USE OF THE CIM FRAMEWORK FOR DATA MANAGEMENT IN MAINTENANCE OF ELECTRICITY DISTRIBUTION NETWORKS

Lars Nordström

March 2006

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Industrial Information and Control Systems
KTH, Royal Institute of Technology
Stockholm, Sweden

TRITA-EE-2006:17
ISSN 1653-5146
ISRN KTH/ICS/R--06/03--SE

Stockholm 2006, Universitetsservice US AB

Abstract

Aging infrastructure and personnel, combined with stricter financial constraints has put maintenance, or more popular Asset Management, at the top of the agenda for most power utilities. At the same time the industry reports that this area is not properly supported by information systems. Today's power utilities have very comprehensive and complex portfolios of information systems that serve many different purposes. A common problem in such heterogeneous system architectures is data management, e.g. data in the systems do not represent the true status of the equipment in the power grid or several sources of data are contradictory. The research presented in this thesis concerns how this industrial problem can be better understood and approached by novel use of the ontology standardized in the Common Information Model defined in IEC standards 61970 & 61968.

The theoretical framework for the research is that of data management using ontology based frameworks. This notion is not new, but is receiving renewed attention due to emerging technologies, e.g. Service Oriented Architectures, that support implementation of such ontological frameworks. The work presented is empirical in nature and takes its origin in the ontology available in the Common Information Model. The scope of the research is the applicability of the CIM ontology, not as it was intended i.e. in systems integration, but for analysis of business processes, legacy systems and data. The work has involved significant interaction with power distribution utilities in Sweden, in order to validate the framework developed around the CIM ontology. Results from the research have been published continuously, this thesis consists of an introduction and summary and papers describing the main contribution of the work.

The main contribution of the work presented in this thesis is the validation of the proposition to use the CIM ontology as a basis for analysis existing legacy systems. By using the data models defined in the standards y and combining them with established modeling techniques we propose a framework for information system management. The framework is appropriate for analyzing data quality problems related to power systems maintenance at power distribution utilities. As part of validating the results, the proposed framework has been applied in a case study involving medium voltage overhead line inspection. In addition to the main contribution, a classification of the state of the practice system support for power system maintenance at utilities has been created. Second, the work includes an analysis and classification of how high performance Wide Area communication technologies can be used to improve power system maintenance including improving data quality.

Keywords: Asset Management, Electricity Distribution Networks, Information Systems, Data Quality, Power System Modeling, Enterprise Architecture, Common Information Model, Ontology.

Acknowledgements

At the end of a very long journey it is of course easiest to remember and thank travel companions who have participated on the journey. It is easy to forget those invaluable guides that you only met briefly during the trip, they are likely to have contributed greatly – perhaps by giving directions when you were lost. So those who feel forgotten in this acknowledgement should see themselves as helpful guides along the way that pointed this author in the right direction, without your help I would have ended up elsewhere – Thank You!

Among the travel companions, I first and foremost want to mention Professor Torsten Cegrell, who has been a superior tutor, and provided guidance and inspiration during the journey. Equally important is of course the ever-present (except Fridays) Judy Westerlund who makes the department into the happy family that it is.

Second in line of course colleagues, former and present; Doctors Mathias Ekstedt, Magnus Haglind, Erik Johansson, Pontus Johnson and Tomas Rahkonen. Thank you all for inspiring discussions and for setting deadlines. This journey would definitely have ended in disaster had you not been present to guide the course of my wanderings.

Third in line, but most important, is of course my little family, my wife Maria and my, soon to be three, wonderful children Ida, Anton and TBD. You are the ones that add sunshine to my life! Last but not least, my parents Sten and Karin, and dear brother Erik. Thank you for tricking me into studies at KTH, I guess that's were this journey began.

Kummelnäs, March 2006

Lars Nordström

List of Publications

This thesis consists of an introduction and summary, covering chapters 1 to 5 and the five publications listed below. A complete list of publications is given at the end of the thesis.

Paper A.

N. Jonsson, L. Nordström "Strategies for implementing IT support for Asset Management" In Proceedings of Powercon 2004 International Conference on Power System Technology, Singapore, Singapore,21-24 November 2004.

Paper B.

L. Nordström, G. Ericsson "A Broadband Wide Area Network as an Enabler of Improved Power System Maintenance" In IEEE Transactions of Power Delivery Volume 21, Issue 1, Jan. 2006 Page(s):108 - 112

Paper C.

L. Nordström "Approaches for Achieving IT support for Asset Management" In Proceedings of CIRED 2005 18th International Conference and Exhibition on Electricity Distribution, Turin, Italy, 6-9 June, 2005.

Paper D.

L. Nordström, T. Cegrell "Extended UML Modeling for Risk Management of Utility Information System Integration" In Proceedings of the IEEE Power Engineering Society's General Meeting, San Francisco, USA, June 12-17, 2005.

Paper E.

L. Nordström, T. Cegrell "Analyzing Utility Information Systems Architecture using the Common Information Model" In Proceedings of 2nd CIGRE / IEEE PES International Symposium on Congestion Management in a Market Environment, San Antonio, USA, October 5-7, 2005.

Foreword

The research work presented herein has been conducted as a project within the EFFSYS[1] research program. The EFFSYS program has been conducted in two stages, and this work has been conducted as part of the second stage running from 2003 to 2005. The EFFSYS program has been financed by the Swedish power industry through its joint research and development company Elforsk AB, the pulp and paper industry through SCA Graphics AB and by the Swedish Energy Agency. EFFSYS's goal is to facilitate cost-efficient maintenance practices within the power and pulp & paper industries. This will be done through establishing long-term collaboration between industry and universities which in turn secures a supply of critical knowledge and competence to the partners in the area of maintenance management.

The research resulting in this thesis can be said to have started in 1996. At the time the author was working on a project focused on specification of SCADA system functionality based on business processes as opposed to basing the requirements only on aspects of power system control. That research was focused on how business analysis could be used within a development project to elicit and specify requirements on SCADA system functionality. The work presented in this thesis has been conducted with a similar theoretical framework: that of systems and process modeling, and in a similar industrial setting: that of power system operation and maintenance. In that sense, the work is a continuation of the research from the late 1990s. In other aspects, the work is different. First and foremost, the work presented here in was conducted during 2003-2005, this is significant since during the 8 years separating the projects there has been a tremendous development in functionality and performance of information systems. Second, the work presented here considers not only a specific SCADA system, but instead addresses generic issues of information systems use for power system maintenance.

Financial support was during the initial period of the research (1996-1998) received from EKC – the Swedish centre of competence in electric power engineering. During the later period of the research, financial contribution was received from the EFFSYS program. Financial support from these programs is gratefully acknowledged.

[1] The EFFSYS acronym should be read as *Efficient System Utilization in the power and pulp & paper industries* (In Swedish: Effektivt systemutnyttjande i elkraft och skogsindutrin)

Table of Contents

One of the symptoms of an approaching nervous breakdown
is the belief that one's work is terribly important

- Bertrand Russell

Chapter 1

Introduction

The importance of proper maintenance of power system components and sub-systems is well known in the power industry. Power distribution systems have always been well maintained and reliable; partly a consequence of utilities operating as monopolies. However, in the re-regulated power industry, a distribution utility is put under pressure both from its owners expecting return on investments, as well as from regulatory agencies keeping a watchful eye on the level of tariffs. These new constraints are changing the way many utilities look at maintenance of equipment. In addition to these business constraints, new challenges are appearing. In the industrialized part of the world the bulk of the equipment is reaching the age for which it was originally designed. This aging is apparent both in primary as well as in secondary equipment. Additionally, the workforce set to maintain the power system is aging, resulting in utilities losing key-competence as people move on to retirement, or is forced to leave as part of cost-cuttings.

It is natural that under these circumstances, utilities are focusing on improving their maintenance processes, the goal being to prolong the life-time of equipment, thereby providing better return on employed capital. Equally obvious is that the utilities will strive to make their maintenance processes cost efficient and to a large degree automated to avoid becoming dependant on single individuals. All of these challenges are forcing utilities to rethink costly time or usage-based maintenance schemes, and introduce more sophisticated asset management strategies.

An important component in the development towards more sophisticated maintenance processes is of course employment of information systems. Today's power utilities have very comprehensive and, unfortunately, complex portfolios of information systems that serve many different purposes. Common problems in such heterogeneous system architectures are high costs for maintenance and upgrades, duplication of system functionality and data, poor end-user satisfaction, and high levels of risk when implementing new systems. In the area of asset management, the lacking quality of data, e.g. data in the systems do not represent the true status of the equipment in the power grid or several sources of data being contradictory is the most apparent problem.

The topic of this thesis is modeling and analysis of maintenance processes and related information systems at power distribution utilities. From an industrial perspective the rationale for choice of this topic is the problems reported from industry of lacking support from information systems for power system maintenance processes. From a scientific perspective, the project is relevant since it provides empirical insight into the use of an ontological perspective on information systems management

The chapter provides a background to the industrial challenges contemporary utilities face when they work to improve their maintenance processes and related information systems. After that a statement of the research objective and the main contribution of the work is presented. Finally, the chapter contains a section describing the outline of the entire thesis.

1.1 BACKGROUND

A key component in successful maintenance is availability of data on the status of equipment, including data about events affecting the status of the equipment *(Sherwin 2000)*. It is in this area that properly employed information systems play an important role. Without data about the current situation planning of future actions or follow-up of actions taken is at best difficult. This notion is of course not new, and has been implemented in industry, see for instance *(Lundqvist 2002)* or *(Sand 2002)*, and described in literature since quite some time. Still, a number of problems remain before the information systems are well aligned to the requirements. This is especially true regarding availability of relevant and correct data to be used in maintenance planning *(Bertling 2005a)*.

A simplistic view of the information systems at a utility that are related to power systems maintenance include four main groups of systems: *SCADA systems, Network Information Systems, Customer Management Systems and Business Support systems.*

We refer to them here as groups of systems since in many cases, each group constitutes several individual systems from different vendors installed at different times and for various purposes. A more detailed presentation can be found in *(Jacobsson 2002)* and *(IEC 2003)*, in brief the systems fill the following purposes.

> *SCADA* – Supervisory Control and Data Acquisition systems are for example used for monitoring and control of electricity distribution networks and its components. The SCADA system enables supervision of voltage, current and power levels, as well as allowing remote operation of switches to reconfigure the network for planned maintenance or as part of restoring a failing network. From a power system maintenance perspective the SCADA system is essential as a tool to detect errors, initiate repair tasks, and manage switching in the grid to allow safe working conditions for field crews.

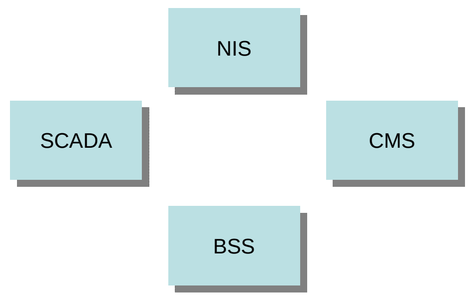

Figure 1 The four groups of systems at a power distribution utility, viewed from an asset management perspective

Business Support Systems (BSS) are similar to those found at most companies in all industries and this includes IT support for payroll, accounts receivable, general ledger as well as purchasing and inventory control. From a power system maintenance perspective, the BSS are important since they contain general ledger information about the assets from a financial perspective. Additionally, for outsourced maintenance operations, purchasing and invoices must be related to actual work performed by field crews.

Customer Management Systems (CMS) consists of support systems for sales, marketing and billing. The most basic support would be a database of existing customers as well as functionality for creating invoices. For maintenance of the electricity distribution network, the CMS systems are important since they contain information about which customers are affected by unplanned or planned interruptions. The CMS is also the system used to record customer reported errors, an essential part in establishing traceable workflows.

Finally the *Network Information System* is the central repository for information about the network its components and related resources such as field spare parts, field crews, work orders and so on. In many aspects the NIS group of systems provide what in many other industries would be seen as a CMMS – Computerized Maintenance Management System. Of course, this last system is the key system for power system maintenance purposes. In the NIS, all information related to the equipment in the power system is stored and manipulated.

Most likely, the software and hardware technologies currently available at utilities are sufficient to manage the needs of power system maintenance. We know that there is already an abundance of software systems available at utilities *(Simonsson 2005)*, and there are several integration frameworks available that could potentially be used to integrate the systems *(CIO Council 1999, EPRI 2003, The Open Group 2002)*. Additionally, there is an abundance of professional services firms wiling and able to help the utilities in their efforts to integrate their information systems further. But since resources are not endless, and utilities are under severe market pressure to be competitive, they need to find ways to work "smarter" when introducing and improving information systems for maintenance processes. Not unlike the need to work "smarter", in the actual operational maintenance work, i.e. use fewer resources to keep the power grid at a sufficiently high level of reliability.

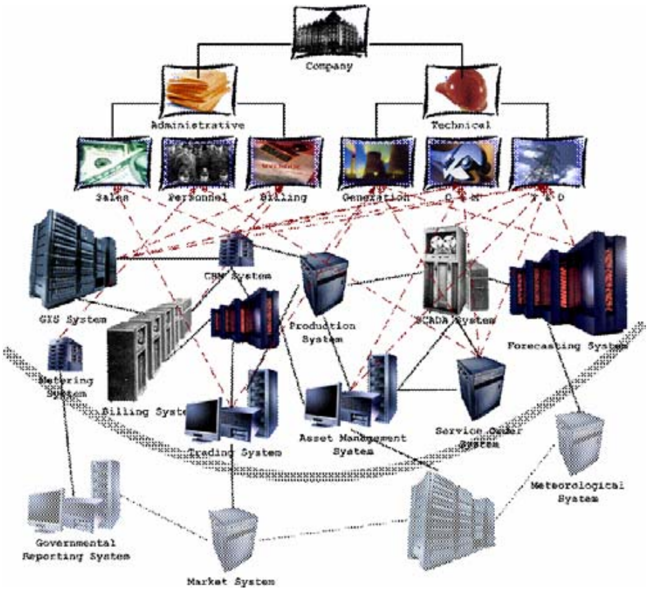

Figure 2 An illustration of the problems faced by many utilities, with a large portfolio of information systems that are interconnected and all support different parts of the business, courtesy of P. Johnson.

With a heterogeneous portfolio of systems, many new problems than are not evident in individual systems appear at a higher architectural level. Examples of such problems are interoperability, information security and data quality, but also organizationally related problems such as end-user satisfaction, and risks when introducing new, or changing existing systems. Research and development within the discipline of Enterprise Architecture, see for example *(Armour 1999, 1999b and Ekstedt 2004)* is addressing these types of problems, often through advocating different types of architectures or models that describe the whole portfolio of systems and processes.

Efficient maintenance of equipment and systems, e.g. electricity distribution networks, requires timely and reliable access to information about the status of equipment and activities planned and performed. Such reliable and timely access to information is however challenged by the heterogeneous portfolio of information systems supporting maintenance process at today's utilities. This is essentially the problem area addressed by the research presented in this thesis can be summarized as follows.

It is in this area that the research presented in this thesis makes its contribution, i.e. how can utilities avoid problems with data quality, better manage end-user expectations and reduce the risks when introducing new, or changing existing information systems, in the area of maintenance of electricity distribution networks.

1.2 RESEARCH OBJECTIVE

In very general terms, the research objective for this project has been to increase the knowledge about, and understanding of problems related to making information systems better support maintenance of electricity distribution networks at modern day utilities.

The overall research question formulated at the outset of the project is if, and how, maintenance of electricity distribution networks can be improved by integration of information systems used for maintenance with the system portfolio at power distribution utilities. More specifically, this has been broken down into the following set of research problems:

Q1. Which areas of information systems use for maintenance of electricity distribution networks are most in need of improvement?

Q2. How can data quality issues related to maintenance of electricity distribution networks be managed in heterogeneous system portfolios?

Q3. Are existing standards for power system management and related communications applicable to analysis of power system maintenance processes and related legacy information systems?

Q4. What are the impacts on introduction of new information and communication technologies on maintenance of power networks?

The overall research question, and the related sub-problems, has been formulated based on the initial research goals set out in the project specification of the research project *(Elforsk 2002)*.

1.3 MAIN CONTRIBUTION

The main contribution of the research presented in this thesis relies heavily on the extensive amount of empirical data gathered during surveys and case studies. The contribution can be divided into several parts. First, in response to the first problem above, current practices and weaknesses in utilities' use of IT for maintenance of electricity distribution networks. has been investigated and categorized. Second, in response to the ensuing research problems, the use of existing information systems standards from the power industry have been applied to the problems identified. The result is a proposition to use existing power industry standards in a novel way by combining them with a set of Unified Modeling Language (UML) modeling extensions thereby creating a framework for analyzing data quality issues in legacy information systems at utilities with a focus on power system maintenance.

Specifically this can be broken down into:

> Demonstration that the Common Information Model developed as part of the IEC standardization in the area Power System Management can be used beyond the intended scope of specifying system interfaces, for analysis of data quality issues in existing information systems used for power system maintenance. This is reported in papers C, D & E.
>
> Creation of a modeling framework for analysis of data quality issues in legacy information systems. The framework is based on the combination of extensions for process modeling in UML with the Common Information Model provided in the IEC TC57 standards on power system modeling. This is more specifically reported in Paper D.
>
> Validation of the proposed modeling framework by applying it to analysis of the processes for inspection and planning of medium voltage over-head lines at a power distribution utility. By applying the framework, valuable experiences were gathered for future refinement. This is specifically reported in Paper E

In addition to the main contribution above, two additional contributions should be noted:

> First, a classification of state of the practice information system support for power system maintenance at utilities was created. The classification is based on a survey of present status of information system support for maintenance of power distribution networks. This is more specifically reported in Paper A
>
> Second, analysis and classification of how high performance wide are communication technologies can be used to improve power system maintenance including improving data quality. This is more specifically reported in Paper B.

The summaries of the included papers, see Chapter 4, includes references to how these contributions are reflected in the publications. The importance of these contributions in relation to work done by others is discussed in Chapter 3 in general and in section 3.2 in particular.

1.4 OUTLINE OF THE THESIS

In this thesis the main contribution of the research work is presented in the included papers. Since the papers are relatively short, this format bears with it the risk that important information about the research is left out. Therefore, the thesis is introduced with five chapters that describe the background to the research as well as the theoretical and methodological foundation for the research project. The introductory chapters should therefore be read as background to, and summary of, the research contribution which is presented in papers A-E.

Consequently, the thesis consists of two major parts. The first part contains chapters 1 to 5 with references and part two contains five publications published as part of the research project. This first chapter provides an introduction to the thesis, and background to the industrial setting. The chapter also specifies the research objective and the main contribution of the research project.

The second chapter contains a theoretical background to the area of data quality and specifically the use of ontologies. The chapter also describes the project outline. An important step in defining the research project was a pre-study conducted at the outset of the project. This pre-study and the survey conducted as part of the study are reported on in Paper A. The survey was an important part in defining this problem, and the second part of chapter two should be read in conjunction with Paper A.

The third chapter provides some additional theoretical and empirical background to the project. As part of the research project, a large amount of literature and scientific papers in the areas of information systems management for power distribution utilities have been studied. Chapter three provides an overview to this field, and describes several related projects and activities.

Chapter four provides a summary of the included papers. The summaries are essentially excerpts from the papers themselves with additions to relate the work to the background present in chapters 1-3. Finally, chapter 5 provides some brief concluding notes on the results of the project and outlines some further work that could be based on the findings of this project.

The second part of the thesis consists of five publications, denoted Paper A – E which summarizes the most important aspects of the research project. A complete list of publications is provided at the end of the thesis.

USE OF THE CIM FRAMEWORK FOR DATA MANAGEMENT IN
MAINTENANCE OF ELECTRICITY DISTRIBUTION NETWORKS

Excuse me, is there anything I can do? I am a scientist, sir. Is there any problem?

Mr Ray, in Finding Nemo.

Chapter 2

Research Design

The industrial rationale for this research project is the problem reported from the power industry of lacking support for power system maintenance from information systems. This relatively general problem can of course be addressed by "working harder", i.e. by assigning more resources to implement systems that are better suited to the needs of the asset management processes. The topic of interest to for this research project is however to develop methods that will aide utilities to improve the support from information systems, without the need of assigning more resources.

As mentioned above, a conceptually similar challenge in the area of maintenance planning is utilities' desire to work "smarter" by spending fewer resources on component maintenance without compromising the reliability of the power system. As a result, many utilities are investigating more sophisticated methods for maintenance planning. For example the use of RCM in the power industry is under development *(Endrenyi, 2001, Goodfellow, 2000)*. The research described in this thesis is conceptually similar to developments and refinements of RCM for power system maintenance see for instance *(Bertling 2002, Bertling 2005b)*. Just as utilities would be well served by improved methods for maintenance planning, e.g. RCM, the utilities would benefit from methods that facilitate implementation, integration and use of information systems for maintenance processes.

In reaction to the open ended research objective posed at the outset of the project, the project has been empirical in nature. As a methodological framework case study research, as presented by Yin in *(Yin 1996)* has been used. Using the taxonomy of Yin the research is exploratory in nature. The theoretical framework for the research is that of Data management, and specifically the use of ontology based frameworks to manage data quality. The work by Wang and Strong has here been influential *(Wang 1996, Wand 1996, Strong 1996, Lee 2002)* in defining the theoretical framework for the research. The concept of ontology based management of data quality is not new, but is receiving renewed attention due to emerging technologies, e.g. Service Oriented Architectures, that support implementation of such ontological frameworks. In the field of information systems management for power system maintenance at electric distribution utilities, the concept of ontologies is of specific importance due to the emergence of the Common Information Model *(IEC 2003a, IEC 2003b)* and its potential use as an ontology *(Newberry 2004, Neumann 2006)*.

The empirical data gathered as part of the project is relatively extensive, more than 15 different power distribution utilities have been involved in the studies and surveys conducted in the course of the research project. At each of the utilities experts have contributed data in interviews and questionnaires, and also supported the work by reviewing reports and results created. The high level of interaction with these utilities, and the data gathered, serve to increase the validity and relevance of the results, please see sections 2.6 and 2.7.

The initial section of the chapter provides an overview of the theoretical framework for the research. The theoretical foundation for the work has been developed gradually along the conduct of the research project. It is therefore not fully reflected in the papers included in the thesis. The chapter continues with a description of the outline of the research project the pre-study, literature studies and performed case study. The chapter is concluded with three sections discussing the quality aspects of the project and the results.

2.1 DATA MANAGEMENT

Data, or information, quality has been the topic of research for several decades, in a way the problem of quality of data did not appear with the advent of the information society but existed earlier. For example in *(Lee 2002),* Zmud's studies from 1978 *(Zmud 1978)* on the concept of quality of information contained in reports and documents unrelated to today's computers and databases is given as an early example of pre-IT data quality challenges. Nevertheless, the importance of the area has grown with the increasing dependence on data in information systems in decision making, planning, and control.

Despite this interest and long history of research, there is still a lack of an unambiguous common definition of the term data quality. This problem is of course in line with the more general problem of agreeing on a definition of the term quality. Nevertheless, Thomas Redman offers the following pragmatic definition of the term in *(Redman 2001)*

> *"Data are of high quality if they are fit for their intended uses in operations, decision making, and planning. Data are fit for the use if they are free of defects and possess desired features"*

The definition is useful in that it points out that the quality of the data is "measured" in a context *"… fit for their intended purpose…."*. In the research presented herein, the definition should be seen in the context of maintenance of electricity distribution networks. So the quality of the data should be judged in relation to its usefulness in the support of maintenance processes. At the same time, the data may have been collected and stored for another intended use. For example, data from the Enterprise Resource Planning system at the utility may be relevant for follow-up of maintenance activities, but the purpose of gathering the data is for business control. The fact that data is stored and used by different units across the organization each with their specific purpose for doing so adds an order of magnitude to the data quality problem. This in turn results in a need for more comprehensive frameworks for data management.

2.1.1 COMPREHENSIVE DATA MANAGEMENT

Much of the research in the data quality field is, as is the case in most information systems and software engineering, research piecemeal and focused on very specifics aspects of the subject. Exceptions with a more comprehensive outlook include Ballou which proposes a set systems modeling and design criteria to facilitate higher quality of data *(Ballou 1985, Ballou 1989, Ballou 1995, Ballou 1998).* A comprehensive effort in the area is being made within the Total Data Quality Management program at MIT. The objective of the TDMQ program is to establish a solid theoretical foundation in the field of data quality. Through co-operation with various industries the plan is to create practical methods for business and industry based on these theories *(www MIT 2006)*

One example of an effort to create a comprehensive understanding of the quality of information for an entire organization is the research by Wang and Strong *(Wang 1996, Strong 1996).* In their research they propose four categories of information quality (IQ) consisting of several dimensions, see Table 1 below.

IQ Category	IQ Dimensions
Intrinsic IQ	Accuracy, Objectivity, Believability, Reputation
Accessibility IQ	Accessibility, Access security
Contextual IQ	Relevancy, Value-Added, Timeliness, Completeness, Amount of data
Representational IQ	Interpretability, Ease of understanding, Concise representation, Consistent representation

Table 1 The Four categories of Data Quality and the constituent dimensions *(Strong 1996)*

In a later paper *(Lee 2002)* the team has created a method for information quality assessment. This method is based on investigations of a large number of academic as well as practitioner's view of the many aspects of information quality. The findings have then been mapped to the data quality categories previously defined; see Table 1, by the team. This later work serves as a strong validation of the categorization of data quality proposed by Wand and Strong.

As can be seen from Table 1 *intrinsic* information quality is related to the inherent qualities of the stored data. That it is accurate, unbiased etc. This is of course an essential characteristic of the data, and is true regardless of the intended use of the data. To judge these inherent qualities of the data, the data must to be verified against complementary measurements of the entities that the data represents. In effect, the intrinsic quality of data can be seen as how truthfully it reflects the entities it represents; this is very much related to the ontological concepts described in section 2.1.2 below. Of course, how truthful the representation needs to be is in itself defined by the level of detail needed for decision making in the organization using the data. In reference to the research presented in this thesis the concept of Intrinsic is referred to as Data Quality in Papers A and B.

The *Accessibility* category refers to how the ease of use of the data once it has been collected and stored in the information system. Accessibility in itself has many facets, one being of course that the data is available for the user that needs it and not stored on a local disk somewhere out of reach of the user. An important facet of accessibility is also security, which oftentimes is an opposing force to accessibility, by imposing limitations to users' rights to access data. As is discussed below, the accessibility aspect is of interest in the research presented herein. This is because the heterogeneous system portfolios at utilities may pose limitations to the users' access to data, even though it is "out there" somewhere. For instance in the pre-study reported in Paper A, there were many examples of users not having access to data without having to physically move from one location to the other, get the data and then re-type it at their own terminal – an obvious example of poor accessibility.

Contextual category of information quality deals with the very important aspect of why the information has been stored, and what its originally intended use is vis-à-vis the currently intended use. Referring back to the definition above *(Redman 2001)* we have it that the quality of the data is defined by its ability to fit an intended use. Clearly the intended use effects how the data is represented, how much of it is stored, at what frequencies it is sampled etc. For example usage data on a specific piece of information, e.g. a Medium Voltage breaker, is used by the SCADA system in a different manner than is the case in a Network Information System. Specific pieces of data from the NIS may not at all be relevant for a person in the control center or it may not be available in a timely manner and therefore provide no value. Again, at power distribution utilities with heterogeneous system portfolios, the contextual aspect is of great importance when the quality of a specific piece of data is to be judged. The term *Data Depth* is used in the papers in this thesis, see for example Papers A & B, this term is in a way similar to that of Contextual information quality. Data Depth refers to the level of detail available about e.g. a particular piece of equipment or event in the electricity distribution network. The level of detail needed is of course related to the context in which the data shall be used.

The *representational* category finally, is related to the contextual category, in that it reflects the quality of the way in which the data represents the entities involved. The representations must of course be concise and consistent yet easy to understand. For example, the identity of a breaker in the distribution network could be on the form STO2_3, where letters represent the name if the substation, and the numbers the location of the breaker within the station. This name of the object shall then, if the representational quality is to remain high, be used consistently throughout all systems. In the framework developed as part of this research, the idea to use the Common Information Model *(IEC 2003b)*, and the naming guides therein, as a basis for analysis of data management issues goes some ways towards addressing these problems.

All of the dimensions of data quality have a common denominator in that they all are built on the underlying assumption that the data represents an external set of entities, be they invoices, breakers or customers. To be able to judge the quality of data, regardless of dimension, it is therefore important to understand how the external "real" world is represented by data in the information systems. A definition and description of all objects in the real world, an ontology, would of course be beneficial to understand how well the data represents the real world.

2.1.2 ONTOLOGY BASED DATA MANAGEMENT

A theoretical basis for managing data quality using ontologies is proposed by Wand and Wang in *(Wand 1996)*. The concept of ontologies in computer science is relatively old, and a useful definition can be found on the Internet *(www Wikipedia 2006):*

> *"In computer science, an ontology is the product of an attempt to formulate an exhaustive and rigorous conceptual schema about a domain. An ontology is typically a hierarchical data structure containing all the relevant entities and their relationships and rules within that domain (eg. a domain ontology)."*

The proposition by Wand and Wang is based on the categorization of data quality described in section 2.1.1 above and is on a set of basic assumptions about the real world and how it is represented in information systems, see table below:

Postulate 1.	Things are modeled in terms of their states and laws
Postulate 2.	The real-world system is a thing, described in terms of its states and laws.
Postulate 3.	An information system is a thing, described in terms of its states and laws.
Postulate 4:	A system can be described as a composite, made of other things.
Postulate 5:	Let the components of a system with a state space S be $\{X_1,...,X_N\}$ with state spaces $\{S_1,...,S_N\}$ respectively. There exists an exhaustive and one to many mapping: $S \rightarrow S_1 x...xS_N$ (every element in S has at least one counterpart in $S_1 x...xS_N$).
Postulate 6.	The data stored in an information system at a certain time represent the state of the information system at that time.

Table 2 The six postulates forming the basis for an ontological foundation for data quality management, from *(Wand 1996)*

The postulates themselves are relatively straightforward, and based on these Wand adds the following two, for this project, important definitions:

> **Definition.** An information system is said to be a representation of a real-world system if observing the state of the information system at a given time enables the inference of a state of the real-world system (at the same or another time).
>
> **Definition** A real-world system is said to be properly represented if: (1) there exists an exhaustive mapping, Rep: $RW_L \rightarrow IS_L$, and (2) no two states in RW_L are mapped into the same state in IS_L (the inverse mapping is a function).

With the scope of the research presented in this thesis in mind, the real world of interest here is the electricity distribution network and the people and systems used to maintain it. Thus, using Wands notation, RW_L represents the set of all possible states that the electricity distribution network may be in. IS_L, is then all possible states in the information system used at the distribution utility.

Here, two important facts must be noted. First, what does "all states in the electricity distribution network" really mean? Does it include the magnitude of current flowing through a line at a specific time? The temperature of the line? The height of the pole supporting the line? The date of manufacture of the pole supporting the line? The place of manufacture of the insulators holding the line? Of course, these questions can only be answered within the context of the intended use for the data. The research presented in this thesis provides an answer to this problem. The use of the Common Information Model (CIM) from the IEC standards *(IEC 2003a and IEC 2003b)* as an ontology provides useful guidance. The CIM provides a well defined set of states in the real world that it is meaningful to represent in information systems. The rigorous process by which standards of this kind are developed serves to ensure a high level of credibility that this set of states is relevant to in the context of maintenance of electricity distribution networks.

The second fact to note is that the term Information System used in Wand's definitions is elusive. As shown in section 1.1 a contemporary utility has many information systems, all involved in the maintenance processes. In which of these will we find the complete mapping of the real world? Even if only a subset of the electricity networks states, such as defined for instance in the CIM, are to be mapped, we have a choice of information system to find the mapping in. Again, this challenge is addressed by the research presented herein. In the proposed analysis framework, see section 3.3 or Paper D & E, the mapping of Real World states across several systems can be documented and analyzed in a consistent and standards compliant way.

2.2 DATA QUALITY AND POWER SYSTEM MAINTENANCE

As discussed above the context of the intended use of data determines how the quality of the data can be judged. In maintenance of electricity distribution networks, the maintenance strategy employed by the organization determines the importance of the quality of the data. Traditional time or interval based strategies are not sensitive to lacking quality in data about the condition of equipment, since maintenance tasks are performed whether needed or not at pre-determined intervals. For more sophisticated strategies, such as probabilistic methods or condition based maintenance strategies data about the condition of the equipment is of course of greater importance.

As is reported in *(Endrenyi 2001)* utilities are still to a large degree employing traditional time or interval based maintenance strategies whereby maintenance activities are performed on a regular basis as specified in maintenance plans. For such strategies the data needed about the equipment is limited to a very basic set including identity and location of the equipment, its specific maintenance interval and tasks to perform, as well as when it was last maintained.

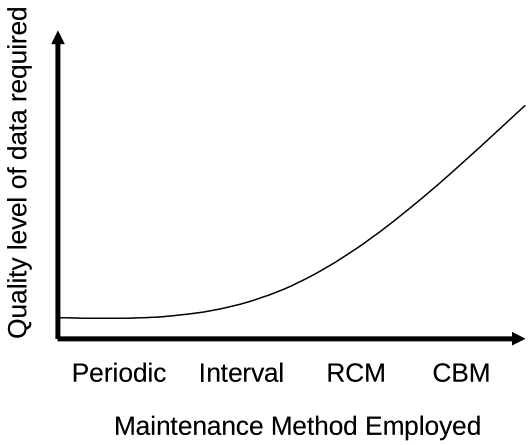

Figure 3 The dependence on high quality data increases as more sophisticated maintenance methods are employed.

In probabilistic maintenance strategies such as RCM, the probability of error of a specific components and the ensuing effect on overall system availability is the determining factor on when and where to perform maintenance. For such strategies condition data is used off-line to create component and system failure models. These models are then used for decision support when planning maintenance, i.e. the models are used to predict which components should be maintained *(Bertling 2005a)*. This maintenance is then performed whether or not it is needed, i.e. the actual condition of the component is not taken into account. Some researchers even claim that RCM is anti-data collection *(Sherwin 2000)* due to this reliance on models, this may be a relevant comment regarding use of condition data for operational maintenance decisions, but clearly the data is used for strategic planning.

In condition based maintenance strategies, the condition of the particular piece of equipment is used to determine whether maintenance of some sort is needed or not. Determining the condition of the equipment is either done off-line or on-line. Off-line, i.e. on-site inspections are the current norm in the power industry *(Endrenyi 2001)*. On-line monitoring is implemented as for instance temperature measurements of transformer oil. The development of intelligent distributed devices such as presented in for example *(Nordman 2005)* is creating an abundance of condition related information that could very well be used in maintenance of electricity distribution networks. Still, whether employing on-line collection of condition data or not a strategy that involves using the condition of equipment as a basis for maintenance planning of course requires a higher level of quality of data on the condition of the equipment. The above presentation of the requirements of data quality is summarized in Figure 3 above.

2.3 IMPLICATIONS FOR THE WORK PRESENTED IN THIS THESIS.

In short, the many systems available at a utility makes the most immediate problems of data quality one of accessibility and contextual information quality. It is likely, that once more information can be accessed by maintenance personnel, there will arise problems of intrinsic data quality and representational data quality. This is so because the more the data is being accessed the more errors in terms of intrinsic and representational quality will be detected. However, these are, for the purpose of this thesis of secondary interest. In terms of the ontological foundations discussed in section 2.1.2 above, the accessibility problems arise from incomplete mappings, i.e. all real-world states are not mapped to information system states, leading to situations where the users have to search for information in several systems.

One of the most important research objectives for this research has been to empirically investigate the accessibility and contextual aspects of data quality in power system maintenance processes. The approach chosen is, similar to that proposed in *(Wand 1996)* to approach the problem from an ontological perspective. In the work we have chosen to use the standards developed by the IEC technical committee 57 on Power Systems Management and related Information Exchange as ontology, a concept recently suggested by *(Neumann 2006)*.

The pre-study reported on in paper A, indicate that there exists an abundance of data about the condition of the equipment However, this data is stored in various non-standardized formats and in several different types of systems. Some of these systems are also not intended for power system maintenance. In data quality terms, as introduced above, this relates to the *contextual* and *accessibility* dimension of data quality. The *accessibility* aspects relates to the data being out there in a system or other but that it is difficult, or impossible, to access for those who needed it in the maintenance process. The *contextual* aspect relates to the fact that data may be stored with a different purpose than planning maintenance, for instance the ERP *(Enterprise Resource Planning)* system contains invoices from in-sourced field crews on a format that make it easy to relate the invoice to a certain department but perhaps not to a specific component in the distribution network.

2.4 PROJECT OUTLINE

The outline of the project can be described in three stages, *Prestudy*, *Literature Review and Framework creation* and finally *Evaluation*. Figure 4below shows an overview of the project stages.

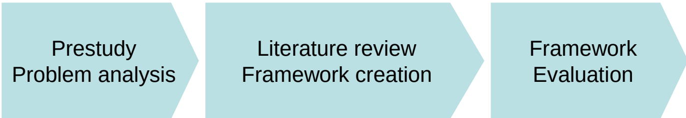

Figure 4 Overview of the project stages.

2.4.1 PRESTUDY

Using the classification of research approaches from *(Yin 1996)* the pre-study stage is essentially exploratory but also to some extent descriptive. The main objective was to verify that the industrial problem reported does exist, and also to gather more information about the details of the problem. The pre-study was conducted during the fall of 2003 in Sweden, and included nine power distribution utilities. To provide a point of reference in the coming analysis one hydropower company, and two pulp and paper mills where also included in the survey. The basic idea behind the study was to get an indication if there are differences in use of IT-support for asset managements within different industries. Secondly the purpose was to investigate where the utilities where focusing their efforts to implement IT support for asset management.

The method used was interviews directed to management for Power Grid, Technology or Maintenance departments. The interviews where structured and followed a pre-defined format with semi-open questions. The questionnaire covered circa 25 different "functional areas" all related to Asset Management. Examples of such functional areas are "Planning of Scheduled Maintenance" "Spare parts inventory" and "Field Crew dispatching" The idea was to investigate the IT support currently in use, and being planned for each of the functional areas. It is important to note that the limited size of the study in terms of respondents made any statistical analysis of the results void. Taking this into account, the results of the survey should therefore be interpreted qualitatively, serving as indicators rather than representing "hard facts". However, the findings of the study see Paper A; verify that the industrial problem exists, and that the main challenges lie in integrating already available systems.

2.4.2 LITERATURE REVIEW AND FRAMEWORK CREATION

The ensuing stage of the project, essentially consisted of creating a better understanding of the many facets of power system maintenance, system and process modeling, IT standards related to the field. The purpose was to find and combine relevant standards, theories and models that could be used to analyze power system maintenance processes and related

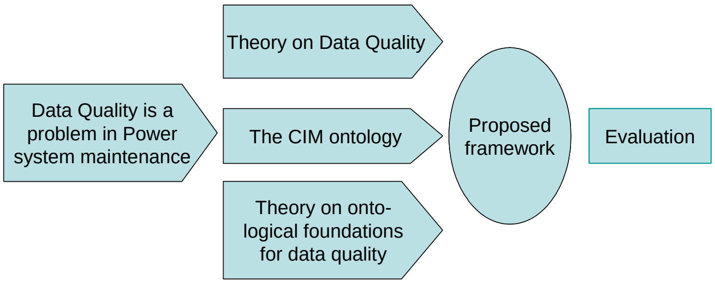

Figure 5 Overview of the research project in terms of subject areas included.

information systems. Sections 2.1, 2.2, and 2.3 together with Chapter 3 provides a presentation of the topics studies and how these have been applied.

In addition to this two additional studies were conducted during this stage of the project. One in which the effect on maintenance processes the appearance of high performance communication networks has, see paper B. The other concerned the application of the new regulatory scheme used in Sweden on distribution utilities to judge the value of investments in asset management systems *(Gammelgård 2004)*. During this second stage of the project a number of meetings were also held with the reference group of the project to get input on appropriate frameworks and their combination. In addition a number of research plan seminars were held were the proposed approach was presented and discussed.

2.4.3 FRAMEWORK EVALUATION

The final stage of the project consisted of evaluating the proposed framework by applying it to the power system maintenance processes at a utility. The case study was performed at one of the larger electric utilities in northern Europe in spring 2005. The area chosen for the case study was maintenance of medium voltage overhead lines, since this is an activity that spans several departments of the utility as well as relying on several support systems for planning execution and follow up of the activities. The scope of the case study was set to create a model of the activities related to planning and execution of inspection of over head power lines. The primary goal of the case study was however not to improve existing activities and systems. Rather the primary goal was to evaluate the proposed modeling approach and comment on the results gained.

2.5 RELIABILITY

The reliability of a study is understood as the project being performed and documented in such a way that another researcher could perform the same study with the same results. Yin *(Yin, 1996)* suggests the use of Case Study protocol and creation of a case study database in which all documents are stored as two tools to ascertain the reliability of a study.

In the research presented here the reliability of the study has been ascertained by a series of seminars presenting and documenting, the research approach. During these seminars important research components such as objective, literature to study, proposed analysis method, etc has been presented and discussed. These seminars have served the purpose of openly presenting and debating the research approach in order for other researchers to provide valuable criticism and feedback on the reliability of the study.

As a second step to ensure reliability copies of all collected documents have been stored in a database. Additionally all conducted interviews have been typed out and the responses have been stored electronically for easy access. This database of information could in theory be used by another researcher wishing to conduct the same study. Please see *(www Nordström 2004)* for a subset of the documentation available in the database.

2.6 VALIDITY

Considering that the research approach is exploratory in nature, the most important aspects of validity are *construct* and *external* validity as defined in *(Yin 1996)*.

Construct validity deals with whether the research is based on objective measures rather than on subjective reasoning. Yin suggests using multiple sources evidence and establishing a chain of evidence to ensure construct validity. In the research presented in this thesis this has been interpreted as ensuring that the complete research project and specifically the creation and evaluation of the analysis framework is based on multiple sources of evidence and that all steps in the process are documented. Additionally, the use of objective measures to evaluate the results is imperative for achieving construct validity.

The construct validity has been ascertained in the study by using several sources of information to gather information about the same subject. For instance during creation and evaluation of the analysis framework presented in papers D and E documentation, interviews and observations have been used to evaluate the effects of the framework. The same is true during the pre-study reported on in paper A, where several interviews and documents on the same subject were conducted.

By basing the proposed analysis framework on openly available and published models *(Eriksson 2000)* and standards *(IEC 2003b)* it is ensured that the terminology used is openly available and well established. The conclusions drawn regarding the applicability of the analysis framework have been verified with key informants participating in the case study.

External validity concerns the issue of whether the results are applicable to a domain outside the particular case. In our case this means that the question is whether the analysis framework proposed in papers D & E can be used outside the case study setting in which it has been tested.

Achieving external validity of the research has been approached by the research design as such. The starting point for the project was a very general industrial problem which could have been defined within most infrastructure related industries such as the telecom or transporting industries. In order to ensure that the reported problem was present in and to better understand the details of it a pre-study was conducted aimed at collecting general data about the problem, see paper A. As a second step, the proposed analysis framework is based on established theories on data quality and ontologies, see section 2.1 openly available and published models *(Penker 2000)* and standards *(IEC 2003)* indicating that the domains in which these are applicable, the approach and study results should be applicable.

As a first step, the scope of case study, i.e. maintenance of over-head medium voltage power lines can likely be said to be valid within the area of maintenance of electricity distribution networks. The processes used as a basis for creating the organizational part of the framework have been taken from the EBR catalogue *(www EBR 2006)* of maintenance activities. Additionally, the systems at the utilities involved in maintenance are generally the same regardless of voltage level or type of maintenance activity performed. It is however possible that the results are not valid in the area of maintenance of substations, especially not at higher voltage levels. It was realized during the pre-study reported in Paper A, that this type of equipment is managed differently at the utilities especially that other types of information systems where used.

2.7 RELEVANCE

Since the research project has been started with an industrial problem as the defining matter, the issue of industrial relevance can perhaps be taken for granted. Even so projects started with the best of intentions can deviate from the intended track. In terms of industrial relevance, the following steps and measures have been taken:

First, a pre study among utilities with the explicit aim to better understand the reported industrial problem was performed. The data gathered during this pre study had great influence on how the project was performed and which areas that were studied in greater detail.

Second, a reference group of experts from industry, software system vendors, consultants and power utilities was formed and associated with the researchers in the project. Project progress was reported to the reference group, and input was taken from them which further directed the work within the project towards relevant fields of subject.

Third, a significant part of the work was conducted with industry defined standards *(IEC 2003a and IEC 2003b)* playing an important part. These standards are at the center of the power industry's efforts to integrate software systems. The standards bodies are at the time of writing starting to describe the standards in such formats that they can be used as ontological foundations for service oriented architectures. This again ascertains the relevance of the conducted research.

Finally, the methods proposed to facilitate analysis of IT support for power system maintenance was put to use in a case study at a power utility, involving personnel at the utility in the analysis thereby gaining valuable insight into the applicability and relevance of the proposed method.

In total, the industrial relevance of the project is high. The final evidence of this is the continued interest in refining the proposed method in a series of studies at the utility involved in the case studies on this research project.

There are no rules here - we're trying to accomplish something.
- Thomas A. Edison.

Chapter 3
Power System Modeling

The concept of creating models of complex phenomena as a step to find solutions to problems is a well established engineering method. Within electrical engineering models are often abstracted and refined to the point where they can be used in algorithmic calculations and predictions of phenomena. Obvious examples are Maxwell's equations for electromagnetic phenomena or Thevenin's theorem for replacement of complex power systems with a single power source and impedance. Within software engineering, modeling is an equally obvious approach to analyze real world problems and design a system that handles the problem. A prominent example in this field is models created in the Unified Modeling Language (UML) that is transformed into skeleton code. Although the scope of the models and the output generated from the modeling process differs, models in electrical and software engineering are similar in that they abstract real world phenomena in order to facilitate human understanding.

Another real-world problem which can be better understood by creating models is the one faced by many utilities with an ever growing complexity in the enterprise systems. Today's power utilities all have large portfolios of information systems that support various parts of the business and the relation between systems, organizational units and business processes is non-trivial. Additionally the relations between systems, processes and organization never reach a steady state, but instead are in a state of continuous change. To address these types of problems, the area of Enterprise Architecture has emerged. Enterprise Architecture is model-driven, meaning that focus is to create models of systems, processes, organizational units and technologies that implement the enterprise system. These models are then used to guide the evolution and development of the entire enterprise system. There is a plethora of modeling semantics and modeling rules that capture different viewpoints, e.g. users, requirements, data models, processes etc. Additionally, to guide the creation of models there exist a large number of frameworks, that define which models should be created and how these are related, see for example: The Open Group Architecture Framework *(The*

Open Group 2002) and the Federal Architecture Framework *(CIO Council 1998)*, or the Zachman Information Framework *(Zachman 1987)*.

The first section in this chapter presents some of the information systems management approaches that are being developed specifically for the needs in the power industry. One of these is the standardization efforts in IEC's Technical committee on Power System Management and related Information Exchange (TC57) and specifically the Common Information Model *(IEC 2003b)*. This reference is of specific importance to the work presented herein, since it has served as a base for the proposed modeling framework. The second section highlights some related work in the area of expanding the Common Information Model and its use from academia as well as from industry. The chapter is concluded with a brief review of the modeling framework created during this research project. The final section is essentially a summary of the contributions presented in papers D and E, with a focus on the relation between the framework and the concepts provided in this chapter.

3.1 POWER INDUSTRY INITIATIVES

The power industry has for a long time been well aware of the potentials and risks of using information and communication technologies (ICT) to support the operation and maintenance of transmission, distribution and generation. Historically there have been two parallel area of development within the ICT field which in the last 5-8 years are merging into one. Note that these areas are in no way opposing developments, the presentation below should be seen as a background to the developments leading to the creation of the Common Information Model.

The first area is the power industry's dependence on reliable wide area communications. The development here includes definition of more and more advanced protocols for communication between field devices, e.g. RTU:s, and central SCADA systems, but also protocols and functionality for local communication and control, see section 3.1.1 below. The other area within the ICT field being addressed by the power industry is, similar to what happens in other industries, the need to integrate information systems into a utility wide architecture and this is elaborated upon in sections 3.1.2 and 3.1.3.

3.1.1 WIDE AREA COMMUNICATIONS

In the area of wide-area communications, scientists and engineers in the power industry has pioneered new developments in communication technologies; see for example *(Cegrell 1975, Marihart 2001)*. From an industry perspective a number of initiatives and standards have emerged during the years. Notable among these developments is EPRI's Integrated Utility Communications Project, initiated in 1986, which resulted in an overall architecture named UCA – or Utility Communications Architecture. Among the outcomes of this project was the Intercontrol Center Comunication Protocol, ICCP, see for instance *(Robinson 1995)*. Another notable example is the development of the ELCOM- protocol among European

SCADA system vendors and the Norwegian Electric Power Research Institute, see *(Ericsson 1997)* for a comparison of the different protocols. In the mid-1990s the developments were more and more being merged into the standardization process of the IEC, resulting in communication protocols such as the IEC 60870. In parallel to this development, EPRI issued a revised and updated Utility Communications Architecture named UCA 2.0, which incorporated changes based on experiences of implementing the earlier standards *(IEEE 2001b)*. The output from UCA 2.0. was eventually proposed to the IEC as a suggestion for an international standard, this together with developments of protocols of European origin resulted in what is now the IEC 61850 set of standards *(IEC 2003d)*.

3.1.2 SYSTEMS INTEGRATION

In the area of systems integration, the prime developments have started from a SCADA/EMS perspective, with the event of the Common Information Model (CIM) standardized by the IEC. The CIM is based on the Control Center Application Programming Interface (CCAPI) project initiated by EPRI. The objective of the CCAPI was to facilitate the integration of Energy Management Systems developed by different vendors. The work has resulted in a standard *(IEC 2003b)*. Essentially the CIM is a model that contains all major objects at a utility and in its grid. The model includes classes and attributes for the objects and perhaps most importantly the relationships between the objects. For convenience the model is partitioned into several packages but it is actually one single connected class diagram. In essence the CIM is data-driven, by modeling the utility and its grid using Class diagrams the CIM provides a comprehensive view of the attributes and relations of data that will be managed in a utility's SCADA and EMS systems.

The initial focus for the system integration efforts was on EMS applications, but the scope

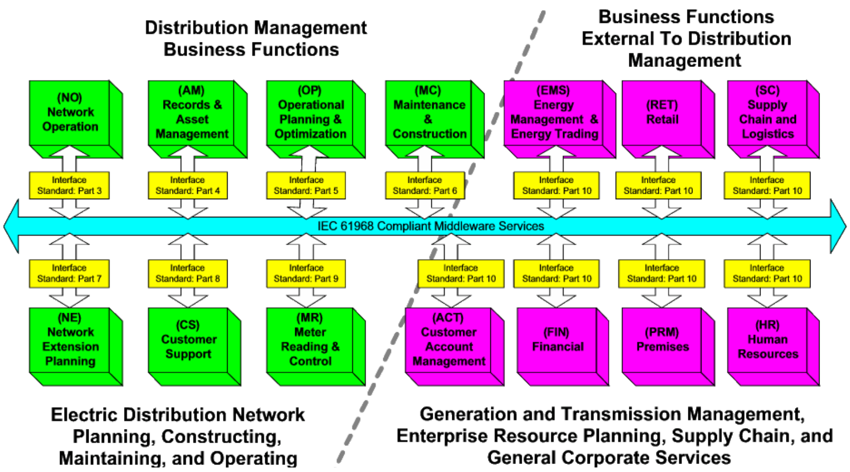

Figure 6 The vision for the activities in Working group 14 is a uniform architecture that supports data exchange between all types of applications

has grown and through the development of the IEC 61968 series *(IEC 2003a)* in working group 14 of TC57, the standards now intend to cover most aspects of IS integration at utilities. The standards in WG14 have two main components, the first and foremost are definition of messages to be exchanged between the systems in a utility wide infrastructure, see Figure 6.

These messages are defined based on use-cases of how systems interact to perform specific power system management tasks, such as dispatching generation or issuing a work order. As a consequence of defining these messages new data objects need to be added to the CIM, for example, the data object power cable needs different data attributes when viewed from an asset management perspective that from a power system model perspective. This forms the second part of the WG14 output.

The modeling of CIM is object oriented and uses concepts such as inheritance to preserve super-class attributes, making it possible that the extensions to the CIM in WG14 are relatively well adapted to the core CIM packages. Presently, the work in TC57 is very ambitious and covers a very broad spectrum of issues. Figure 7 below shows the entire scope of standardization activities within TC57.

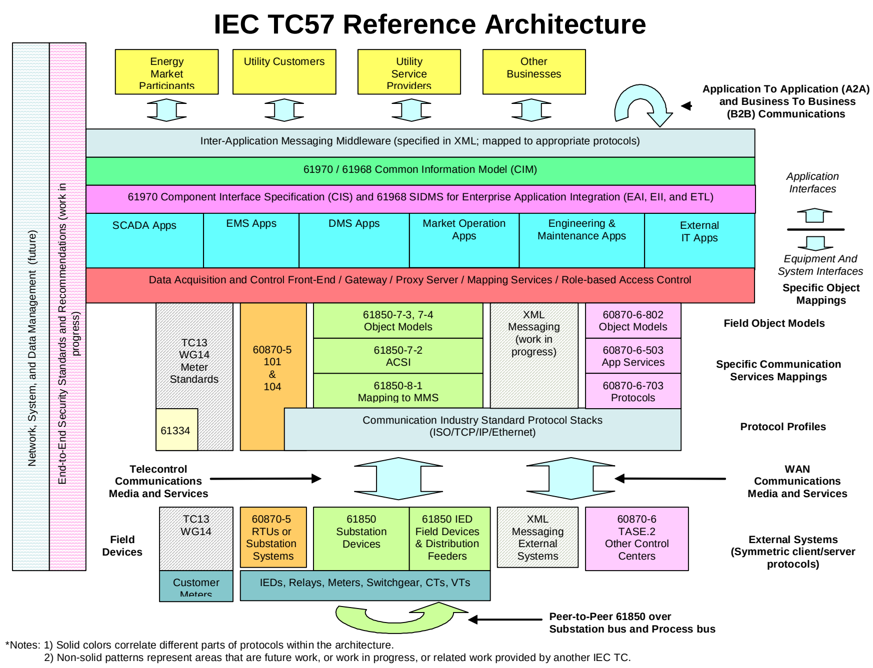

Figure 7 The TC57 reference architecture showing the relation between the standards being developed and where they are to be used in a utility wide information and communications architecture *(IEC 2003c)*.

It is natural that during the development of this work there will be conflicts and inconsistencies in the data. Some of the challenges are outlined in *(Britton 2005)* and *(Kostic 2003)*. Within TC57, these issues are being managed within a separate working group, WG19, with the task of coordinating the many activities within the entire TC57. It can also be argued to which extent the activities are complementary and consistent with general IT industry developments in the area of modeling and systems integration such as Service Oriented Architectures and the use of Web Services for integration.

In addition to the work within IEC, a number of extensions to address shortcomings of the CIM have been proposed by researchers and experts from industry, some of which has been included in the standardization process, see section 3.2.1. The entire CIM model is available online at (*www CIM User Group 2006)*. A comprehensive overview of all TC57 and related initiatives is given in *(IEC 2003c)*

3.1.3 INTELLIGRID

In parallel to the developments within IEC TC57 EPRI has for some time been developing an Enterprise Architecture Framework for the Power Industry within the Intelligrid project (www EPIR 2004). The architecture framework, which is conceptually similar to the TOGAF and FEAF frameworks *(The Open Group 2002, The CIO Council 1998)*, is named Integrated Energy and Communications Systems Architeture, IECSA, and can be seen as a continuation of the UCA 2.0 effort but now including information system integration aspects in a much wider sense. The specifications for the Intelligrid architecture *(EPRI 2003a)* reads: *"the Intelligrid Architecture is a set of high level concepts that are used to design a technology independent architecture as well as identify and recommend standard technologies, and best practices"*. The concepts include among other things the use of object models and modeling services to give standardized names to data, the IECSA proposes the use of the IEC TC57 standards, i.e. *(IEC 2003b, IEC 2003d)*, in this area The IECSA also includes development of security policies and implementation of security technologies as well as network and system management to monitor and control the information infrastructure in a manner similar to the monitoring and control of the power system.

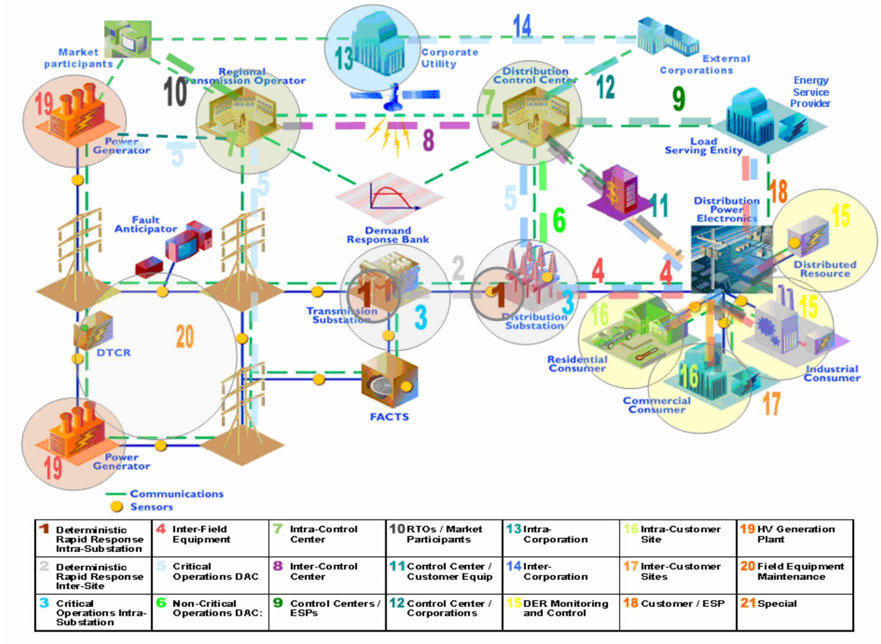

Figure 8 The Intelligrid architecture is based upon 21 different environments each having been the focus of specific efforts within the Intelligrid project.

The IntelliGrid Architecture is based on the concept of *Environments*, which is defined as a logical grouping of power system requirements that could be addressed by a similar set of distributed computing technologies. Within a particular environment, the information exchanges used to perform power system operational functions have very similar architectural requirements *(EPRI 2003b)*. The definition of the environments is based on Use Cases similar to those used in TC57 WG14. These Use Cases have been developed through active industry contribution in modeling workshops to ensure relevance and validity. Since the power system functions defined in these Use Cases may require multiple types of information exchanges, a particular power system function may cross several environments.

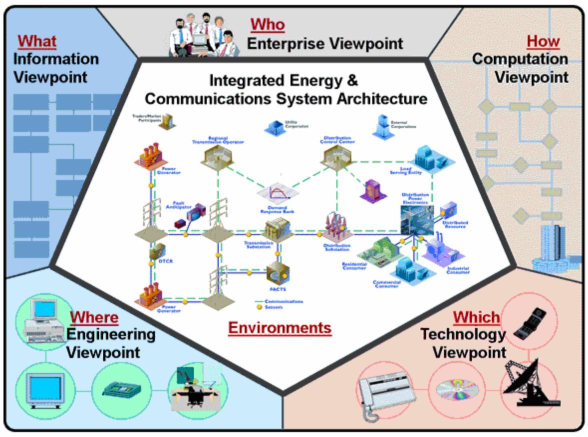

Figure 9 The 5 Architectural viewpoints expressed in the IECSA *(EPRI 2003a)*

Based on the Functional Requirements expressed in the environments, the IECSA team has developed a comprehensive UML meta-model that can be used to describe an integrated utility architecture from 5 different viewpoints, Information, Enterprise, Computation, Engineering and Technology. This structure is in turn based on the RM-ODP modeling framework *(ISO 1995)*. The idea is that this UML meta-model should be used by utilities in support of application development. Among other things, the meta-model provides a set of blocks for rapid prototyping of potential Use Cases. Logical interfaces between components – devices, computers, networks, and operators – can be tried out using the models created.

The concepts developed within the Intelligrid project are very much in line with the research presented in this thesis. The scopes of the efforts are of course different in size and to some extent also in focus. The Intelligrid initiative strives to enable the creation of future systems architectures through the use of models, not unlike other Enterprise Architecture Frameworks. The work presented herein also suggest the use of models to analyse system architectures, the focus is however on analysis of data quality issues and how this effects maintenance of distribution networks. Likely, some of the concepts created in the Intelligrid project can be used to address some data quality issues in legacy information system architectures, but it is not explicitly described or verified how this could be done.

3.2 RELATED WORK

As has been shown above, the Common Information Model and the related frameworks from TC57 form a platform on which to base modeling, design and implementations of systems. It is natural that under the course of such work, areas not explicitly covered by the frameworks will be discovered that requires extensions of the frameworks. This section provides an overview of some related research and development work in the area of extending and applying the CIM and the related frameworks. The section also contains references to, and a brief review of some related work in the area of modeling of information exchange especially related to asset maintenance of electricity distribution networks, not specifically related to the CIM.

3.2.1 EXTENSIONS TO THE CIM

Although the CIM is wide in scope and contains a large amount of data models, the application of the standard is bound to discover areas which are not well suited to some specific needs. For example in *(Wang 2003)* Wang proposes extension to the CIM to cover electric distribution networks and proposes modified models for distribution lines and distribution loads. Another example of extensions of the CIM in the area of power system maintenance is found in *(Dong 2002)* who proposes extension specifically related to maintenance information, such as measurement data, failure cases and documentation. Dong goes on to propose a digital library of equipment data based on the CIM which could potentially be used to share maintenance information between utilities. This is an interesting development of the CIM in an attempt to increase the contextual dimension of data within the context of maintenance, see section 2.1.1. This development has partly been adopted in soon to be published standards from TC57 on the subject of Asset Management *(IEC 2006)*. Clearly, should these extensions prove to be valid, this provides relevant input to the CIM as an ontology as it is used in this thesis. As is stated in section 2.1.2, the rationale for using the CIM as an ontology is that it represents a valid set of states in the electricity distribution network that should be represented in the information systems of the utility. The extensions proposed by Dong, and to some extent Wang serves to add to this subset of states.

Another area related to the CIM which is seeing a lot of attention is the relation between the data models in the CIM and the models specified in IEC 61850 standard for substation automation *(IEC 2003d)* For example both in *(Kostic 2003a)* and *(Zhanjun 2004)* work is presented on the subject of mapping the data models in the CIM to the data models in the 61850 standard. This is important to the maintenance of electricity distribution networks and this research since some of the data necessary for proper maintenance may be contained only in local systems in e.g. substations, in theory compliant with the 61850 standard. To gain access to such data and relate it to data models in central SCADA and NIS systems the relation between the two data models needs to be understood, and mappings created. If the whole utility automation system including Intelligent Electronic Devices, e.g. RTUs, is included in the Information System concept used in section 2.1.2, the states of the electricity distribution network represented by data in substations is included in the overall mapping. For the purpose of the framework proposed in this research this is of lesser importance given that the interface and mapping between the models in the CIM and the IEC 61850 standards are consistent. This is however debated, and the subject of research, see for instance *(Kostic 2003c)*.

3.2.2 APPLICATION OF THE CIM

There exist a relatively large number of references to different types of application of the Common Information Model, most of them are related to use of the CIM to exchange data. The researchers report experiences with implementing the standard and related protocols, a typical example in this field is the work presented by Vaahedi et. al. in *(Vaahedi 2001)* in which the experiences with implementing a CIM based data exchange mechanism is reviewed, another example can be found in *(Shenwin 2004)*. These two examples describe relatively straightforward applications of the CIM as it has been intended, i.e. in support of systems integration specifically for exchange of data between Energy Management Systems.

The work presented in this thesis is on application of the CIM that goes beyond its intended scope as a specification of system interfaces. In this particular field there are two related works which are of interest. The first by Newberry *(Newberry 2004)* seems to have a similar approach as that taken in the framework developed in this thesis. In Newberrys work the CIM has been used as a "vocabulary" to define terms to be used in system modeling. The work has been developed at Tennesse Valley Authority and resulted in implementation of an automated approach which takes business models, creates messages to be exchanges between systems, and links these to a corporate vocabulary in form of the CIM which makes the models easier understood by utilities. This work is different from that presented herein in the temporal domain at which it considers the systems and the data. In Newberry's work the models created are to be used as specifications of new systems to be procured or developed in-house. This is of course an important step in creating proper information systems support. However, the work presented in this thesis starts at an earlier stage by allowing analysis of legacy systems and how these are used by existing, or potentially future, business processes. By this difference in when the modeling is applied, the scope and results of the modeling effort are dissimilar. In Newberry's work, the output is "messages to be exchanged by future systems" in the work presented here in, the output is models that can be used to analyze data quality problems.

A second related study, by de Vos and Rowbotham *(de Vos 2001)* deals with the related subject of model transformations between systems managing same or similar data. This work is also very much related to that presented herein. The focus of the work presented by DeVos lies on model transformations between power network models in EMS applications, essentially at the core of the field of application of the CIM. The work is however interesting since it is related to how models of similar equipment are different in different systems. In the research presented herein, similar model inconsistencies appear between for instance NIS and SCADA systems, which has contextual and representational implications on the data quality. The work presented by DeVos relates to similar models of different granularity in the representation, and differing modeling schema, which is related to the intrinsic quality attributes of data.

The concept of using the CIM as a vocabulary, or ontology, is as stated the focus of the research presented in this thesis. Similar work is presented by Neumann et.al. who in *(Neu-*

mann 2006) provide examples of how the CIM could potentially be used as an ontology and describes some issues that, if managed would increase the usefulness of the CIM as an ontology. This work is very interesting and also in line with developments within the standardization bodies involved. It is of specific importance since systems integration using ontologies is in line with the recent developments within the W3C on the subject of Web ontologies (*www W3C 2006)* in support of Service Oriented Architectures. Again, the work is different from that presented here by the assumptions in Neumann's work that the system integration effort can be made from scratch using a Greenfield approach, while the framework in this research explicitly acknowledges the existence of legacy systems and data. Additionally, there is a difference in focus in that this research specifically considers maintenance of electricity distribution, whereas the concepts presented in Neumann's work takes a wider scope starting with operational systems.

3.2.3 INFORMATION MODELING FOR ASSET MANAGEMENT

During the work presented in this thesis a number of different approaches to manage the problem of data quality in power system maintenance was studied. The concept of process and system modeling in order to identify system dependencies is well established and this section presents related pieces of work on the subject that are of interest although they do not utilize the CIM as ontology.

In *(Werner 2000)* Werner et al. presents an XML based notational framework to facilitate exchange of information between applications involved in power system maintenance. In the paper the authors present an examination on how two specific systems interact and how the data exchange between these systems can be described in XML. The framework presented could very well be modified to include the CIM as a base for the information exchange. In this case the ideas and concepts would be very similar to those presented herein. However, there would still be a difference in that the work we present here takes it output in the maintenance process at the utility, and not how two specific systems interact. The same group of researchers proposes a component based architecture for information systems for asset management in *(Vetter 2000)*. This work builds on that presented in *(Werner 2000)* and describes the system architecture from a component perspective. Again, this work is related to the framework presented herein, the difference lies in that while the work presented by Vetter propose a systems architecture it is not clear how data quality issues can be addressed by this architecture.

In *(Huo 2003)* Huo and Zhang presents an approach to implement information systems support for power system maintenance. The approach involves five steps, Identify Asset, (2) Identify Performance Requirements, (3) Assess Performance, (4) Plan Maintenance, (5) Manage Maintenance Operations. In the paper some of these steps are described in details and models of the maintenance planning step are in IDEF0 format are presented. The idea is that these models should support the implementation of the information systems. The work is related to that presented herein, by taking a similar starting point in the maintenance processes, and creating models of these. Using the models created by Huo and

Zhang it may very well be possible to examine data and system dependencies using for instance the CIM as an ontology.

In short the work presented in this thesis is different from those presented above in that it explicitly utilizes an established standard, the CIM, as a basis for the analysis, and also that it considers existing legacy systems in the analysis. However, seen in a larger and longer-term perspective the work is very much related and could very well be combined to provide not only analysis of existing systems but also design guidelines or architectures, similar to those presented by Vetter et. al. including use of the CIM.

3.3 THE FRAMEWORK IN REVIEW

One of the main contributions of this research project is the formulation and evaluation of a modeling framework, specifically adapted to analyze information systems support for maintenance of electricity distribution networks. The framework was developed over a period of time and eventually tested in a real world setting at a distribution utility. The area of application of the framework was inspection and planning of maintenance of medium voltage over-head lines. The development and testing of the framework is reported on in papers D & E of this thesis. However, to provide a more complete picture of the framework than that presented in papers D& E, and also to highlight the relation to other work presented in this chapter, the framework is described in this section.

3.3.1 MAIN CHARACTERISTICS

As has been presented, utilities are faced with several challenges when managing their portfolio of information systems. Power system maintenance processes span several aspects of a utility's business *(Kostic 2003b)* and is dependant on several legacy systems *(Lundqvist 2002)*. The maintenance processes thereby also involves many organizational units within the utility involving many end-users. Finally, power system maintenance is dependant on high quality data about the status of equipment in the field *(Endrenyi 2001, Sherwin 2000)*. When developing the framework, the top problems to be addressed where consequently those of data quality, dependence on legacy systems, and user interaction in terms of managing end-user requirements.

Influenced by Wand and Wang *(Wand 1996)*, it is proposed that the models shall be created using a standardized well-defined terminology for the data objects in the power system, an ontology. The framework has therefore been based on the Common Information Model *(IEC 2003b)*. By doing so, the problem of bias towards existing systems and their ontologies is avoided. Additionally, by basing the models on an external ontology, objects that may not represented in the legacy infrastructure, but nevertheless exist in the real world are included. Although the TC57 standards are intended to create specifications for new systems, they do not hinder the analysis of legacy system architectures. By including information about which legacy system is used to manipulate the data objects the framework shows how the maintenance processes interact with the legacy systems

Finally, to manage the challenge of several end-users with different expectations and requirements the modeling process has been specifically designed with this in mind. The modeling approach as such takes it output in the end-users current work-flow, and follows the activities step by step and documents systems used and data manipulated. As a reference work-flow during the design of the framework, the EBR *(www EBR 2006)* specifications, which is a well-documented set of maintenance procedures utilized among Swedish utilities, have been used. The UML models created are therefore relatively straight forward to understand for a non-expert.

3.3.2 PROCESS AND OUTPUT

Essentially, the modeling approach consists of three main steps and provides UML models of maintenance processes and related information systems as its output. The framework is based on using Assembly line diagrams introduced by Eriksson-Penker *(Eriksson 2000)*. Furthermore the approach uses classes defined in CIM and its extensions. Additionally, the abstract components listed in the IEC 61968 standard *(IEC 2003a)* are used to identify functional overlap. The underlying philosophy is to use existing tools and standards, in this case UML with extensions and the TC57 standards. The approach consists of three steps described in detail below.

FIRST STEP – DEFINITION OF INCLUDED ACTIVITIES

Since the analysis starts from the business processes involved, e.g. inspection or outage management, the first step involves defining the starting and ending activity and thereby set a scope for the ensuing modeling effort. Once the start and end has been determined, the involved processes are broken down into activities. These activities may already have been documented and defined in the utility's working processes, or they may be less well defined. Depending on the level of definition the effort needed to determine these activities will vary. In the case study conducted as part of our research the processes were based on standardized maintenance activities described in *(www EBR 2006)*.

SECOND STEP – IDENTIFICATION OF DATA CLASSES

The second step involves the most work, and requires the analyst to spend time with utility staff working in the processes to observe their work to learn about the steps involved in the activities and which data is accessed and created. The resulting information is documented in assembly line diagrams, see Figure 10 and Figure 11 for examples.

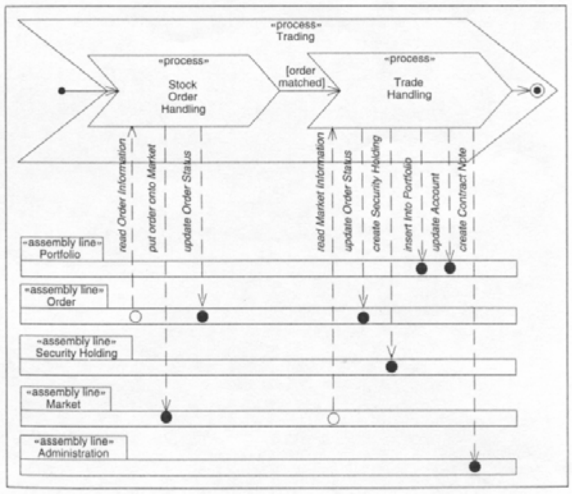

Figure 10 Example of an assembly line diagram showing the process work-flow (top) and the data objects manipulated (bottom), figure from *(Eriksson 2000)*

To add a level of detail to the assembly line diagrams, the systems used to access or write data is noted on the arrow connecting the activity with the data layer. The data objects in the data layer form the important connection to the CIM ontology, since they are taken directly from the standard.

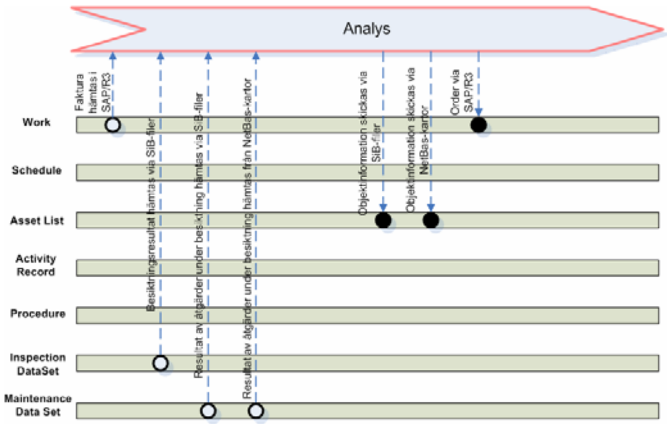

Figure 11 Example of a diagram created during the case study involving planning and maintenance of medium voltage over-head power lines.

Users are often very familiar with the concept of systems and less familiar with the more abstract concept of objects. Therefore it is feasible to capture the information about which legacy systems are used in the maintenance processes during the analysis and modeling.

THIRD STEP – FUNCTIONALITY MAPPING

The final step involves determining which system functionality is available and how this is distributed over different systems. Here, the Assembly line diagrams created during the second steps are used in conjunction with the abstract component listing from *(IEC 2003a)*. From the diagrams created in step 2, the systems involved can be identified, and depending on activity and data used, the related abstract component can be identified.

The results of the functionality mapping is a matrix, having systems on the horizontal axis and abstract components as defined in *(IEC 2003a)* on the vertical axis, see Table 3 below.

Abstract Component	System A	System B	System C
Trouble call handling and coherency analysis	X		X
Protective relays analysis	X		
Fault location by analysis of fault detectors and/or trouble call localisation	X		X
Supply restoration assessment		X	
Customer incident information			X

Table 3 Mapping of system versus abstract component defined in IEC 61968-1

3.3.3 OUTPUT AND DOCUMENTATION

The Assembly Line diagrams created during the second step of the modeling effort provide consistent documentation of the interaction between business processes and classes of data in various information systems. By analyzing the models, information can be gained on potential overlap or duplication of data, an important data quality issue, see section 2.1.1. For example, if two parallel arrows connect an activity and the same class, both for instance reading data, but doing so from different systems, there is a risk of data of the same object being stored in multiple locations.

Using the terminology from section 2.1.2 the phenomenon can be explained as that the activity references an object from the real world, that is mapped to one object in the Information System and that these objects are instantiated in different systems at the utility. The term object is here used in an abstract sense as a container of states. An example would be pole which has a set of attributes such as location, height and line. These values of these attributes are examples of states in the real world and in the information system.

The functionality matrix created during the third step provides an easily accessible overview in which system that an abstract component has been implemented. Should there be several systems which provide functionality related to one single abstract component, it is a clear indication of functionality sharing or overlap.

The benefit of using the approach is that it provides a straightforward method to create consistent documentation of use of data and functionality across several systems. The output created consist of unambiguous UML models, and standards based functionality listing in which data and functionality duplication and overlap can be identified and documented.

Chapter 4

Summaries of Included Papers

This chapter provides an overview of the publications included in the thesis. The order in which the papers are presented here reflects the chronological order in which the presented work was conducted, e.g. the work resulting in paper B was conducted before the work presented in Paper C. This is not necessarily reflected in the publication dates of the papers.

For each of the papers a brief summary of the contents is given. Additionally, the relation of the paper to the overall project is elaborated upon.

PAPER A

Strategies for Implementing IT support for Asset Management at Electric Utilities.

Narcisa Jonsson and Lars Nordström

In Proceedings of International Conference on Power System Technology, Singapore, Singapore, 2004.

Paper A presents the result of a survey on IS support for Asset Management conducted during the fall of 2003 in Sweden. The survey included nine power distribution utilities of varying sizes. The rational for the survey was to get a better understanding of the industrial problem identified at the outset of the research project. Secondly the purpose was to investigate where the utilities where focusing their efforts to implement information system support for power systems maintenance.

In general the surveyed utilities where very "IT friendly" and displayed a high adoption of use of information systems in operations. All surveyed utilities show a high degree of investment in information systems and related technologies. Also, the level of usage of IT among staff was very high. Although questions on the level of usage where not included in the survey it became apparent during the discussions that almost all employees across all utilities used computers daily. The only *blind spot* was usage among field crews. Most field maintenance staff put little trust in the IT tools provided, and as a rule brought printouts with them out in the field. However, the vast majority of the utilities, with the exception of one, were planning or investigating methods to enable use of IT support also in the field. Although IT systems were abundant at the utilities and usage was high, most users worked in isolation without efficient ways to collaborate with others through the systems. Furthermore the level of integration between the existing systems was low. In many cases, data could not be transferred between systems without a user intervening to "copy and paste" or e-mail the needed data.

This paper contributed greatly to improving the understanding of the industrial problem which constituted the project definition for the research project. The results from the survey clearly showed that although the utilities have a large portfolio of information systems to support their maintenance processes, much remains undocumented and unsupported by the systems. The study was also important in pointing out the challenges to data quality that exist in the large and heterogeneous system architectures at the utilities. The data, although present in the systems, is not used since it is not easily accessible – an accessibility data quality problem. Alternatively the data can be accessed but is on a format not easily adapted to the needs – indicating a contextual data quality problem.

PAPER B

A Broadband Wide Area Network as an enabler of Improved Power System Maintenance

Lars Nordström and Göran N. Ericsson

In IEEE Transactions of Power Delivery Volume 21, Issue 1, Jan. 2006 Page(s):108 – 112..

This paper presents a parallel effort to that of the ontology based modeling framework forming the main contribution of the research work. The idea with the paper was to investigate and document new opportunities that appear when developments in the areas of power system communications and power system maintenance are studied in conjunction. The main focus here is to elucidate the implications with a broadband utility WAN as an enabler for improved maintenance. An obvious area in which improved communication would benefit power systems maintenance is through increased availability of data - directly addressing one aspect f the accessibility problem. The input to the research regarding information systems support for power system maintenance comes from the survey reported on in Paper A.

Communication is and will increasingly be a necessary tool for the operation and maintenance of the power network, as well as for administrative purposes. With the introduction of broadband utility WAN, improvements will mainly be found in communications for administrative operational purposes. Here, the broadband possibilities will act as an enabler for transmitting large bulks of data from end to end. It is also in this class of communication that the bulk of maintenance data belongs. In this paper the implications of using a broadband WAN is elucidated for each of the functional areas presented in Paper A. In general, the high-speed communications make it possible to transfer large amounts of data, providing the actual means of more structured handling of data loads. For example, byte-size demanding maps, drawings, manuals, etc., can now be transferred in digital form to/from the central office and a substation. Since relevant data about the power system equipment is the key to successful maintenance, this development is critical for future development of maintenance processes. The study described contributes indirectly to the results in the research project. Although the main focus of the research project is on modeling and analysis of information systems to better understand challenges to data quality. A necessary step to improve the accessibility category of data quality is to employ new technologies. By employing wide area communications more data can be gathered about the field equipment and this paper presents the areas in which this development is likely to have the greatest impact.

PAPER C

Approaches for Achieving IT support for Asset Management

Lars Nordström

In proceedings of 18th International Conference on Electricity Distribution CIRED 2005, Turin Italy.

The main contribution of this paper is that it points out a potential conflict between the development of the IEC 61968 standards for information systems integration, and other developments in the industry, e.g. the employment of large ERP suites. The paper provides an overview of different system integration approaches, and relates these to the developing standards in the IEC TC57.

Among utilities the EAI approach is currently the one most favored, see for example (*Vojdani 2003)* or *(Becker 2000).* The EAI approach is also being promoted by the standardisation efforts in IEC TC57 WG14, were work is being done to standardize the information exchange mechanisms between system components on a utility information bus. The choice of the EAI approach is perhaps natural with utilities having so many domain specific engineering systems, e.g. Load flow, SCADA, short circuit calculation, etc. than for instance an insurance broker or a logistics company. The heterogeneous system architecture at a utility can simply not be contained within one comprehensive ERP solution. However, the EAI approach does not preclude the use of an ERP suite of software within the information systems architecture.

As described in *(Vojdani 2003)* EAI can very well be used to integrate systems from across the domains of business and technical support. The presentation in *(Becker 2000)* recommends the use of the Common Information Model (CIM. and the information exchange mechanisms in *(IEC 2003b).* to enable this cross domain integration. By standardizing data formats and information exchange, integration between technical and business systems is facilitated. For Asset Management this is very valuable since cross domain integration is required for successful information systems support. In the following section some especially important aspects to consider for Asset Management are presented.

This paper introduces the challenges apparent when introducing information systems support for Asset Management. Since Asset Management spans so many organizational departments and requires support from many systems it would benefit greatly from a truly Integrated Utility. However, when using current integration approaches to achieve this Integrated Utility vision, two additional aspects need to be considered. These are the relation between Business Process and data and the allocation of this data over the existing and new systems. The paper argues that analysis of legacy systems and the relation between business processes and systems two aspect can and should be done using the standardized CIM framework and well established UML extensions.

PAPER D

Extended UML Modeling for Risk Management of Utility Information System Integration

Lars Nordström and Torsten Cegrell

In Proceedings of the IEEE Power Engineering Society's General Meeting, San Francisco, USA, 2005.

The main contribution of this paper is the presentation of the framework for information systems analysis developed as part of this research project. In the paper, the focus has been put on risk management of information system integration in general. This is a much more general concern than that of ensuring high level of quality in data, which is the main topic of the overall research project.

In the paper, it is argued that although the power industry initiatives described in section 3.1 above goes a long way to manage some of the risks of failure in IS projects; they support management of too few of the typical risks, specifically those introduced by the lack of interaction between business process and information systems. Of specific interest in Paper C are the risks of changing scope, conflict between user department and perhaps most importantly failure to manage end-user expectations. Of these the latter two, are of specific importance for managing data quality issues, since they relate to the accessibility and contextual dimensions of data quality. To the extent that the framework can reduce conflicts between user departments, the contextual dimension of data quality can be improved. This is so because reduced risk of conflict leads to possibilities of defining data models adapted to a wider context of use. To manage the challenge of several end-users with different expectations and requirements the modeling process the modeling approach starts from the end-users current work-flow, and follows the activities step by step and documents systems used and data The UML models created are therefore relatively straight forward to understand for a non-expert.

The purpose of the paper is to present the modeling approach based on a novel application of a set of UML extensions to include analysis of the utility's maintenance activities interaction with Information Systems. The Common Information Model provides a good basis for analysis it, understandably, fails to address some important risks in IS projects. The CIM and the standards are data oriented, and focus on the important aspect of relations between classes. However many of the risks involved in IS development is related to the organization and users that will use the new or integrated ISs. Hence, the contextual and accessibility dimensions of data quality may not be properly addressed. By including the business processes in the analysis and modeling of the systems, these additional aspects can be analyzed. Additionally, by using classes from the CIM ontology and use them in the combined Activity and Assembly Line diagrams, it is ensured that the created business models are consistent with the standards.

PAPER E

Analyzing Utility Information Systems Architecture using the Common Information Model

Lars Nordström and Torsten Cegrell

In Proceedings of 2nd CIGRE / IEEE PES International Symposium on Congestion Management in a Market Environment, San Antonio, USA, 2005.

The main contribution of this paper is the report on the application of the proposed framework. The paper presents experiences with applying the modeling approach, using established notation and standards that can be used to analyze utility-wide information system architectures. There already exist several frameworks and methods that support modeling and analysis of such architectures. The contribution of the work presented in this paper, is that the modeling has been done with the Common Information Model *(IEC 2003b),* as a basis, and experiences from this application are reported upon. The performed case study shows that use of the CIM in the proposed modeling approach has facilitated analysis of distribution of functionality over systems as well as risks of low data quality in the of accessibility and contextual categories.

The evaluation was performed as a case study at one of the larger electric utilities in northern Europe. The area chosen for the case study was over-head power line maintenance, since this is an activity that spans several departments of the utility as well as relying on several support systems for planning execution and follow up of the activities. The scope of the case study was set to create a model of the activities related to planning and execution of inspection of over head power lines. The primary goal of the case study was however not develop models with the purpose of improving existing activities and systems. Rather the primary goal was to evaluate the proposed modeling approach and comment on the results gained. The utility was conducting a comprehensive modeling and process re-engineering effort in parallel to the modeling done in the case study.

The experiences of the application are that the approach is similar to other approaches and provides nothing new in terms of methodology or tool support. Additionally, a complete analysis of enterprise wide information systems architecture needs to include other models to capture such aspects as performance, security and system interfaces. However, the benefits in using this approach is the use of the ontology available in the CIM as framework for the modeling effort as well as relying on the abstract components defined in *(IEC 2003a)* By using these components as a base, the created model is compliant with existing standards, and the functionality is documented in a format consistent with contemporary standards.

.

Chapter 5
Concluding Remarks & Further Work

There is already work in progress continuing on the results presented in this thesis as well as work happening in parallel. This section presents some concluding remarks on the research presented herein as well as ideas for further studies, some of which have been picked up by others, and some of which are for potential study by this author or other researchers.

5.1 CONCLUDING REMARKS

As has been presented, utilities are faced with several challenges when managing their portfolio of information systems. One of the challenges is that power system maintenance processes span several aspects of a utility's business and is dependant on several legacy systems. The maintenance processes involve many organizational units within the utility thus involving many end-users. At the same time sophisticated power system maintenance methods are dependant on high quality data about the status of equipment in the field. The research reported in this thesis consists of several studies approaching the problem outlined above.

Although the TC57 standards are intended to create specifications for new systems, they do not hinder the analysis of legacy system architectures. The framework proposed in this research shows that it is possible, and beneficial, to use the IEC standards in analysis of legacy systems. By including information about which legacy system is used to manipulate the data objects the framework shows how the maintenance processes interact with the legacy systems.

Naturally, the approach needs further refinement before it can be used full scale to analyze information systems architecture. First it fails to address many important aspects of information systems architectures such as performance and security. Second, it can be argued that the approach requires a significant amount of work, and the "only" output is a blueprint of the current systems and processes. The migration forward will then require engineering of future processes and systems, which will require an equal effort. Third, the abstract components used in the functionality mapping are but one of many possible functional descriptions of systems at a utility.

In summary, the studies and framework developed have proven useful, and the fact that ensuing studies have already been conducted serves to prove that the results have been relevant.

5.2 FURTHER WORK

The further work presented here consists of both potential and already started projects.

DISTRIBUTION OF COMPONENT DATA

The project has shown that data on power grid components (breakers, transformers etc) and their subcomponents regarding usage, previous problems, performed repairs etc is not consistently managed within power utilities. The reasons include legacy equipment not providing online access, to the same component being managed by several systems but from different perspectives, e.g. information about a breaker being available both in SCADA, CMMS, and substation control systems. As a continuation of this project a study that aims at creating taxonomy of data abstraction levels related to component reliability could be conducted. Ideally, the taxonomy is consistent with the component models being created in IEC 61968-4/5/11. The purpose of the taxonomy is to support creation of guidelines for data storage to facilitate condition based maintenance but also as input to reliability-centered maintenance planning.

PERFORMANCE ASPECTS OF STANDARD COMPLIANT INTEGRATION

Integration of technical support systems, e.g. SCADA, into utility-wide enterprise architecture opens up many possibilities as well as threats. When deciding on choice of methods and tools for integration criteria such as security, performance, and maintainability need to be considered. However, these factors, and other, are interdependent making the choice of integration approach less than trivial. A project focused on evaluating the interrelation between performance and maintainability would be interesting. Integration done compliant with IEC 61968 can be compared with more simplistic integration. An evaluation can then be made of performance versus maintainability to find a trade-off between openness and performance. In general suitable follow-on projects include more formalized and automated approaches to decision-making in the maintenance processes. Options here include use of Bayesian Network based algorithms for which data to use when taking decisions on maintenance actions, and how this data must be made available from the various systems. In short, the goal may be changed from creating a perfect system architecture to that of having decision support tools that facilitate the process of finding the right information at the right time from the right system.

List of Publications

The work presented in this doctoral thesis has resulted in a number of publications, not all included in this thesis. The complete list of publications, in order of publication date, is presented below:

M. Ekstedt, P. Johnson, Å. Lindström, E. Johansson, L. Nordström "Management of Enterprise Software System Architectures: Focusing on Information Economy and Model Consistency" Proceedings of the Second Conference on Software Engineering Research and Practice in Sweden, SERPS'03, Lund, Sweden, October 23-24, 2003

M. Gammelgård and L. Nordström "Effects of new regulatory frameworks on utilities investment in Asset Management" In Proceedings of ICOMS 2004 International Conference of Maintenance Societies 2004, Sydney, Australia, May 25-27, 2004.

N. Jonsson, L. Nordström "Strategies for Investment in IT Systems for Asset management" In Proceedings of NORDAC 2004, Nordic Distribution and Asset Management Conference, Espoo, Finland, 23-24 August, 2004.

N. Jonsson, L. Nordström "Strategies for implementing IT support for Asset Management" In Proceedings of Powercon 2004 International Conference on Power System Technology, Singapore, Singapore,21-24 November 2004.

L. Nordström "Approaches for Achieving IT support for Asset Management" In Proceedings of CIRED 2005 18th International Conference and Exhibition on Electricity Distribution, Turin, Italy, 6-9 June, 2005.

M. Simonsson, Å. Lindström, P. Johnson, L. Nordström, J. Grundbäck, O. Wijnbladh "Scenario-based Evaluation of Enterprise Architecture: A top-down Approach for Chief Information Officer Decision Making" Proceedings of 7th International Conference on Enterprise Information Systems, Miami, USA, May 24-28, 2005.

L. Nordström, T. Cegrell "Extended UML Modeling for Risk Management of Utility Information System Integration" In Proceedings of the IEEE Power Engineering Society's General Meeting, San Francisco, USA, June 12-17, 2005.

L. Nordström, T. Cegrell "Analyzing Utility Information Systems Architecture using the Common Information Model" In Proceedings of 2nd CIGRE / IEEE PES International Symposium on Congestion Management in a Market Environment, San Antonio, USA, October 5-7, 2005.

L. Nordström, G. Ericsson "A Broadband Wide Area Network as an Enabler of Improved Power System Maintenance" In IEEE Transactions of Power Delivery Volume 21, Issue 1, Jan. 2006 Page(s):108 – 112

References

Allan, D. M. (2005), "Asset Management Challenges in Ageing Power Systems", In Proceedings of 2005 International Symposium on Electrical Insulating Materials, June 5-9, 2005, Kitakyushyu, Japan.

Armour, F., Kaisler, S., Liu, S. (1999), "A Big-Picture Look at Enterprise Architecture", IEEE IT Professional Vol. 1, No 1, 1999.

Armour, F., Kaisler, S., Liu, S. (1999b), "Building an Enterprise Architecture Step by Step", IEEE IT Professional Vol. 1, No 4, 1999.

Ballou, D.P., Pazer, H.L (1985), Modeling data and process quality in multi-input, multi-output information systems, Management Science Volume 31 No 2, 1985, pp. 150–162.

Ballou, D.P., Tayi, G.K. (1989), Methodology for allocating resources for data quality enhancement, Communications of the ACM Volume 32 No 3, 1989, pp. 320–329.

Ballou, D.P., Pazer, H.L. (1995), Designing information systems to optimize the accuracy–timeliness trade off, Information Systems Research Volume 6 Number 1, 1995, pp. 51–72.

Ballou, D.P., Wang R.Y. (1998), Pazer, H., Tayi, G.K., Modeling information manufacturing systems to determine information product quality, Management Science Volume 44 Numeber 4, 1998, pp. 462–484.

Becker, D., Falk, H., Gillerman, J., Mauser, S., Podmore, R., Schneberger, L. (2000), "Standards-Based approach Integrates Utility Applications" in IEEE Computer Applications in Power, October 2000.

Bertling, L., (2002) "Reliability Centered Maintenance for Electric Power Distribution Systems", Ph.D. Thesis, Royal Institute of Technology, Stockholm, Sweden, ISBN, 91-7283-345-9

Bertling, L., Allan, R., Eriksson, R. (2005), "A Reliability-Centered Asset Maintenance Method for Assessing the Impact of Maintenance in Power Distribution Systems" IEEE Transactions on Power Systems, Vol. 20, No. 1, February 2005.

Bertling, L. (2005b), "On evaluation of RCM for maintenance management of electric power systems" In Proceedings of Power Engineering Society General Meeting, 2005 June 12-16.

Britton, J., DeVos, A. (2005), "CIM based standards and CIM evolution" In IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005.

Brown, R.E., Humphrey, B.G (2005), ”Asset Management for Transmission and Distribution” IEEE Power & Energy Vol 3 No: 3 May/June 2005.

Cegrell, T (1975), “A Routing Procedure for the TIDAS Message-Switching Network” In IEEE Transactions on Communications Volume 23, Issue 6, Jun 1975 Page(s):575 – 585.

CIO Council (1999), “The Federal Enterprise Architecture Framework Version 1.1”, Chief Information Officer Council, 1999.

Dong, X., Liu, Y., LoPinto, F.A., Scheibe, K.P., Sheetz, S.D. (2002), “Information Model for Power Equipment Diagnosis and Maintenance”, In Proceedings of Power Engineering Society Winter Meeting, 2002. IEEE, 2002.

DeVos, A., Rowbotham, C.T. “Knowledge Representation for Power System Modelling” In proceedings of 22nd IEEE Power Engineering Society International Conference on Power Industry Computer Applications, 2001. 20-24 May 2001 Page(s):50 - 56

Ekstedt, M. (2004), Enterprise Architecture for Information Systems Management, Ph.D. Thesis, ETS, 2004.

EPRI, Electric Power Research Institute (2003a), “The Integrated Energy and Communications Systems Architecture, Volume I User Guidelines and Recommendations”, EPRI, Palo Alto, CA and Electricity Innovation Institute, Palo Alto, CA:2003.

EPRI, Electric Power Research Institute (2003b), “The Integrated Energy and Communications Systems Architecture, Volume II Functional Requirements”, EPRI, Palo Alto, CA and Electricity Innovation Institute, Palo Alto, CA:2003.

EPRI, Electric Power Research Institute (2003c), “The Integrated Energy and Communications Systems Architecture, Volume III Models”, EPRI, Palo Alto, CA and Electricity Innovation Institute, Palo Alto, CA:2003.

EPRI, Electric Power Research Institute (2003d), “The Integrated Energy and Communications Systems Architecture, Volume IV Technical Analysis”, EPRI, Palo Alto, CA and Electricity Innovation Institute, Palo Alto, CA:2003.

Elforsk (2002), “Programbeskrivning EFFSYS Effektivt Systemutnyttjande i Elkraft och Skogsindustrin” In Swedish, Elforsk, 2002, Available at http://www.elforsk.se/effsys

Endrenyi et.al (2001). “The present status of Maintenance Strategies and the impact of Maintenance on Reliability”, IEEE Transactions on Power Systems, vol. 16, No 4, pp. 638-646, Nov.,2001.

Ericsson, G., Johnsson, A. (1997) “Examination of ELCOM-90, TASE.1, and ICCP/TASE.2 for inter-control center communication” In IEEE Transactions on Power Delivery Volume 12, Issue 2, April 1997 Page(s):607 - 615

Eriksson, H-E., Penker, M. (2000), “Business Modelling with UML -Business Patterns at Work”, New York : John Wiley & Sons, 2000, ISBN: 0471295515

Gammelgård, M., Nordström L. (2004) “Effects of new regulatory frameworks on utilities investment in Asset Management” In Proceedings of ICOMS 2004 International Conference of Maintenance Societies 2004, Sydney, Australia, May 25-27, 2004.

Goodfellow, J.W., (2000) “Applying Reliability Centered Maintenance (RCM) to Overhead Electric Utility Distribution Systems” In proceedings of Power Engineering Society Summer Meeting, 2000, 16-20 July 2000.

Hipkin, I (1997). "The implementation of information systems for maintenance management", in International Journal of Production Research, Vol. 35, no 9, 1997, pp 2429-2444.

Huo Z., Zhang Z. (2003), "CMMS and Its Applications in Power Systems", In Proceedings of IEEE International Conference on Systems, Man and Cybernetics, 2003.

IEEE (2001) Institute of Electric and Electronics Engineers, IEEE, Standard 1471, 2001.

IEEE (2001b) Institute of Electric and Electronics Engineers, "Fundamentals of Utilities Communication Architecture" In Computer applications in Power Publication Volume: 14 Issue 3, page(s): 15 – 21, July 2001

IEC (2003a), International Electrotechnical Commission, "IEC 61968-1 Application integration at electric utilities – System Interfaces for distribution management Part 1: Interface Architecture and General Requirements", IEC Reference number IEC 61968-1:2003(E).

IEC (2003b), International Electrotechnical Commission, "IEC 61970-301 Energy management system application program interface Part 301: Common Information Model (CIM) Base", IEC Reference number IEC 61970-301:2003(E).

IEC (2003c), International Electrotechnical Commission, "IEC TR 62357 Power System control and associated communications – Reference Architecture for object models, services and protocols" IEC Reference number IEC/TR 62375:2003(E).

IEC (2003d), International Electrotechnical Commission, IEC 61850-1 Communication networks and systems in substations – Part 1: Introduction and overview" IEC Reference number IEC/TR 61850-1:2003(E)

IEC (2006) International Electrotechnical Commission, "(Future) IEC 61968-4 Application integration at electric utilities – System Interfaces for distribution management Part 4: Interface Standard for Records and Asset Management", To be published..

Ip, W.H., Lee, K.C., Yung, K.L., Yam, R. (2000), "SCADA in an integrated maintenance management system" In Journal of Quality in Maintenance Engineering Vol 6, No. 1, pp 6-19, 2000

ISO/IEC (1995) "Open Distributed Processing Reference Model Part 3: Architecture" ISO/IEC 10746-3: 1995.

Katayama, S., Tsuchiya, T., Tanaka, T., Tsukui, R., Yusa, H., Otani, T. (2002), "Distributed Real-time computer Network Architecture – Power Systems Information Model coordinated with Agent Applications" In Proceedings of Transmission and Distribution Conference and Exhibition 2002

King, G., Keohane, R., Verba, S. (1994), "Designing Social Inquiry: Scientific Inference in Qualitative Research", Princeton University Press, 1994.

Kostic, T., Preiss, O., Frei, Ch. (2003a), "Towards the Formal Integration of Two Upcoming Standards: IEC 61970 and IEC 61850" In Proceedings of Conference on Large Engineering Systems, 7-9 May 2003.

Kostic, T. (2003b), "Asset Management in Electrical Utilities: How Many Facets It Actually Has" In Proceedings of Power Engineering Society General Meeting, 2003, 13-17 July 2003.

Kostic, T., Preiss, O., Frei, C. (2003c), "Understanding and Using the IEC 61850: A Case for Meta-Modelling," Elsevier Journal of Computer Standards & Interfaces, vol. 27/6, pp. 679-695, 2005.

Lee, Y.W., Strong, D.M., Kahn, B.K., Wang, R.Y. (2002), "AIMQ: A methodology for information quality assessment" International Journal of Information & Management, No 40, 2002, pp. 133-146.

Lundqvist, C-G., Jacobsson, J. (2002), "Enhancing Customer Services by efficient integration of modern IT-systems for Asset Management and Network Operation", In Proceedings of 2002 International Conference on Power System technology, PowerCon 2002, Kunming, China, October 14-16, 2002.

Mauser, S.F., Gillerman, J., Nordell, D. (2000), "Utility Information Integration - Vision, Benefits, Strategies, and Status" in Proceedings of 33rd Hawaii International Conference on System Sciences, Hawaii, 2000.

Marihart, D.J. (2001), "Communications Technology Guidelines for EMS/SCADA Systems" In IEEE Transaction on Power Delivery, Vol 16. No 2, April 2001.

Neumann, S., Britton, J., DeVos, A., Widergren S., (2006) "Use of the CIM ontology" IN Proceedings of DistribuTECH Conference & Exhibition, February 7-9, 2006 - Tampa, Florida.

Newberry, K. (2004), "An integrated approach to business vocabulary management, and software development", In Proceedings of Power Systems Conference and Exposition, 2004, 10-13 Oct. 2004.

Nordman, M., Lehtonen, M. (2005), "An Agent Concept for Managing Electrical DistributionNetworks", IEEE Transactions on Power Delivery, vol. 20, no. 2, April, 2005, pp. 696-703.

Pintleton, L., Du Preez, N., Van Puyvelde, F. (1999), "Information technology: opportunities for maintenance management," Journal of Quality in Maintenance Engineering Vol 5, No. 1, pp 9-24, 1999.

Redman, T. C, (2001), "Data Quality: The Field Guide", Digital Press ISBN: 1-555582516

Robinson, G., Zhou, M.J. (2004), "Utility Applications Should Be Integrated With An Interface Based On A Canonical Data Model, Not Directly With Each Other", In Proceedings of Power Systems Conference and Exposition, 2004. IEEE PES, 10-13 Oct. 2004.

Robinson, J, Saxton, T., Vojdani, A., Ambrose, D., Schimmel, G., Blaesing, R.R, Larson, R., (1995) "Development of the Intercontrol Center Communications Protocol (ICCP) In proceedings of Power Industry Computer Application Conference, 1995. 7-12 May 1995 Page(s):449 - 455

Sand, K., Öye, R., Hansen, P.I., Lövseth, K. (2002), "Distribution System Asset Management: Network Information Systems versus ERP systems". In Proceedings of NORDAC 2002, Nordic Distribution and Asset Management Conference, Copenhagen

Schubert, J. (1985), "Power System Control Critical Reviews and Visionary Approaches", Ph.D. Thesis. School of Electrical and Computer Engineering, Chalmers University of Technology, Gothenburg, Sweden, 1985, Shahidehpour, M., Ferrero, R. (2005), "Time Management for Assets" Chronological Strategies for Power System Asset Management" In IEEE Power & Energy Magazine May/June 2005.

Shahidehpour, M., Wang, Y. (2003), "Communication and Control in Electric Power Systems", 1st Edition, 2003, John Wiley & Sons, ISBN 0-471-45325-0

Shenming, Z., Jianguo, Y., Zhihong, Y., Mei, C., Qiang, S. (2004), "Implementation of Standard IEC 61 970 in EMS Systems", In Proceedings of Powercon 2004 International Conference on Power System Technology, Singapore, Singapore,21-24 November 2004.

Sherwin, D. (2000), "A Review of Overall Models for Maintenance Management" Journal of Quality in Maintenance Engineering Vol 6, No. 3, pp 138-164, 2000

Simonsson, M., Lindström, Å., Johnson, P., Nordström, L., Grundbäck, J., Wijnbladh, O. (2005) "Scenario-based Evaluation of Enterprise Architecture: A top-down Approach for Chief Information Officer Decision Making" Proceedings of 7th International Conference on Enterprise Information Systems, Miami, USA, May 24-28, 2005.

Spewak, S. (1992), "Enterprise Architecture Planning: Developing a Blueprint for Data, Applications and Technology", John Wiley & Sons, 1992.

Strong, D. M.,Lee, Y.W., Wang, R.Y. (1997), "Data Quality In Context" In Communication sof th e ACM May 1997/Vol. 40, No. 5.

TOG, The Open Group (2002), "The Open Group Architectural Framework Version 8", The Open Group, 2002

Uslar, M., "Semantic interoperability within the power systems domain", In Proceedings of the first international workshop on Interoperability of heterogeneous information systems, ACM Press, Pages: 39 – 46.

Vaahedi, E., Chang, A., Mokhtari, S., Muller,N., Irisarri,G. (2001), "A Future Application Environment for B.C. Hydro's EMS" In IEEE Transactions on Power Systems, Vol. 16, No. 1, February 2001

Verho, P., Nousiainen, K. (2003),"Advanced use of information systems provides new possibilities for asset management of high voltage devices," In Proceedings of The 18th Nordic Symposium on Electrical Insulation, NORD-IS 03, Tampere, Finland, June 11-13 2003.

Vetter, C., Werner, T., Kostic, T. (2000), "Building an asset management system for electric utilities on a component-based environment" In Proceedings of Powercon 2000 International Conference on Power System Technology, Dec, 2000

Vojdani, A.F. (2003),"Tools for Real-Time Business Collaboration" In Transactions on Power Systems, Vol. 18, No. 2, May 2003, pp 555-562.

De Vos, A., Rowbotham, C.T., "Knowledge representation for Power System Modeling" in Proceedings of PICA 2001 The 22nd International Conference on Power Industry Computer Applications 20-24th May 2001, Sydney, Australia.

Wang, X., Schulz, N. N., Neumann, S. (2003), "CIM Extensions to Electrical Distribution and CIM XML for the IEEE Radial Test Feeders", In IEEE Transactions on Power Systems, Vol 18, No 3, August 2003.

Wang, Y.R., Strong, D.M. (1996), "Beyond Accuracy: what data quality means to data consumers, Journal of Management Information Systems 12 (4), 1996, pp. 5-34.

Wand, Y., Wang, Y.R. (1996), "Anchoring Data Quality Dimensions Ontological Foundations" in Communications of the ACM November 1996/Vol. 39, No. 11

Werner, T., Vetter, C., Kostic, T., Lohmann, V. (2000), Data Exchange in Asset Management Applications for Electric Utilities using XML. In Proceedings of the 5th International Conference in Power System Control, Operation and Management, APSCOM 2000, Hon Kong, October 2000.

Wu, J., Schulz, N.N. (2005), "Overview of CIM-Oriented Database Design and Data Exchanging in Power System Applications" In Proceedings of Power Symposium, 2005. Proceedings of the 37th Annual North American 23-25 Oct. 2005 Page(s):16 - 20

Yin, R. (1994), "Case Study Research, Design and Methods", 2nd Edition, Sage Publications, 1994.

Zachman, J.A., (1987), A Framework for Information Systems Architecture", In IBM Systems Journal, Vol. 26, No 3.

Zhanjun, G., Zhencun, P., Peng, B., Bin, W. (2004), "A New modeling approach to Protective Relaying and Fault Information Systems", In Proceedings of International Conference on Power System Technology, Powercon 2004, Singapore, Singapore, 21-24 November 2004.

R. Zmud (1978), Concepts, theories and techniques: an empirical investigation of the dimensionality of the concept of information, In Decision Sciences Volume 9 Number 2, 1978, pp. 187–195.

INTERNET REFERENCES

CIM user Group (2006) The CIM User Group web site http://www.cimuser.org

EBR (2006) Elbranschens rationalisering, EBR-E, http://www.ebr.nu

EPRI (2004) Intelligrid project web site http://www.intelligrid.info

MIT (2006) "The MIT Total Data Quality Management Program http://web.mit.edu/tdqm/.

Nordström (2004) http://www.ics.kth.se/personal/larsn

W3C (2006) The Web ontology language overview http://www.w3.org/TR/owl-features/

Wikipedia (2006) http://en.wikipedia.org/wiki/Ontology_(computer_science)