Software architecture for Smart Metering systems with Virtual Power Plant

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Abstract—This paper presents a novel architecture for Smart Metering systems which enables their seamless, secure and efficient integration in wider SmartGrid software structures. Smart metering solutions represent one of the fastest evolving areas in the field of power distribution systems. There is an extensive interest of leading software vendors in the field, for development of architectures that can efficiently manage transmission, processing and storing of tremendous amount of data produced by such metering devices deployed at the end-end side. The integration of these systems into existing power system software architectures (outage management, workforce management, etc.) represents a major challenge for research community. In such an environment it is of fundamental importance to adopt standardized data exchange mechanisms. The proposed architecture is conceived as modular and scalable structure so that it can support implementation of novel power distribution concepts as Virtual Power Plants (VPPs). The proposed architecture has been successfully tested and verified in real life operation as one of modules of Smart Metering system named Meter Data Management (MDM).

I. INTRODUCTION

The demand for electricity has been steadily growing over last decades. Considering that traditional energy resources are limited, energy efficiency is emerging to be a fundamental concern at all levels of power system: at the generation and transmission (Energy Management Systems – EMS), power distribution (Distribution Management Systems – DMS) and eventually at energy consumer side. The development of advanced smart meters allows individual consumers to take part in the process of energy saving. While the first generation of such meters could only measure consumption, the latest models allow measurement of various consumption parameters. Moreover, these meters allow some consumers to be turned off if needed. This way, meters cease to be passive devices only; they have become important part of a complex and general supervisory and control system [6]. It is expected that these systems will allow energy savings during critical consumption peaks.

The primary goal of smart-metering system is to gather data from remote power consumption meters and transfer this information to the general supervisory and control systems of power utilities. The network of meters is a large distributed system incorporating hundreds of thousands (or even millions) of devices. When developing software for such large scale systems, it is extremely important to realize highly reliable and robust software architectures using optimal technologies. As Smart Metering software handles sensitive data which can be misused (i.e. energy theft, customer identity theft, unauthorized load shedding) – it is necessary to incorporate advanced security techniques in all phases of design. They are expected to work without any interruption and therefore all components must be exceptionally reliable and fault tolerance should be taken into account at all levels. Another important aspect to be considered in these systems is the fact that smart-metering systems have to exchange data with other subsystems and applications used by power utilities which makes the clear and concise definition of integration interfaces an important concern.

On the other side, evolution of power systems goes in direction of development of SmartGrids [10]. Such complex systems that are supposed to manage tremendous amount of data must be built in a scalable and modular manner. Clusterisation of those systems is considered to be one of key methods to tackle enormous communicational and computational requirements of SmartGrids. Virtual Power Plants (VPPs) [8,9] are emerging as one of promising solution for aggregation of Distributed Energy Resources, (DERs), consumers, producers and prosumers (entities that can produce and consume energy). Virtual Power Loads (VPLs) can be seen as one of subsets of VPPs. It considers virtual aggregation of distributed consumers equipped with own smart meters but grouped into one logically single entity (managed by a Virtual Meter). Virtual Meter can be used for grouping of variety of consumers according to many different criteria. Such device can be tuned to monitor consumption of certain group of consumers only upon exceeding certain limits or to, coupled with measurements performed at transformers, help losses calculation at certain segment of distribution network. Obtained data can be used for accounting and billing purposes but also for network planning and reconfiguration.

The architecture presented in this work aims at facilitated integration of various existing smart metering products, but also other software systems used by power utilities (outage, energy and distribution management systems etc.). It uses the latest available technology and products which have been chosen as best suited for use in smart metering systems. Microsoft’s Windows Communication Foundation (WCF) was
taken for inter-process communication as it is an industry accepted standard which addresses areas like interoperability, scalability, robustness and security out of the box and does not burden software developers with a need for only additional development. The OSI Soft’s PI is well-know in industrial applications of this kind, takes a role of a central data repository. The PI system is built to allow the storage of millions of process variables and excellent performance when running queries on stored data.

Considering that merging of the aforementioned architecture with other subsystems represents a critical point of distribution power systems, the most important achievement of this work is actually a novel integration solution based on Enterprise Service Bus (ESB).

II. STATE OF THE ART

Although the concept of smart metering is relatively novel, considerable research efforts have been invested in this area. One of key components regarding implementation of this concept in power distribution systems is Advanced Metering Infrastructure (AMI). These systems collect raw data measurements, store and prepare them for further processing [7]. Some authors estimate that by only introducing AMI systems one can save 3% on system maintenance [6]. These savings come from reducing maintenance costs and faster system restoration after outages. Upon integration of AMI systems with other subsystems, we can expect up to twice as much savings. Collaboration and integration are key aspects of smart-metering systems, which will definitely greatly impact adoption of the products at the market [1]. Because of above mentioned facts, in this phase of AMI systems development their fast, simple and secure integration with other systems is extremely important. It is necessary to choose well tested and proven industry standards as a basis for this integration. Some works show various smart-metering system architectures, but they are either highly specialized solving a specific problem or only show a high level architecture barely touching integrations without defining data models and integration interfaces [2, 3].

Considering wider adoption of the proposed concept especially with respect to emerging SmartGrids we can envisaged that proposed architecture can be one of key enabling technologies for Virtual Power Plant (VPP) [8, 9]. VPP is as a concept that aims at aggregation of distributed resources (including also storages and consumers/prosumers) and present them to the rest of the energy system as a single technical and commercial entity can be seen as a solution for this need. Such a module/cluster inside a wider Smart Grid environment should have certain autonomy and it would represent a kind of distributed computing but also trading node/unit. Our existing solution is just a first step towards realization of VPP. At the present we can fully support a formation of so-called Virtual Power Loads (VPL) that is an elementary VPP.

III. PROPOSED ARCHITECTURE

The most important goal of Smart Metering systems is to gather measurement values from remote measurement devices (meters) and integrate them into a complex and unified system for acquisition and control in power distribution systems. With the introduction of novel meters it is now possible to control consumption per individual consumer. This evolution makes distribution management systems more complex. The integration with other subsystems and a clearly defined data flow between them becomes more and more important.

![Open Smart Metering architecture](image)

The measurement devices manufacturers usually provide an infrastructure for centralized measurement acquisition through Data Concentrators gathering signals from multiple meters. As a utility controlling a power distribution system can purchase metering equipment from different vendors, it became necessary to develop central systems which would gather data from various AMI systems operated by a single utility. These central system is called Meter Data Management (MDM) system which besides data gathering, also performs data processing (e.g. validation, estimation, editing – VEE). The connection between central MDM systems and different AMIs is implemented through specialized software components named Head End Systems.

As the values measured by meters are getting increased importance for other subsystems (Outage Management Systems – OMS, Customer Management System - CMS, Distribution Management System - DMS and Work Management System WMS) their integration with MDMs can be implemented through an Enterprise Service Bus (ESB) – using the data model and interfaces proposed in this paper. The architecture of the proposed system is shown in Fig. 1.
IV. DATA MODEL

A key element of complex distributed software system is a Data Model, which has to precisely define objects (and their attributes) which are exchanged between the components of the system. The Data Model in UML fashion for the system with the architecture we proposed is shown in Fig. 2. The central element of this system is the Meter object which represents a remote, intelligent consumption meter. These meters can be grouped into classes and areas which facilitate classification, search and the implementation of commercial regulations. They can have more attributes (vendor specific, static characteristics of the meter) and more tags which represent measured values. They can have more channels, which measure various consumption parameters, or even be used for measuring water, gas or heat consumption.

A virtual meter is an abstraction that may consists of multiple meters or be a part of a meter (some of its channels). Through these, it is possible to create virtual meters which supervise consumption in a part of the distribution network (summing the consumption measured by meters in that part of the network). Data processing functions can handle virtual meters just as they handle regular meters. It is possible to validate and estimate data or send data into other subsystems.

V. IMPLEMENTATION

The proposed novel architecture for smart metering systems is based on a three-tiered architecture with clearly defined boundaries and interfaces between its components. Inter-process and even some intra-process communications were realized with Microsoft’s Windows Communication Framework (WCF) version 3.5. This technology offers adequate performance, security and scalability while having a short development cycle and simplified maintenance.

The central data repository is implemented on OSI Soft’s PI system. PI has excellent performance in capturing and querying extremely large sets of process values. The PI system contains two databases: the PI database is used for storing measured, real-time values and the AF database stores all other data which does not change so frequently: data about system configuration (meters, groups, users, etc.). While the PI database is based on proprietary data storage mechanisms suitable for storing extremely large datasets and their fast searching, the AF is based on Microsoft SQL Server general database management system.

The lowest layer of the MDM application is the Data Access Layer (DAL) which is an adapter between the database and the middle tier. The DAL was designed having in mind that the repository might change in future (e.g. use a different real-time database instead of PI).

The Smart Connector component is used for direct communication with remote meters produced by specific vendors. A different connector is developed for each type of meter: at present we had two available connectors. When in operation, smart-metering systems are expected to receive large amounts of field data in bursts which is due to the fact that meters share common configurations and are configured to send their data at the same specified time. To prevent possible choke points in connectors, internal buffers which temporarily store data prior to processing are introduced.

![Data Model of Smart Metering System (UML model)](image)

The middle, business layer (BL) takes care of the user identities, access control and data protection. Apart from these basic functions, the BL also implements custom business logic (like data validation and estimation, or statistical preprocessing of meter data). The BAL also implements a special sub-component with WCF interfaces used for integration with other systems. Besides the definition of a unified data model, these interfaces are the most important results of this research. Fig. 3. shows the proposed architecture of an open MDM system.

The user interface (UI) was developed in Microsoft Silverlight in combination with Microsoft RIA Services. The choice of these technologies also improves the scalability and
simplifies the maintenance of the system. SilverLight allows developing of applications with rich set of functionalities (almost like standard Windows applications) enabling them also to communicate through Internet. Silverlight is available on other platforms, and it implements fairly good data security policies. Microsoft’s "Geneva" Framework is used for building claims-based secure communication between UI and BL services, and for implementing federated security scenarios.

![Figure 3. Open MDM system deployment](image)

Figure 3. Open MDM system deployment

Figure 4. shows screenshots of the MDM system developed for the given architecture. All components of this system were implemented in C# programming language, using the Visual Studio 2008 development environment.

![Figure 4. User interface of MDM system](image)

VI. CONCLUSION

This paper presents a novel architecture for Smart Metering systems, which allows rapid development, scalability and easier maintenance. These seemingly contradictory goals were achieved by choosing accepted industry standards. The proposed architecture is modular allowing new concepts in supervision and control to be easily incorporated in power distribution systems. The Data Model shown contains Virtual Meters which is a part of a wider concept called Virtual Power Plant. The proposed architecture was implemented within a Meter Data Management system, thereby proving its worth.

REFERENCES

[10] [http://www.smartgrids.eu](http://www.smartgrids.eu)