

Research Article

From IEC 61131 to IEC 61499 for Distributed Systems: A Case Study

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A new concept for distributed control systems based on the new IEC 61499 standard is tested in this work in cooperation with LAE Engineering GmbH, a medium-sized company. Based on a catalogue of requirements, a customer-related testbed is developed. In the following this testbed is used as a reference to realise an IEC 61499 compliant-distributed control system based on PC technics. By doing this, rules are defined to convert user-owned IEC 61131 function blocks to IEC 61499 compliant function blocks. Concluding, some trends for IEC 61499-based distributed control systems will be summarised.

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1. THE PROBLEM

Especially for medium-sized companies, it will become more and more important to create solutions of automation problems that are optimally coordinated with the customer in order to maintain the competitiveness also in future. Thereby, these medium-sized companies can feature themselves by manufacturer independence and usage of the hardware that the customer prefers, which maybe replaced in only some cases by better matching components. It is also possible in smaller projects to use hardware that already exists at the customer but is not working at full capacity. Doing this, the acquisition cost of new hardware is reduced, and a distributed system is created. These points would require an enormous know how of the staff and the existence of many Engineering Support Systems to program and parameterize control units of different manufactures. A better way of creating a distributed system would be to have one Engineering Support System and to program and parameterize as many as possible different control and visualisation units by using automation components. Furthermore, it should be possible to exchange the created automation components easily. Last but not least it should be possible to plan the optimal usage of the communication bandwidth and the computing power. This can be achieved by transferring only changed data points and executing only algorithms with changed input values.

Additionally, it should be possible to develop the controlling components independently from the manufacturer and to encapsulate the company's own intellectual property. All components forming the control system can then be stored in a company-wide library. This will allow to replace a damaged or not correctly working component easily by a new one and to download the control algorithms and parameterisation automatically by the control system itself (Plug and Participate).

Although such approaches have been sketched by many authors before [1–3], application in practice is rather sparse. This contribution is a first step to pave the way towards those goals.

2. NEW POINTS OF VIEW FROM THE IEC 61499

In a first step to support these new requirements, the International Electrotechnical Commission (IEC) launched the International Standard IEC 61499, which became official in 2005. This new standard should be an extension to the well-known and used standard IEC 61131 for programming logic controllers. So it is possible to use the programming languages instruction list, ladder logic, and structured text as well as high-level languages like C, java, and Delpi to create the control algorithms for the basic function blocks of IEC 61499. Furthermore, it is possible to describe an IEC 61131 configuration by using the defined software model of IEC

61499. The differences between both are the new system layer at the top, the changed function block interface, and the introduced execution control chart (ECC) at the root of the software model [4].

The new system layer potentiates the development of the whole control system with all controllers, I/Os, visualisation, and data logging devices in one project, which will make it easier to realise changes in the equipment and communication. Another effort in cases of trouble is to simply get the system overview and to backup all project files.

Furthermore, the execution control is changed from cyclic to an event-driven one [5]. This allows to reduce the computing power and the communication bandwidth to a necessary minimum if only algorithm with changed input data is executed and only data packages with changed data values are transmitted.

Concerning the self-reconfiguration of a control system in cases of disturbance or any other change in the production environment, the IMS Research and Development Program has accomplished the research projects PABADIS [6] und HMS [7]. To match the different partial results of these and other global, European, and national projects, the R&D initiative OONeida was founded. The aim is the creation of a technological infrastructure for a new open knowledge economy for automation components and automated industrial products [8].

To protect the own intellectual property at this new open knowledge economy, the guideline of encapsulation and hiding was adopted from the IEC 61131 to the IEC 61499. To guarantee the reusability and portability of the once developed components between the different Engineering Support Systems, the second part of the IEC 61499 defines the requirements for the Engineering Support System.

3. CUSTOMER-RELATED TESTBED

For the further work, a state-of-the-art testbed related to the customers requirements was established in cooperation with LAE Engineering. It is supposed to show what is currently done concerning communication, manufacturer independence, and programming of control systems.

3.1. Communication: industrial ethernet

In most manufacturing plants, field buses like AS-Interface, CAN, and Profibus are the currently used communication platform, but there is a widely accepted trend to use Industrial Ethernet in future. The manufacturers of automation technology as well as the customers support this trend, because Ethernet in combination with new transport protocols like Powerlink, Ethercat, Profinet, and so forth offers more opportunities by the same rate of actualisation. So it will be possible to use the different communication media copper, optic and wireless fiber with data transfer rates up to 1 giga-bit per second.

3.2. Used hardware

Based on the results of a market research, the systems from Bernecker + Rainer Industrie-Elektronik GmbH (B&R) and Phoenix Contact GmbH&Co.KG (Phoenix) were used for

the testbed. From B&R we used a combined visualisation and control unit (PowerPanel 200), a PLC (System2003, CP476-DP), and a modular remote I/O (X20) with 6 digital in- and outputs and 2 analog inputs. From the Phoenix products a PLC (ILC350-PN), one compact and one modular remote I/O (ILB PN 24, FL IL 24 BK-PN-PAC), an interbus proxy (FL PN/IBS) combined with I/Os, and two modular and manageable switches (FL SWITCH MM HS) were chosen.

3.3. Control functionality

The control functionality described in the following is developed together with LAE Engineering. Main business segments of this company are calendaring techniques, power generation, and building automation. That is why only main control operations from all of these segments are realised and not one complete control system of a calender or a block-type thermal power station.

From the segment calendaring techniques, a function block to control an engine with one rotation direction and a watchdog timing to detect any disturbance is used. In another function block, a start up sequence of a calender according to DIN EN 12301 is implemented. The different steps of these sequences are *horn active*, *retention time*, and *release of start*.

To record the alarms, an alarm management consisting of two or more function blocks is implemented at every control unit. All alarm activations are registered in groups of 8 by function blocks of the type *AlarmDetection*. These function blocks communicate with the function block of the type *NewAlarm*, which is used to register the occurrence of one or more new alarms, quit all active alarms or only to turn off the horn.

The most commonly used function blocks from the department of power generation have the functionality to calculate the average value of a data point and to register the daily and monthwise power consumption. To test a function block with a wide-spread functionality and huge memory consumption, the function block of the type *PZN_Archiv* was also taken from the power generation department. With this block, it is possible to register the power production per 15 minutes of the last 24 hours and to send the last value to the visualisation, which sends a rising edge to a boolean input to get the next value.

For communication purpose between the control units, a bidirectional Ethernet-based client server architecture is used and the TCP/IP packets are sent every 500 milliseconds, whether the included data points have changed or not. Thus, the consumed communication bandwidth is every time the same.

Because of getting a faster communication between the control unit and the remote I/Os, the Ethernet-based protocols Profinet I/O and Powerlink are used. Thus, it is possible to get the current state of each remote I/O every 10 milliseconds to the appropriate control unit.

4. CONVERTING THE TESTBED TO IEC 61499

At the second part of the work it should be demonstrated that the control functionality of the testbed can also be realised

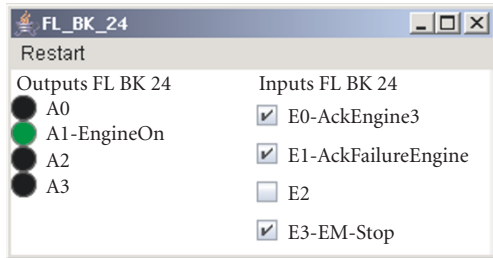


FIGURE 1: Graphical interface of a remote I/O.

with a distributed control system based on the IEC 61499 standard. The remote I/Os are realised as several devices with a graphical interface for boolean and integer in- and outputs as shown in Figure 1 and the whole control system is PC based. The communication between the remote I/Os and the control devices is based on UDP-datagrams, because of missing communication function blocks realising the Ethernet-based protocols Profinet I/O or Powerlink.

In the following the control system will be described top down with the beginning at the system layer. But the focus is directed to the translation of the function blocks to IEC 61499, because they are the skeleton of the distributed control system and realise the control functionality. Because of this we will define some converting rules in Section 4.2 to build in further work an automatic translator.

4.1. System layer

The highest layer of a distributed system is the system layer shown in Figure 2. It includes the configuration of all devices like control devices, remote inputs and outputs, human machine interfaces, and data logging devices. To support the system integrator in building and in cases of disturbance in checking the communication connection between the different devices, network segments represented by arrows are used. Thus, they are used only for documentation purpose at the system layer.

4.2. Control components: function blocks

In this section of the work, the translation from IEC 61131 to 61499 will be shown exemplarily at some function blocks. As a conclusion, some rules how to convert IEC 61131 function blocks to IEC 61499 function blocks will be defined.

4.2.1. FB—AverageCont

Both function blocks in Figure 3 represent an average value calculator for one data point, but the left is IEC 61131 based, and the other, at the right side, is IEC 61499 based. Both of them have the same data interface, but the right function block is extended by a management interface consisting of two event pairs. The event pair *INIT-INITO* is used to trigger a state change at the ECC and therefore the execution of the initialisation algorithm by occurring of an event at *INIT* and to send an information about the termination of this algorithm by the event output *INITO*. The same is done with *REQ-CNF* which triggers the state change to the ECState with the main algorithm of the function block.

The programming language of the algorithms is up to the function block developer and could be different at each algorithm. So it is possible to combine the advantages of low level programming languages like IL, LD, FuB, and ST with the advantages of high level programming languages like C, Java, and Delphi in one function block. Another advantage of this liberty is a smooth change from IEC 61131 to IEC 61499 for the system integrators as well as for the system distributor. Because of that it was possible to copy the source code for the *INIT* and *REQ* algorithm from the IEC 61131 function block to the IEC 61499 shown in Algorithm 1.

4.2.2. FB—Counter

The function block *Counter* is used for the registration of the current daily and monthwise power consumption by using a rising edge at the data input *Input*. This rising edge of a data point at a remote I/O could be detected with the function block *E.R.TRIG*, defined in annex A of the IEC 61499-1. The output event *E0* of this function block has to be connected with the event input *REQ* of the new IEC 61499-based function block *Counter*, shown at the right side of Figure 4.

Because there is also an edge detection performed for the boolean inputs *DayChange* and *MonthChange*, they are converted to event inputs of the new function block. Furthermore, these edge detections allowed or denied the execution of several code fragments. Thus, this code fragments should be translated into several algorithms and associated inside an ECAction with an ECstate. This ECstate can only be reached from the ECinitialstate by the occurrence of an event at the converted event input.

According to the IEC 61499, each event input can be linked with all data inputs, which leads to a sampling of all data inputs by the occurrence of an event at the event input. However, the linked set of data inputs should be cut to a minimum, to reduce the necessary calculation power and execution time. Thus, this set should only contain the required data inputs and the changed data outputs. At the example of Figure 4, the event inputs *Day-* and *MonthChange* are only linked with data input *PulseRatio*, because the triggered algorithm only requires this updated value. Contrary to this, the algorithm executed by the occurrence of the event *SetCounter* only requires the updated values of the data inputs *SetCounterValue* and *CounterMax*.

4.2.3. FB—Engine

The two function blocks in Figure 5 realise the functionality of controlling an engine with one rotation direction and a watchdog timer to detect any disturbance as well as the acknowledgment of the operation of the engine for visualisation. For the realisation of a runtime supervision of the starting, stopping, and short signal interruptions, the timing function block *TON* is used.

To realise this functionality with an IEC 61499 function block, the composite function block in Figure 6 has to be created. This composite function block is built up by using the function block *FB_Engine_Body* with the main functionality, extended by an event output to start and stop the timer and an event input to register the expiration of the timer. As

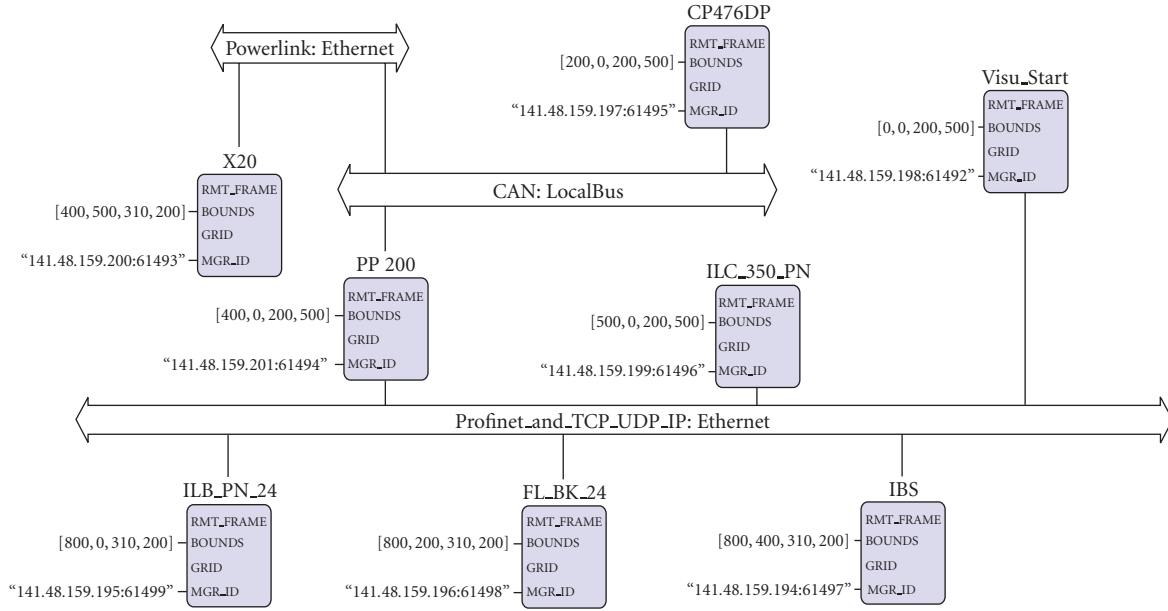


FIGURE 2: System layer of the testbed.

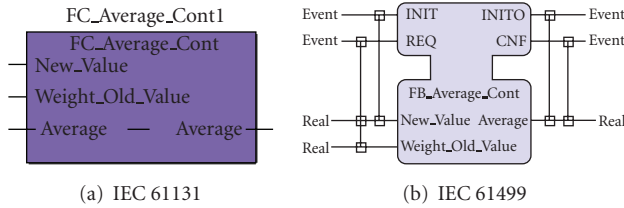
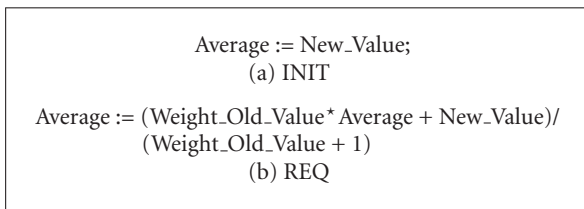


FIGURE 3: Function block for the average value.



ALGORITHM 1: Algorithm for the average value calculation in ST.

timer, the function block *E_Delay* is used, which is defined in annex A of the IEC 61499. If the value of a boolean condition like *EngineOn XOR AckOn* causes the start and the termination of the timer, they could be realised with standardised basic function blocks inside the composite function block.

A positive and a negative edge detection is performed for the boolean data input *Start* of the IEC 61131-based function block. According to the section before, this can be done using the function blocks *E_R_TRIG* and *E_F_TRIG*. The two output events can be merged by means of the function block *E_Merge*, but it is better to avoid this and to use the two events *Start* and *Stop* of the new function block instead. This makes it possible to have the ECCinitialstate always activated and to associate one successor with the stopping and another successor with the starting algorithm.

4.2.4. FB—StartUpChain

To control a start-up sequence of a calender according to DIN EN 12301, the function blocks in Figure 7 are used. The horn is activated first for the defined time at the data input *TIME1*. Afterwards, there is a time gap of the time defined at *TIME2* for the service personal to vacate the calender. After this it is possible to start the calender during the time *TIME3*. If *TIME3* expires without starting the calender, the chain must be started again.

The described control sequence is implemented in the IEC 61131 function block by linking three switch-on delay function blocks. As described in the section before, these timer function blocks could be converted to function blocks of the type *E_Delay*. Afterwards, the output event *EO* of the expired timer has to be connected with the event input *Start* of the following timer.

Because there is only an edge detection done for the boolean input *Start*, it is possible to use the same data interface for the new function block and to extend it with the management interface as described in Section 4.2.1.

4.2.5. FB—AlarmDetection

The function block *AlarmDetection* is used to register different alarms in groups of eight and to save them at a byte variable. The activation of the eight different alarms occurs by a low signal or if the logic is inverted by a high signal.

Beside this, the function block provides the opportunity to register each unacknowledged alarm. The reset of the acknowledgment could be done by the event input *Ack*.

The bitwise addressing to set, reset, and write a single alarm and acknowledgment bits to the byte variables as well as the reading of the single bits out of the byte variables has to be done with different bit masks and the boolean combination with the source byte.

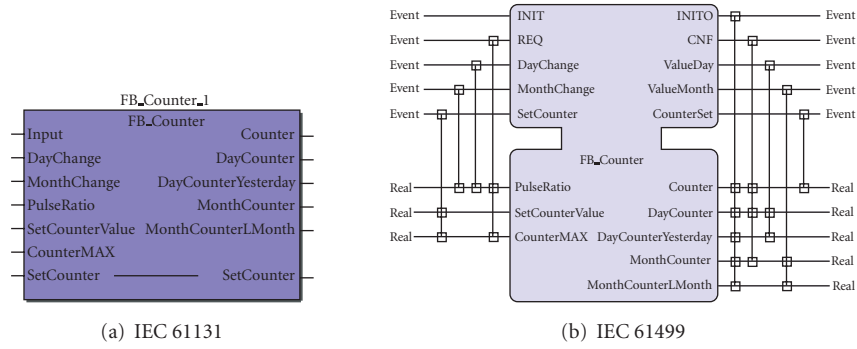


FIGURE 4: Function block to count the power consumption.

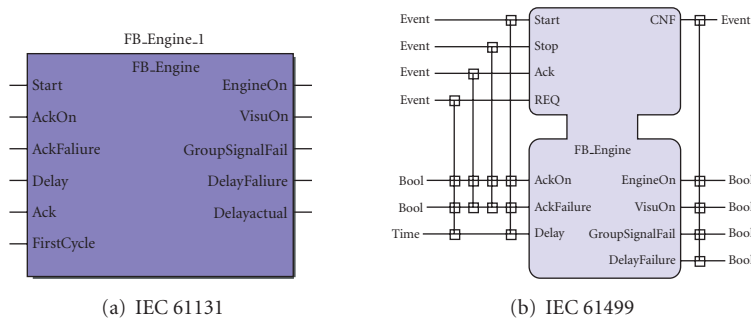


FIGURE 5: Function block for controlling an engine.

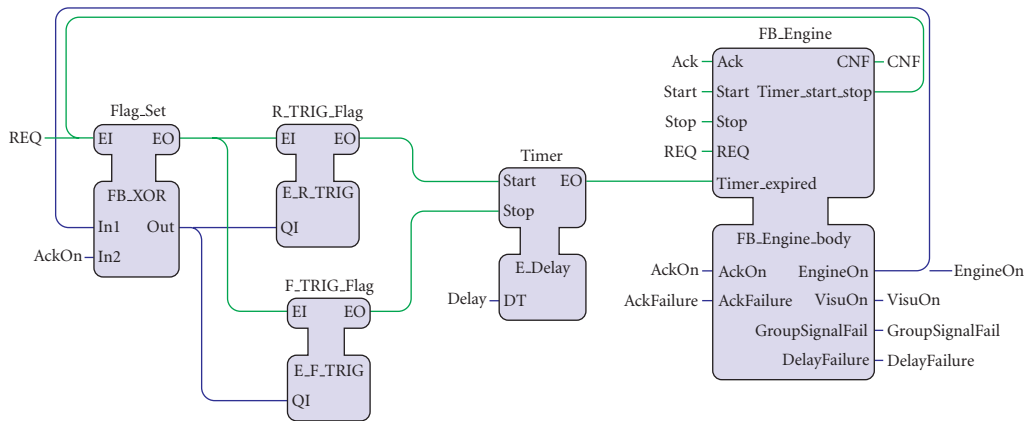


FIGURE 6: Composite function block for controlling an engine.

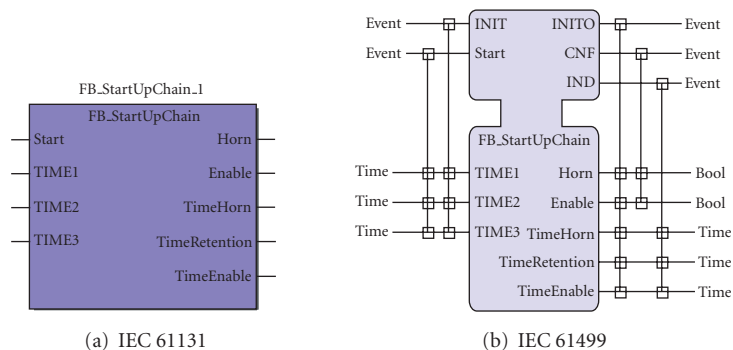


FIGURE 7: Function block start up chain.

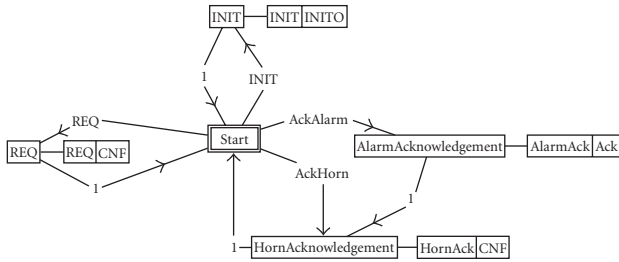


FIGURE 8: ECC of alarm control function block.

4.2.6. FB—NewAlarm

The activation of the horn by the occurrence of any new alarm and the acknowledgment of the horn as well as all active alarms can be done with the function block *NewAlarm*.

As shown in Figure 8 the ECtransition to the successor of the ECstate reached by *AckAlarm* has no condition and is therefore always true. This is done because this successor is reached from the ECinitialstate by the event *AckHorn* and resets the data output *HornOn*, which is also a part of the *AckAlarm* functionality. Before this, the output event *Ack* has to be published. This event output is linked with the input event *Ack* of all function blocks, which register the alarms, by using the event splitter *E_SPLIT*, defined in annex A of the IEC 61499-1.

4.2.7. FB—PZN_Archive

For the implementation of a ring buffer for 24 hours and 4 measured values per hour, the function block in Figure 9 is used. Furthermore, the oldest and not taken over data pair consisting of the station number, a time stamp, and the consumed or produced power is presented at the data outputs. The consumed or produced power is calculated by the number of positive edges at the boolean input *Input* and the values of *TransformerConst* and *TransmitterConst*.

By resetting the boolean in- and output *Flag* of the IEC 61131 function block, a take over of the data and a request for new data is signaled. If there is new data available, the function block will set the boolean input and output *Flag* again. By converting to IEC 61499, this boolean input and output is transformed to an event input and an event output.

It should be noticed that it is possible to copy and paste the source code of the original function block into one algorithm, but it is better to separate the source code according to rule 3.1 in different algorithms. By doing this, the algorithms are shorter, easier to validate, and better to understand, but the ECC for controlling the algorithms will get more complex.

4.3. Translation rules

Due to the earlier explanations in this section, we define the following general rules for the translation of IEC 61131 function blocks to IEC 61499 ones.

Rule 1

The same data interface should be used for the IEC 61499 function blocks and the ones of IEC 61131 except the boolean

inputs and outputs. The copied interface has to be extended by a management interface consisting of the event pairs *INIT-INITO* and *REQ-CNF* as shown in Section 4.2.1.

Rule 2

Every boolean input or defined bit within a byte or word structured data input will become an event input if there is an edge detection performed at the original function block (Figure 10).

- Every boolean input or defined bit within a byte or word structured data input will become two event inputs if there is a positive and negative edge detection performed at the original function block.
- If there are two or more IEC 61131 function blocks within one POE connected through a local boolean variable or through a defined bit of a local byte or word structured variable, the translated function blocks will be connected through events as described in Section 4.2.6.

Rule 3

Every code fragment triggered through an edge detection of a boolean variable has to be implemented as an own algorithm in the new IEC 61499 function block and associated within an ECAction to an ECState reachable through the event of the converted boolean value from the ECinitialstate.

Rule 4

Each IF-Condition should be divided in one Then and one ELSE algorithm as shown in Figure 11. The switching condition of the transition from the successor ECstate to the ECstate associated with the THEN algorithm is the IF clause itself. The complement of the IF clause is used as switching condition of the transition to the ECstate associated with the ELSE algorithm.

Rule 5

To reduce the necessary computing power for sampling of the data inputs and updating of the data outputs, each in- and output event should only be connected with a minimal set of required data inputs or changed data outputs (Figure 4(b)).

Rule 6

To set, to reset, to read, and to write bits within a data point of the type byte or word, defined masks have to be combined with the original data point (boolean algebra) (see Table 1).

5. CONCLUSION

As a result we can draw the conclusion that the transformation of an IEC 61131-based control system to an IEC 61499-based one is possible. This is done by transforming all the used basic and composite function blocks first. After this, the control functionality of the whole system can be implemented by connecting the translated function blocks by means of data and event arcs at the application view of the system. At this step the aspects of communication and I/O

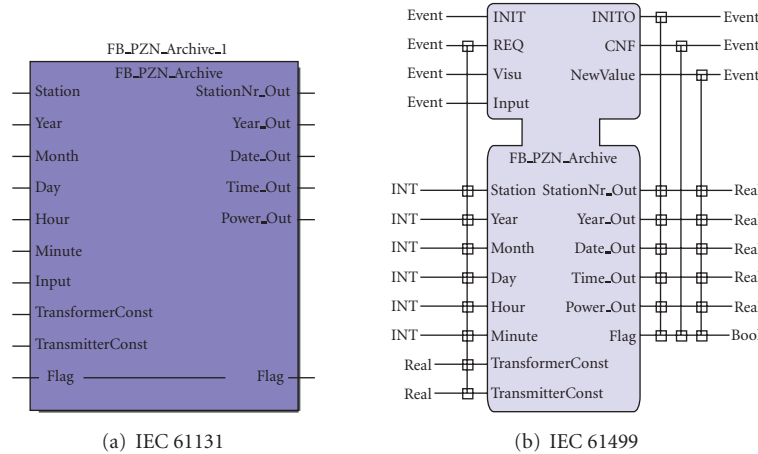


FIGURE 9: Function block to realise a ring buffer.

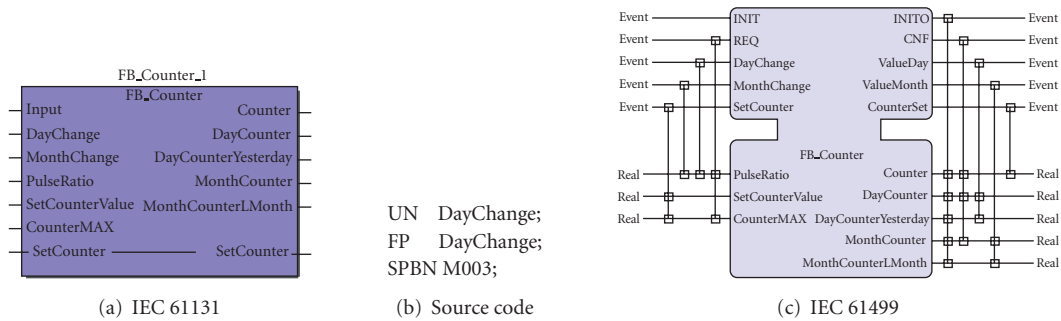
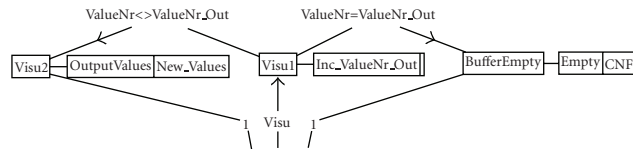


FIGURE 10: Converting the Boolean input DayChange.

```

If (ValueNr <> ValueNr_Out) then
    /* OutputValue
Else
    /* empty*/
End.If;
    
```

(a) Source code



(b) Execution control chart

FIGURE 11: Representation of an IF-Condition at the ECC.

TABLE 1

| (a) Writing a bit | | (b) Reading a bit | |
|-------------------|---|-------------------|-------------------|
| IEC 61131: | UN Alarm7; = L 0.6; M0:= 0; IF Alarm7=False then | IEC 61131: | UN L 6.7; = X; |
| IEC 61499: | M0:=M0 or 64; End_IF; | IEC 61499: | X:= M6 and 128; |

declaration are not yet taken into account. If the application is ready, the single components represented by function blocks are mapped to the resources of the used devices. Finally the communication between the devices and the I/O declaration has to be implemented by using special Service Interface function blocks for each device.

Using this way of system engineering eases the creation of customized automation solutions as a distributed system

because the communication and I/O mapping are separated from the development of the control functionality. This will make it possible especially for medium-sized companies to delegate the development of function blocks encapsulating the control, the visualisation, and the data logging to other companies. Afterwards, the main contractor of a project only maps the function blocks to devices and establishes the communication between them.

Currently, the classical programming methods for PLCs following the IEC 61131 are still dominating although the standard has reached the end of its lifecycle. Also the world of hardware will evolve step by step. This means that classical PLCs will coexist with new devices and will constitute heterogeneous distributed systems with different types of hardware and software. As a consequence, two different programming standards based on two different paradigms will coexist for at least a decade. This, in turn, as a consequence requires methods to integrate both “worlds” rather than to do a sharp cut and replace one by the other one with all transitional problems that this will definitely cause.

This will even emphasize the need for a stepwise transition in programming as it has been shown in this contribution and at the international exhibition SPS/IPC/Drives 2006 [9].

Another major issue is a smooth and seamless, stepwise process to migrate the company-owned software solutions from IEC 61131 to IEC 61499. Some steps towards this direction have been shown in this contribution.

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