOS 4600*, 2012.

[WID15a] WIDOS. *Original Betriebsanleitung*, 2015.

[WID15b] WIDOS. *Working Instructions WIDOS WI-CNC*, 2015.

Appendices

A Translation rules

A.1 Data type

A.1.1 UDT

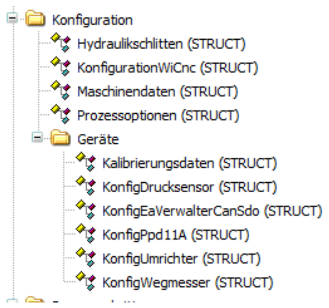
A.1.1.1 Problem

UDTs are not found in Siemens.

A.1.1.2 Translation rule

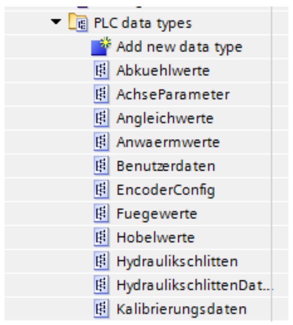
The UDTs of CoDeSys are the PLC Data types in TIA Portal.

A.1.1.3 Example



Konfiguration
- Hydraulikschlitten (STRUCT)
- KonfigurationWiCnc (STRUCT)
- Maschinendaten (STRUCT)
- Prozessoptionen (STRUCT)
- Geräte
  - Kalibrierungsdaten (STRUCT)
  - KonfigDrucksensor (STRUCT)
  - KonfigEaVerwalterCanSdo (STRUCT)
  - KonfigPpd11A (STRUCT)
  - KonfigUmrichter (STRUCT)
  - KonfigWegmesser (STRUCT)

(a) UDTs in Codesys



PLC data types
- Add new data type
- Abkuehlwerte
- AchseParameter
- Angleichwerte
- Anwaermwerte
- Benutzerdaten
- EncoderConfig
- Fuegewerte
- Hobelwerte
- Hydraulikschlitten
- HydraulikschlittenDat...
- Kalibrierungsdaten

(b) PLC types (UDTs) in TIA Portal

A.1.2 VAR section

A.1.2.1 Problem

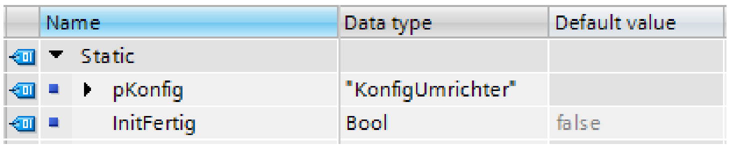
The variable section `VAR` is not found in TIA Portal.

A.1.2.2 Translation rule

The `VAR` section of CoDeSys can be taken as the *Static* variable section of Siemens.

A.1.2.3 Example

```
VAR
pKonfig    : POINTER TO KonfigUmrichter;
InitFertig    : BOOL;
END_VAR
```



Name	Data type	Default value
Static		
pKonfig	"KonfigUmrichter"	
InitFertig	Bool	false

A.1.3 Global variables

A.1.3.1 Problem

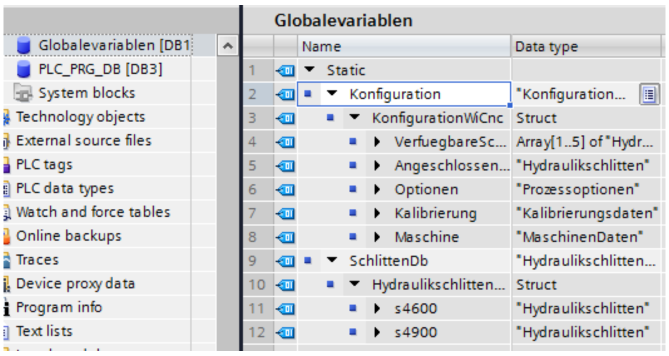
Global variables cannot be declared in TIA Portal.

A.1.3.2 Translation rule

The variable declaration VAR_GLOBAL can be transferred to Siemens as a Data Base POU.

A.1.3.3 Example

```
VAR_GLOBAL
   Rezept : RezeptWiCnc;
   Konfiguration : KonfigurationWiCnc;
   SchlittenDb : HydraulikschlittenDatenbank;
END_VAR
```



- Globalevariablen [DB1
- PLC_PRG_DB [DB3]
- System blocks
- Technology objects
- External source files
- PLC tags
- PLC data types
- Watch and force tables
- Online backups
- Traces
- Device proxy data
- Program info
- Text lists

Globalevariablen

	Name	Data type
1	Static	
2	Konfiguration	"Konfiguration...
3	KonfigurationWiCnc	Struct
4	VerfuegbareSc...	Array[1..5] of "Hydr...
5	Angeschlossen...	"Hydraulikschlitten"
6	Optionen	"Prozessoptionen"
7	Kalibrierung	"Kalibrierungsdaten"
8	Maschine	"MaschinenDaten"
9	SchlittenDb	"Hydraulikschlitten...
10	Hydraulikschlitten...	Struct
11	s4600	"Hydraulikschlitten"
12	s4900	"Hydraulikschlitten"

A.2 Configuration

A.2.1 Tasks

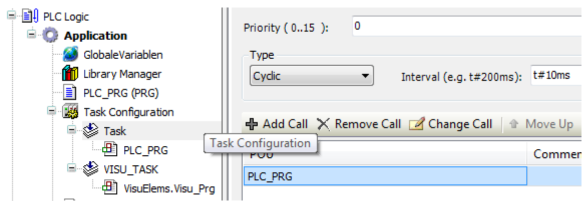
A.2.1.1 Problem

Tasks are not a programming element in TIA Portal.

A.2.1.2 Transfer rule

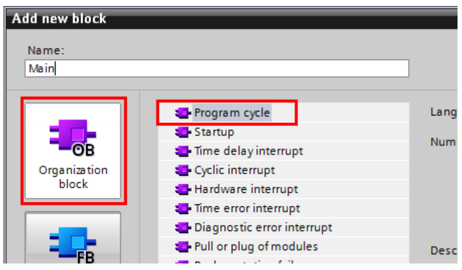
The cyclic tasks in CoDeSys can be taken as the organization blocks in TIA Portal with a “Program cycle” function.

A.2.1.3 Example



Priority (0..15): 0
Type: Cyclic
Interval (e.g. t#200ms): t#10ms
PLC_PRG

(a) Task in Codesys



Name: Main

(b) Task in TIA Portal

A.3 POUs

A.3.1 Program

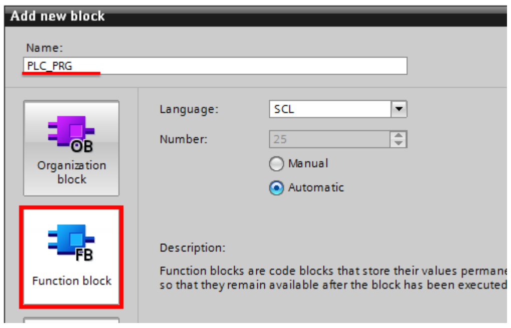
A.3.1.1 Problem

Programs are not program elements available in Siemens.

A.3.1.2 Transfer rule

A program can be represented in TIA Portal as a single-instance FB, which is instantiated inside an OB (task).

A.3.1.3 Example


Add new block

Name: PLC_PRG

Language: SCL

Number: 25

( ) Manual

[✓ Automatic]

Description:

Function blocks are code blocks that store their values permane
so that they remain available after the block has been executed

A.3.2 FB-type

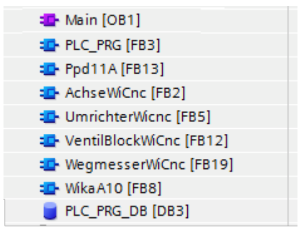
A.3.2.1 Problem

TIA Portal does not name FB-types after that name.

A.3.2.2 Transfer rule

A FB-type of CoDeSys is a multi-instance FB in Siemens.

A.3.2.3 Example


Main [OB1]
PLC_PRG [FB3]
Ppd11A [FB13]
AchseWiCnc [FB2]
UmrichterWicnc [FB5]
VentilBlockWiCnc [FB12]
WegmesserWiCnc [FB19]
WikaA10 [FB8]
PLC_PRG_DB [DB3]

A.3.3 FB-instance

A.3.3.1 Problem

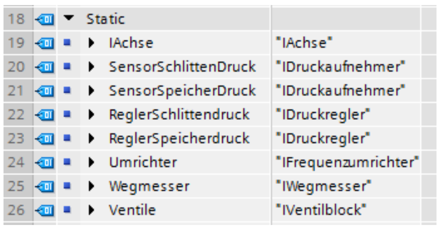
TIA Portal does not name FB-instance after that name.

A.3.3.2 Transfer rule

The process to create a FB-instance is the same in TIA Portal and in CoDeSys. That is, through the creation of a new variable selecting as data type the wished FB-type. This variable must be created in the section variable “static”.

A.3.3.3 Example

```
VAR
   Heizelement : HeizelementWiCnc;
   Achse : AchseWiCnc;
   Aussentemperatur : AussentemperaturWiCnc;
   Speicherdruck   : WikaA10Can;
   Schlittendruck   : WikaA10Can;
   Propventil : Ppd11ACan;
   Umrichter : UmrichterWiCnc;
   Wegmesser : WegmesserWiCnc;
   Achsausgaenge : VentilblockWiCnc;
END_VAR
```



18	Static	
19	IAchse	"IAchse"
20	SensorSchlittenDruck	"IDruckaufnehmer"
21	SensorSpeicherDruck	"IDruckaufnehmer"
22	ReglerSchlittendruck	"IDruckregler"
23	ReglerSpeicherdruck	"IDruckregler"
24	Umrichter	"IFrequenzumrichter"
25	Wegmesser	"IWegmesser"
26	Ventile	"IVentilblock"

A.3.4 Classes

A.3.4.1 Problem

TIA Portal does not include the programming element ‘Class’.

A.3.4.2 Transfer rule

A class can be transferred to TIA Portal as a FB-type.

A.3.5 Methods of a FB

A.3.5.1 Problem

The programming element 'Method of a class' is not available in TIA Portal.

A.3.5.2 Transfer rule

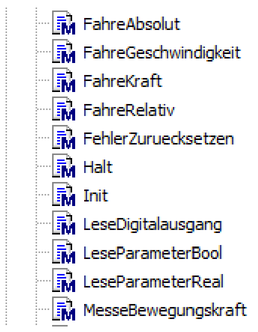
The rules to implement a method in a FB-type with TIA Portal are the following ones:

- The name must begin with the letter "M", then the name of the FB-type that the method belongs to and finally the name of the method. In between of every word a dot must be written.

  e.g. M.WikaA10.Linearisierungspunkt

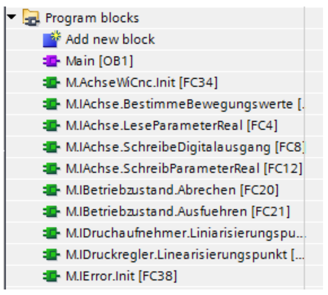
- Methods must be added to the FB-type inside a switch case.
- The FB-type must add a new variable called "Method" of type integer. This variable is used as the selector for the switch case.
- The inputs and outputs of the method must be declared as input and outputs in the FB-type.
- A tag table of user constants must be created in order to serve as the index of the switch case. (This table is important because its values can be reached from any POU in the project)

A.3.5.3 Example



```
FahreAbsolut
FahreGeschwindigkeit
FahreKraft
FahreRelativ
FehlerZuruecksetzen
Halt
Init
LeseDigitalausgang
LeseParameterBool
LeseParameterReal
MesseBewegungskraft
```

(a) Method of a Class in Codesys



```
Program blocks
    Add new block
    Main [OB1]
    M.AchseWiCnc.Init [FC34]
    M.IAchse.BestimmeBewegungswerte [.
    M.IAchse.LeseParameterReal [FC4]
    M.IAchse.SchreibeDigitalausgang [FC8]
    M.IAchse.SchreibParameterReal [FC12]
    M.IBetriebzustand.Abrechen [FC20]
    M.IBetriebzustand.Ausfuehren [FC21]
    M.IDruchaufnehmer.Liniarisierungspu...
    M.IDruckregler.Linearisierungspunkt [...
    M.IError.Init [FC38]
```

(b) Method of a Class in TIA Portal

A.3.6 Interfaces

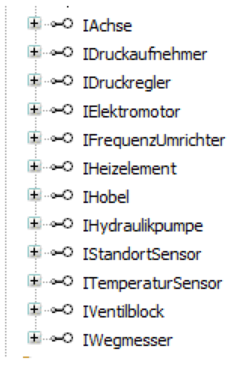
A.3.6.1 Problem

An interface is not a programming element available in TIA Portal.

A.3.6.2 Transfer rules

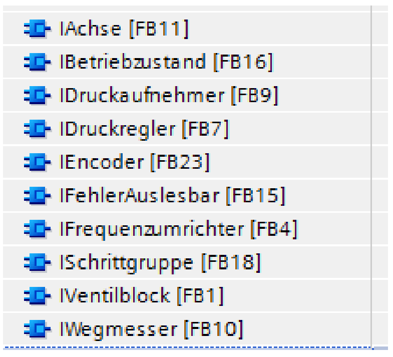
- An interface-FB, starts its name with an "I".
- An interface is transferred to TIA Portal as a multi-instance FB without instructions.

A.3.6.3 Example



IAchse
IDruckaufnehmer
IDruckregler
IElektromotor
IFrequenzUmrichter
IHeizelement
IHobel
IHydraulikpumpe
IStandortSensor
ITemperaturSensor
IVentilblock
IWegmesser

(a) Interfaces in Codesys



IAchse [FB11]
IBetriebzustand [FB16]
IDruckaufnehmer [FB9]
IDruckregler [FB7]
IEncoder [FB23]
IFehlerAuslesbar [FB15]
IFrequenzumrichter [FB4]
ISchrittgruppe [FB18]
IVentilblock [FB1]
IWegmesser [FB10]

(b) Interfaces in TIA Portal

A.3.7 Methods of an interface

A.3.7.1 Problem

Methods of an interface are not a programming element available in TIA Portal. TIA Portal is not able to do prototype-functions.

A.3.7.2 Transfer rule

The rules to implement a method in an interface with TIA Portal are the following ones:

- The name must begin with the letter "M", then the name of the interface that the method belongs to and finally the name of the method. In between of every word a dot must be written.

e.g. M.IDruckaufnehmer.Linearisierungspunkt

- Methods must be added to the interface inside a switch case.
- The interface must add a new variable called “Method” of type integer. This variable is used as the selector for the switch case.
- The inputs and outputs of the method must be declared as input and outputs in the interface-FB.
- A tag table of user constants must be created in order to serve as the index of the switch case. (This table is important because its values can be reached from any POU in the project)

A.3.7.3 Example

```
//Methods of an interface in TIA Portal
CASE #Methode OF
   "LESEPARAMETERREAL":
      "M.IAchse.LeseParameterReal"(Parameter := #Parameter,
                                   Wert => #Wert);
      ;
   "BESTIMMEBEWEGUNSWERTE":
      "M.IAchse.BestimmeBewegungswerte"();
      ;
   "SCHREIBEDIGITALAUSGANG":
      "M.IAchse.SchreibeDigitalausgang"(Ausgang:=#Parameter,
                                        Wert:=#ReglerFreigabe);
      ;
   "SCHREIBEPARAMETERREAL":
      "M.IAchse.SchreibParameterReal"(Parameter:=#Parameter,
                                      SollFrequenz:=#SollFrequenz,
                                      SollDruck:=#SollDruck);
      ;
END_CASE;
```

A.3.8 Property

A.3.8.1 Problem

Properties are not programming elements available in TIA Portal.

A.3.8.2 Transfer rule

The rules to make a property in TIA Portal are the following.

- A property is transferred to TIA Portal as a FC.
- The name of a property-FC starts with "P.", then the name of the interface followed by a dot and at the end the name of the property.

  e.g. P.TempSensor.Temperature

- A property is not a prototype but a FC with operations.
- A property has an input variable called *set* in case that the property has a set method.
- A property has an output variable called *get* in case that the property has a get method.
- The interface-FC calls the properties inside the body, without switch case.
- The interface has an in/output variable for the result of the property. This variable must have the same name as the property.

A.3.8.3 Example

```
//Properties of an interface in TIA Portal
"P.IAchse.Position"(#Position);
"P.IAchse.Geschwindigkeit"(#Geschwindigkeit);
"P.IAchse.Beschleunigung"(#Beschleunigung);
"P.IAchse.Regelfreigebe"(#ReglerFreigabe);
```