Concept for an Energy Data Aggregation Layer for Production Sites

A combination of AutomationML and OPC UA

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***Abstract*—In industrial production facilities, technical Energy Management Systems are used to measure, monitor and display energy consumption related information. The measurements take place at the field device level of the automation pyramid. The measured values are recorded and processed at the control level. The functionalities to monitor and display energy data are located at the MES level of the automation pyramid. So the energy data from all PLCs has to be aggregated, structured and provided for higher level systems. This contribution introduces a concept for an Energy Data Aggregation Layer, which provides the functionality described above. For the implementation of this Energy Data Aggregation Layer, a combination of AutomationML and OPC UA is used.**

Keywords—technical energy management; energy efficiency; AutomationML; OPC UA; aggregation server.

I. Introduction

Technical Energy Management Systems (tEnMS) are an instrument of the organizational energy management as defined in the ISO 50001 [1]. TEnMS are used to measure, monitor and display energy consumption related information in production sites. A tEnMS can be installed in parallel to the automation system or integrated into the automation system. The former approach requires additional hardware, therefore, the latter is advantageous. A tEnMS is usually allocated at the MES level of the automation pyramid [2]. Also, PLC programs for collecting measured values from sensors and actors are needed at the control level of the pyramid (see Fig. 1).

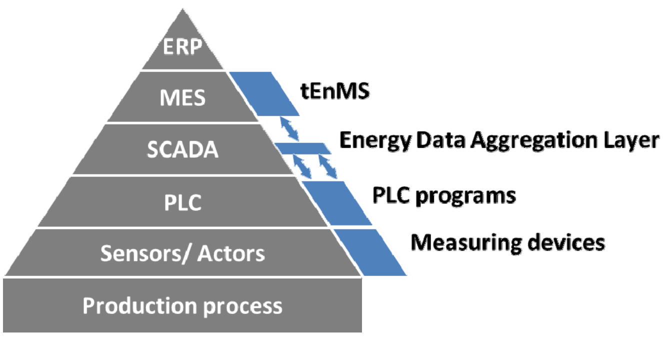

Fig. 1. tEnMS integrated in the automation pyramid

The need for tEnMS-specific PLC programs results in extra engineering effort. This engineering effort is an obstacle for companies with respect to using an integrated tEnMS.

The research project *Integrated Plant Engineering to increase Energy Efficiency (IAE4)*[1], executed at the University of Applied Sciences and Arts in Hannover, aims to reduce the engineering effort needed to integrate tEnMS functions into the PLCs. A typical system is used in the project. The typical system consists of *1* to *n* PLCs. Each PLC acts as a PROFINET controller, to which *1* to *m* PROFINET devices are connected. All PROFINET devices provide various measurements, which are relevant for tEnMS. Furthermore, each PLC has its own OPC UA [3] server, which runs directly on the controller. This OPC UA server provides all measured energy related values from the devices that are connected to the controller, to higher-level systems. Above the PLCs, at the SCADA level, an Energy Data Aggregation Layer aggregates all measured values from all PLCs. This Energy Data Aggregation Layer is implemented as an OPC UA aggregation server. The aggregation server provides the collected data for systems on the next higher level of the automation pyramid, e. g. for a tEnMS integrated in the MES. The typical system is shown in Fig. 2.

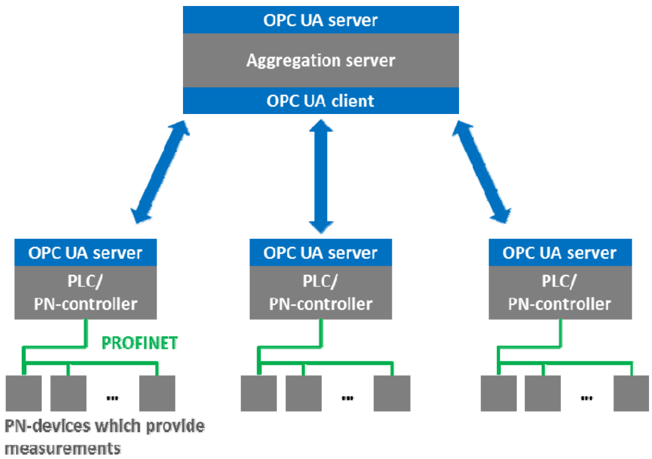

Fig. 2. Typical system

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A main part of the IAE4 research project is the automatic generation of the Energy Data Aggregation Layer based on available engineering information.

This paper focuses on the hierarchical structure and on the information content of the Energy Data Aggregation Layer. According to this concept, all measured values from all PLCs are arranged in a hierarchical structure. This hierarchical structure is modeled in the vendor neutral modeling language AutomationML (AML) [4]. The resulting model is called *Energetic Production Site Model*. It is then mapped to an OPC UA address space for the aggregation server. The aggregation server structures the aggregated data according to the hierarchical structure of the model (see Fig. 3).

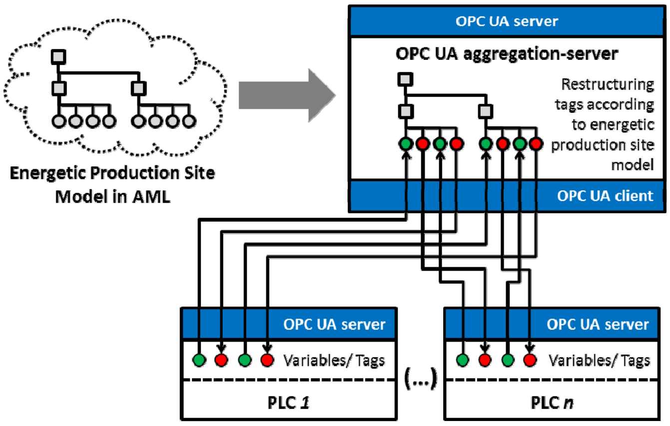

Fig. 3. OPC UA aggregation server

The body of this paper is organized as follows: Section II gives a brief overview on related work. Section III presents the structure of the Energetic Production Site Model. Section IV shows how the Energetic Production Site Model can be implemented in AML. Section V provides guidance on how to transform the AML model into an OPC UA address space for the aggregation server. The paper ends with a brief summary and conclusions.

II. Related Work

This section shows related work on energetic plant modeling and OPC UA. In the subsections below related papers are briefly summarized and conclusions, for the work presented in this paper, are drawn.

A. Related work regarding energetic plant modeling

The following two papers address the modeling of production components from an energy point of view:

In [5] an ontology-based method for the energetic modeling of production plants is presented. For this purpose, the lightweight-ontology *OntoEnergy* was developed. The motivation for the development of OntoEnergy was to create a uniform semantics for the interaction of automation components and energy management systems. To have uniform semantics of the energy data provided by the OPC UA servers on the PLCs in the typical system, mentioned in I, is a major requirement for the implementability of the concept introduced in this paper.

In [6] the description language *Energy Information Description Language (EIDL)* is presented. EIDL was developed for the energetic description of machine tools. A machine tool is modeled in EIDL in a hierarchical structure. The highest hierarchical level is the machine tool itself. The lowest hierarchical level represents devices such as electrical drives. Intermediate levels are composite components, or subsystems such as the main spindle or the tool change system. Each component within the machine tool is assigned energy measurements.

The paper summarized above shows an approach to model all components from a machine tool, relevant for an energy point of view, in a hierarchical structure. Parts of this approach can be adopted for the modeling of production sites. However, a completely new description format was developed for the modeling. So future applications, that use the created models, must always have an input interface for this format. To avoid this, the approach presented in this paper uses an already existing, vendor-neutral description format.

B. Related work regarding OPC UA

The next two papers address OPC UA, respectively the generation of OPC UA server address spaces:

In [7] the concept for an OPC UA aggregation server is presented. The described OPC UA aggregation server is similar to the IAE4 aggregation server. It consists of an OPC UA client and an OPC UA server. The client aggregates data from subordinate OPC UA servers, which are located on subsystems (e. g. PLCs) or devices with integrated OPC UA servers. The aggregated data is mapped by the OPC UA aggregation server in its own address space and made available to higher-level systems. However, unlike the aggregation server presented in this paper, the IAE4 aggregation server does not simply aggregate the data from the PLCs and maps them in its own address space, but maps it into an externally supplied address space.

In [8] the two standards OPC UA and AutomationML are compared. Transformation rules are formulated to transform an AML model into an OPC UA information model. The transformation rules introduced in the mentioned paper were later adopted into the DIN SPEC 16592 [9], which describes the Transformation from AML to OPC UA.

III. Structure of the Energetic Production Site Model

In [10] the concept of balancing groups is defined as a summary of energy consumers and energy infeed points. The sum of the energy fed into a balancing group is equal to the sum of the energy consumed. This concept can be used in an adapted form to structure the energy data of a production site. For this purpose, two different forms of balancing groups are defined below: *physical balancing groups* and *user defined balancing groups*.

A. Physical balancing groups

The following concept for the hierarchical structuring of physical balancing groups is based on the concept of the hierarchical structuring of resource efficiency indicators, which is defined in NE 162 [11].

Physical balancing groups are balancing groups resulting from the hierarchical arrangement of production sites. The hierarchical arrangement of production sites is standardized in [12]. Accordingly, a production site consists of the following hierarchical structural elements: site, area, process cell, unit, equipment module, control module. So when defining an Energetic Production Site Model consisting of physical balancing groups, there are six hierarchical levels of physical balancing groups, according to the hierarchical structural elements mentioned above. A physical balancing group at site level represents the highest hierarchical level of balancing groups. There is only one physical balancing group at site level within an Energetic Production Site Model. A physical balancing group at site level contains any number of physical balancing groups at area level. Each physical balancing group at area level contains any number of physical balancing groups at process cell level and so on. A physical balancing group at control module level therefore represents an element at the lowest hierarchical level. In case of the used typical system, a control module is a PROFINET device which provides integrated measurements. Fig. 4 shows the hierarchical structure of physical balancing groups modeled in an UML class diagram.

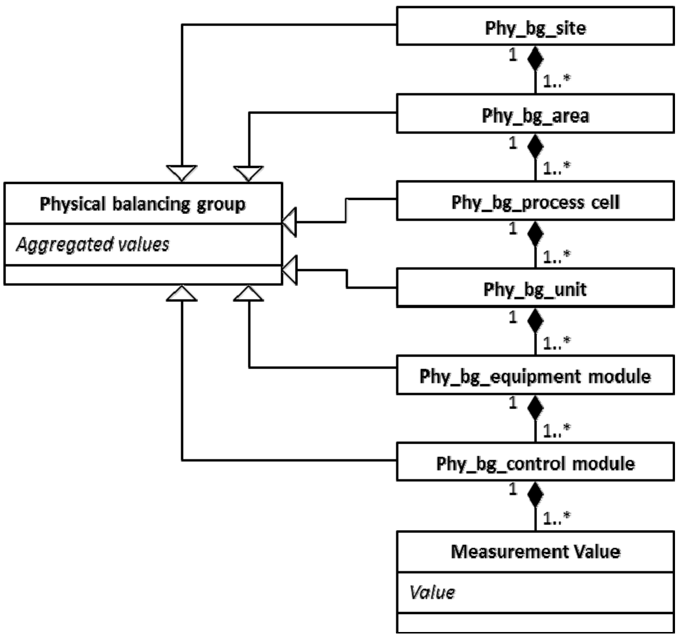

Fig. 4. Hierarchical structure of physical balancing groups

All physical balancing groups above the control module level contain physical balancing groups of the hierarchical level below and the corresponding aggregated data. That means e. g. that an equipment module, which contains *n* control modules, which provide a current measurement value each, provides the sum of all measurement values. A Unit which contains *m* of the mentioned equipment modules in turn provides the sum of the sums of all measurement values and so on.

B. *User defined balancing groups*

There are several sets of measurement values which are interesting for certain stakeholders only. For example, summaries of all consumers that are connected to the same electrical sub distribution are of interest to the person responsible for the electrical energy supply of the production site. Or, for analysis purposes, all consumers of one type (e. g. all pumps) on the site should be grouped together. For such applications, the concept of user defined balancing groups is developed. User defined balancing groups are assembled groups of any physical balancing groups.

C. *Exemplary Energetic Production Site Model*

In summary, it can be said that physical balancing groups can be modeled according to the hierarchical structure of production facility. Measured values are located only at the lowest hierarchical level. All higher hierarchical levels contain aggregated values only. Aggregated values can consist of sets of other measured or aggregated values. Fig. 5. shows an exemplary Energetic Production Site Model. This model consists of a hierarchical structure of physical balancing groups and of some user defined balancing groups.

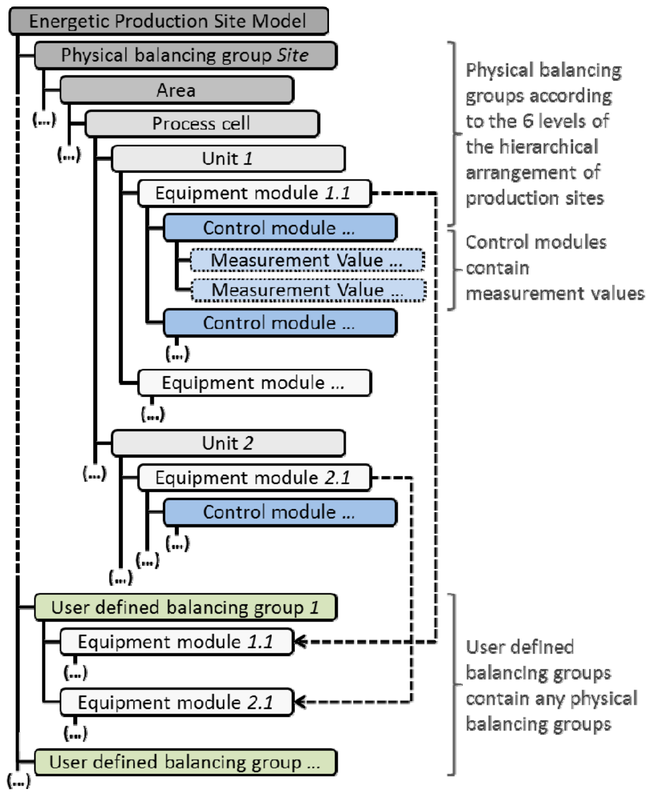

Fig. 5. Exemplary Energetic Production Site Model

IV. IMPLEMENTATION OF AN ENERGETIC PRODUCTION SITE MODEL IN AUTOMATIONML

The decision for creating the Energetic Production Site Model in AML was made for several reasons. One reason is that the Energetic Production Site Model has to be transferred to an OPC UA address space, and some use cases for the combination of AML and OPC UA have already been specified in the companion specification DIN SPEC 16592 [9]. Another reason is that the Energetic Production Site Model shall be generated automatically at a later time. Device description files and models of the hardware configuration of production plants serve as the information base for the automatic generation. For modeling hardware configurations in AML there are already application recommendations [13, 14].

The core concept of AML consists of four parts [4], which have to be briefly introduced:

When modeling in AML, the actual model is created in the so-called *Instance Hierarchy*. The Instance Hierarchy is a hierarchical arrangement of so-called Internal Elements. According to object-oriented programming, an internal element in the instance hierarchy can be compared with an object instance. An Internal Element can have attributes of various Datatypes.

The second part of the AML core concept are the *System Unit Classes*. A System Unit Class also consists of a hierarchical arrangement of internal elements. System Unit Classes can be instantiated several times within the Instance Hierarchy. So recurring structures can be defined once as a System Unit Class and can then be instantiated as often as needed in the Instance Hierarchy.

The *Interfaces* represent the third part of the AML core concept. Interfaces can be assigned to Internal Elements. Interfaces can be used for relations between several Internal Elements inside the Instance Hierarchy, but they can also be used as a link to external data formats. Some predefined types of interfaces can already be found in the AML base library.

The fourth part of the AML core concept are the *Roles*. A Role represents an abstract behavior that can be assigned to an Internal Element. Some predefined types of Roles can already be found in the AML base library. Roles can also be derived from each other, so all already predefined Roles are derived from the so-called AML base Role.

To implement the Energetic production Site Model, described in III, in AML, two new Roles for physical balancing groups and for user defined balancing groups are defined.

A. Modeling physical balancing groups

To model the hierarchical levels of physical balancing groups, six more Roles, one for each hierarchical level, are derived from the Role for the physical balancing groups. Each of the six Roles represents one of the hierarchical levels of physical balancing groups. The Role representing the physical balancing group itself is derived from the *Resource Structure* Role, which is one of the predefined Roles within the AML base library.

The hierarchical arrangement of the physical balancing groups is then modeled within the Instance Hierarchy. The Role for the corresponding physical balancing group is assigned to each Internal Element within the Instance Hierarchy.

A measurement value is modeled as a System Unit Class consisting of an Internal Element with an Interface of the Interface type *Signal Interface* assigned. This Interface type is from the AML base library. It represents e. g. the value of a variable on a PLC.

B. Modeling user defined balancing groups

User defined balancing groups are defined in III.B as a composition of any physical balancing groups. So an Internal Element inside the Instance Hierarchy, which represents a user defined balancing group, must contain relations to all physical balancing groups which are composed in it. Such a behavior can be modeled in AML using the *group* concept. A group element according to the group concept in AML is defined as a composition of several other elements. Therefore, the element which represents the group must have the Role group assigned. The elements which shall be grouped together must be referenced by the group element. So to model user defined balancing groups according to the group concept, the Role for the user defined balancing group has to be derived from the Role group from the AML base Role library.

C. AML model

Fig. 6 shows the exemplary Energetic Production Site Model from Fig. 5 now represented in AML. The red lines and frames in the figure show that the user defined balancing group only contains references to Internal Elements from the hierarchy of the physical balancing groups.

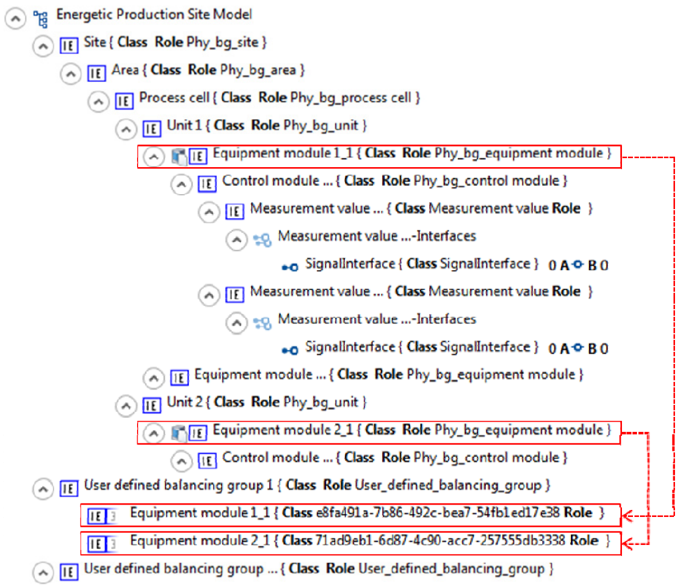

Fig. 6. Realization of an Energetic Production Site Model in AML

V. Transformation of the AML model into an OPC UA address space

Within the concept of an Energy Data Aggregation Layer introduced in I, an OPC UA aggregation server structures the information aggregated from the PLCs into the physical and user defined balancing groups defined in the Energetic Production Site Model. The hierarchical structure and the information contained can now be accessed by OPC UA clients from higher level systems.

The information within every OPC UA server is organized in a so-called *address space*. The OPC UA address space consists of *nodes* and *references*. Nodes are separated into *node classes*. Examples for node classes are *variables* or *objects*. References are relations between nodes. They are separated in *reference types*. Node classes und reference types are defined in the so called OPC UA information model. The OPC UA base information model, consisting of base node classes and base reference types, is specified within the OPC UA specification [15].

To implement an energy data aggregation layer, the balancing groups and the information within have to be mapped from the AML model into an OPC UA address space. For this purpose on the one hand for each element type in AML a corresponding element type in OPC UA is needed. On the other Hand correspondence tables for mapping AML elements to the OPC UA counterparts are needed.

Because not for each AML element a corresponding element in the OPC UA base information model exists, in DIN SPEC 16592 [9] some new node and reference types are defined. A complete OPC UA information model for mapping the AML core concept to an OPC UA address space, called *OPC UA Information Model for AutomationML*, is already public available [16].

Correspondence tables and instructions for mapping AML to OPC UA are provided in DIN SPEC 16592. It is shown how to expand the OPC UA Information Model for AutomationML with self-defined AML elements, such as self-defined System Unit Classes or Roles. Thus, the self-defined Roles for the balancing groups and the System Unit Class, which represents a measured value, can be transferred to the OPC UA information model.

The correspondence tables show which element or element relation from the AML core concepts corresponds to which node class or relation type in the OPC UA basic information model extended with the OPC UA Information Model for AutomationML. Using these tables, correspondences for all AML elements from the Energetic Production Site Model can be found in the extended OPC UA information model. Thus it is possible to map the Energetic Production Site Model directly to an OPC UA address space.

VI. SUMMARY AND CONCLUSION

Within this paper, a concept for an Energy Data Aggregation Layer, using a combination of AutomationML and OPC UA, has been presented. An Energetic Production Site Model, in which energy data is structured, has been introduced and defined. It was shown, how such an Energetic Production Site Model can be implemented in AML. Finally, guidance for the transformation of the AML model into an address space for an OPC UA aggregation server was given.

The concepts introduced in this paper have been or will be prototypically developed and implemented on real test systems at the University of Applied Sciences and Arts Hannover.

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