RULE BASED ENGINEERING OF ASSET MANAGEMENT SYSTEM FUNCTIONALITY

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Abstract. If the total lifetime costs, industrial plant performance and risk are in balance, the plant reaches its most effective production. It is the task of an Asset Management (AM) System to establish and preserve this balance, but in fact, electronic and automatic AM is still not widely established due to the engineering effort and investment behind. This paper describes a method to automate parts of the engineering of an AM, thus reducing the engineering costs and making AM systems more attractive. We focus on the AM functions which are based on the evaluation of several process values, check them for consistency, and thus detect erroneous/illogical value combinations indicating either a defect of a sensor or actuator or a defect of a plant component related to them. These AM functions can be implemented e.g. in a PCS, which already has access to all the required process variables. The paper describes a method which allows automating the engineering process for asset management functionalities, if combined with an object / aspect oriented data model, which stores the plant engineering information. The introduction of a rule based engineering approach allows a systematical analytic evaluation. It uses the electronically stored plant information in order to identify component assemblies, which process values are a part of an AM function. The instantiation of a resulting AM function into the PCS can thus be performed automatically.

1. Introduction

Technical realisation and costs are two main contrary aspects meeting during the whole lifetime of a plant. Both aspects should be taken into consideration if the efficiency, productivity and safety of plants are discussed. The lifetime itself is usually separated into four main phases which are: engineering, installation, production and deconstruction phase. The weightings of the two aspects depend on the phases. This article focuses on the engineering and production phase because the production depends on technical process realisation, worked out in the engineering phase.

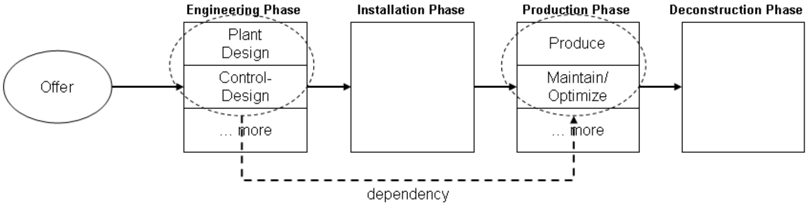

Fig. 1: Lifetime phases of a plant

After signing the contracts, every process-plant-design-workflow starts with the engineering phase. This phase covers different stages including plant design, process engineering, electrical and instrumentation (E&I) engineering and the process control engineering. The last two mentioned stages are largely based on the results of the preceding engineering tasks. Process engineers specify the process with its operation conditions, process parameters, process steps (in case of batch processes); whereas the plant design determines the arrangement of equipment and instruments. The technical realisation of the defined process remains with the E&I and process control engineering. It can be split into the mandatory and additional task [10]. Mandatory are all tasks, that are necessary for the simple production of a product, e.g. process control equipment (PCE) is needed and their inputs and outputs have to be analysed and manipulated by the process control system (PCS). If the focus is only on investment costs, the consequence will be a rudimentary technical implementation with the simplest PCE. If the production has an unpredicted change of conditions, problems arise. The other extreme focuses only on the technical aspect. Today, this can lead to the explosion of the costs. Intelligent sensors can provide a lot of functionality - but they are expensive. Their implementation into the process control structure is time intensive and the implementation requires costly engineering effort.

During the production phase, the maintenance costs are usually dominant. These costs cover the operator's costs to the repair cost. They are indirectly linked to the E&I and process control engineering stages. It depends on the installed sensors and actuators which process information is available in the PCS. It is the functionality of the PCS providing the information for the operator to assess the actual plant state, as well as providing remote-intervention methods. A simple technical implementation can lead to an increase of maintenance costs, if more operators are necessary to run a plant or complete plant breakdowns occur too often. Plant breakdowns cause production downtime or damages of plant equipment. Damages can endanger the environment and staff. All these problems influence the maintenance costs.

Asset Management: The aim of the total plant engineering is to find the balance between the total lifetime costs, plant performance and risk [1]. So-called Asset Management Systems (AMS) are introduced to support these tasks. AMS include all actions to save the reliability and the value of a plant [12]. It is the task of an AMS to establish a balance between asset performance and the investment / maintaining costs of asset management functionality. But, in comparison to pumps and valves, AMS are not responsible for the direct plant functionality. This can be compared with "air bags" or "ESP functions" of a car – they do not add a direct functionality to the car, but in spite of increased car prices, today they are introduced and established because they decrease the driving risk, increase the car reliability and prevent the car from exceptional conditions. In the same way, AMS increase the reliability of the plant, but they are not essential for the plant functionality and increase the total engineering cost. This is one of the main reasons why AMS are still not widely used. But there are convincing reasons to introduce AMS: there performance and efficiency, can be measured in terms of cost and downtime avoidance.

Plant Asset Management (PAM) is a sub-domain of AM and focuses on the avoidance of unintentional downtimes caused by technical failures. It is the task of the plant process control engineering, to establish asset management functionality for a given plant with a given process. "Online Plant Asset Management includes assessment of the plant, decisions on maintenance measures and their execution." [12] PAM should support the operators to keep the production running. This encompasses maintenance, equipment assessment, repairs and substitution of equipment. Necessary for this support is that information about plant equipment conditions can be used by maintenance staff to start counter actions. The importance of PAM can be clarified by the simple fact that the failure of a relatively cheap field equipment item can cause cost intensive downtimes and damages. PAM covers all techniques handling this problem.

This paper proposes implementing asset management functionalities on the basis of the already existing process control equipment. The information processing is done by the PCS. It analyzes the actual values of different, independent process control components and detects erroneous, illogical value combinations indicating an alternation in the plant components' conditions. This methodology works with every sensor providing a process value and does not require diagnosis functionality in the sensor itself. The paper demonstrates that, within this setup, it is possible to automate the engineering process for asset management functionalities, if combined with an object / aspect oriented data model which stores the plant engineering information [3, 11]. Software programs are able to access the plant data and can use the information and interpret them. The introduction of a rule based engineering approach allows a systematic and analytical evaluation. It uses the electronically stored plant information to identify component assemblies. Their process values are a part of an AM function. The instantiation of a resulting AM function into the PCS is performed automatically. A scheme is shown in figure 9 and the corresponding section gives more detailed information about the automatic engineering process.

2. Plant Asset Management

In this paper, PAM is divided into different types and the methodologies used for the data acquisition. The type describes the strategy defining the moment of equipment replacement. The methodologies explain the way of data acquisition. The extracted information is the basis for the PAM type, to define the equipment's condition.

Types of PAM: A study in the USA (2001) compared the most important PAM types [9], the results are summarized in figure 2. New approaches appear from time to time but their success is not certain. The three main types are:

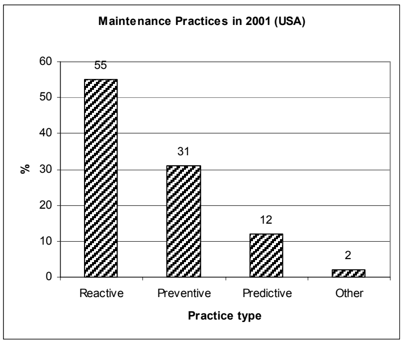

Fig. 2: PAM types in the USA (2001)

- **Reactive PAM**: The strategy is simple: 'run till failure'. It has low investment and maintenance costs. No additional functionality has to be implemented in the PCS. But if technical equipment fails, the repair/replacement costs increase and the feedback to connected neighbour processes may lead to unpredictable follow up costs. The downtime of the plant is unavoidable and leads to production losses. This PAM type is useful for slow, robust and clear processes.

- **Preventive PAM**: This concept follows a fixed schedule. The schedule includes aspects to determine the degradation of plant equipment. The equipment and process failures can be reduced. It is possible to replace plant components during a planned plant downtime. Additional costs arise with the implementation of the preventive functionality. This PAM type is widely used and useful for plants where the cost of the equipment is low compared to the profitability of the plant.
- **Predictive PAM**: This strategy detects the onset of degradation. Actual values and plant factors are evaluated and forecasts of the future functional capabilities can be made. The maintenance is based on the needs of the actual plant condition and not on a fixed schedule. This concept leads to an increased equipment operational life and improved safety, accompanied by a decrease of failures, plant downtimes and repair costs.. These advantages are faced with the higher investment cost for the equipment and the diagnostic functionality in the PCS. This PAM type is a consequent continuation of the preventive PAM and arises from the increasing profitability-pressure to plant-owners. Monitoring current, detail and summary health diagnostic information of plant equipment and unit functions is expected to become a potent main stream candidate for future plant operation improvements.

Methodologies of PAM's information acquisition: The three types of PAM need data to determine the status of the field components, but in different quantity. The reactive approach only needs the information whether the corresponding equipment is running correctly. On the contrary, the predictive system requires more data to assess the actual and future condition of the plant equipment.

The field equipment is the most important part of this concept. It provides the data which is monitored and evaluated by the PAM. The generated information can than be passed to the maintenance personnel. Over the last years, different approaches have been developed to rate the condition of a plant component [5]. The main approaches are listed below.

Reference value (see Fig. 3): This is the simplest, but the least significant solution. Reference values containing information about maximum, minimum or optimal values, are stored in the PAM and define the allowed range of values. The associated plant equipment process values are continually compared to them. Whenever a process value is out of the allowed range, a reaction has to be undertaken. Simple faults can be detected in this way. It however fails, if the equipment is malfunctioning but the process value is still in the allowed range (e.g. if a valve is locked).

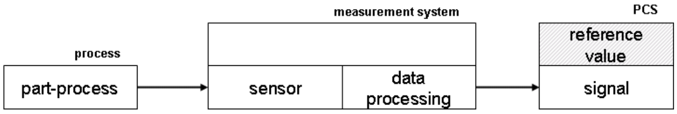

Fig. 3 Reference value

Redundancy (see Fig. 4): It means the multiple existence of plant equipment intended for the same task with the possibility to replace each other in case of failures. This technique increases the fail-safety, because the actual condition of the redundant equipment can be compared. If the conditions differ, reactions can be started. The main disadvantage of this methodology is the additional equipment. Two types of redundancy can be distinguished: homogeneous and heterogeneous redundancy. Heterogeneous redundancy is preferred, because the different measurement methods are able to detect more error conditions.

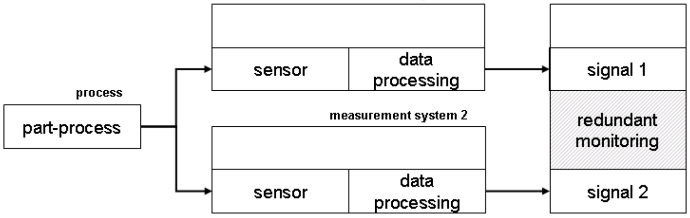

Fig. 4: Redundancy

Self-monitoring (see Fig. 5). Self-monitoring is a build-in functionality of a device itself, therefore the engineering effort is relatively low. It uses internal reference values, redundancy, test signals or process simulation models to check its healthy [10]. It is not possible to detect errors concerning the electric, the internal data evaluation and the installation. The self-monitoring functionality depends on the equipment's measurement principles and the design. The variety of detectable errors is limited: examples for failures which can not be detected by self-monitoring are given in [7]. Furthermore, this methodology requires special and expensive field devices. Usually, this process control equipment requires special fieldbus-systems or PCS components to provide their full functionality. Using this new technology, existing plants need a complete reinstallation of the PCS and new field components. The resulting investment costs are significant.

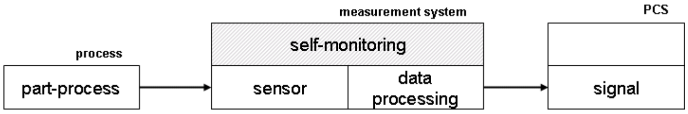

Fig. 5: Self-monitoring

Cost: As mentioned above, the implementation of Asset Management (AM) functionalities increases the installation and/or engineering costs. Additional equipment is needed, and / or additional PCS functions have to be implemented. That is the reason why AM is often regarded as an additional feature because it is not mandatory to run a plant. The extra investment costs are opposite to the aim of many manufactures, to spend only the minimum money to build a plant. In order to see the effects of an AMS, not only the investments, but the complete lifetime costs of a plant have to be considered. AMS shall prevent the plant from cost-intensive failures, plant downtimes and production losses. The result of higher investment costs is a decrease of the maintenance efforts. The saved costs by avoidance of a breakdown have to justify the investment. “Many manufactures have reported substantial returns after 18 – 36 month of functional integration […] lower costs, improved process efficiency, and better machine operation and output, […]” [4].

Actual systems: Today, the systems only provide their full functionality if they are implemented in a homogeneous system. This means, most parts of the field equipment, PCS and AMS are from the same supplier or at least from cooperating companies, due to the lack of openness and standards [8]. As a result, the use of intelligent or additional redundant field device equipment increases the costs. Furthermore, there are implementation costs during the process control engineering. The AM functionality has to be added to the system. Depending of the PAM’s type, more or less efforts have to be taken, which results in engineering costs. Both points make it impossible for smaller enterprises to justify the investment costs for them.

The following approach shows a new way supporting the development of AM functionality without the need of new process control equipment and minimum efforts to configure the PCS.

3. Automatic Instantiation of AM Functionality

Idea: Process control engineering is based on the definitions of the plant design and process engineering stage. The results of both stages are presented in P&I (pipe & instrumentation) diagrams and the data sheets of the plant equipment. But it is no longer needed to analyse them in a tedious manual way. Actual engineering tools store the information in a hierarchical object model. This allows an algorithmic access to the plant information, but those data are usually stored in proprietary and unstable data format which may change from version to version and which is usually different from tool vendor to tool vendor. Therefore, in order to develop re-usable software algorithms that investigate the existing plant information, it is useful to export the data into neutral, tool-independent file formats, like CAEX (Computer Aided Engineering eXchange) [3, 11]. These file formats also provide a seamless information flow between the engineering stages. More important for our approach is the possibility to use the stored data as basis for the automation of repetitive process control engineering tasks, like PAM functionality [2]. CAEX contains all necessary plant details to find and implement a certain set of asset monitors automatically. For this, a rule based reasoning approach is introduced. It is based on a new idea of PAM information acquisition which is independent from plant equipment self-monitoring capabilities. It is named “overlapping field device monitoring” (see paragraph “Overlapping field device monitoring”). The evaluation is executed by the PCS and needs only the standard input and output values of the plant equipment. They are usually supported by every analogue or digital plant device.

This makes the approach independent of the measurement principles and of the plant equipment vendors. The plant project can be planned independently. The selection of field devices is not subject to restrictions, it is flexible. The most appropriate field devices for the process can be chosen. Heterogeneous systems are possible.

Asset Management functionality must not to affect the core functions of the PCS. “Additional data flows must never result in bus overload or perceptible lengthening of response time, or in any other way interfere the core functions of the control system.” [12] With our presented approach, no additional data has to be transmitted from the field devices to the PCS. This means an additional merit for the PCS system. But it is confronted with the higher efforts in the process control engineering stage, which leads to higher investment costs. The automation of this task reduces the engineering efforts and makes this approach more interesting to the plant owners. Another big advantage of our approach is that the operators can use their familiar software tools of the PCS.

With the integration of the AM functionality, no new tools are required. The result is a homogeneous software environment.

Overlapping field device monitoring (OFDM) (see Fig. 6): This methodology assesses a group of plant components. It is not the aim of OFDM to determine the state of a single sensor or actuator, instead, OFDM aims at detecting wrong, ‘illogical’ plant equipment conditions. The relationship of different measured quantities on the one side and other quantities or control outputs on the other side are analysed and inconsistencies between them are revealed. This strategy allows to detect occurring faults, without exactly determining their causes. The fault detection is based on an analytical evaluation of physical/logistic correlations.

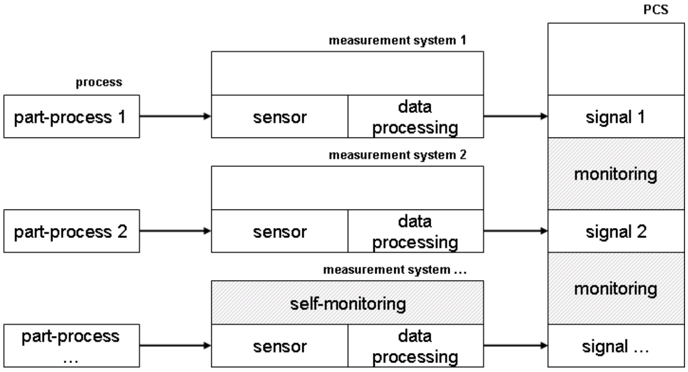

Fig. 6: Overlapping Field Device Monitoring

For example, in figure 7, a level and a pressure sensor are attached to a vessel and they monitor each other. The Equation <1> and <2> set the correlation between them and the result can be used to evaluate the state of this component assembly. The used indices stand for level sensor (L) and pressure sensor (P). ρ stands for the density of the fluid, stored in the tank; g is the gravitational acceleration constant.

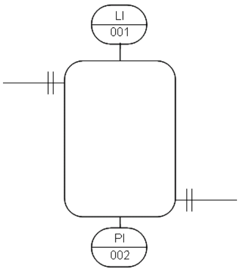

Fig. 7: Simple OFDM for a level indication of a tank. The level and pressure sensor monitor each other.

$$p_P = \rho_{Fluid} \cdot g \cdot h_P \qquad \langle 1\rangle$$

$$\Delta h = h_L - \left(\frac{p_P}{\rho_{Fluid} \cdot g} \right) \qquad \langle 2\rangle$$

A more advanced approach uses the accounting equations, e.g. mass balances, to make assessments about the plant status. Figure 8 shows an asset monitor which is based on the conservation of mass. (Reactions in the system are not allowed, because they may lead to an energy conversion which cannot be apprehended by the mass balance alone.) Two pipes join to one pipe. The two single input flows are measured by the sensors F1 and F2. The resulting flow is indicated by F3. With the simple equation of continuity (see <3> “general equation of continuity“ and <4> “continuity equation for liquids”), the three sensors can monitor each other. A violation of the continuity indicates a malfunctioning of one sensor or a leakage in the pipe system.

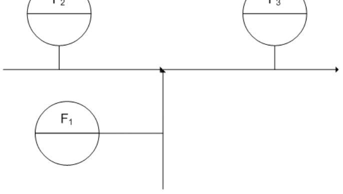

Fig. 8: 3 flow sensors which can monitor each other by the use of the continuity equations.

$$\dot{m}_{F_1} + \dot{m}_{F_2} = \dot{m}_{F3} \tag{<3>}$$

$$\dot{V}_{F_1} + \dot{V}_{F_2} = \dot{V}_{F3} \tag{<4>}$$

The two examples clarify that there are always multiple plant equipment components necessary to get overlapping field device monitoring functionality. But it should be pointed out that for all component assemblies matching the generic framework of figure 8 (flow measurement in each flow branch of a joining system), this AM functionality can be implemented. In a large plant, there are typically dozens or even hundreds of such pipe joints, which only differ in the symbol names of the concerned plant equipment components. This common feature, the specific generic component assembly, can be used as starting point for the automatic rule based engineering process.

Rule based engineering strategy [6]: The results of the plant design and process engineering stages are stored in P&I diagrams and the plant equipment data sheets. They include all necessary plant information being relevant for the process control engineering stage. The advantage of the electronic availability of this information is that the data can be accessed by computer programs. With analytical methods and mathematical algorithms it is possible to extract plant information and to use it for further tasks. In the approach introduced this paper, CAEX is the data format which is used as a basis for the further automatic engineering strategy.

Before the automatic reasoning algorithm can start, two preparative steps have to be accomplished. First, generic component patterns have to be defined. The definition is based on the role concept of CAEX. In CAEX, each plant component can be assigned to a "role" in the plant description, e.g. to be a vessel, valve, pump, etc. The structured combination of roles builds the generic patterns being summarized in a pattern definition file. These patterns are later used to find the real components in a specific plant. Once defined, the generic patterns can be reused in every new process control engineering project. Furthermore, conditions have to be defined describing relations of pattern components and including action / reaction behaviours. The rule concept is particularly suitable to describe these conditions, because the conditions are normally based on causalities between sensor and actuator values, expressible by the "if … then …" formalism.

The rules have 3 subparts. The first one contains information about the plant equipment which has to constitute the AM functionality. It refers to the generic pattern definition. For the example of figure 7, it refers to the pattern: tank with attached level and pressure sensor. The last part contains the rule-logic, describing the "if ... then …" causality. In its mathematical description, it just contains universal symbol names as operands. They are totally independent of the actual project and its real component and signal names. The second part is responsible for the mapping of the universal symbol names of the third part to the plant specific names, defined in the first part. The rules are stored in libraries. They can be reused, too.

Because of the different PCS vendor philosophies and the lack of standards, the functional realisation of the instantiated AM objects in the PCS depends on the PCS. The PCS-specific logic has to be defined once in the PCS system. In the case of this approach, a library contains a class for each AM functionality/ logic. This library is transportable and can be installed on each PCS of the same vendor. During the automatic reasoning process, objects of this AM class will be instantiated. The advantage of this strategy is that the results are valid and reproducible.

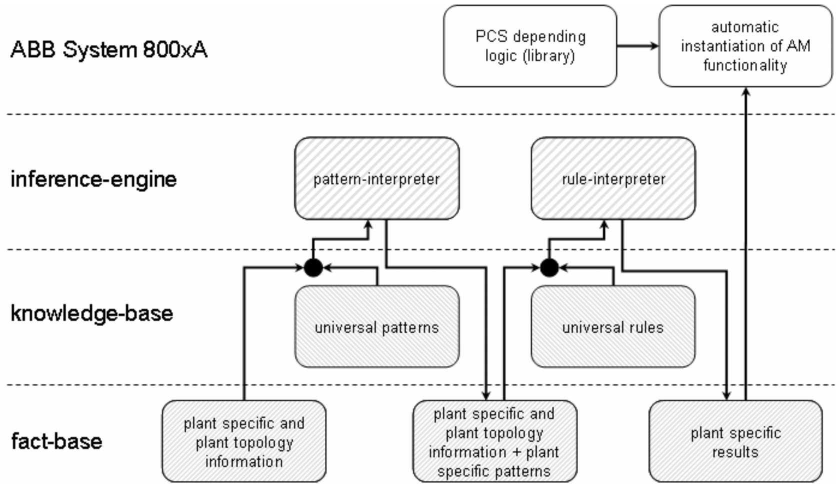

Fig. 9: Reasoning process of the automatic instantiation of AM functionality

The analysis of the topology based on plant information is executed in two steps, see figure 9. In the first step, an algorithm takes the generic pattern definitions, scans the CAEX data and searches for all corresponding plant – component patterns where AM functionality can later be assigned to. Once extracted, these plant component patterns are the basis for the second step: the rule based evaluation. The rules are applied to specific patterns, and the universal variables are replaced by the real PCS signal names. Having the PCE signal names and AM functionality as defined in a PCS depending library file, objects of the AM functionality can now be instantiated and configured automatically. Only the last step depends on the particular type of PCS used, see figure 9.

4. Conclusion

To assess the efficiency and productivity of a plant, its total costs, performance and risks have to be considered. Especially the costs over the lifetime are important. The technical realisation, defined in the engineering phases of the plant, has strong influence on the production costs. Maintenance, repair and production downtime costs can fast exceed economised investment costs. In this context, the avoidance of plant breakdowns is the most important aspect. They can lead to damages of plant equipment and the environment. The efficiency of a plant is measured on its cost per output. If there is no output, the economic balance is negative.

Asset Management Systems have been established to find the balance between the total lifetime costs, plant performance and risk. The avoidance of unintentional downtimes caused by technical failures is in the focus of the sub-domain called Plant Asset Management. It manages all aspects keeping a plant in production process, like equipment assessment, repair and substitution schedules.

Today, AM engineering is tedious because the instantiation and parameterization of individual Asset Monitors needs to be executed manually. The resulting AMS does not use the complete potential of AM, because only the AM functionality of special, critical plant equipment components is realised. Some important AM information may be overseen. Furthermore, existing AMS are focused mostly on single sensors. But intelligent self-monitoring sensors with internal diagnosis functionalities are not able to take into account the conditions of adjacent components. As a result, complex components like heat exchangers are difficult to equip with AM functionality.

The approach presented in this paper bridges this gap. It only uses actual process values of different plant components and assess them by using mathematical, logic correlations. No special diagnosis information is necessary from the sensors or actuators. Additionally, the engineering efforts to build the AMS are reduced significantly. Starting with the electronically stored plant information, the automatic reasoning identifies all plant components of a type defined in a rule. The referenced AM functionality is then instantiated and parameterized automatically. Thus, new diagnosis information, based on the evaluation and combination of different process values, is created, which goes beyond the accumulation of individual devices' diagnosis signals.

To demonstrate the feasibility and the advantages of the described approach, a software-tool has been successfully developed, which implements the described method. The only prerequisites for this approach are the plant description in CAEX format and the pattern descriptions and rule descriptions. A standard set of universal patterns and rules is available and can be reused. The extracted results have been automatically instantiated in the process control system 800xA (ABB).

The application of rule based engineering to investigate plant information in a vendor independent and neutral way shows how concept of the artificial intelligence can help control engineers to engineer up-do-date control systems with modern AM functionality with reduced effort. This is a further step of applying object orientation in the world of automation engineering.

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