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SUGGESTED ARCHITECTURE OF SMART METERING SYSTEM

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The architecture of supervisory-managerial systems is presented by using widely accepted industrial standards *OPC Unified Architecture* (UA) and *IEC Common Information Model* (CIM). It is suggested for some specific classes from CIM to be derived from the appropriate UA classes and to maintain the hierarchy of classes in both models and definitions of functions for data exchange, which are formed based on recommendations from CIM. By combining these two standards, we have obtained an integrated solution, which is characterized by a special data model with a wide range of functionality. Standards provide integration of all subsystems in big supervisory-managerial systems. Interfaces for data exchange are designed in such a way to be in accordance with both UA and CIM standard, providing a generic approach defined in UA standard by data from specific supervisory-managerial (*Smart Metering*) systems.

Key words: AMI, CIM, MDM, OPC, UA.

1. INTRODUCTION

Industrial production process requires optimal system architecture design, especially in *Smart metering* systems. Requirements of the system users have brought to the need for developing more complex systems and solutions with multi-layered and distributed architecture. Problem in defining the architecture represents a number of physical quantities that will be supervised and that provide management. Significant characteristics of this system are quantities and data security, as well as continuous work of the system which would have to be supported by the architecture of *Smart metering* systems. Parts of such systems are developed by different manufacturers so it is necessary to pay attention to standardization of the format of messages and methods of data exchange.

Software architecture of *Smart metering* systems, which enable the acceptance, storage and processing of quantity values in satisfactory time framework, is defined in this paper. The existing architectures and software technologies are considered and a suggestion is given for the improvement of architecture and standards applied in this field.

Introduction of architecture provides management with the big number of quantities, application of appropriate standards that integrate the systems into a broader management framework at the level of an enterprise. The following hypothesis comes from this: *By forming the appropriate software architectures for big Smart metering systems, it is possible to accomplish the management of the big number of quantities with acceptable performances.*

Today, energy sources are of limited capacity and, in addition, energy efficiency and energy savings are very significant. Savings can be accomplished: when producing and transmitting electrical energy (*Energy Management System – EMS*), when distributing electrical energy (*Distribution Management Systems – DMS*) and, at the lowest level, with the consumers themselves. Smart meters participate in the process of saving electrical energy. In addition to consumption measuring, smart meters can include or exclude particular consumers; in that way, they provide savings of electrical energy in case of critical network load.

The paper is based on experimental results. System performances, related to integration, with the assistance of the latest standards from this field are measured, as well as the improvement of performances.

2. ARCHITECTURE OF *SMART METERING* SYSTEMS

Today, the demand for electrical energy is constantly rising. Sources of electrical energy are limited which causes for the energy efficiency to become extremely important at all levels (EMS, DMS) and at the level of consumers themselves. New generations of smart meters provide the individual consumers to participate in the process of saving the electrical energy, the execution of certain orders (to include and exclude the consumer). Smart meters are not only input elements anymore, but they become an important part of a complex system for supervision and management.

Electric distribution network with smart meters makes a high-distribution system with extremely big number of devices. Such a software architecture development system requires a high level of security, reliability and compatibility with other subsystems. It is necessary to keep the data on consumers away from illegal use, which causes for *Smart metering* to support the latest security mechanisms and standards. Such software is included into critical infrastructure, so it is necessary for it to be constantly available; for that reason, all the components need to be extremely reliable and resistant to failures. Such systems need to exchange data with other subsystems and applications which are used in distribution companies. Clear and consistent integration model, with the use of well-defined interfaces and data models, gains extreme importance.

Architecture suggested in this paper has a goal to provide a simple integration of various existing *Smart metering* products and other subsystems of electric distribution companies (failures detection, production and distribution of electric energy, etc.). For that reason, the latest technologies and products are used for architecture development for the integration of *Smart metering* system.

Contribution of this paper is a new way of the *Smart metering* solution integration with other subsystems for electrical energy distribution. The latest standards for data exchange in systems for production, transmission and distribution of electrical energy are used: IEC's *Common Information Model* (CIM) and *OPC Unified Architecture* (UA). Such a model has a goal to make these two standards closer and to provide an easy integration of a greater number of the existing systems that are used in distribution systems and set of interfaces that provides an easy way to access the data from the system.

2.1. Results of other authors

Smart metering concept is relatively new. Literature describes the role of these systems as key elements in the production and distribution of electric energy system [1, 2, 3, 4]. Estimation is that it is possible to save up to 3% on the price of system maintenance trough implementing these systems [1]. Savings refer to the basis of reducing the number of workers necessary for maintaining the system and more rapid restoration of power after interruption. When AMI are completely integrated with other subsystems, we can expect that savings can be doubled. Collaboration and integration are key aspects of *Smart metering* system. These aspects will be essential when selecting a product which will have a key role in the market [2]. When we take into account all the above-mentioned, rapid and simple integration of AMI systems with other subsystems is a very relevant field. It is necessary to choose well-tested and proven industrial standards as a basis for integration. Currently, there are a few suggestions for architecture of *Smart metering* system, but they are closely specialized and they solve only one problem or they are at a high level and do not refer to real problems of integration, so data models and interfaces for integration are not defined [3, 4].

In addition to financial benefit, easier system management and energy savings, there are also the advantages of introducing *Smart metering* that refer to social advantages, as well as environmental protection. Although these advantages cannot be measured precisely, we can assume that they will become an important part of entire saving [5, 6]. In this paper, we suggest for entire integration of *Smart metering* system to be based on two widely accepted standards: IES's *Common Information Model* (CIM) and *OPC's Unified Architecture* (UA). These two standards are suggested because they cover all the requirements for modern and secure integration.

2.2. Standards for electric energy systems

For the production and transmission of electric energy (EMC), there is an original standard developed – CIM. Model is rather detailed and it contains a great number of different types of data on electric and other components of the system for electrical energy transmission and distribution. There are discussions in scientific literature on data exchange based on XML in order to obtain optimal speed and simplicity of integration [7, 8]. The most important suggested architectures from the part of leading national organizations for standards in electric companies [9] are: *Roadmap E-Energy/Smart Grid, NIST IOP Roadmap, IEC SMB SG 3, BMWi E-Energy Program, BDI initiative – Internet der Energy, Microsoft SERA, CIGRE D2.24, European Union Mandate CEN/CENELEC M/441*, other studies, *frameworks* and programs.

2.3. OPC foundation

OPC foundation is a non-profit organization that aims at developing software standards for data exchange in distributed management systems. Their first specification OPC DA referred to server for access to quantities (Data Access). Interfaces for the exchange of current values of quantities from supervised system were defined in it [10]. DA specification has experienced a wide application in process industry, in telecommunication systems and in systems for distribution (systems for production, transmission and distribution of electric energy, water, oil and gas) [11, 12]. Specification was based on *Microsoft* DCOM technology, which was poorly supported out of *Microsoft Windows* operative systems. For that reason, new specification was published – OPC XML DA, where inter-process communication was based on web service approach by which messages are transmitted in *eXtensible Markup Language* (XML) format through *Simple Object Access Protocol* (SOAP) [13, 14]. XML DA specification covered only the access to current values of quantities, it was not widely accepted and OPC *Unified Architecture* directly appeared.

With the appearance of specification for *Unified Architecture* (UA), OPC UA specification represents an open, object-oriented architecture with an entire set of new functions. Although UA specification is relatively new, there are already the suggested methods of the existing servers migration based on previous specifications DA specification on UA [15]. Most papers that refer to UA deal with integration with existing industrial standards [16, 17], while the others deal with the improvement of system's architecture [18, 19] or secure aspects in communication [20].

2.4. Suggested architecture

Task of Smart metering system is to collect measured values from remote measuring instruments (smart meters) and to integrate those data into a complex and unified system for payment. Data obtained can be used in Smart metering systems that are used in electric energy distribution, that control the consumption of individuals, which provides more precise and reliable management of the entire electric energy distribution process. Integration of these systems in such a way to accomplish a clear and secure flow of information is essential [21].

With Smart metering devices we also get software component for centralized approach to values measured, collected from a bigger number of meters. Such systems are called *Advanced Metering Infrastructure system* – AMI. Electric distribution company can own smart meters from various manufacturers. It is necessary to develop central system that unifies all the data that belong to one company in one place. Such a centralized system is called *Meter Data Management* – MDM system. MDM systems also perform the pre-processing of data (e.g. prediction, validation, change). Between MDM system and AMI system, there is relationship achieved through software *Head End* system [22].

Data collected from the meter become increasingly important for other subsystems (Subsystem for *Outage Management System* – OMS, Subsystem for *Customer Management System* – CMS, Subsystem for *Distribution Management System* – DMS and Subsystem for *Work Management System* – WMS). Integration between MDM system and other subsystems can be performed by using *Enterprise Service Bus* (ESB), with the use of data model and interface suggested in this paper. Suggested architecture of Smart metering system is presented in Fig. 1.

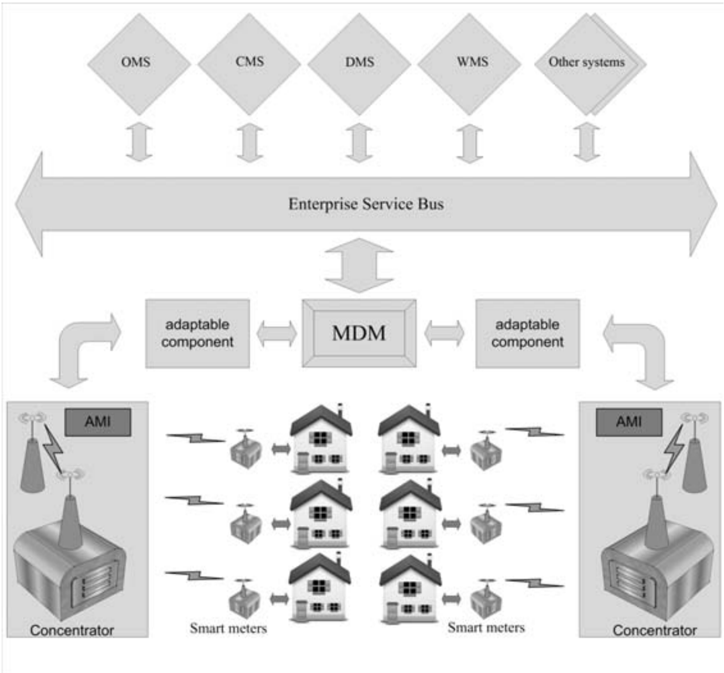

Fig. 1 – Suggested architecture of *smart metering* system.

3. *SMART METERING* SYSTEMS INTEGRATION MODEL

In each distribution system, the problem is the integration of its components that software manufacturers produce and develop in different periods. Let's suppose that two *Smart metering* subsystems are developed by two manufacturers in different time frames, the integration of such systems would be a problem [23, 24]. This is why the defining of the interface and data models that are used in subsystems during data exchange is extremely important. Suggested data models will experience bigger or smaller changes in the future; the reason is extension of such solutions. For that reason, it is necessary to define data model and interfaces in such a way that they can easily be extended with new objects and functions, without jeopardizing the work of existing systems in that way [25].

Smart metering is significant when designing new systems; every second subsystem will use the data on consumption obtained from the meter. For that reason, standardization related to this field is very important [26, 27]. Two widely accepted industrial standards, which cover *smart metering* field, are recognized: a) OPC *Unified Architecture* (UA) covers the field of industrial applications and it defines interfaces that have a higher level of generating [28]. Functions defined in UA specification (in its fourth part) cover a wide range of activities such as: access to current values of quantities, access to historical values, alarms, etc. b) IEC *Common Information model* (CIM) defines data model for the subsystems for generation, transmission and distribution of electric energy. Data exchange, according to this standard, is performed on the basis of specific interfaces [29, 30].

Suggested solution for the integration of these two standards implies for some specifications from CIM to be derived from appropriate UA classes, but to maintain class hierarchy in both models and definitions of functions for data exchange are given, which are formed based on recommendations from CIM. Based on the combination of these two standards, we have obtained an integrated solution, which is characterized by special data model with a wide range of functionality.

3.1. Data model

Data model is made of *Node* classes. Class of the model suggested contains common attributes for all classes, such as: identifier, name, description and path. Model also contains other necessary classes that are important for MDS systems: *ObjectNode* (basic class for physical objects) and *VariableNode* (through which all the quantities that can be measured are modelled).

Standard CIM, unlike UA standard, is narrowly specialized standard system where special object models are defined for production, transmission and distribution of electric energy. In CIM, a big number of classes for modelling different components in electric system are defined. In this paper, classes used in *Smart metering* systems are considered. Those classes are: *IdenifiedObject*, *MeterAsset*, Reading and *MeasurementValue*. *IdenifiedObject* – basic class of CIM object model that is similar to the *Node* class from UA standard also contains unique identifier, name, description and path to the object. CIM models smart meters by using the class *MeterAsset* (which is derived from *Asset* class). Functions that smart meter can perform include: consumption measurement, load management, including/excluding the consumer, payment etc. [32]. *MeteringReading* contains a group of values obtained from one meter. Reading class models one measured value (derived from *MeasurementValue*), and contains data on value measured, time when the value was measured and measurement quality.

Connecting classes hierarchy of these two models (CIM and UA), which is suggested, sets UA classes at a higher level in hierarchy. These two classes are more generally imagined in relation to classes from CIM standard. Figure 2 shows solution suggested for connecting these two models. All physical objects are derived from UA class *ObjectNode* and it seems logical that CIM class *Asset* must be derived from this class. Following the same logic, CIM class *MeasurementValue* is derived from UA class *VariableNode*. CIM class *IdentifiedObject* and UA class *Node* have the same set of attributes, they can be collected in one basic class for both models. After that, all other classes can be derived from this basic class: *MeterReading* directly, and *Asset* and *MeasurementValue* through *ObjectNode* and *VariableNode*, respectively.

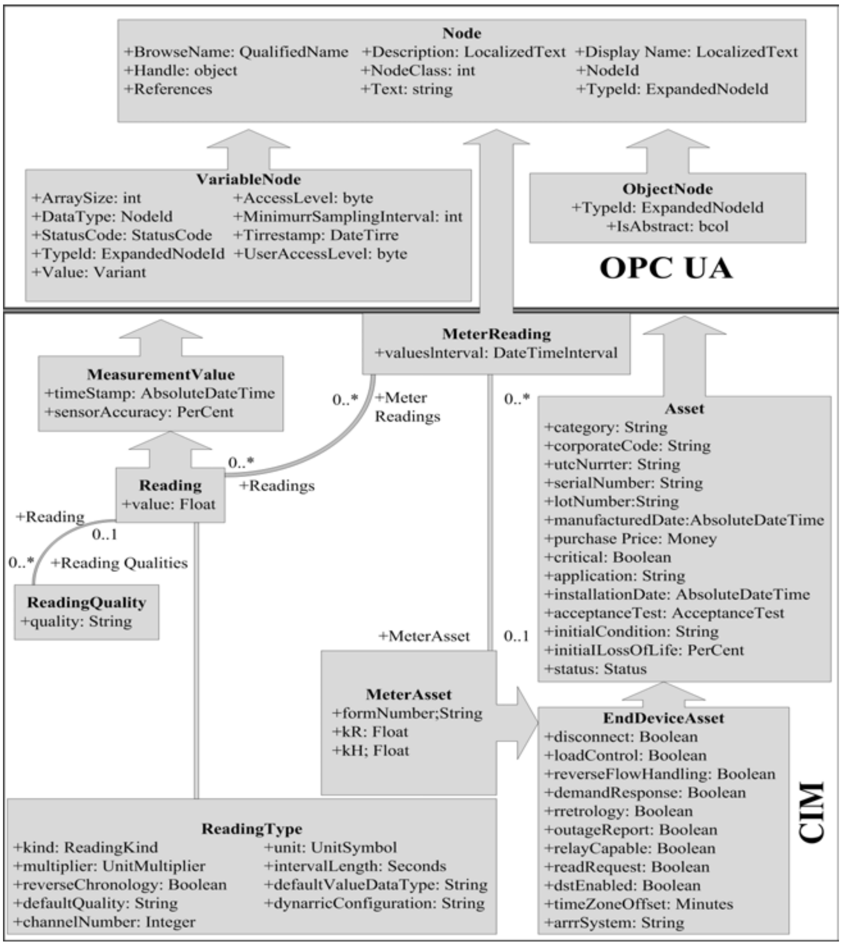

Fig. 2 – Suggested CIM and UA integration.

3.2. Interfaces for integration

UA specification defines interfaces for access to current and historical values of quantities, data model change, as well as address space search. All interfaces are devised in such a way that they support latest standards for providing data transfer security. They are grouped in *service sets*, and it is possible to implement only a subset of those services that are required for specific application. Key differences between OPC UA and previous OPC specifications are: 1) OPC UA defines a unified data model, simplifies design of the system based on UA specification. Previous versions of specification have defined special models for each specification (DA, HDA, AE) [33]; 2) OPC UA allows dynamic adding and erasing of quantities (which was impossible in previous versions); 3) Quantities themselves can be grouped into views and different access rights can be defined for different clients.

Description of service sets in OPC UA includes: *Discovery Service Set, SecureChannel Service Set, Session Service Set, NodeManagement Service Set, View Service Set, Query Service Set, Attribute Service Set, Method Service Set, Method Service Se and Subscription Service Set.*

CIM standard provides the integration of different software solutions for electric systems based on CIM. It is possible to set aside a part of model that we want to implement and thus form a profile based on CIM standard. Suggestor of CIM standard, *Electric Power Research Institute* (EPRI), has defined procedures and patterns for documents for making a profile [34].

With defining the way of profile-making, the existing documents define the rules for naming the functions based on actions that those functions perform. Functions that serve for obtaining some value begin with *Get*, functions that serve for making new object begin with *Create*, while names of functions that serve for modification of the objects' value begin with *Update*. Functions defined in such a way can be grouped into UA sets of functions. For the needs of MDM system development, the following sets of functions are suggested: 1) *MeterAsset Service Set* – contains the functions for the work with meters (*MeterAsset*), for example add, change, delete meters; 2) *MeterReading Service Set* – contains functions for working with measurements (*MeterReading*), for example reading, change and deleting values measured 3) *Event Service Set* – implements the interfaces that provide for MDM system to send the client those events he is subscribed to. Some of the possible events are: *MeterAssest changed, Meter Asset added, Meter Asset Deleted*, etc. This set of services is implemented by communication model with subscription (Publish-Subscribe) [30, 31].

Suggested unified architecture for MDM systems combines the best characteristics of both systems (CIM and UA) by working with unified data model. Since we use two models for communication – *Request/Response* model and *Event-Listeners* model, this architecture is favourable for a wide range of applications and it can be easily configured so that it suits small, medium and big electric distribution systems. Important fact is that the use of computer resources (primarily work memory and other computer resources) is not significantly increased by unifying these two object models.

3.3. Results of testing

Suggested architecture of *Smart metering* systems is tested by using series of tests of the system performances (using real values from pilot project). Meters are set in such a way that they read only one quantity –electric power consumption by intervals. In one-month period, the consumption is read in each 15 minutes. For each meter, 96 readings are obtained per a day, total 2880 readings monthly per a meter. Period is a month because majority of validation rules and reports on payment are made at monthly level. Series of tests are performed in order to determine the system performances for key aspects of integration: 1) Duration of export from CIM system and import to OPC UA system, 2) Size of XML files that contains data and that is transferred between CIM and OPC UA systems, 3) Occupation of working memory for CIM and OPC UA servers in order to show the difference in working memory use.

Experiments are performed with different number of smart meters: from one to 1000 meters in a group. Results are shown in Table 1. From the presented results of integration experiments between CIM and OPC UA systems, it is possible to derive two important conclusions. Firstly, use of working memory is approximately the same in systems based on CIM and OPC UA servers. From that, we can conclude that impact on the increase of memory occupation of unifying these two models is very small.

Second conclusion, related to the speed of import and export of data file shows that such integration can be used in real time because export and import of data for big systems can last a couple of minutes, which can be acceptable in big *Smart metering* systems.

Table 1

Experiment results of CIM and OPC UA system integration

Experiment results of CIM and OPC UA system integration **Total number of meters**	**Occupation of memory in CIM server [MB]**	**Duration of CIM export [s]**	**Size of message from CIM [MB]**	**Duration of import in OPC UA [s]**	**Occupation of memory by OPC UA server [MB]**
1	5.23	0.98	0.64	0.99	5.83
10	6.72	1.63	6.43	1.62	7.37
100	18.9	9.78	64.1	11.1	22.3
500	92.5	36.6	323.1	37.8	87.1
1000	119	39.9	641.3	46.1	166

Suggested model of data combines the best characteristics of model (UA and CIM) and provides for the objects to be exchanged in such a way that they satisfy both standards. Interfaces for data exchange are devised in such a way that they satisfy both standards, UA and CIM, and thus they provide an approach to data from *Smart metering* system.

4. CONCLUSION

Main hypothesis of this paper was that it is possible, by forming appropriate software architecture for big *Smart metering* systems, to achieve management of the big number of quantities with acceptable performances. Architecture of *Smart metering* systems that enables rapid development of components, solution scalability and easier maintenance is presented. These, apparently opposed goals, are achieved by using widely accepted industrial standards *OPC Unified Architecture* and *IEC Common Information Model* (CIM) as pillars of architecture development. When these two standards are combined, they provide the integration of all subsystems in big *Smart metering* systems. OPC UA specification is generic and it defines a wide range of different functions, while CIM interfaces and data model are specific for electric distribution companies (which include *Smart metering* systems). Data model presented in this paper combines good characteristics of both models and thus provides for all objects that are exchanged to be compatible with both standards. Interfaces for data exchange are designed in such a way that they are in accordance both with UA and CIM standard, providing generic approach defined in UA standard by data from specific *Smart metering* systems. It can be concluded that synergy of this approach will bring additional value into every system that applies suggested recommendation.

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