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Configuration a meter data management system using axiomatic design

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Abstract

Smart grids are energy networks based on digital technology used to supply and monitor energy flows via two-way digital communication; when coupled with smart metering systems, smart grids reach consumers and suppliers by providing information on real-time consumption. A smart grid allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. The EU aims to replace at least 80% of electricity meters with smart meters by 2020. Meter Data Management System (MDMS) is a critical component to realizing the potential benefits of smart grids infrastructure; this system analyzes the data collected and sent by the Smart Meter to set electric power costs and to let consumers use energy efficiently. Most meter data management systems on the market today integrate multiple collection systems and act as the central data repository providing validated 'clean' data for all downstream systems such as billing, customer care, network management and business intelligence. Implementation and/or adopting an MDMS requires a comprehensive understanding of the true systems capabilities, systems key features and the ability of those features to perform; it also requires to rationalize the number of functionalities by eliminating redundancies. As a result, the configuration a MDMS with optimum functionality in an efficient manner is a tedious task. This paper explores the potential of Axiomatic Design as an alternative approach to configure an optimal MDMS tailored to the client needs.

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Keywords: Axiomatic design; meter data management; configuration

1. Introduction

Deployment of the smart grids is an essential undertaken in the process of transforming the functionality of the electricity infrastructure (transmission and distribution) to achieve the EU 20/20/20 targets, i.e. a 20% reduction in EU greenhouse gas emissions from 1990 levels; raising the share of EU energy consumption produced from renewable resources to 20%; a 20% improvement in the EU's energy efficiency.

A smart grid is an electricity network that can integrate in a cost-efficient manner the behavior and actions of all users connected to it – generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety. Smart grids allow companies and households to produce electricity (for example – using photovoltaic panels or wind turbines) and sell it on to other consumers through existing networks [1].

A Meter Data Management System (MDMS) is a system or an application which maintains all information to be able to calculate the energy bill for a customer based on the meter data retrieved from Advanced Metering Infrastructure (AMI) head end(s). The energy bill information is typically forwarded to consumer relationship and billing systems [2].

2. Smart grids standardization context

Based on the content of the M/490 EU Mandate [1] the Smart Grids Task Force [3] was set up by the European Commission in 2009 to advice on issues related to smart grid deployment and development. Generally, the scope of work for the Smart Grids Task Force was to develop a framework to enable the European Standardization Organizations perform standard enhancement and development in the field of Smart Grids. The framework consists of a set of consistent standards integrating a variety of digital computing and communication technologies and electrical architectures, and associated

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processes and services that will achieve interoperability and will enable or facilitate the implementation in Europe of the different high level Smart Grid services and functionalities flexible enough to accommodate future developments [1].

The Smart Grid Architecture Model (SGAM) has been developed to ensure interoperability and to foster a common understanding between various stakeholders active on developing Smart Grid Technologies; it consists of five layers representing the business objectives and processes, functions, information exchange and models, communication protocols and components.

The SGAM spans three dimensions: Domains (Generation, Transmission, Distribution, Distributed Energy Resources (DER), Customer Premises), Zones (Process, Field, Station, Operation, Enterprise, Market) and Interoperability (Component Layer, Communication Layer, Information Layer, Function Layer, Business Layer) [4]. Fig. 1 below presents the SGAM framework.

On this model the MDMS may be viewed as back-office systems integrating all collection endpoint data from Asset Maintenance Management System, Customer Relationship Management (CRM), Trading System, AMI System, Distribution Management System (DMS), Geographic Information System (GIS) including Outage Management and SCADA, Intercompany Data Exchange and Internet Portals. On Fig. 2 below are presented, in the Domains-Zones plane of the SGAM, the components of a MDMS.

The role of the MDMS into a smart metering chain is presented on Fig.3.

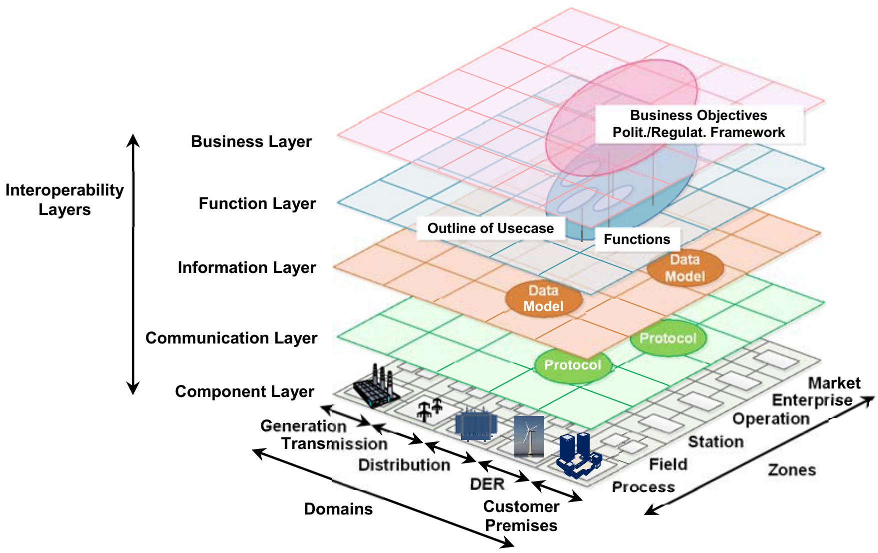

Fig. 1. SGAM framework [4]

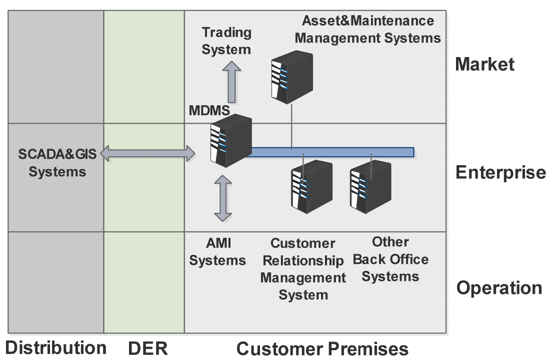

Fig. 2. MDMS related Customer Information system. Component Layer

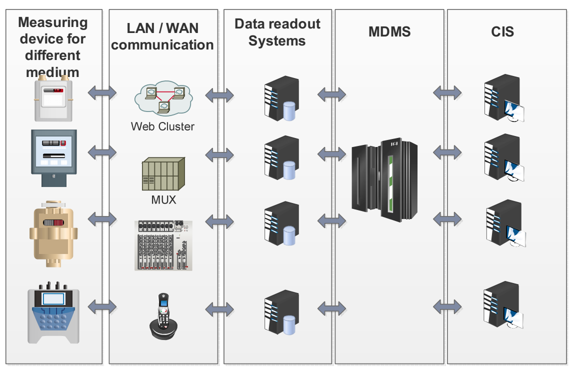

Fig. 3. Example of smart metering chain

3. Adoption a Meter Data Management System

Adoption a Meter Data Management System solution could be challenging for Public Utilities Companies.

The architecture of a Meter Data Management System depends on the software environment and the characteristics of each utility supplier (electricity, gas and water) however based on the literature review [5, 6, 7, 8, 9, 10] these features can be grouped in few common key/core elements/features, as follows:

- Integration of data collection system (a centralized data repository for meter readings and adapters to collection systems);
- Interval data management;
- Bill determinant calculation;
- Versioned data storage;
- Two-way communications between Customer Information System (CIS) and AMI systems;
- Provide a platform to enable other AMI applications and business processes.

Consultancy companies [7] prepare regular studies and reports concerning vendors of MDMS solutions, classifying the vendors and solutions using rigorous criteria; such studies can be used by the Public Utilities Companies as guidance for selecting a MDMS solution.

Vendors, also, prepare comprehensive studies [5, 11, 12, 13, 9] presenting proprietary solutions, implementation strategies and methodologies.

Focused to elaborate a structured approach toward the assessment of the MDMS capabilities, Accenture [9] proposes a framework along two dimensions: technical scope and functional scope (see Fig.4).

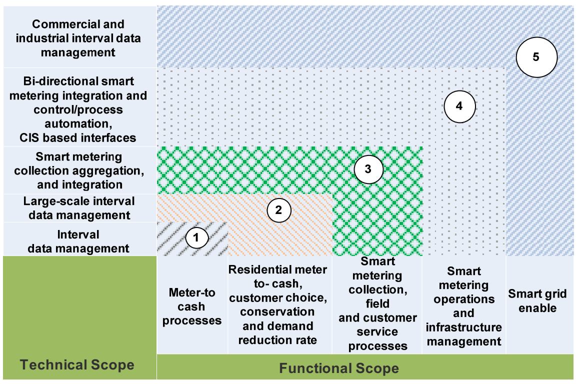

Fig. 4. MDMS maturity model framework (adapted from [9])

According with Accenture's MDMS maturity model framework there are five levels of maturity when an assessment of capabilities arrive. Each level relates a state of functional scope with a state of technical scope.

Software Engineering Institute from Carnegie Mellon University proposes a complex Smart Grid Maturity Model [14] as a tool that utilities can use to plan their smart grid evolution, measure progress toward and prioritize options. The model describes eight domains, which contain logical groupings of incremental smart grid characteristics and capabilities that represent key elements of smart grid strategy, organization, implementation, and operation [14].

4. Problems in adoption a Meter Data Management System

Every Utility Company has an informational landscape (Customer Information System – CIS) developed over the time and which have reached certain level of maturity.

Smart grid and deployment of smart meters bring a major change in the Utility practices. Passing from a register read per month to a register read every 15 minutes (or every 5 minutes) has critical effects on data volumes. Many legacy CIS use relational database technology while the smart metering concepts require deployment of true time series database environment.

To remain competitive Utilities must accelerate the replacement of inflexible customer information systems and add new capabilities to improve business performance.

The MDMS market today offers a host of solutions consisting of functionalities that may be expected from a MDMS, however every solution is designed around certain functionalities and based on specific/proprietary architectures and technologies.

The problem/challenge/question arriving when selecting a Meter Data Management System is: How to integrate MDMS with existing and new systems/processes from the CIS landscape?

5. Using Axiomatic Design to configure a Meter Data Management System solution

According to most dictionaries the verb ''configure'' means put together or arrange something in a particular way or for a specific purpose in the way that the user prefers.

Axiomatic design [15, 16] is a design theory and methodology based on the Independence Axiom and the Information Axiom. The methodology contains corollaries and theorems which guide/help designers mapping functional space to physical space (see Fig. 5).

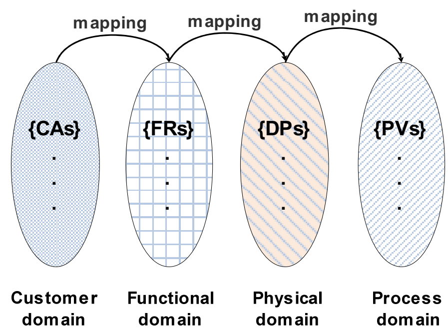

Fig. 5. Domains mapping [15]

The intention of this paper is to demonstrate the use of axiomatic design methodology to address the question: How to select / adopt a MDMS solution to maximize the integration of existing / legacy CIS while minimizing the business disruption risk.

This procedure is based on the context of standardized smart grid concept and the Smart Grid Architecture Model framework, hence a defined set of customer attributes. As the procedure intends to configure a solution rather than developing a solution the primary focus is on mapping between the functional domain and the physical domain.

5.1. Identification of functional requirements

The key/core elements/features common for an MDMS solution are presented above; transforming these features into functional requirements may be a challenging undertaking.

This paper is based on a desktop study consisting of reviewing surveys of successful project implementations [17], analyzing several acquisition procedures, requests for proposal [18, 19, 20, 21], reviewing several technical and benchmarking reports [8, 11, 10] and assessing solutions proposed by different vendors - contrastive comparison [6, 12, 13, 22].

The first outcome of the study is a synthetized list of 204 functional requirements structured into a hierarchy with five levels.

Further, an investigation of a CIS landscape was conducted to identify existing design parameters related to the functional requirements from this list.

A MS Excel based tool has been developed - a snapshot of the model is presented below (Fig. 6) - to conduct the assessment; the rows contain the functional requirements (FR) structured on five hierarchy levels labeled as 1 in Fig. 6.

The model contains on the columns the design parameters related to the functional requirements also structured in a hierarchy of five levels, labeled as 2 on Fig.6 below. The model was used to assess two potential solutions: *Solution (a)* from CIS landscape and *Solution (b)* as a candidate solution. Each design parameter is a module (application) which is related to a functional requirement on the corresponding point of hierarchy.

Suh [23] states that "the sequence of software development begins at the lowest level, which is defined as the leaves. To achieve the highest-level FRs, which are the final outputs of the software, the development of the system must begin from the inner-most modules shown in the flow chart that represent the lowest-level leaves."

Accordingly, the assessment process commenced by relating the design parameters with the functional requirements from the lowest level of the hierarchy.

The tool presented on Fig.6 is designed to count when a relation between a design parameter and a function requirement is established.

Both potential solutions (*Solution a*, *Solution b*) have been investigated from the perspective of functional requirements and, where the case was, the functions were related with the specific design parameters.

The second outcome of the study is the assessment that the potential *Solution (a)*, existing on client CIS landscape, responds by its design parameters to 123 of the functional requirements. However, the potential *Solution (b)*, which is a candidate for implementation, responds to all 204 functional requirements. According to its own objectives and considering risks associated with the maturity of the solutions the client elected to conserve the existing MDMS functionalities provided by existing system (*Solution-a)* and only implement the complementary functionalities provided by *Solution-b*. This decision for a combined configuration required restructuring of the existing CIS landscape and development of an implementation methodology.

	A	B	D	X	AD	BI	BY	GZ	HB	HV	IB	JG	JW	OY	OZ
2	FR MDMS	Design Parameters Solution A						Design Parameters Solution B						Solution a	Solution b
3		DPa.1	DPa.2	DPa.3	DPa.4	DPa.5	DPa.6	DPb.1	DPb.2	DPb.3	DPb.4	DPb.5	DPb.6		
4	FR.1 Display Application/Solution Version	x						x						1	1
6	FR.2 Assure Asset Management		x						x					1	1
26	FR.3 Support AMI Installation			x						x				1	1
32	FR.4 Provide Meter Data Collection				x						x			1	1
63	FR.5 Support Exception Management					x						x		1	1
79	FR.6 Support Service Orders						x						x	1	1
84	FR.7 Support Commissioning													1	1
91	FR.8 Support Billing													1	1
144	FR.9 Support Customer Service													1	1
147	FR.10 Provide Real-Time Applications													1	1
157	FR.11 Provide External Support and Analysis													1	1
171	FR.12 Assure Reporting													1	1
182	FR.13 Support Outage Management													0	1
187	FR.14 Support Revenue Protection Support													0	1
192	FR.15 Provide Demand Control/Demand Response													0	1
209														123	204

Fig. 6. Snapshot of the Assessment Tool/Model

Taken into account the matrix design presented in Fig. 6, this case can be formalized using the concepts of axiomatic design, as presented in equation 1.

It can be noted that the matrix design is coupled and from Fig. 6 can be concluded that 123 off the functional requirements are provided by two design parameters.

According to Theorem 3 [16] ‘‘when there are more DPs than FRs, the design is redundant design, which can be reduced to an uncoupled design or a decupled design, or a coupled design.’’

Theorem 4 [16] state that in an ideal design, the number of DPs is equal to the number of FRs and the FRs are always maintained independent of each other.

The third study outcome is the transformation of a MDMS configuration problem in a matter of axiomatic design. The gain is the possibility to apply the entire formalism (axioms, corollaries, and theorems) of axiomatic design, developed over the time, to a MDMS configuration.

$$\begin{Bmatrix} FR.1 \\ FR.1.1 \\ FR.2 \\ . \\ . \\ . \\ FR.15.5.2 \\ FR.15.5.3 \end{Bmatrix} = \begin{bmatrix} X\,X\,0\;0 & 0\;0\;0 \\ 0\;X\,X\,0 & 0\;0\;0 \\ 0\;0\;0\;0 & 0\;0\;0 \\ .\;\;.\;\;.\;.\;\; .... & .\;\;.\;. \\ .\;\;.\;\;.\;\;. & .\;\;.\;\;. \\ .\;\;.\;\;.\;\;. & .\;\;.\;\;. \\ 0\;0\;0\;0 & X\,X\,0 \\ 0\;0\;0\;0 & 0\;X\,X \end{bmatrix} * \begin{Bmatrix} DP.1 \\ DP.1.1 \\ DP.2 \\ . \\ . \\ . \\ DP.15.5.2 \\ DP.15.5.3 \end{Bmatrix} \qquad (1)$$

On the base of Theorem 4, the first attempt was to decrease the number of design parameters to arrive to match the number of functional requirements.

The process commenced with the lowest level of hierarchy and after several iteration it was arrived at the highest level of FRs.

The next section explains the contents of the model, i.e. the functional requirements represented at the highest level of the hierarchy, shows the design parameters at the highest level and provides explanation on the design parameters.

FR.1: Display Application/Solution Version;
FR.2: Assure Asset Management;
FR.3: Support AMI Installation;
FR.4: Provide Meter Data Collection;
FR.5: Support Exception Management;
FR.6: Support Service Orders;
FR.7: Support Commissioning;
FR.8: Support Billing;
FR.9: Support Customer Service;
FR.10: Provide Real-Time Applications;
FR.11: Provide External Support and Analysis;
FR.12: Assure Reporting;
FR.13: Support Outage Management;
FR.14: Support Revenue Protection;
FR.15: Provide Demand Control/Demand Response.

DP.1: Solution Manager System Applications;

This design parameter refers to: a standard platform for Application Lifecycle Management (ALM).

DP.2: Meter Data and Operations Management (Device Management) Applications;

This design parameter refers to: management of technical data, logistics, and operations to procure, install, remove, and replace meter devices such as smart meters. Validate, manage, analyze, and process meter and energy data. Perform discrete meter readings, time series, replacement value procedures, and data management tasks and analysis. Transfer high volumes of data accurately on time for further processing or to external parties. Define and offer customer-individualized energy products, insights, and new services. Support geography-based district planning for traceable roll outs of smart meters

DP.3: Smart Meter Roll - Out Applications;

This design parameter refers to: creating calculation and visualization roll-out scenario, structure information (devices, device location, data from GIS), calculate meter type related efforts, simulate scenarios and pre-classifies connection objects.

DP.4: Meter Data Life Cycle Applications;

This design parameter refers to: Meter lifecycle management processes supporting warehousing, mass deployment, and operations. Application optimizes warehouse and workforce processes to support mass installation, meter maintenance, and other meter-related processes.

DP.5: BPEM (Business Process Exception Management) Applications;

This design parameter refers to: analyzes and monitor mass activities and dialog transactions enables to process and corrects critical processes and their incorrect elements.

DP.6: Plant Maintenance (PM) and Customer Services (CS);

This design parameter refers to: cost-efficient maintenance methods, such as risk-based maintenance or preventive maintenance, and provides comprehensive outage planning and powerful work order management

DP.7: Enterprise Asset Management (EAM);

This design parameter refers to: a foundation for managing physical assets, production equipment, power grids, machinery, vehicles, or facilities. Enterprise asset management (EAM) software increase operational efficiencies, improve asset usage, reduce costs, and manage capital expenditures throughout the asset lifecycle.

DP.8: Customer Relationship and Billing (ISU/CCS);

This design parameter refers to: core processes of a utilities company consumption and revenue collection. For consumption, meter-reading orders have to be created, and the results have to be uploaded into the system. To collect revenues, client billing must be generated, invoices issued, and payment reconciled.

DP.9: Customer Relationship Management (CRM);

This design parameter refers to: integration of sales, service and marketing through business processes and enterprise applications.

DP.10: Real-Time Data Platform (in memory);

This design parameter refers to: possibility to explore and analyze vast quantities of data from virtually any data source with high speed. Real Time technology gives the power to instantly access and analyze transactional and analytical data.

DP.11: Business Intelligence Applications;

This design parameter refers to: applications that simplify data manipulation, allowing users to access, navigate, analyze, format, and share information across a corporate environment.

DP.12: PI (Process Integration) Platform;

This design parameter refers to: a collection of components that work together flexibly to implement integration scenarios.

The architecture includes components to be used at design time, at configuration time and at run time.

DP.13: Work Management (WM) component;

This design parameter refers to: outage management in the supply grid. Application can manage the correction of the fault and determine which customers are affected.

DP.14: Governance, Risk, and Compliance (GRC) Solutions, Fraud Management;

This design parameter refers to: uncovering hidden trends and patterns in large amounts data to detect fraud in near real time, adapt to evolving fraud patterns and enhance prevention with improved fraud strategy management, reduce the risk of fraud with advanced analytic capabilities.

DP.15: Demand Side Management (DSM).

This design parameter refers to: the management of energy demand by influencing the quantity of consumed energy (energy efficiency) or the patterns of energy use (demand response).

Nomenclature

FR	Functional Requirement
DP	Design Parameter
PV	Process Variable
CA	Customer Attribute

6. Conclusions

Configuration of a MDMS solution considering a set of Functional Requirements and Design Parameters can be challenging however it can be simplified by deploying the formalism of the Axiomatic Design methodology. It is noted that system integration addressed through the Axiomatic Design it is very sensitive to the methodology employed on the decomposition of the Functional Requirements. It is preferable that a Functional Requirement, at the highest level, be configured using Design Parameters of the same platform.

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