Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Assessing Impact of ICT System Quality on Operation of Active Distribution Grids

J. König, *Student Member, IEEE,* L. Nordström, *Member, IEEE*

***Abstract* — This position paper presents starting research on assessment of ICT system characteristics and their impact on controllability and observability of future electricity distribution grids. The aspects of controllability and observability for active grids are key factors for guaranteeing safe, efficient and reliable network operation. An assessment framework is proposed for analyzing the impact of ICT system quality on controllability and observability of the power distribution grid.**

The proposed assessment method is based on architectural models extended with a probabilistic inference analysis engine. For this, a combination between Enterprise Architecture meta-models and extended influence diagrams are proposed. The paper presents how the framework is constructed and the method on applying it for analysis. The paper is concluded with an example providing an instantiation of the assessment framework.

***Index Terms*—ICT Quality, ICT Infrastructure, System Analysis, Quality Assessment, Enterprise Architecture.**

I. Introduction

In the near future distribution grid operators will face new challenges and requirements for monitoring and controlling their system. Due to the integration of distributed energy resources into the distribution grid, the former paradigm of uni-directional flow of power from the transmission grid is changing. This implies that previously implemented automation, control and supervision functionality needs to be revised to ensure safe and reliable operation. From a system operation perspective, it can be said that the observability and controllability of the distribution grids changes [1].

When the concept of active distribution grids are discussed the role of Information and Communication Technology (ICT) is often stated as critical [2]. Without a proper ICT infrastructure capable of supporting the future functionality, controllability and observability of the distribution grid will not be achieved. However, it is much less common for the characteristics of this supporting ICT infrastructure to be discussed or analyzed. It is often assumed that the contemporary high speed of development within the ICT field will provide the necessary tools and systems for operation of the future distribution grid. With the increased interdependence between the distribution system and the ICT infrastructure, proper assessment of ICT system characteristics are critical in order not to risk the reliability of the power system.

Architectural modeling is a well-recognized approach in the ICT community for describing and understanding complex systems. A variety of models can be found, all suited to fit a purpose. Within system development models are used as blueprints describing both static and dynamic relations between system components, i.e. supporting different viewpoint of the development process. Similar models exist for the information being processed at operation. One approach used for organizing an enterprise's information system portfolio is Enterprise Architecture (EA). The discipline of EA partly comprises a base of architectural models applicable for supporting decision-making [3]. Other models e.g. used for simulation or impact analysis are aimed to support other stakeholders and their purpose. Independent from the purpose modeling is an effective way of spreading information in a coherent way and powerful method for gaining overview of complex interactions and relations between systems and their components. Thus, using models provide useful support when constructing high quality ICT infrastructure.

A. Scope

This paper presents the first steps in development of a method, supported by modeling formalisms, intended for evaluation of ICT system characteristics that are critical to achieve observability and controllability of active distribution grids. The long term goal of the research is to provide a tool for decision support when designing protection, automation and control systems architectures for active distribution networks.

B. Paper outline

The subsequent section includes a descriptive overview of the proposed analysis method. Section III continues with a thorough descriptions of the comprised ICT quality attributes. In section IV, the analysis framework is presented in detail. Section V includes an example where the analysis framework is applied and in section VI concluding remarks and future work is discussed.

This work was supported by EKC² - The Swedish centre of Excellence in Electric Power Engineering.

J. Konig and L. Nordstrom are with the department of Industrial Information & Control Systems, School of Electrical Engineering, KTH – The Royal Institute of Technology, SE-10044 Stockholm, SWEDEN. (phone: +46-8-790 6824; e-mail :{johank | larsn}@ics.kth.se).

II. ICT ANALYSIS

The proposed method provides the means for rational decision making when designing ICT systems and infrastructure. The analysis method is delimited as prior straitened to only regard distribution system operation, i.e. the ability for the system's operative control and supervision functionality to execute properly.

A. Analysis Method

The analysis method combines architectural models and non-functional system quality attributes. By capturing the attributes in an Extended Influence Diagram (EID), further described in section II.B, architectural scenarios can be evaluated, see Fig. 1.

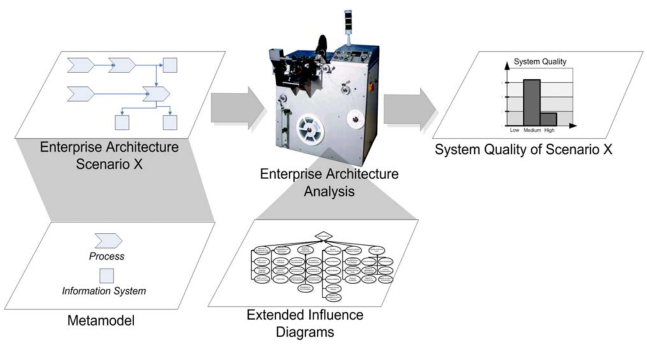

Fig. 1. Relation between Enterprise Architecture models and Extended Influence Diagrams for system quality evaluation. [3]

In order to conduct system architecture analysis, at first infrastructure and its behavior must be captured in an architectural model. EA is a well known concept within the IT domain and provides a structured tool for managing an enterprise's information system portfolio [3]. Some EA frameworks comprise meta-models, i.e. models providing descriptive information regarding components and their relations. A meta-model commonly contains predefined entities and relations, where; *server*, *application* and *network* are example of entities, whereas; *uses, assigned to* and *realizing* are example of relations. When creating models for system architecture analysis it is desirable to use a meta-model that supports a well defined purpose.

The second step includes assessing the quality attributes needed for analysis. The attributes to be assessed depends on the analysis of interest and the system components involved. Reasonable here is to include all the components captured in the architectural model. If for instance the analysis focuses on the attribute *availability* of, let us say an Internet service, of interest here could be to assess the percentage of time the modem is available and also the percentage of time the server providing the service is available.

After collecting data regarding the attributes for each included component, the analysis engine provided in the framework can then be used to determine the system quality of the modeled scenario.

The analysis method thus includes three steps:

- Creating an architectural model of the ICT system to build or modify using concepts from the developed meta-model.
- Collecting data for the component attributes, such as response times, existence of certain equipment, etc
- Using the analysis framework to determine the degree of ICT system quality in the specific ICT system solution.

The purpose of the research presented in this paper is therefore to development of a method intended for evaluation of ICT system characteristics that are critical to achieve observability and controllability of active distribution grids.

B. Developing the Analysis Methods

The framework for conducting ICT system quality imposes a theory foundation defining non-functional quality attributes, e.g. security, performance etc., through measurable quantitative attributes, e.g. existence of firewall, response time etc. EIDs provide a graphical tool for representing causal dependency inference between nodes, including a probabilistic engine based on Bayesian networks [4]. A node may here for instance represent a non-functional qualitative attribute or quantifiable sub-attributes. By causally relating nodes, a value of one node will causally influence the value of a second node. For instance, depending on whether the sky is filled with dark clouds or not, the possibility of rain will differ, i.e. here we have a causal relation between cloudiness and possibility of rain. In a similar manner non-functional quantitative attributes can be measured by causally relating quantitative measures, i.e. the EIDs represent, and define, qualitative attributes through measurable quantitative attributes. For example, the qualitative attribute of performance can be defined by its quantitative attributes *response time* and *throughput,* see Fig. 2.

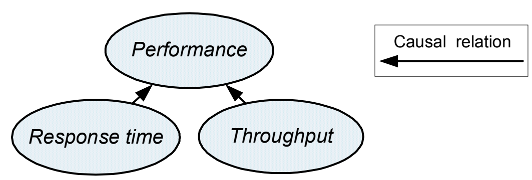

Fig. 2. An EID representing the causal relation between the attribute *performance* and the quantifiable attributes *response time* and *throughput*.

However, only measuring response time and throughput does not automatically generate a performance metric. In order to generate a valid output, first it needs to be decided to what extent the two metrics influence the performance. For example; the two quantifiable measures are said to have two states, either *OK* or *NOT OK,* with them depicting whether the response time or the throughput is within a pre-set limit. For an *OK* performance here, both the response time and the throughput must hold the value *OK*, leading to an AND logic, see Table I.

TABLE I
EXAMPLE OF STATE LOGICS FOR RESPONSE TIME AND THROUGHPUT AND THEIR AFFECT ON PERFORMANCE

Response time		*OK*		*NOT OK*	
Throughput		*OK*	*NOT OK*	*OK*	*NOT OK*
Performance	*OK*	1	0	0	0
	NOT OK	0	1	1	1

With the presented logic; if the probability of *OK* response time were to say 98%, and *OK* throughput 95%, the overall probability for *OK* performance would be their product, i.e. here 93%.

C. Meta-model

By defining meta-models that incorporate these attributes, and a description of how to model specific solutions, architectural scenarios can be modeled and evaluated based on the attribute relations presented in the EID [3]-[5]. These extended meta-models are referred to as abstract models, i.e. an abstract model is a meta-model with the extension of entity attributes and attribute-relations [5]. Fig. 3, shows an abstract model including the entities; *messaging service*, *server* and *network*, all with the attribute of *response time*.

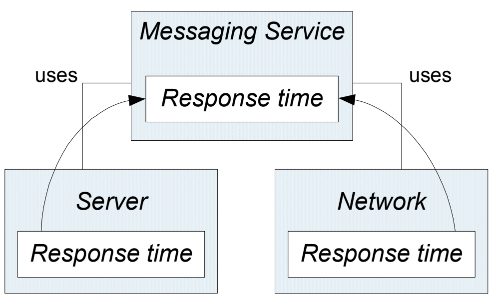

Fig. 3. Example of an abstract model combining meta-models and quality attributes.

The abstract model provides common entity relations found in meta-models, but more also the attribute relations found on each entity. The instantiation of and abstract model is referred to as a concrete model. Examples on where abstract models have been proposed for architectural analysis is found in [6],[7].

III. ICT System Quality

The theoretical foundation presented in this paper is focused on runtime quality attributes affecting the system's controllability and observability from an ICT perspective. Runtime quality attributes are attributes assessable under system operation, such as *Accuracy*, here affecting the capability to achieve correct or agreeable functionality; *Security*, i.e. the capability to avoid malicious attacks concerning data, functions and systems; *Performance*, i.e. the capability to provide appropriate time for response and throughput; and *Availability* i.e. the proportion of time a component is up and running [8].

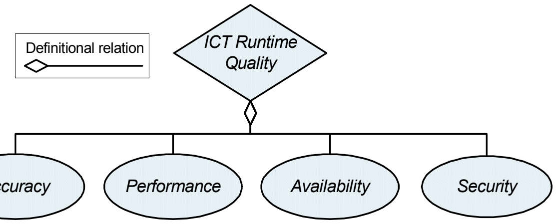

Fig. 4. An EID representing the non-functional quality attributes defining the ICT runtime quality.

These attributes are partly a subset of those presented in the ISO/IEC 9126 standard of software quality evaluation [9], which also includes attributes less valid at runtime such as interoperability and suitability. Consequently, by regarding these attributes when constructing ICT infrastructures you increase the trustworthiness of active power grid operation. To facilitate analysis these qualities are modeled in an EID and defined through quantitative attributes. The level of detail for the breakdown of the non-functional attributes into measurable quantifiable measurable attributes is here fairly limited. This breakdown however only represents a first layer to illustrate the concept, and future work includes improving the level of detail, see section VI.

A. Accuracy

Accuracy is an important dimension for correct system operation and is here defined both for system components and data objects, however affecting each other. For system components, accuracy is static and affects processing and writing of data objects, and is thus defined as the percentage of accurate operation. Here accurate means; the capability of providing correct of agreed result or effect with the needed degree of precision [9]. From a data perspective, accuracy is referred to as the nearness of a value *v* to some value *v'* in the attribute domain, which is considered to be correct [10].

B. Security

Security is defined as the capability of protecting information and data so that unauthorized persons or systems cannot modify them and authorized persons or systems are not denied access to them [9]. As a result of a security breach, the system component is set in a state where it can no longer function properly. The difference compared to the stand-alone availability attribute is that security focuses on the easiness of setting the system out of order at a specific point of time. The risk of breach is a balance between the easiness and the threat.

C. Availability

Availability is defined as the proportion of time the system, or a system component, is expected to be available during the operation window [11]. Availability is assessed through the Mean Time To Failure (MTTF), Mean Time To Repair (MTTR) [9], in accordance with (1).

$$Availiability = \frac{MTTF}{MTTF + MTTR} \qquad (1)$$

D. Performance

Performance is divided into two metrics; response time and throughput. Response time is defined as the time interval between arrival and delivery of data [12], or time for responding to an event [13]. Throughput is defined as the number of forwarded data objects [12], or the number of processed events [13], over a period of time. Both metrics are measured as the percentage of time the objects in question meet their objectives [13], where the objective is dynamic, i.e. varying depending on situation needs.

As previously stated the detail level of the presented attributes only represents a first layer. Future work will include more thorough detail.

IV. Analysis Framework

Since modeling is an extensive and resource consuming task it is of high importance that the tool, in this case the abstract model, does support the modeler's needs with precision. The abstract model presented in this paper is a modification of the ArchiMate meta-model [14] by reducing irrelevant entities and adding attributes and their relation. ArchiMate is a framework provided by The Open Group for creating architectural models for information systems. The framework contains a meta-model categorized into three layers; *business*, *application* and *technology,* with defined interactions between each layer. Of interest here is to view the layers; *application,* and *technology*, where the prior is mostly software and the latter being hardware related. The interaction between each layer is formalized through services. Further, each layer is categorized into three aspects; *information*, e.g. data objects, *behavior*, e.g. functions or services, and *structure,* e.g. communication networks or software components. The meta-model also defines relations between each entity, e.g. functions *read* or *write* data objects.

A. Abstract Model for ICT Quality Analysis

The abstract model presented in Fig. 5, describes relations between entities and their attributes. The model entities include;

- Application Service – provide functionality to external users e.g. an automated control of a breaker or informing a system operator in event of a breaker failure.
- Application Function – provide system internal functionally e.g. an internal function of a state estimator or an optimal power flow application.
- Application Component – the main structural part of the application layer and describe a replaceable component e.g. the network diagram component in a Distribution Management System (DMS).
- Data Object – describes data and contains data attributes, not to be confused with quality attributes, in accordance with IEC 61850 [15] e.g. information regarding voltage measurements or equipment status.
- Infrastructure Service – used to provide accessibility between the infrastructure and the application layer e.g. services presented in IEC 61850-7-2 [16]; client requesting the services *get** or *request**.
- Node – a typical system component represented as a Node is an RTU, i.e. a physical device running an operating system. Additionally, substation computers and PLCs are modeled as Nodes.
- Network – typically used to represent communication channels such as a LAN, VLAN or a WAN

Further definitions of the entities and their relations are found in the ArchiMate meta-model.

B. Abstract Model Entity Relations

Beginning at the top, an Application Service contains all quality attributes included in the analysis framework; *accuracy*, *availability*, *performance* and *security*. It is only attributes from Application Functions that are directly causally influencing the Application Service.

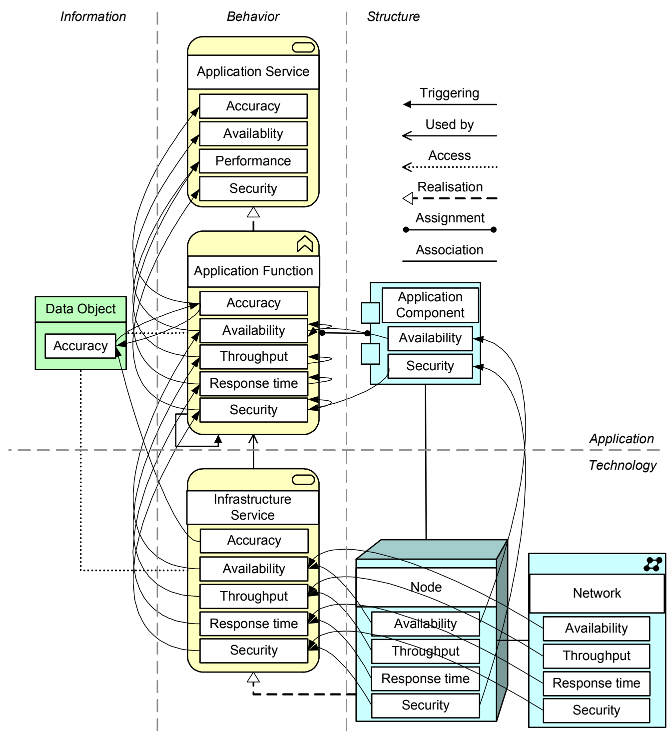

Fig. 5. The abstract model for assessing ICT system quality from a controllability and observability perspective.

Application Functions are used to realize Application Services and are assigned to Application Components. The availability of an Application Function depend on the Application Component to with it is assigned, other triggering Application Functions and the Infrastructure Service providing Data Objects. An Application Function can access Data Objects through a read relation or create Data Objects through a write relation –

depending on the arrow of the access relation. When a Data Object is read, the accuracy of it will affect the accuracy of the function, and vise versa. Thus, the attribute relation is not cyclic since it depends on whether it is a read or a write relation. Throughput and response time are causally influenced by Infrastructure Services and other triggering Application Functions, this since they are limiting the ability of executing functionality. In consistency with throughput and response time, security holds equivalent attribute relations although with the extension of influence from the security of Application Components. Thus, if the security was to be breached and the Application Component was set unavailable this would affect all assigned Application Functions.

To be able to add, replace or remove Application Functions, Application Components must be added, replaced or removed. Since the Application Component does only represent a structural piece of application and therefore cannot execute, only its availability and security will affect the Application Function. These qualities are in turn causally influenced by the associated Node's.

Data Objects can either read or written and are accessed through Application Functions or Infrastructure Services. The Inaccuracy of Data Objects both hold for data and data attributes, i.e. if data is represented inaccurately or if a value is inaccurate, the Data Object is inaccurate.

Accuracy of data objects are influenced by the accuracy of the Infrastructure Service, where an Infrastructure Service can for instance provide measurements to Application Function. However, quality functions e.g. found in IEC 61850-7-3 [17], where the trustworthiness of a data value in a Data Object is represented as a data attribute, can reduce the probability of incorrect execution. Inaccuracy may for instance be caused by malfunctioning measurement equipment or protocol errors. If an infrastructure realizing a service is unknown, or by any reason not of interest, it may be viewed as external. An external Infrastructure Service has the same attributes as any other Infrastructure Service but lacking the causal influence from Nodes and Networks. However, Nodes and Network will still affect the Infrastructure Service but the attributes are measured directly at the service. By seeing the services as external, less modeling of unknown or unnecessary infrastructure, e.g. the Internet, is possible. More on this will be threatened in future work.

Nodes are entities realizing Infrastructure Services. A Node does not hold the attribute of accuracy even though it can process information. Instead, for instance a measurement device converting analog measurements into digital with certain accuracy is captured by the accuracy of the Infrastructure Service. The connection between nodes is defined through the Network entity. A Network does only hold attributes causally influencing infrastructure services.

V. Concrete Example

This section provides an example of applying the analysis framework to potential active distribution network. A concretization of the abstract model is based on an example for managing an increased penetration of Distributed Generation (DG) presented in [18]. With increasing penetration of DG into the power distribution grid, the risk of voltage rise effects and increased fault levels arise. These risks result in curtailment of production capacity for the generators, resulting in less energy production. A possible solution in order to stabilize the load is to control a voltage transformer located at a feeder. The transformer holds an on-load tap changer controlling the demand side via a relay. The relay set-points, i.e. the values where control actions should be carried out, are automatically managed by an Automatic Voltage Controller (AVC), which in turn receives set-point values from a control schedule function included in a DMS. In order for the control schedule function to determine set-point values it receives data in form or network state estimates and network constraints, see Fig. 6. Network constraints commonly comprise information regarding distributed generator capacity, OLTC tap steps and network voltage limits.

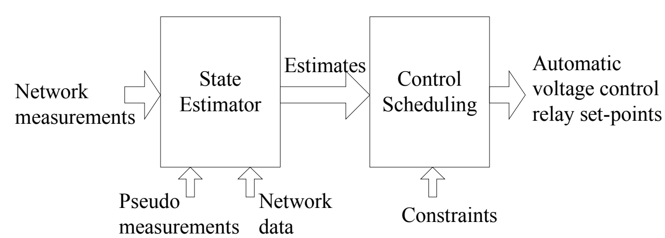

Fig. 6. Functional blocks with input and output data.

The DMS also includes a state estimator, providing network estimates to the control scheduling function. The state estimation function block is fed with three types of data inputs; network measurements, pseudo measurement and network (topology) data.

A. System Setup

The setup for this example is, as prior noticed, derived from [18] and includes a radial grid with a primary substation containing a 132kV/33kV voltage transformer. AVC relay is implemented at the voltage transformer located at the primary substation (see Fig. 7). The AVC's functionality is to control the OLTC mounted on the transformer. DMS is also located at the primary substation, where the application is running on a real-time micro-computer.

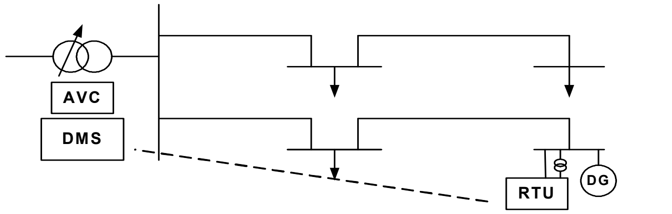

Fig. 7. Example setup including grid topology, OLTC transformer, DMS, AVC, RTU and the DG.

A DG source, in form of a wind power plant is connected at a 33kV busbar at one of the feeders, also holding a Remote Terminal Unit (RTU) used for monitoring the operation. Data from the RTU is communicated via a remote network to the DMS containing measurements, e.g. bus voltage, real power, reactive power, etc., used for estimating the state of the distribution grid. The voltage level data normally comprise more than a raw value of the voltage level, as for instance; a point number associated with the measurement, an analog value, a quality stamp and a timestamp [19]. Network data for the primary substation, including 132kV measurements are communicated to the DMS via a local substation communication channel.

A. *Instantiation of Abstract Model*

Fig. 8, presents a model of the ICT systems that implement the functionality described in the preceding example. In the concrete model, the set point control decision is represented as an `Application Service`, i.e. the service of deciding the relay values. It is seen as a service since it provides value to an external user, in this case a distribution system operator. Thus, instead of using the automatic set-point service the decision of controlling the relay's set-point values could have been conducted by the operator. A following service not included here is the actual control of the delay.

The `Application Service` of controlling the relay's set-point values is realized through the control scheduling `Application Function`. In order for the control scheduling to trigger execution, estimates and constraints must be present. The estimates are provided by the state estimator, whereas the constraints are provided by an external `Infrastructure Service`, here External Infrastructure Service B. The external service could for instance represent data sent from a local database or from a system located elsewhere. The state estimator and the control scheduling are located on the same physical processing unit, the micro-computer, and assigned to a single `Application Component`, the DMS Network Control. Thus, if either of these static components is affected in any way, both functions will be affected.

For the state estimator to produce estimates and send these to the control scheduling function, first all data must be input. If either of the pseudo measurements, network data, measurements from the DG 33kV busbar or 132kV

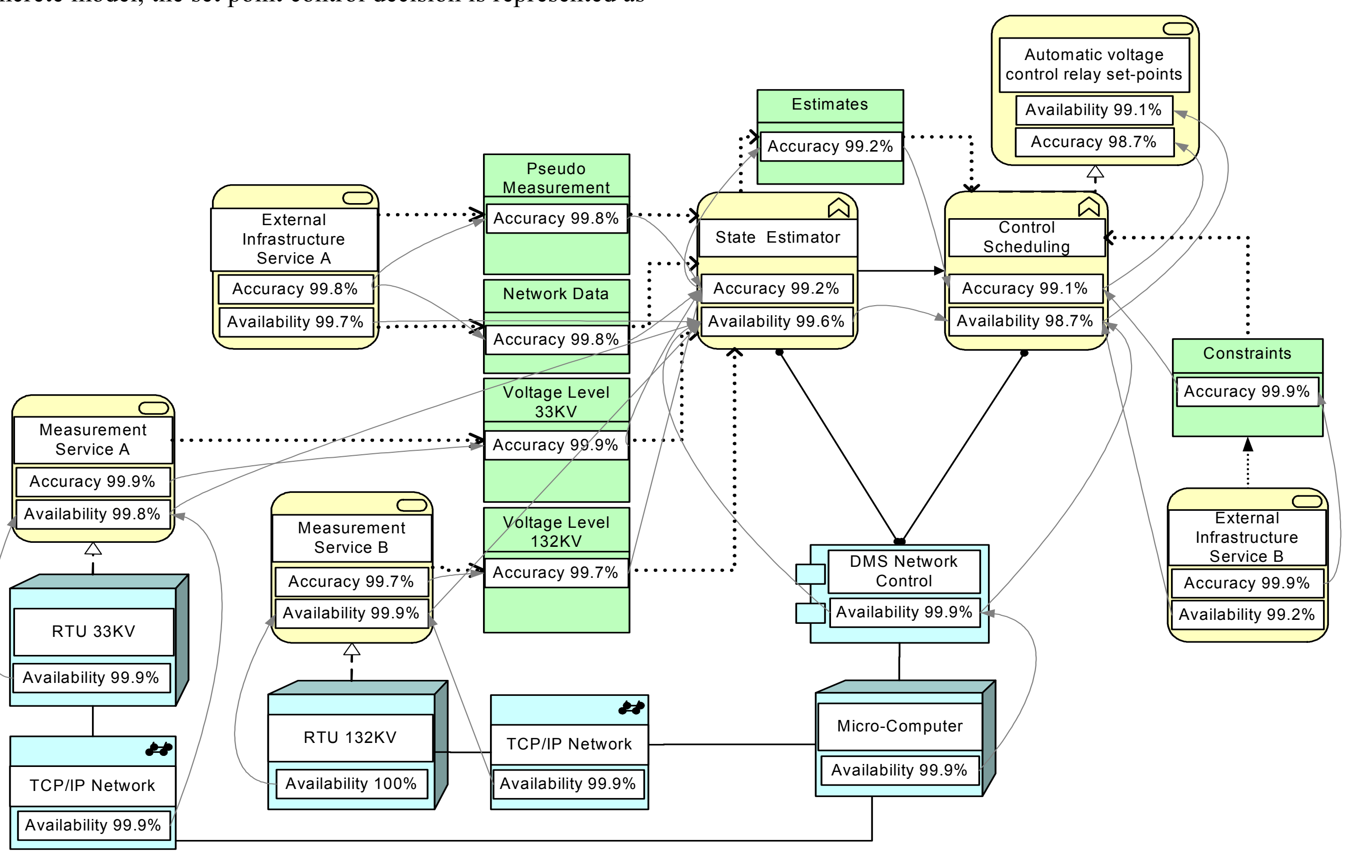

Fig. 8. Concretization of the abstract model based on the presented example including the attributes of availability and accuracy. The attributes are aggregated in consistency with the causal relations.

measurements from the primary substation does not hold the necessary quality or are unavailable, then the state estimator will not operate satisfactorily.

The accuracy of the produced estimates depends on the accuracy of the input data, and also on the accuracy of the state estimator function processing these data. The pseudo measurements and the network data is accessed through the External Infrastructure Service A. The network measurements are provided by two RTUs, one located at the primary 132kV busbar and one at the 33kV busbar holding the DG. The RTUs communicate the data via TCP/IP networks. The quality of the `Infrastructure Service` providing data accessibility is affected by the quality of the relating RTU and TCP/IP network.

B. Architecture Evaluation

The architectural evaluation is one of the fundamental concepts in the presented method. Here, the evaluation includes the attributes of accuracy and availability, though the same reasoning hold for remaining attributes. In order for the application service to function properly all components must be used, i.e. it is not possible to reuse old values or execute functionality without obtaining all inputs. The provided numbers are strictly fictive. Fig. 9, shows the service quality level for different scenarios. The service quality can be interpreted as the ICT system quality with the services of controlling and observing the power grid.

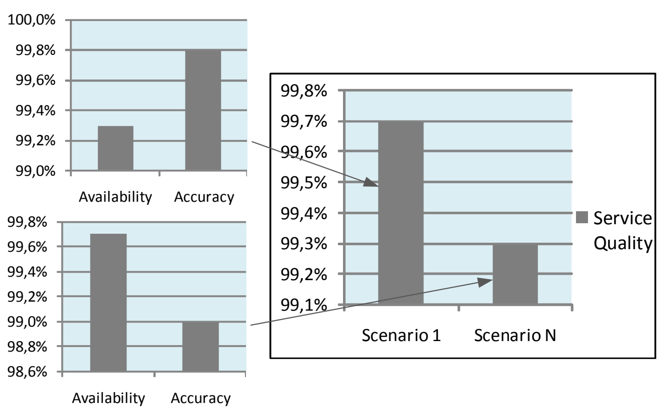

Fig. 9. Example of analysis result showing the application service quality for different scenarios based on availability and accuracy.

Depending on the focus of the analysis the quality attributes can be weighted, causing different influence. Thus, if the focus were on security, the attribute could be weighted with greater impact on the service quality than the other attributes, causing a security evaluation focus.

VI. Concluding Remarks and Future Work

Abstract models can be used for architectural evaluation of ICT system characteristics that are critical to achieve observability and controllability of active distribution grids. However, a constant balance exists between the necessary level of detail and the modeling effort. Depending on the stakeholder, the detail level of interest differs, and thus should be adjusted in order to reduce unnecessary modeling costs. An interesting domain for using the presented method is when control and supervisory systems are integrated with enterprise systems, resulting in increased system complexity. Of interest is also to improve the framework for analysis of integration of system components close to the process, here the distribution grid. Thus, the concept of active distribution grids and "Smart Grids" depict scenarios with a rapidly increasing integration of new ICT system components with functionality stressing the capacity limits of present ICT infrastructure. This integration also opens up new security threats and increases need for the processing of data, resulting in reinvestment to uphold the ICT quality.

A. Future Model Improvements

To be able to use the presented analysis framework in an efficient way, the meta-model entities must be more thoroughly defined. Whether this means adding more entities or giving a more detailed description on how each entity should be used, is yet to come. For instance, data objects may further be described by separating data and data values. Also for the future is to further investigate the possibility of using the concept of external services. Other models e.g. Intelligrid, CIM, IEC 61850 etc., are important sources for input for this framework improvement.

B. Enhancement of EID

The theoretical foundation presented in the EIDs, describing causally relating attributes, should further be improved. The non-functional attributes; accuracy, performance, availability and security, must all be further detailed by influencing quantifiable attributes. For instance, performance could be measured through queue size, cable latency, error rate, etc [20]. A further step is to investigate the possibility of including more non-functional attributes affecting the system operation at runtime, e.g. interoperability. Future work also includes the development of the probabilistic framework – not just better definitions but also how calculations can be improved for a more thorough analysis.

C. Implementing Tool Support

A concern regarding the analysis framework is the assessment of attribute values. However, implementing the models into a tool providing simulation capacity may prove to be a solution. Of interest is to use a tool supporting both power grid simulation and ICT system operation. Such a tool would allow dynamic simulations of events in the ICT system and how that affects the power systems. For example, interesting would be to simulate the impact of an inaccurate measurement or unavailability of an infrastructure service on the power system under specific conditions. Thus, combining both systems in a simulation environment would enable analysis of how ICT quality impacts the power grid operation.

VII. References

[1] C. Bendel, D. Nestle, "Decentralized Electrical Power Generators in the Low Voltage Grid - Development of a Technical and Economical Integration Strategy" *International Journal of Distributed Energy Resources*, Volume 1, Number 2, (2005) p.63-70.

[2] M. Friedewald, C, Cremer, M. Weber, I. Maghiros, F. Abadie, C. Pascu,. "Emerging Trend Update 3 – The Role of ICTs as Enabler for Energy Efficiency" Institute of Prospective Technological Studies, EPIS Work Package 1 – Deliverable 1.3 ETU3, JRC European Commission, version 1, 2007

[3] P. Johnson, M. Ekstedh, *Enterprise Architecture – Models and Analyses for Information Systems Decision Making*, Edition 1:1 Studentlitteratur, 2007

[4] P. Johnson, R Lagerström, P. Närman, and M. Simonsson, "Enterprise Architecture Analysis with Extended Influence Diagrams." *Information System Frontiers*, Volume 9, Numbers 2-3. (2007), p.1387-3326.

[5] P Johnson, E Johansson, T Sommestad and J Ullberg, "A Tool for Enterprise Architecture Analysis", *Proceedings of the 11th IEEE International Enterprise Distributed Object Conference (EDOC),* Annapolis, 15-19 Oct. 2007, pp 142-152

[6] R. Lagerström and P. Johnson, "Using Architectural Models to Predict the Maintainability of Enterprise Systems", *12th European Conference on Software Maintenance and Reengineering, CSMR 2008,* p.248-252, 2008

[7] P. Närman, P. Johnson and L. Nordström, "Enterprise Architecture: A Framework Supporting System Quality Analysis", *11th IEEE International Enterprise Distributed Object Computing Conference, EDOC 2007*, p.130-130, 2007

[8] L. Bass, P. Clements and R, Kazman, *Software Architecture in Practice,* Addison-Wesley, Reading, MA (1998)

[9] *ISO/IEC 9126-1, Software Engineering – Product Quality – Part:1 Quality Model*, International standard, ISO, Genève, Switzerland, 2001

[10] T.C. Redman, *Data Quality for the Information Age,* Artech House Boston, MA, 1996

[11] C. Ford, I. Gileadi, S. Purba, M. Moerman, *Patterns for Performance and Operability – Building and Testing Enterprise Software,* Auerbach Publications, Taylor & Francis Group, 2008

[12] R. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling,* John Wiley and Sons, Inc., New York, 1991

[13] C.U. Smith, L.G. Williams, *Performance Solutions: A Practical Guide to Creating Responsive, Scalable Software*, Addison-Wesley, Boston, 2002

[14] Lankhorst M. et al, Enterprise Architecture At Work, Springer Verlag, Heidelberg, 2005

[15] *IEC 61850-7-1 Communication Networks and Systems in Substations, Part 7-1: Basic Communication Structure for Substation and Feeder Equipment – Principles and Models,* IEC 2003

[16] *IEC 61850-7-2 Communication Networks and Systems in Substations, Part 7-1: Basic Communication Structure for Substation and Feeder Equipment – Abstract Communication Service Interface (ACSI),* IEC 2003

[17] *IEC 61850-7-2 Communication Networks and Systems in Substations, Part 7-1: Basic Communication Structure for Substation and Feeder Equipment –Common Data Classes,* IEC 2003

[18] G. Strbac, N. Jenkins, M. Hird, P. Djapic, G. Nicholson, "Integration of Operation of Embedded Generation and Distribution Networks", Manchester Center for Electrical Engineering, Tech. Rep. 2002

[19] EPRI "Use Case: Wide-Area Monitoring and Control – Automated Control Functions", EPRI Use Case Repository, [Online] Available: http://smartgrid.epri.com/usecaserepository.html

[20] M. Chenine, L. Nordström and P. Johnson, "Factors in Assessing Performance of Wide Area Communication Networks for Distributed Control of Power Systems", PowerTech 2007