Requirements for an energy data information model for a communication-independent device description

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***Abstract*-With the help of an energy management system according to ISO 50001, industrial companies obtain the opportunities to reduce energy consumption and to increase plant efficiencies. In such a system, the communication of energy data has an important function. With the help of so-called energy profiles (e.g. PROFIenergy), energy data can be communicated between the field level and the higher levels via proven communication protocols (e.g. PROFINET). Due to the fact that in most cases several industrial protocols are used in an automation system, the problem is how to transfer energy data from one protocol to another with as less effort as possible. An energy data information model could overcome this problem and describe energy data in a uniform and semantically unambiguous way. Requirements for a unified energy data information model are presented in this paper.**

Keywords- energy management, energy data information model, requirements engineering

I. Introduction

In industrial plants, an increase in energy efficiency is one of the challenges, facing ecological and economic objectives [1]. With the application of the ISO 50001 standard [2] and the associated introduction of an energy management system (EnMS), the energy consumption of a factory can be continuously analyzed and optimized with regard to energy efficiency. In order to be able to use an EnMS without restrictions, technical components (soft-/hardware) are required, which are summarized in the literature under the term "technical energy management system" (tEnMS) [3]. A tEnMS is used to collect, communicate, store, evaluate and display energy data. In addition it is possible to influence the energy consumption (e.g. reduce load peaks of the plant) of consumers with the help of the tEnMS via so-called load management functions [4]. A tEnMS can be installed in parallel to the automation system or in an integrated setup. In the parallel setup, additional devices have to be installed to perform the energy measurement or the load management functions. In the integrated setup, devices that are needed anyhow for control functions can be used to perform energy measurement and load management functions, so less additional hardware is required. The disadvantage of the integrated setup is that special software (so called "energy PLC programs") is required for the transmission of energy data, which causes high engineering effort [3]. This increased effort is due to the fact that energy data from the field level can be transmitted via different communication protocols with the help of so-called energy profiles, and the transfer of energy data from one protocol to another requires adaptation effort, since energy data has not yet been described in a uniformly standardized way.

To overcome these constraints, a draft concept of an information model for energy data has been presented in [5]. This unified energy data information model (UEDIM) can potentially be used to describe energy data uniformly and in a semantically unambiguous way, so that a seamless communication of energy data between the field level and the energy management system can be achieved.

Since the UEDIM has only been formulated as a draft concept so far [5], a systematic requirements analysis is still missing. Therefore, this paper aims to solve this problem by providing requirements for the UEDIM, as a basis for subsequent modeling and implementation.

In order to formulate requirements for the UEDIM, relevant literature is presented and discussed in section II. The subsequent section III localizes the UEDIM in the communication hierarchy. Subsequently, the requirements for the UEDIM formulated in section IV. Section V summarizes the paper and provides an outlook regarding further research activities.

II. State of the Art

In order to define the requirements for the UEDIM, this section first examines which different field devices are suitable for providing energy data. Then, the section takes a closer look at which communication technologies are used for data transport and how energy data are interpreted and processed.

A. Sources of energy data

Different Ethernet-based or non-Ethernet-based devices can be used as a source for energy data. For example, they can be connected via IO-Link or PROFINET.

Some Ethernet-based devices, such as frequency converters, support a so-called energy profile. An energy profile is linked to the use of a specific communication protocol. Energy profiles are e. g. PROFIenergy [6] for

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PROFINET, sercos Energy [7] for sercos III or CIP Energy [8] for DeviceNet and EtherNet/IP. As shown in [9], energy data can be provided in a semantically standardized form by using an energy profile. In this way, measured values such as power consumption (kW) or total energy meter values (kWh) can be acquired from a PLC. With the help of the respective energy profile, the measured values can be mapped into a standardized format, because the semantics are precisely specified (data type for interpreting the raw data, unit of the transmitted measured value, etc.). In addition to measurement data acquisition, load management functions can be used, e. g. to switch energy consumers to energy saving modes or sleep modes during production breaks. In this context, the current device status (e.g. operating mode or energy saving mode) or remaining ramp-up or ramp-down times can also be retrieved.

As described in [10], non-Ethernet-based IO-Link devices can measure energy data (e.g. current motor current) in addition to the primary function of the device (e.g. switching a load relay). In this case, energy data is provided via a point-to-point communication interface.

According to [11], the amount of installed Industrial Internet of Things (IIoT) devices increases rapidly. These IIoT devices (e.g. sensors or actuators) can also provide energy data using Ethernet-based communication interfaces. Common IIoT-Protocols such as Message Queuing Telemetry Transport (MQTT) or OPC Unified Architecture (OPC UA) can be used to exchange energy data via the factory intranet or the internet.

For Ethernet-based or non-Ethernet-based devices that do not support energy profiles, energy data is not provided in standardized semantics. In this case, energy data has to be processed to provide interpretable information. For example, received measured values may be available as raw values and must be scaled, and the data type has to be changed to become usable for energy monitoring purposes.

B. Communication of energy data to the energy management system

The energy data acquired via the mentioned sources must be provided on suitable communication interfaces (e.g. OPC UA or MQTT) in order to make them available to the tEnMS. In the case of IIoT devices, the data is already provided via suitable communication interfaces. Energy data of the other described field devices can be aggregated on a PLC via the mentioned communication paths and has to be transformed to be provided by suitable communication interfaces.

As summarized in [12], the common IIoT protocols OPC UA and MQTT each focus on different properties. The focus of OPC UA is on the standardized semantic description of the OPC UA address space model [13], which is provided by so-called OPC UA Companion Specifications. In direct comparison, MQTT has no such specifications to support standardized semantics. The focus of MQTT is on the transmission of small amounts of data, which is advantageous when a limited network bandwidth is available.

Such OPC UA Companion Specifications also exist for the provision of standardized semantics for energy data. In the case of PROFIenergy, a Companion Specification has already been drafted to cover this specific energy profile [14]. A general Companion Specification already exists for the sercos III bus system, which also covers the functionalities from the sercos Energy [15]. The development of a general Companion Specification for the Common Industrial Protocol (CIP) was also announced in 2020 [16].

Fig. 1 shows the energy data flows in the context of an automation hierarchy when using different energy profiles (parts A, B, C and D) and when the respective OPC UA Companion Specifications are used.

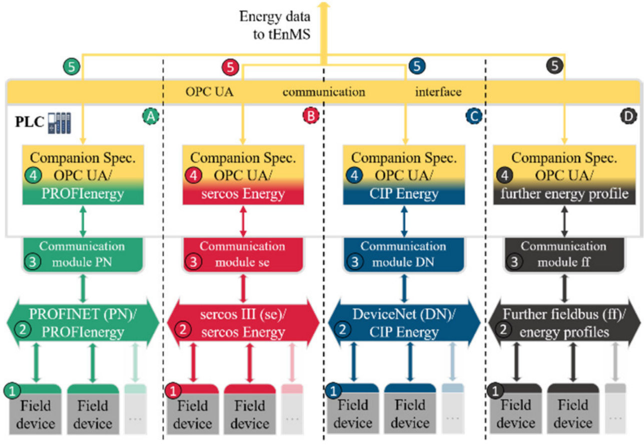

Fig. 1. Energy data flow with use of OPC UA Companion Spec.

The energy data is transported from the respective field devices (1) to the PLC via the energy profile-specific fieldbus or Industrial Ethernet system (2). The PLC has bus system-specific communication modules (3) so that energy data from the individual bus systems can be received. The energy data from parts (A), (B), (C) and (D) are mapped in a standardized manner according to the energy profile-specific Companion Specification (4) via an OPC UA interface. The energy data is made available to the tEnMS, based on the energy profiles, in different semantics in each case (A5, B5, C5, and D5).

III. THE POSITION OF THE UEDIM IN THE COMMUNICATION HIERARCHY

On the basis of the energy data flows summarized in sections II.Aand II.B., it can be concluded that currently energy data from the different sources is provided in different, non-standardized semantics to the tEnMS. This section describes how a UEDIM can be positioned in the communication hierarchy to provide standardized semantics of energy data.

To show the energy data flows of these field devices, Fig. 2 shows the different types of field devices that can provide energy data:

- (A) Non-Ethernet based devices (e.g. IO-Link devices)
- (B) Fieldbus devices that do not support energy profiles (e.g. Modbus TCP devices).
- (C) Fieldbus devices that support energy profiles (e.g. PROFIenergy devices).
- (D) IIoT devices that provide energy data to the tEnMS or an alternative cloud-based energy management system (CbEnMS)

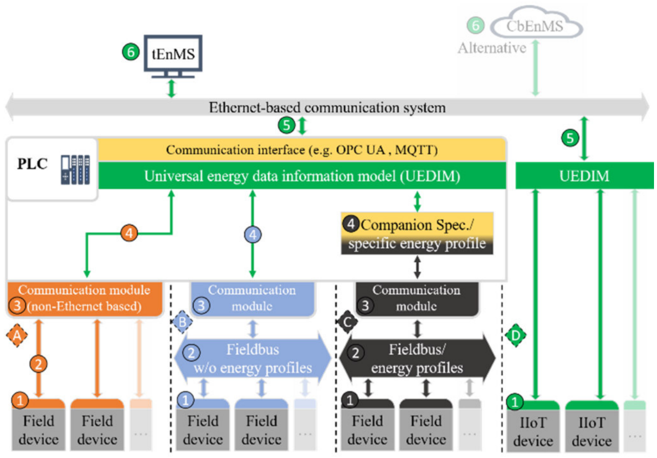

Fig. 2. Field of use of the universal energy data information model

In part (A), energy data from a field device (1) is transferred to the communication module (3) of a PLC via a non-Ethernet-based communication system (2) (e.g. point-to-point connection using IO-Link). In part (B) and (C), energy data of the field devices (B1, C1) is transferred to the PLC by using the existing Ethernet-based communication system (B2, C2) via the corresponding communication module (B3, C3). The energy data from field devices of (A) and (B) can be mapped on the UEDIM located on the PLC (4). Field devices of (C) can map energy data to the PLC only by using a suitable companion specification like OPC UA companion specification (4). With the UEDIM, the PLC has the possibility to provide the semantically standardized energy data (5) to the tEnMS or an alternative CbEnMS (6). In addition, IIoT devices can provide energy data directly in the standardized semantics of the UEDIM (e.g., via OPC UA or MQTT).

IV. Requirements for a Universal Energy Data Information Model

In this section, requirements for the UEDIM are defined. Within the scope of requirements engineering, both functional and non-functional requirements have been determined on the basis of a literature research.

Fig. 3 shows the individual requirements, which are additionally divided into three groups for better classification:

- Specific requirements for the UEDIM (1)
- Requirements for the interfaces to energy data obtained from the heterogeneous field level and to the tEnMS or CbEnMS in the higher-levels (2).
- General requirements for the UEDIM (3)

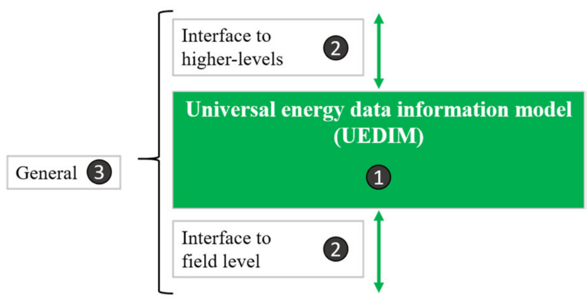

Fig. 3. Groups of requirements for a UEDIM

In table I, the requirements for a UEDIM are explained in detail and assigned to the requirement groups.

TABLE I. Requirements for a UEDIM

Requirement group	Functional (f) and non-functional (nf) requirements and explanation
Internal energy data (1)	**Standardized semantics of energy data (f):** The energy data should be represented in the UEDIM in standardized semantics to enable uniform access to these energy data. In the context of modeling the UEDIM, ontologies shall be included in order to represent energy data in a semantically standardized terminology [17].
	Support of established tEnMS functionalities (f): Established energy management functionalities of existing energy profiles [6] [18] [8] should be supported.
	Usage of existing OPC UA Companion Specifications (f): The usage of the UEDIM must ensure that the established OPC UA Companion Specifications [14] [15] [16] are used if the source of energy data is an energy profile supporting device.
	Integration of new technologies (nf): The UEDIM should be executable on IIoT devices so that they can provide energy data to the tEnMS/ CbEnMS, as required in [11].
Interfaces to energy data from field level and to higher-levels (2)	**Exchange of energy data with the field level (f):** The energy data of non-Ethernet-based (e.g. IO-Link) and Ethernet-based field devices (e.g. Modbus TCP or PROFINET) should be representable in the UEDIM (see section II.A).
	Compatibility with established communication interfaces (nf): The energy data represented in the UEDIM should be provided via the established OPC UA or MQTT communication interfaces to take advantage of the respective focus of the communication system, as described in section II.B.
General (3)	**Reduction of engineering effort (nf):** The creation of energy PLC programs, which primarily realize energy data mapping, is associated with a high engineering effort [3]. The design of the UEDIM should aim at reducing this engineering effort.
	PLC processing time (nf): If energy data is transferred between the field level and higher-levels of the automation system, the PLC cycle time by using the UEDIM shall be based on common PLC cycle times that are achieved with comparable PLC programs (using the OPC UA Companion Specification [14]) in the industry.
	Modularity of the UEDIM (nf): The energy management functionalities should be able to be individually activated or deactivated from the tEnMS [19]. In the UEDIM, the functionality modules (measurement acquisition or stand-by management features from the established energy profiles) must therefore be conceptualized separately so that they are independent of each other.

V. Conclusion and Future Work

In this paper, requirements for a unified energy data information model (UEDIM) have been presented. In order to do this, relevant literature was first presented and discussed in the scientific context. Subsequently, the UEDIM was positioned in the communication hierarchy. Based on the literature, requirements for the UEDIM have been determined.

The next step is to model the UEDIM based on the requirements presented in this paper. First, a conceptual model will be elaborated, which will then be extended and improved in iterative steps. In order to test the function of the created information model, the existing OPC UA Companion Specifications can be used as a reference.

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