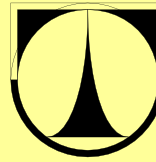




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Experiment Instructions
September 2019

SCD
**Sequence Control of a Drilling
Machine by SIMATIC S7-300**

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These experiment instructions are supposed to give a working guide for the laboratory task "Sequence control of the drilling machine" to Czech students of the international bilateral project: "Experimental work and Simulation of Control systems" subproject "Industrial use of PLC and Control Systems" which is carried out in laboratories at the University of Applied Science Zittau/Görlitz, Germany. The project was developed in cooperation of the Technical University of Liberec and the University of Applied Science Zittau/Görlitz in 2005.

The objective of this laboratory exercise is to familiarize the students with the programming of a control system S7-300 using STEP 7, which is supplied with the optional package S7-GRAPH FB for a sequence control.

The subproject "Industrial use of PLC and Control Systems" is carried out as the "International laboratory exchange programme" and this student's guide was partly financially supported by the EU – Small projects of Euro region Neise-Nisa-Nysa, Nr. CZ 2003/005 - 095.03.01- 0083 in 2005.

1 Introduction

SIMATIC is a worldwide established automation system for implementation of industrial control systems for industrial use. The programmable controller SIMATIC S7-300 is known as one of the automation systems which enables integrated configuration, data management and communication throughout the complete automation system. The basic tool for SIMATIC 300 is STEP 7 that offers the following languages: instruction list IL, ladder diagram LAD, function block diagram FBD, structured control language SCL and S7-Graph. The language **S7-GRAPH** is an implementation of a sequential function chart SFC and used for **sequence control**.

The programming of our laboratory task will provide an overview of the programmable controller SIMATIC S7-300 and programming in the environment of STEP 7. The objective of this laboratory task is to create a program for a sequencer with Steps and Transitions for automatic drilling machine and its testing.

2 Technological Task

The students will perform laboratory experiments and programming on a model of an automatic drilling machine and a programmable logic controller S7-300. The scheme of the drilling machine is depicted on the figure 2.1. The programmable logic controller consisting of a standard rail, 24V power supply, CPU 314 and a digital input/output module (16DI +8DO) is exposed on the Figure 1.1.

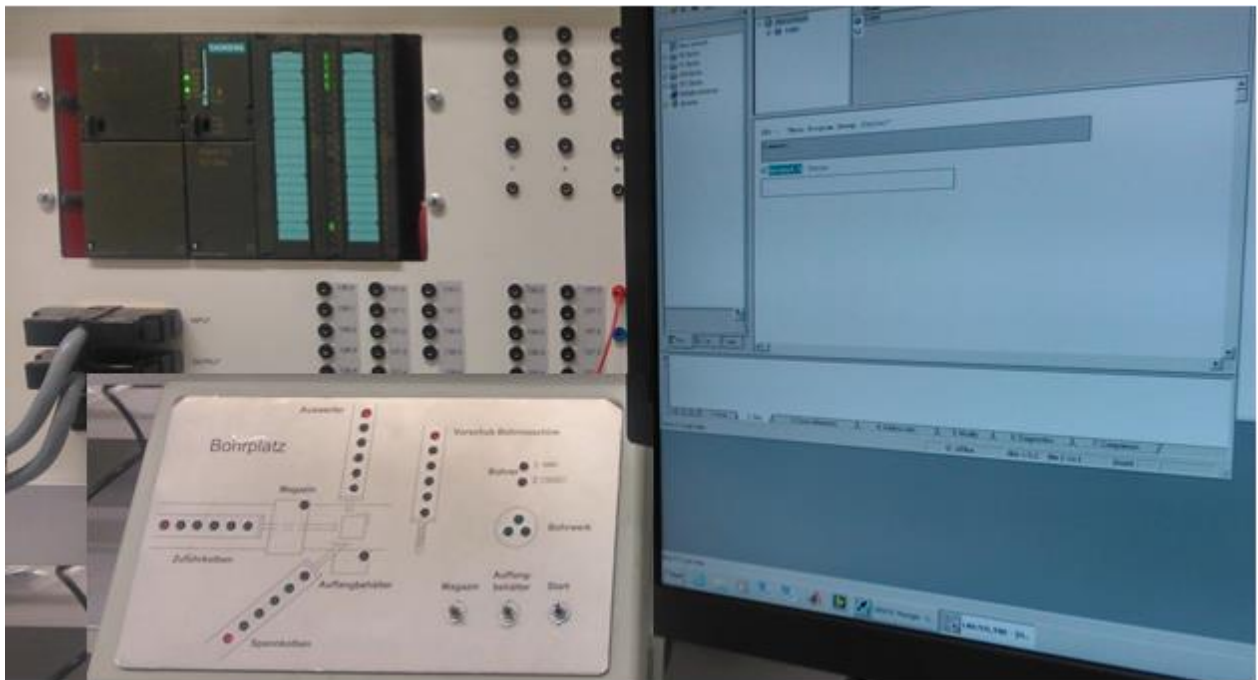


Figure 1.1: Programmable logic controller S7-300 with connections.

2.1 Technological scheme of the automatic drilling machine

The technological scheme on the figure 2.1 shows the set-up of the drilling machine. The machine consists of the following elements:

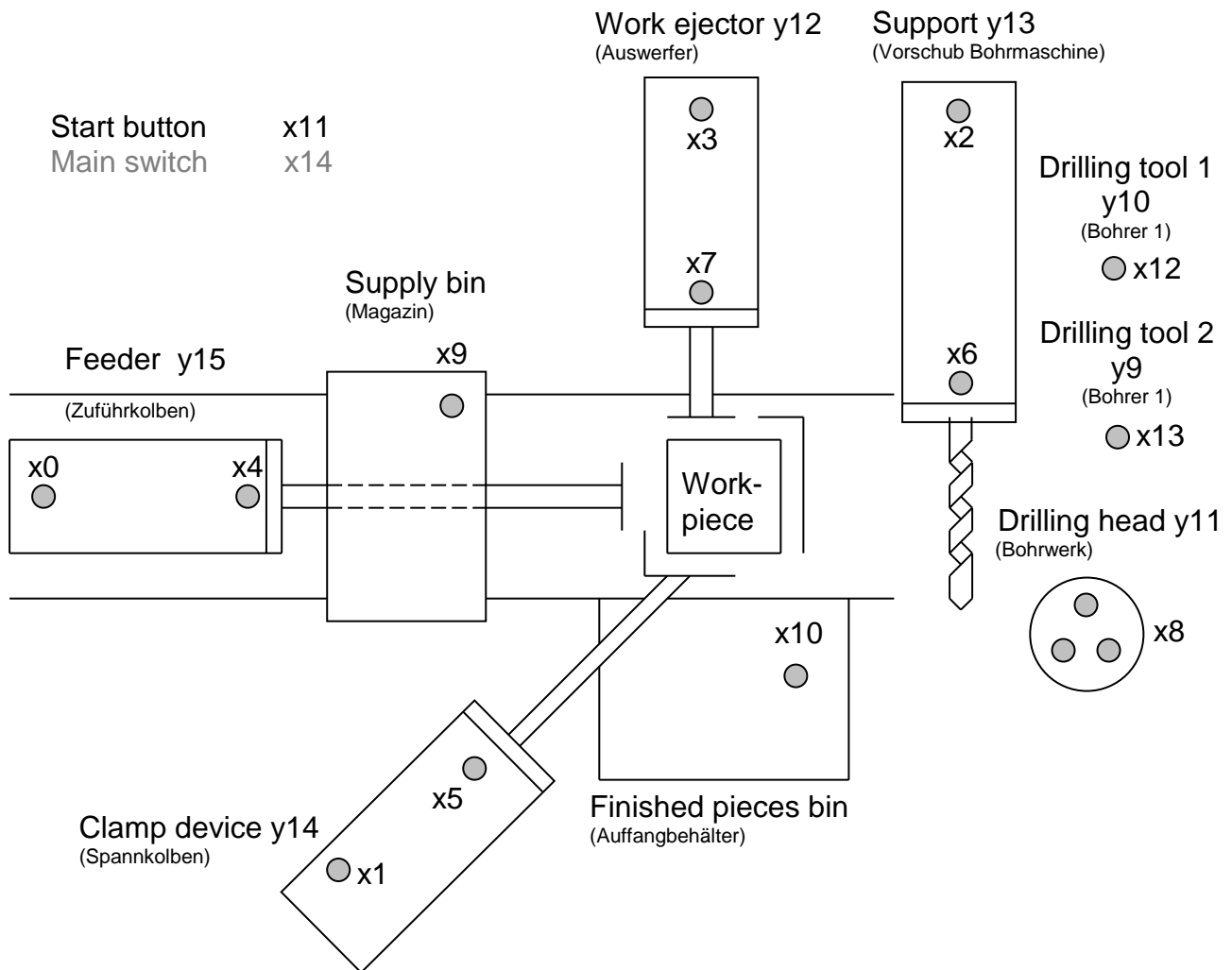


Figure 2.1: Set up of the automatic drilling machine

- **Feeder** with feedback signals: “home” and “working position”. The feeder places one work piece from the supply bin to working position. The feedback signal “working position” indicates that the work piece is on the platform and it can be clamped.
- **Clamp device** with feedback signals: “home” and “working position”. Working position indicates that the work piece has been already clamped.
- **Work ejector** with feedback signals: “home” and “working position”. After drilling and release (unclamp) the work ejector removes the work piece and places it in the finished pieces bin. The working position indicates that the work piece has been removed.
- **Supply bin** of work pieces with a feedback signal: “bin is not empty”.
- **Finished pieces bin** with a feedback signal: “bin is full”.
- **Support** with a **drilling head** that has two drilling tools. The support has two feedback signals: “home” and “working position”. The working position indicates

that the support with the drilling head has been moved to the bottom limit position (down). The home position of the support with the drilling head indicates that the support is in its upper position (up).

- **The drilling head** can work with two drilling tools and it has three feedback signals: "Drilling tool 1 is set", "Drilling tool 2 is set" and "Drilling head rotates". The drilling head is **ready for operation** and can be moved up or down when a drilling tool is set and the drilling head rotates (motor is turned ON). The drilling tools can be set when the support is in the home position and the drilling head does not rotate.

The air cylinders from the feeder, clamp device, work ejector and support are equipped with a spring, which ensures the removal of cylinders to their home positions, when the input from PLC is equal to zero.

For the performance of the program sequencer the following conditions have to be met:

General conditions:

- 1) The automatic system of the drilling machine has been switched on with the **main switch**.
- 2) The starting of the operational (drilling) cycle is performed by the **start button**.
- 3) When the automatic drilling machine is stopped with the main switch then the drilling machine parts have to be set to their **home position** and a complete new drilling cycle will be started if the main switch is on again.
- 4) You have to feed a work piece, clamp it and then make the drilling head ready for operation before you can start the drilling by moving the support in the working position. After drilling and moving the support in the home position you can unclamp and eject the work piece.

Special conditions:

- 1) Drilling cycle can only be started when the supply bin is not empty and the finished pieces bin is not full.
- 2) Feeder goes to the home position after the clamp device has clamped the work piece
- 3) The work piece can be fed only when the supply bin is not empty and it can be ejected only when the finished pieces bin is not full.
- 4) When the drilling cycle is interrupted because the supply is empty or the finished pieces bin is full then the switching ON the start button continues the operation after filling the supply bin / removing the finished piece.

2.2 Initial state

The initial state of the automatic drilling machine is defined as follows:

- The support with the drilling head, feeder, clamp device and work ejector are in their home position.
- The the drilling tools are unset and the drilling head motor is stopped.
- There is no work piece on the working platform.

2.3 Student's Task

Create a program for a sequence control in the environment of SIMATIC Manager and Step 7 (S7-GRAPH) for automating of the drilling machine that is described in the chapter 2.1. Please carry out:

- 1) *Description of the SIMATIC S7-300 workstation*
- 2) *A concept of dividing the drilling operation into individual steps, accepting the given number of variants as well as the general and the special conditions exposed in the previous chapter.*
- 3) *Table of Input and Output signals*
- 4) *Flowchart of the drilling process.*
- 5) *Program of sequencer S7-GRAPH with Steps and Transitions (Petri Net) with programme in LAD (Ladder logic; a representation similar to relay logic diagrams).*
- 6) *Printing the program*

The following variants are prepared for the students:

Variant 1

The **drilling cycle** of the variant comprises the drilling of **only one work piece** with a rough drill as the drilling **tool 1**. The following operation is finishing with a parallel reamer, which is considered as the drilling **tool 2**.

Variant 2

The **drilling cycle** of the variant comprises the drilling of **one work piece with the drilling tool 1** and **the second work piece with the drilling tool 2**.

Variant 3

The **drilling cycle** of the variant comprises the drilling of one work piece with the drilling tool 1 and the second work piece with the drilling tool 2 (similar to the variant 2). It is necessary to **wait 2 seconds** in the working position before ejecting the work piece.

Variant 4

The variant is similar to the variant 3 but it is necessary to calculate **how many work pieces have been made** since the time when the main switch was switched ON.

Variant 5

The **drilling cycle** of the variant comprises the **drilling of 10 work pieces**. After **4 pieces** have been drilled, the **drilling tool 1** has to be changed for the **drilling tool 2**.

3 Programmable Controller SIMATIC S7-300

In this chapter the structure of the programmable controller is described. We decided to deal with S7-300 Station, the addressing of signals and variables and the functional diagram.

3.1 S7-300 Station

SIMATIC S7-300 is a modular programmable controller – S7 station comprises the following components: Rack, Power supply (PS), Central processing units, Interface modules, Signal modules (SMs), Function modules (FMs), Communication processor (CPs) and Subnets. Generally, the programmable controller may consist of several racks, which are linked to one another by a bus cable. The power supply, CPU and I/O modules are plugged into the central racks. The rack contains 8 slots for modules. Every slot has a fixed address in the S7 station. This slot address consists of the number of the mounting rack and the number of the slot.

The I/O modules can be separated from the central rack when expansion racks are connected to the central rack by interface modules.

The preparing and programming of a control system for an automated machine is performed in a programming device - a PC with Windows. The program of control uses the Central processor unit CPU of the SIMATIC Station S7. The programming device contains **off-line** data. A project must be created for every task on the programming device. This consists of **hardware configuration**, **user program off-line** and **symbol tables**. The **on-line** data consist of the user program and the system data in the CPU, which are stored in the load memory, the work memory and the system memory.

Generally the load memory consists of a user program including configuration data that are loaded from programming device.

Work memory is a high speed RAM integrated in the CPU. The relevant control program is executed in the work memory.

System memory contains the addresses of variables that the executed program accesses. The addresses are accommodated in these areas: input area (E), output area (A), bit memories (M), Timers (T), counters (Z) and temporary local data.

There are 8 I/O modules that can be plugged into the central rack of the S7-300 station with a single wire configuration. Our laboratory task uses the S7-300 Station. It is equipped with:

CPU 314 C – 2PN/DP	
Input and output module: DI 16/DO 16xDC 24V	
Addresses of Input:	E136.0-E137.7
Addresses of Output:	A136.0-A137.7

This hardware configuration doesn't have any assembly racks and neither the slots.

3.2 Defining the System Signals

The switches and the contactor of the automatic drilling machine are controlled via the inputs and outputs of the digital input/output module of the programmable controller SIMATIC S7- 300 with the Station CPU314. The input/output module has 16 inputs and 16 outputs. The default values of input addresses to the PLC are **E136.0 to E137.7** and the outputs from PLC are **A136.0 to A137.7** (in our laboratory task we are using only A137.0 - A137.7). These addresses are described as **Absolute Addresses**. It is possible to use Symbolic Addresses, for example X1 or "Clamp_in _home".

A list of INPUT (feedback signals) and OUTPUT signals can be made from the technological scheme on the figure 2.1 (See the Tab. 3.1 and 3.2). We decided to use the Symbolic Addresses X0 to X14 for Inputs and Y9 to Y15 for Outputs.

Symbolic Address	INPUT explanation	Absolute Address
X0	Feeder - Indication of home position	E136.0
X1	Clamp device - Indication of home position	E136.1
X2	Support - Indication of home position	E136.2
X3	Work Ejector - Indication of home position	E136.3
X4	Feeder - Indication of working position	E136.4
X5	Clamp device - Indication of working position	E136.5
X6	Support - Indication of bottom limit (working) position	E136.6
X7	Work Ejector - Indication of working position	E136.7
X8	Drilling head rotates	E137.0
X9	Supply bin is not empty	E137.1
X10	Finished pieces bin is full	E137.2
X11	Start button is ON	E137.3
X12	Drilling tool 1 is set	E137.4
X13	Drilling tool 2 is set	E137.5
X14	Main switch is ON	E137.6

Tab. 3.1: Input signals (Feedback signals) to the PLC

Symbolic Address	OUTPUT explanation	Absolute Address
Y9	Set Drilling tool 2	A137.1
Y10	Set Drilling tool 1	A137.2
Y11	Turn ON motor of drilling head	A137.3
Y12	Remove the work piece to finished pieces bin	A137.4
Y13	Move support in the working position	A137.5
Y14	Clamp work piece	A137.6
Y15	Insert work piece from the supply bin	A137.7

Tab. 3.2: Output signals (Feedback signals) from the PLC

3.3 Sequential Function Chart (SFC)

Before creating a program for the sequencer in the S7-GRAPH FB it is necessary to divide the drilling machine operation into individual steps. The result is a Sequential Function Chart (SFC). The basis for creating the Sequential Function Chart is the technological scheme of the drilling machine. After that you can create the program for the Sequential Function Chart..

A **Sequential Function Chart** represents a sequence of **simple steps and transitions** (see figure 3.1). The steps are executed in a fixed order and the transitions consist of conditions that control how the process moves to next individual step.

To specify the structure of the Sequential Function Chart, follow the steps outlined below:

- 1) Divide the drilling process into steps and specify the order of the steps!
- 2) For each step specify the actions that must be performed in the step!
- 3) Decide which conditions must be met for every step so that the process can move on to the next step!

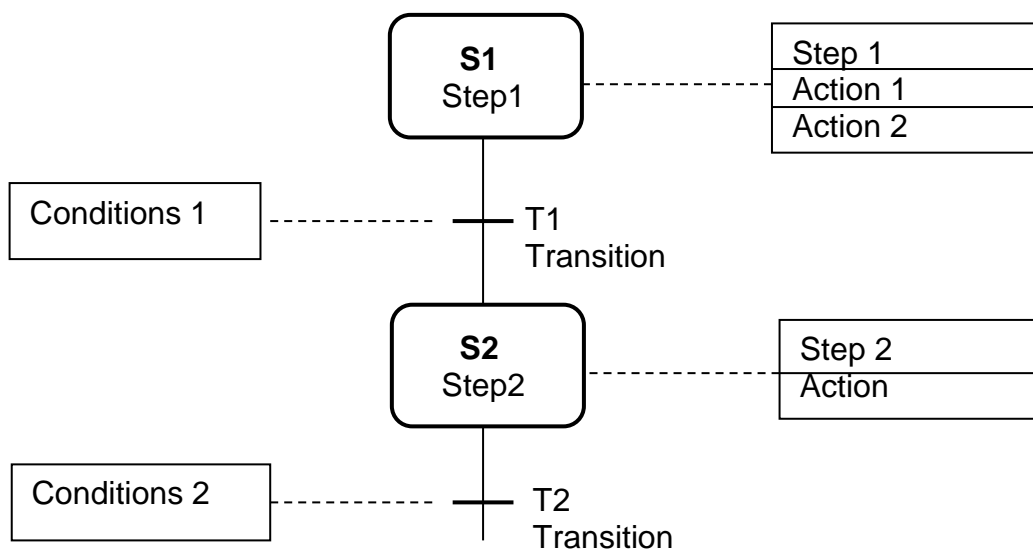


Figure 3.1: Structure of the SFC

It is possible to use alternative branches (see figure 3.2a) and jumps (see figure 3.2b).

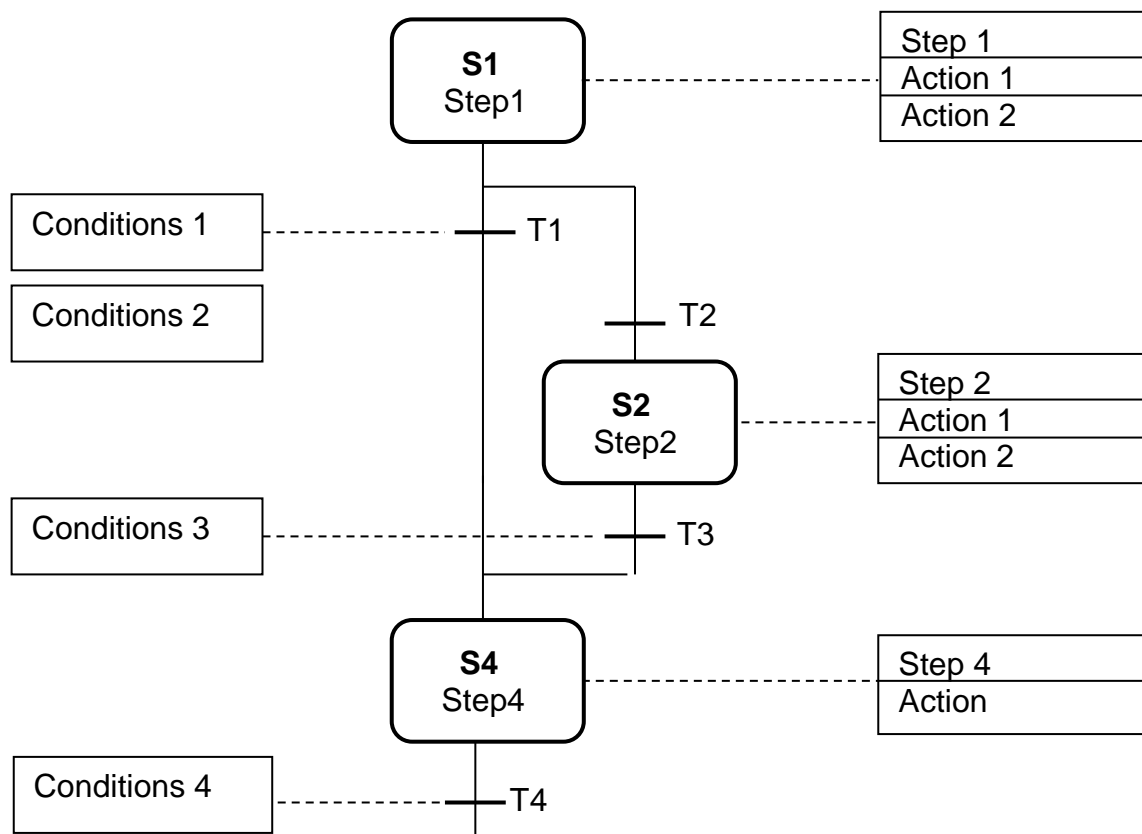


Figure 3.2a: Structure with alternative branches

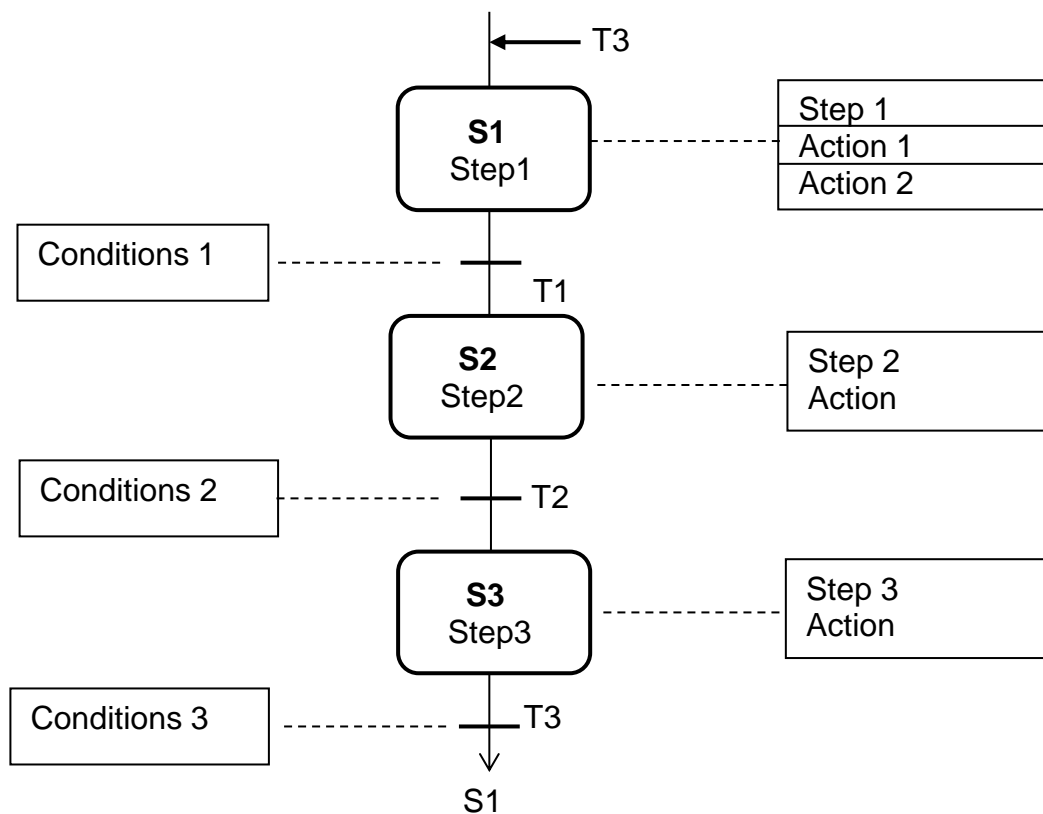


Figure 3.2b: Structure with jumps

4 Creating the Program in the SIMATIC Manager

The SIMATIC Manager (figure 4.1) is a software tool working with objects in STEP 7 environment.

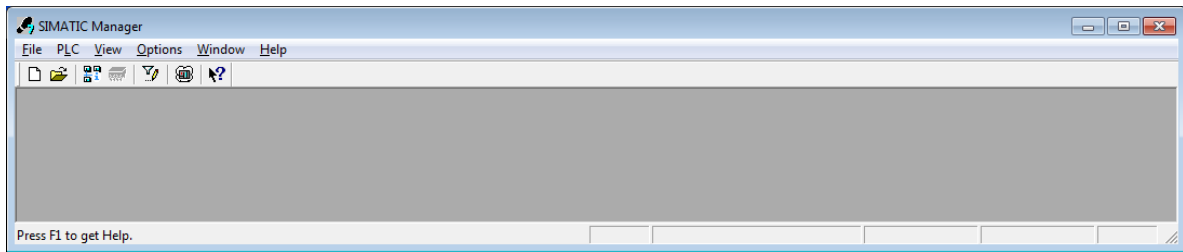


Figure 4.1: SIMATIC Manager

These logical objects correspond to real objects in the technological equipment.

A project may contain several stations (programmable controllers) connected to one another. A station contains a CPU that consists of a program in STEP 7. This program is a “container” for other objects such as the “**Blocks**”, which contain other compiled blocks.

To ***select an object*** means to click on it once with the mouse so that it is highlighted. To ***name an object*** means to click on the name of the selected object or select the item “EDIT”. To ***open an object*** means to double click on that object.

In this laboratory manual is not possible to describe in detail the SIMATIC Manager, the programming in S7 – Graph and other tools. We only intend to offer the information necessary for the students to be able to create a sequencer for the control of the automatic drilling machine.

The basic procedure for using the STEP 7 programming for a new project is the following:

Set up a new project

- > **Configure the Hardware**
- > **Configure the communications**
- > **Create a user program**
- > **Test the Program**

In our laboratory task the communication configurations are set. It is not necessary to carry out the complete configuration.

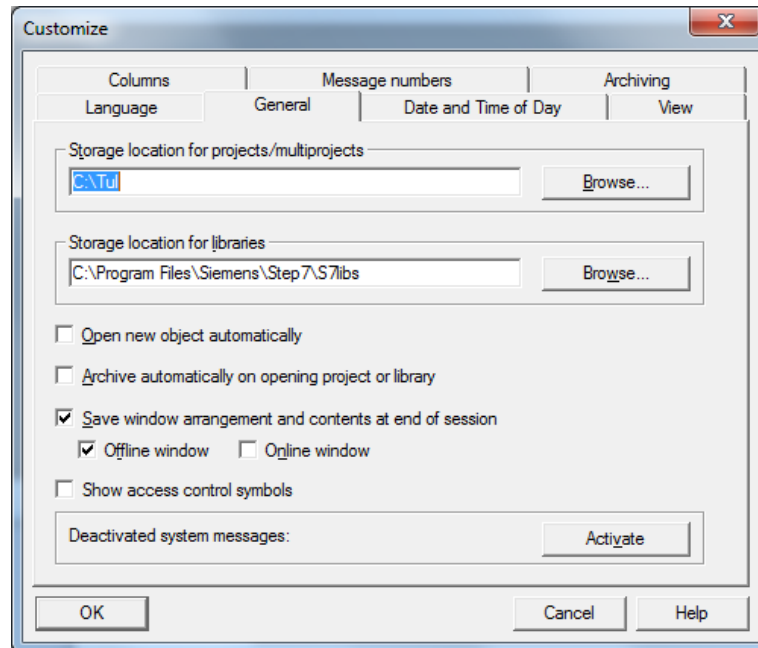
4.1 Creating a project and an S7 program

In the SIMATIC Manager it is necessary to create a new project folder. There are two possible ways: without and with the "Project Wizard". We use the way without the wizard because we have to make some changes in the hardware configuration.

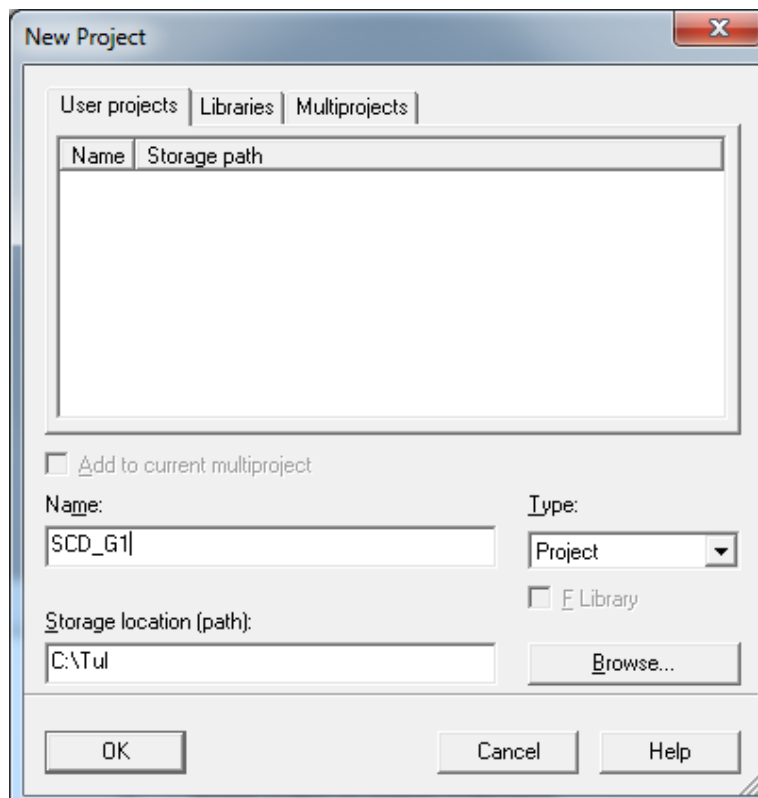
There are the following steps to do:

Start SIMATIC-Manager (figure 4.1)

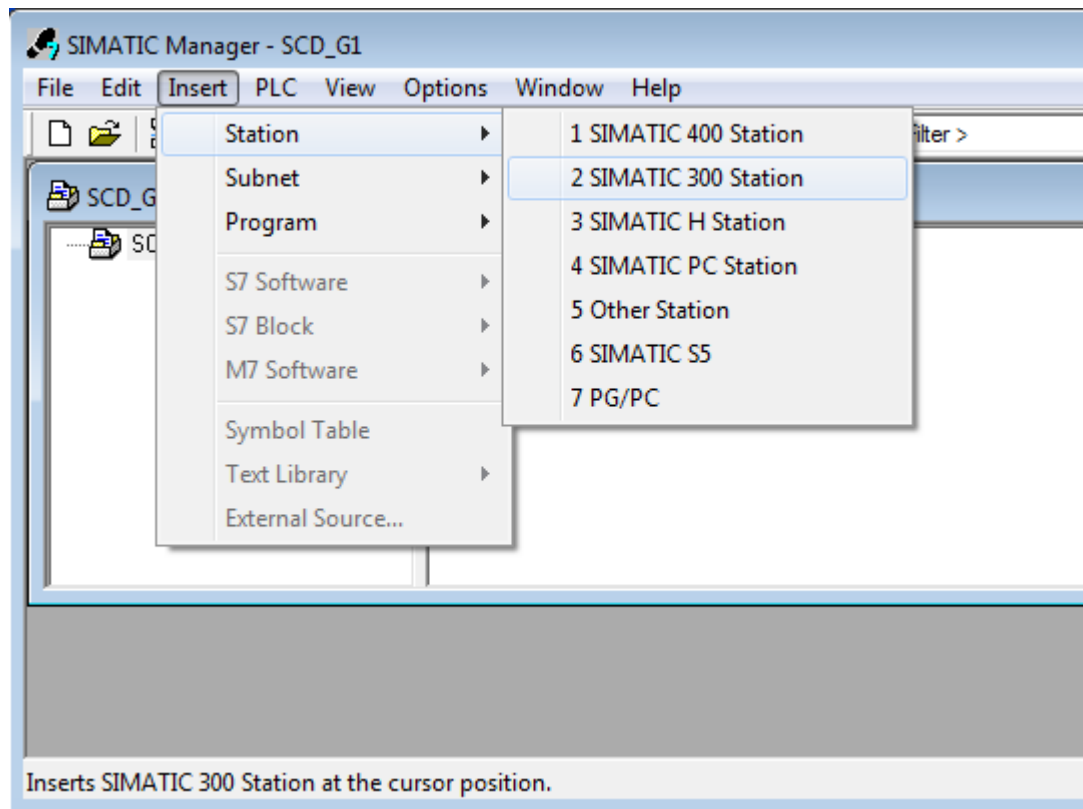
"Options" -> "Customize" -> Path of own USB-Stick or "C:\TUL" -> "OK"



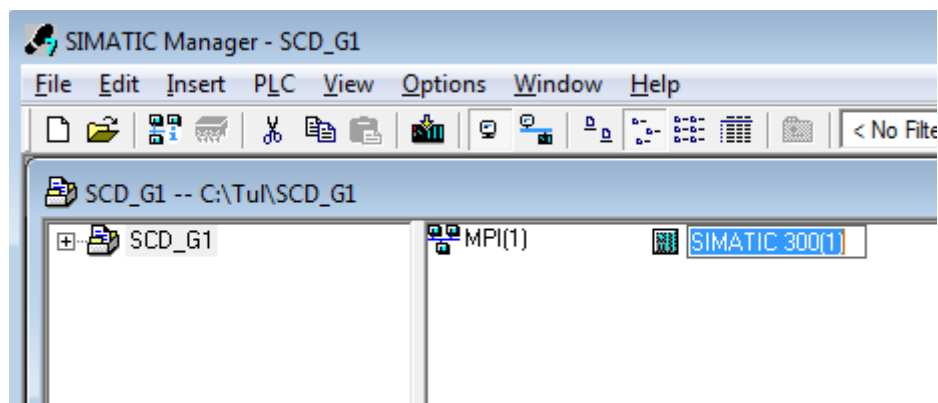
"File" -> "New" (Ctrl+N) -> Name -> i.e. "SCD_G1" (max 8 Letters) -> OK



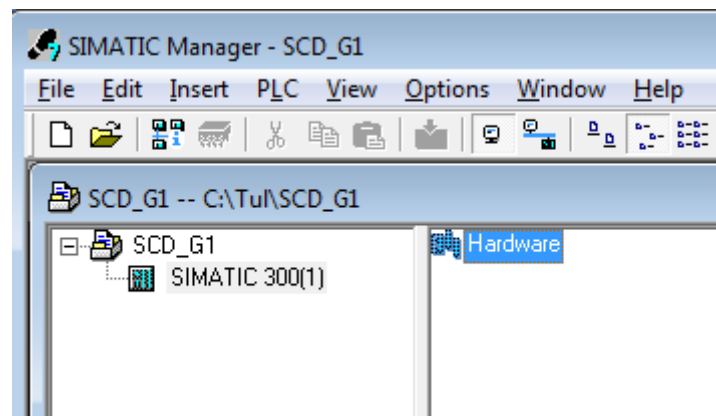
"Insert" -> "Station" -> "SIMATIC 300 – Station"



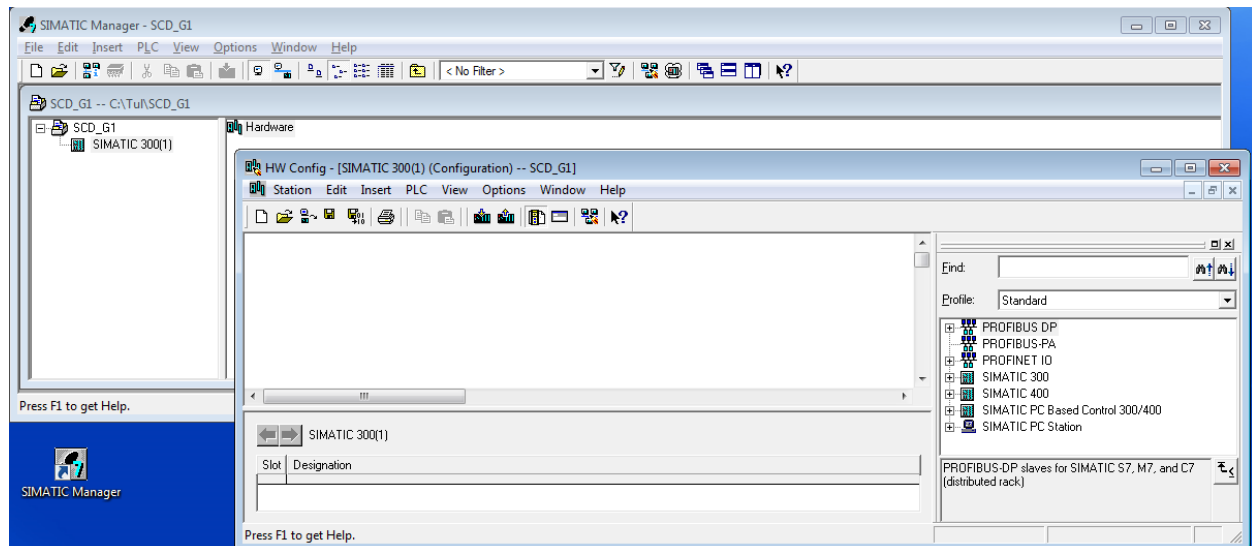
->



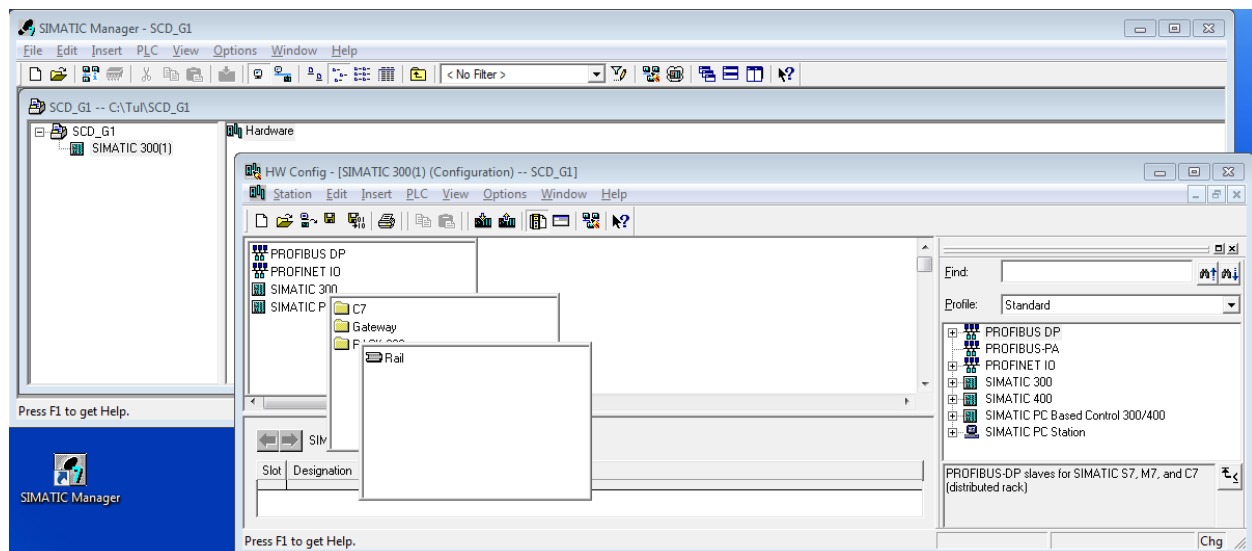
"SIMATIC 300" -> "Hardware" -> open (double left click)



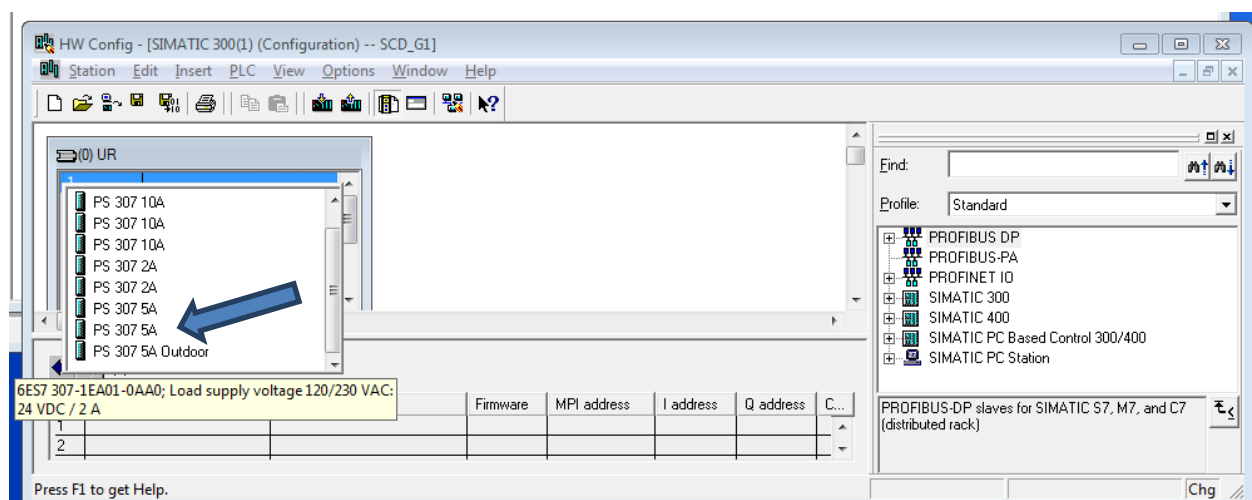
->

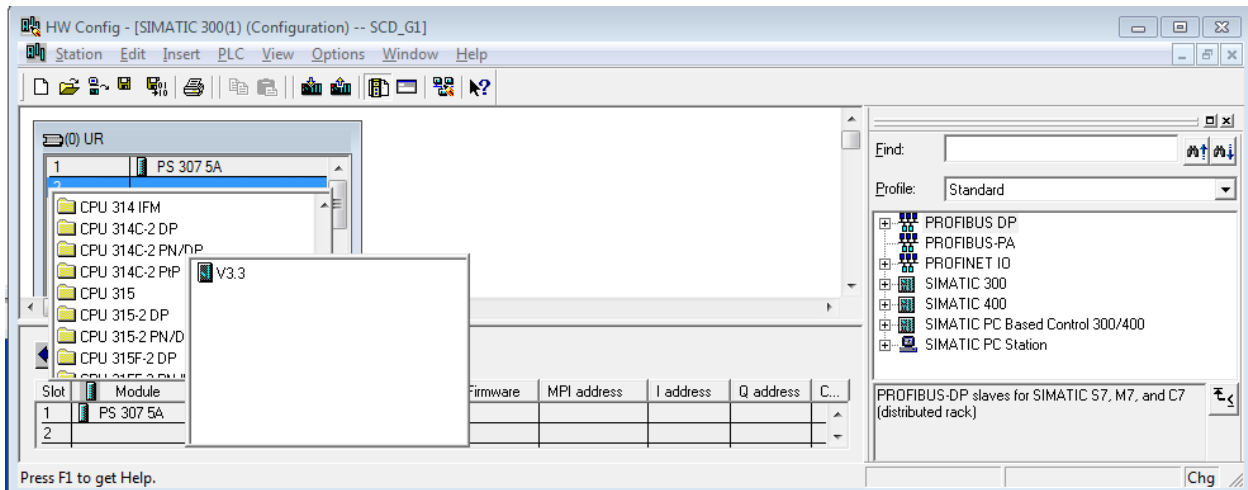


"Insert" -> "Insert Object" -> "SIMATIC 300" -> "RACK300" -> "Rail"

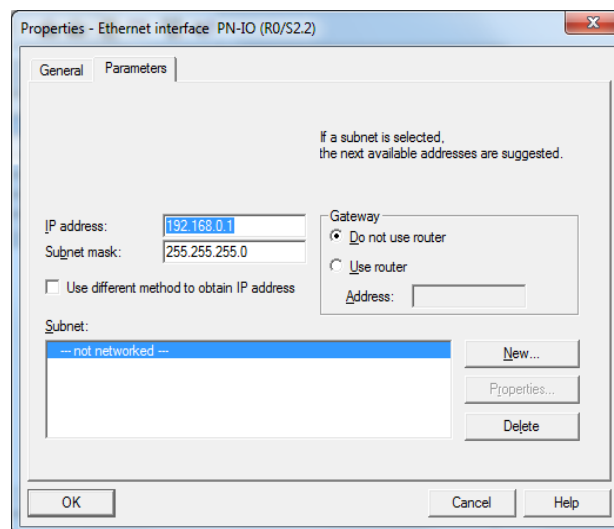


"Insert" -> "Insert Object" -> "Power Supply PS 307 5A"

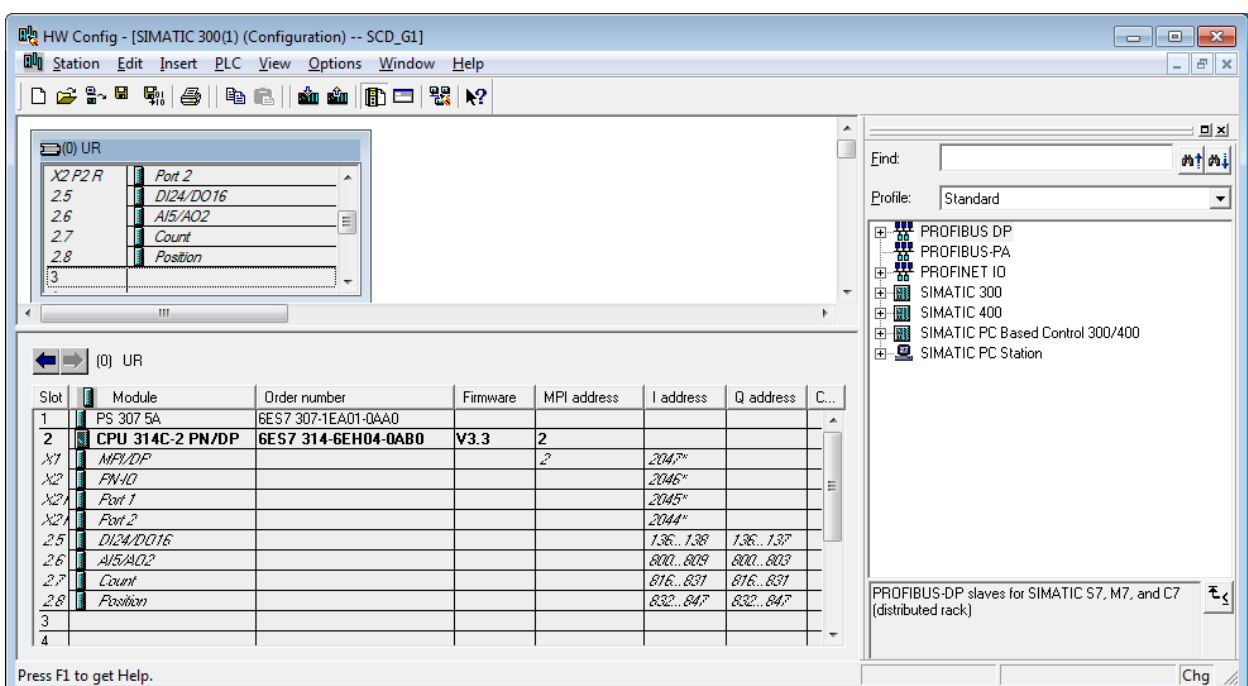


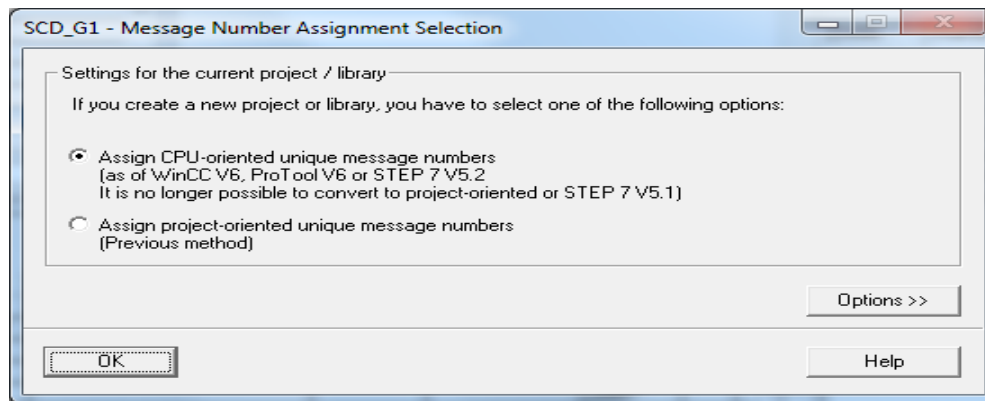
"Insert" -> "Insert Object" -> "CPU: 314C-2 PN/DP" -> "V3.3"

->

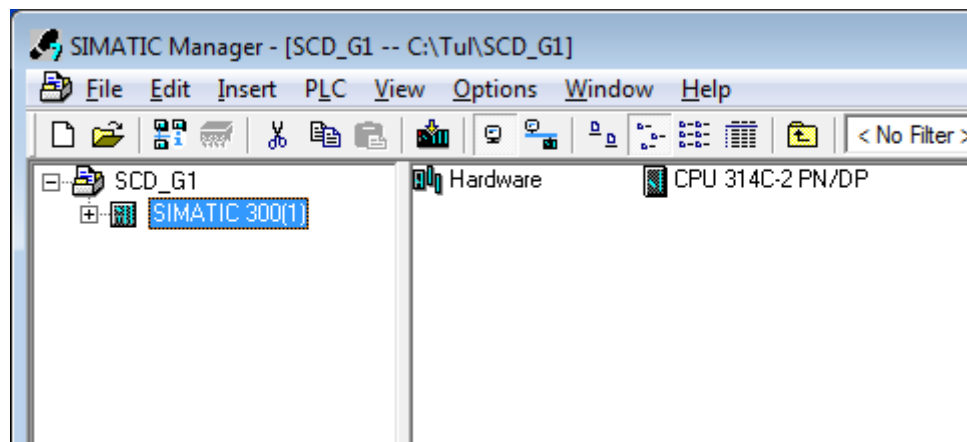


-> "OK"

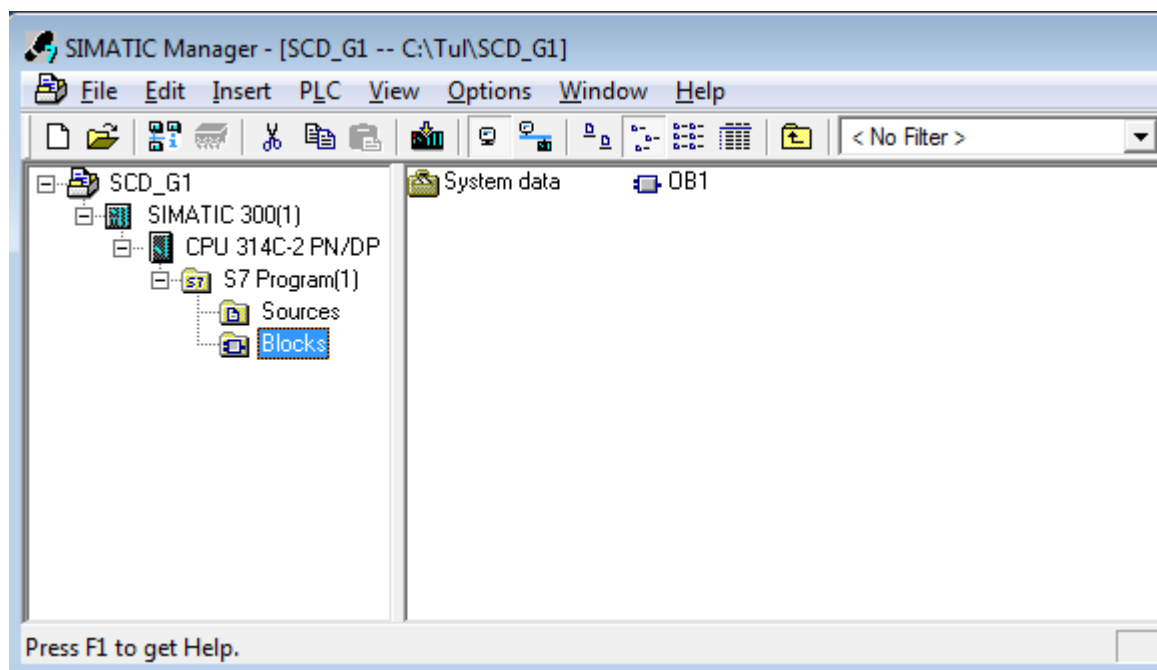


Close HWConfig (Save changes -> "Yes")

-> "OK"



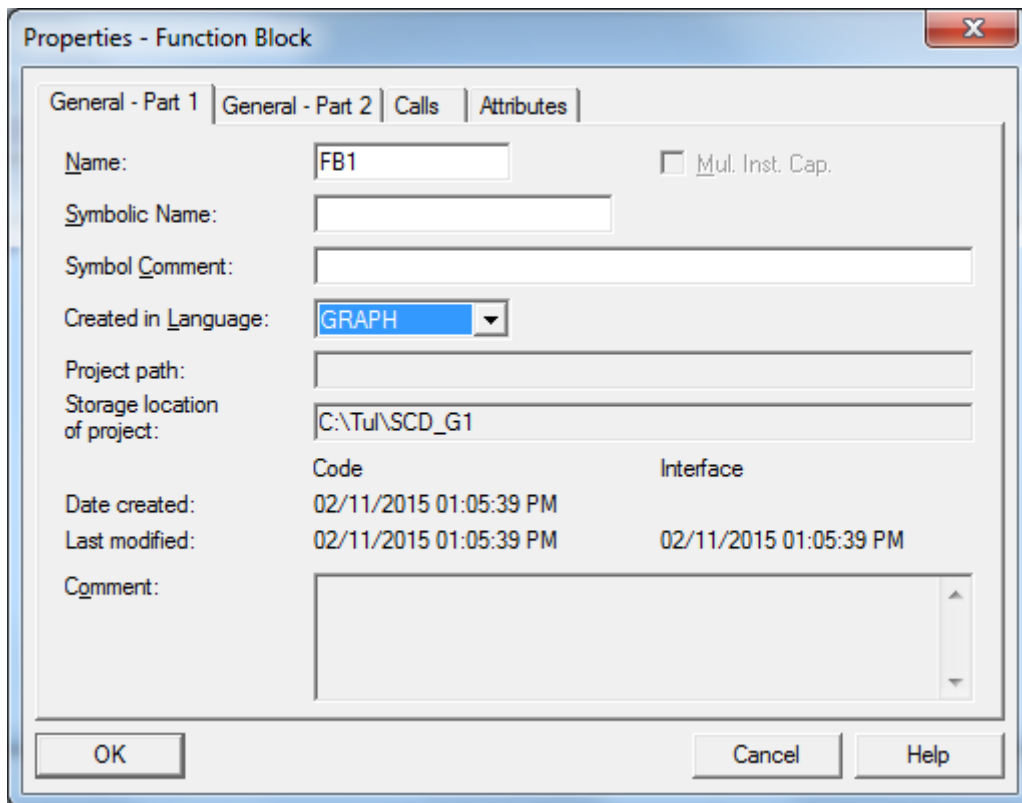
The result is the SIMATIC Manager with the new project and the S7-Program(1).
If you click through the entries we can see the folder for the SIMATIC 300 Station, the folder for the CPU 314C-2 PN/DP and the folder for the S7 Program (1).
The OB1 is already created.



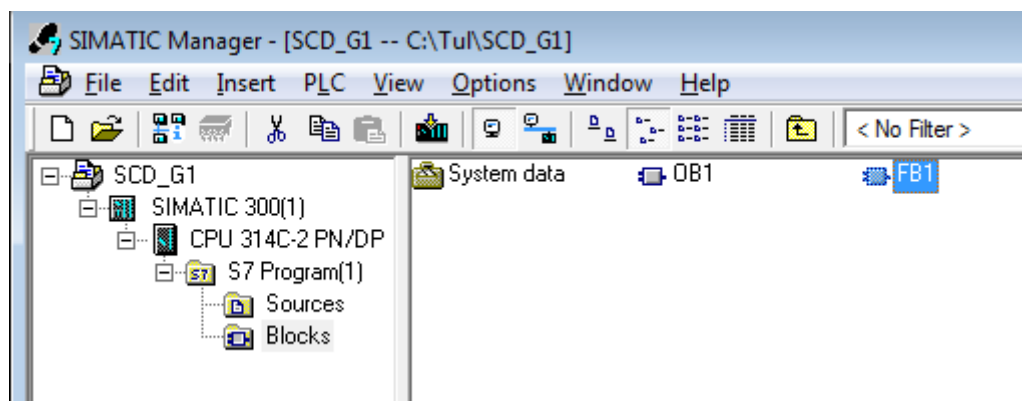
Our task is to create a sequence program with GRAPH 7. The container for GRAPH 7 is the **Function Block (FB)**. Therefore it is necessary to create a Function Block. We must select the folder “Blocks” and the required steps are the following:

„Insert“ > „S7 Block“ > „Function Block“

After that the window „Properties“ will be opened and it has to be filled.



-> „OK“

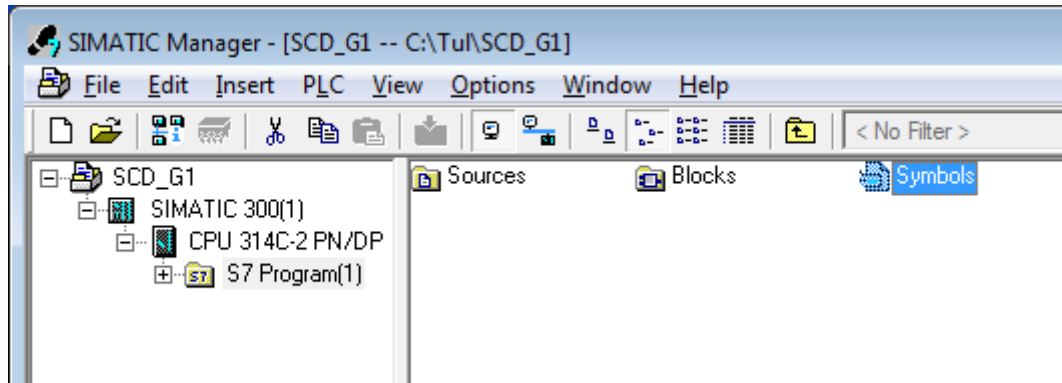


4.2 Creating a Symbol Table

In the chapter 3.2 we introduced symbolic address-variables. If we want to use these in our program we have to create a **Symbol table**.

It can be carried out by the following steps:

1. Open the “S7 Program(1)” folder by a double left click on it



2. Open the symbol table in the “S7 Program(1)” folder by a double left click on “**Symbols**”.
3. Edit the table
4. Save the symbol table using the menu command “**Table**” > “**Save**” and exit.

By editing of the table you match the required symbolic representation, the Address (for Example E136.0) and the Data type of the input or output (BOOL).

Symbol Editor - [S7 Program(1) (Symbols) -- SCD_G1\SIMATIC 300(1)\CPU 314C-2 PN/DP]

	Status	Symbol	Address	Data type	Comment
1		Cycle Execution	OB 1	OB 1	
2		X0	E 136.0	BOOL	Feeder - Indication of home position
3		X1	E 136.1	BOOL	Clamp device - Indication of home position
4		Y9	A 137.1	BOOL	Set Drilling tool 2
5					

Press F1 to get Help.

4.3 Creating an S7 – Graph FB and Programming the SFC

For the programming of the Sequential Function Chart (SFC) with Steps and Transitions it is necessary to create an S7-GRAPH FB.

By a double left click on the FB1 icon (S7 Program(1)\Blocks, see) the system inserts the first step and the first transition. To display conditions and actions, activate the menu command

“View” > “Display With” > “Conditions and Actions”.

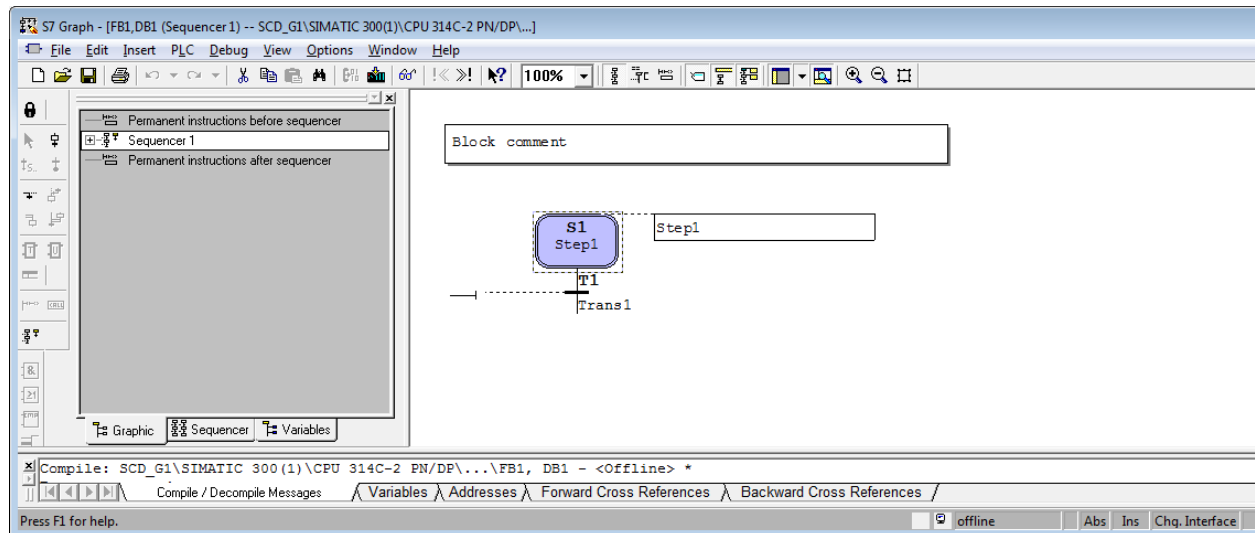


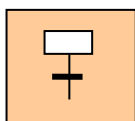
Figure 4.2: Window S7 GRAPH - SFC FB1

The Sequential Function Chart has a **toolbar** on the left side of the window. It includes icons for inserting a step and a transition, opening and closing of alternative branches and also for jumps. There are two ways of creating a Sequential Function Chart and they are described bellow.

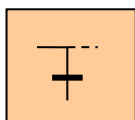
1) Direct mode

Start the S7-GRAPH editor by a double click on FB1

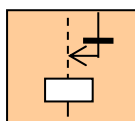
Select the menu command **“Insert” > “Direct”**



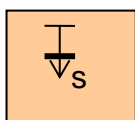
Select a transition and click with a mouse on this icon and as a result you will **Insert a step und a transition** (or “Insert” > “Step + Transition”)



Select a step and press this icon and you will **Open an alternative branch** (or “Insert” > “Alternative Branch” > “Open”)



Select this icon and then select a transition and you will **Close the alternative branch** (or “Insert” > “Alternative Branch” > “Close”)

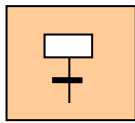


Select a place from where the jump starts and then click this icon. Then select the place where the jump is directed. This is the way how you can **Insert a jump** (or “Insert” > “Jump”)

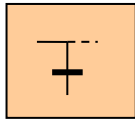
2) Drag-and-Drop

Start the S7-GRAPH editor by a double click on FB1

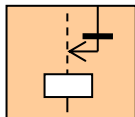
Select the menu command “Insert” > “Drag/and-Drop”



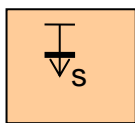
Select the icon “**Insert step + transition**” with the mouse and click on the last transition of the individual element.



Select the icon “**Open an alternative branch**” and open an alternative branch by clicking on the appropriate step.



Select the icon “**Close an alternative branch**”. First select the transition 1 and then the transition 2. The transition 1 defines “from” which point the connection has to start, the transition 2 defines, “where” the branch should be connected.



Select the icon “**Insert a jump**”. First select the transition from where the jump starts and then select the step, where the jump is directed.

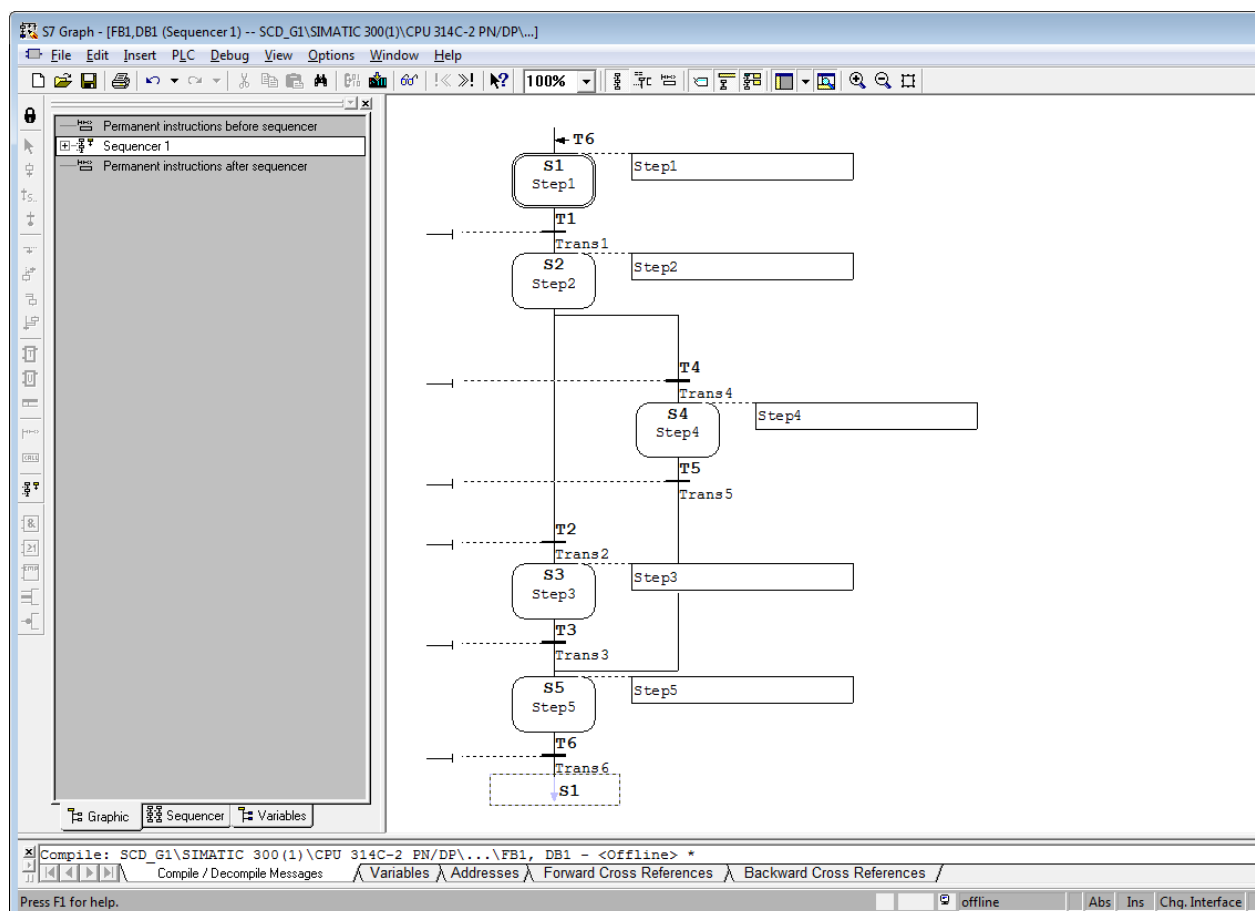


Figure 4.3: Creating of an example

4.4 Programming a Step Action

We will use and illustrate only the **Drag-and-Drop** method. We have to select the menu command

“Insert” > “Drag-and-Drop”

1. Select **“Insert” > “Action”**.

-> **Result:** The mouse pointer appears in the position as shown below:



(It is possible to exit the mode by hitting the ESC-key)

2. Insert an empty action line by clicking in the action box of a step.

Very easy way: Click with the right mouse button in the step action box
“Insert New Element” > „Action“

3. Enter the action:

The action consists of an instruction and an address. The following steps are necessary for our action:

- **S** Set the output
- **R** Reset the output
- **N** Non holding: As long as the step is activated, the signal state of the address is 1.
- **D** Delay. The address is set to 1, after the defined delay it is deactivated and the value of the address changes to 0.

Very easy way: Click with the right mouse button in the step action box
“Insert New Element” > „Action“

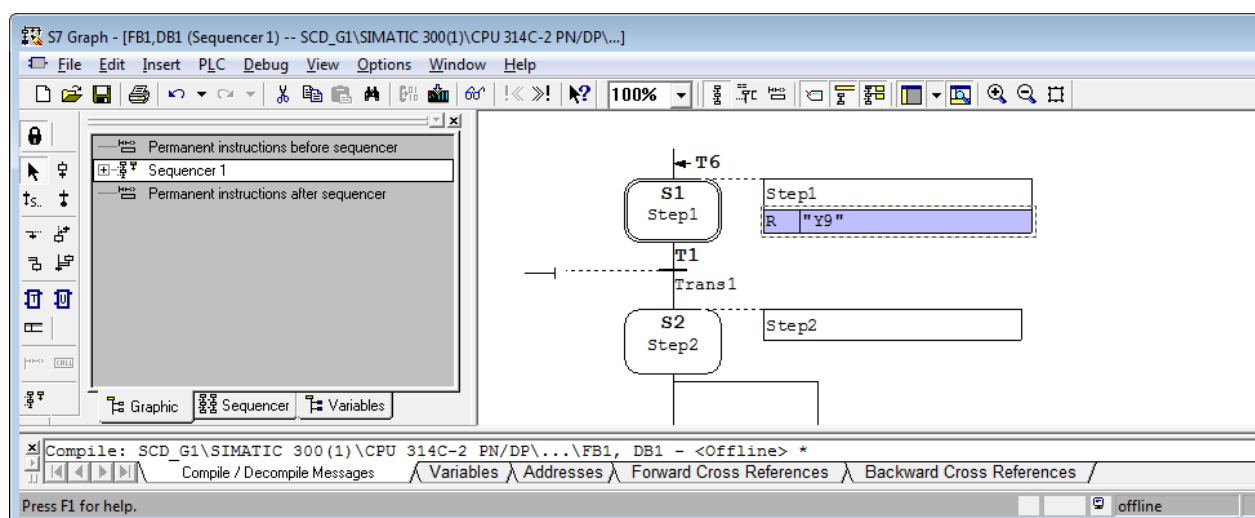
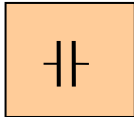


Figure 4.4: Creating of the Step Action

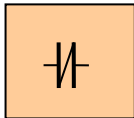
4.5 Programming the Transitions

The bit logic instructions “open contact”, “close contact” and “comparator” are used to enable the step conditions in the transitions. To program the transitions:

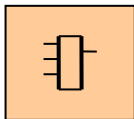
1. Set the “LAD” view (“View” > “LAD”) and select the appropriate icons in the “LAD/FBD” toolbar



Insert normally-opened contact



Insert normally-closed contact



Insert comparator

2. Place the symbols at the appropriate points by clicking at the transition.
(It is possible to exit the mode by hitting the ESC-key)
3. Enter the addresses. Click on the position and select the required text field. Then enter an absolute or symbolic address (for example E136.0 or “X0”).

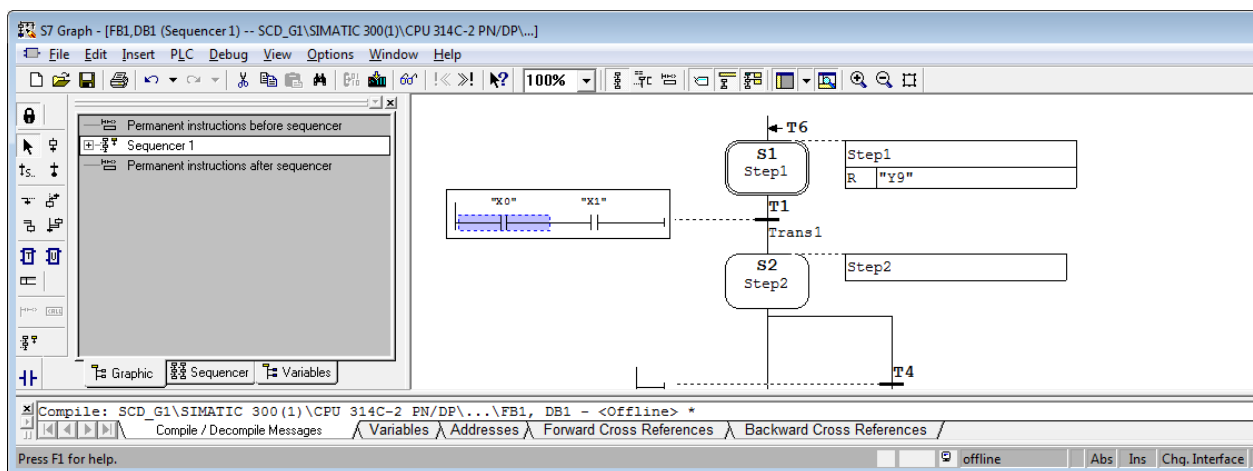


Figure 4.5: Programming transitions

Save the Block and exit.

The system will add some necessary Blocks automatically (FC72, DB1, SFC64).

4.6 Programming OB1

After saving FB1 one has to program OB1 (in the Mode “**View**” > “**STL**”) by opening OB1 and typing in (in the space below the second comment) only the first line “CALL FB 1, DB1” of the code in figure 4.6 and then “Enter”, the programming system will add all the other lines. Save the Block and exit.

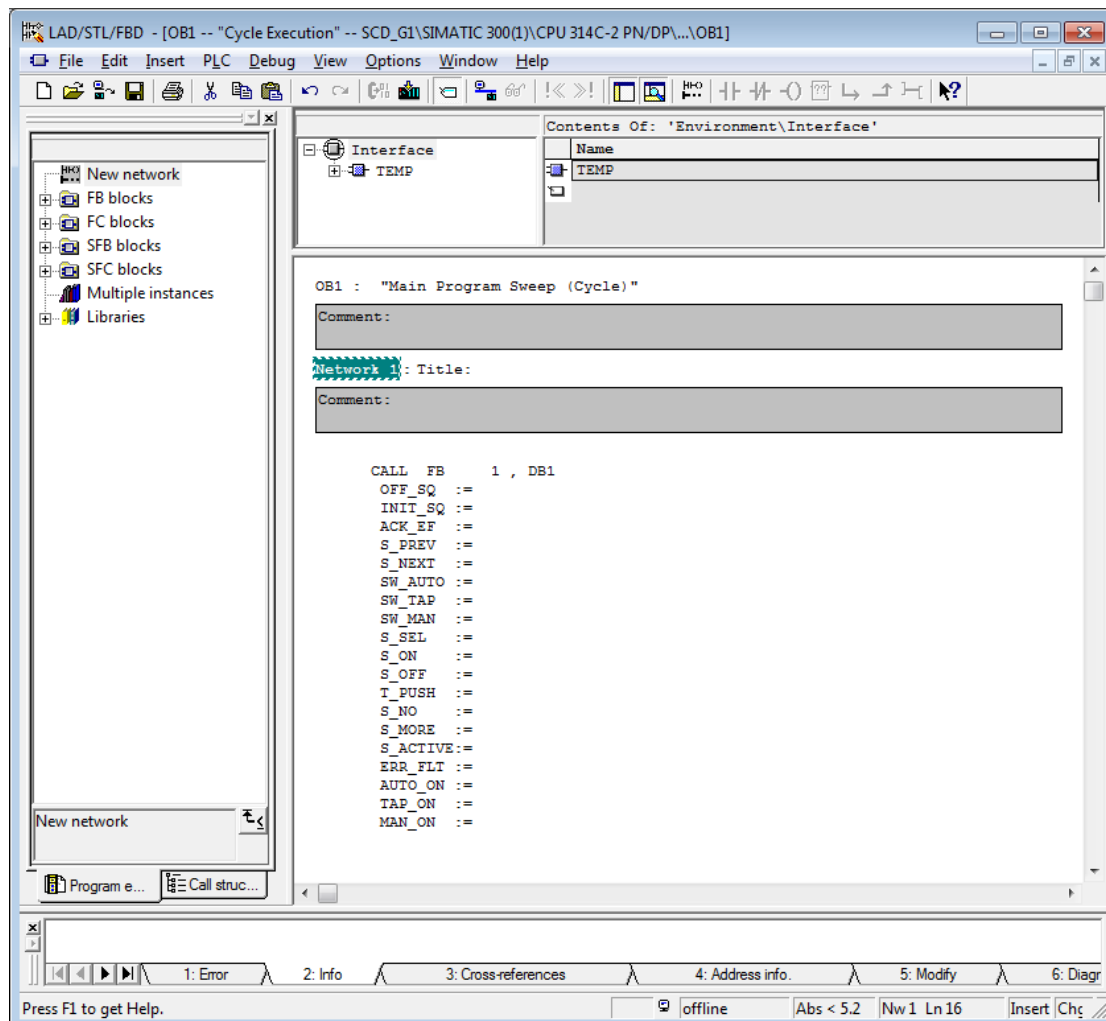


Figure 4.6: Programming OB1

4.7 Downloading and Monitoring the Program

Go into the level “**S7 Program(1)\Blocks**” and download the Data into the PLC.

“**PLC**” > “**Download**”

Overwrite existing objects and quit requests for load, STOP and starting with "Yes" :

You can monitor the running of the Function Block; **go into the block** and

“**Debug**” > “**Monitor**”

These guidelines cannot describe all the details and specifics of programming a PLC. They only provide the instructions that help the students with programming of the drilling machine.

5 References

- [1] Manual S7-GRAPH V5.3 for S7-300/400 Programming Sequential Control Systems
- [2] Proske, D.: Steuerungstechnik, Kombinatorische Systeme Teil 1, 2003, Hochschule Zittau/Görlitz
- [3] Proske, D.: Steuerungstechnik, Sequentielle Systeme Teil 2, 2003, Hochschule Zittau/Görlitz
- [4] Berger H.: Automating with STEP 7 in STL and SCL, Programmable Controllers SIMATIC S7- 300/400, 2005, 3rd edition, Publicis Corporate Publishing, Erlangen