Risk Analysis of Smart Grid Enterprise Integration

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***Abstract*— The application domain of Smart Grid is a matter of a great interest of scientific and industrial communities. A comprehensive model and systematic assessment is necessary to select the most suitable Enterprise Architecture (EA) development or integration project from many alternatives. In this paper, a Fuzzy Influence Diagrams with linguistic probabilities is proposed for the Smart Grid EA conceptual model and risk analysis. The proposal relies on a methodology devoted to decision-making perspectives related to EA and risk assessment on Smart Grid initiatives based on fuzzy reasoning and influence diagrams (FID).**

I. Introduction

Electric utilities are turning their attention to Smart Grid deployment including a wide range of infrastructure and application-oriented initiatives in areas as diverse as distribution automation, energy management, and electric vehicle integration. The challenge of integrating all of these Smart Grid systems will place enormous demands on the supporting IT infrastructure of the utility, and many utilities are turning to the discipline of EA for a solution [1]. System interoperability, information management and data integration are among the key requirements for achieving the benefits of Smart Grid. For instance, the use of Advanced Metering Infrastructure can reduce the time for outage detection and service restoration. However, this will require integration of Outage Management System (OMS) with a number of other applications, including Meter Data Management System (MDMS), GIS, work management system, SCADA/DMS and distribution automation functions.

The concept of Smart Grid affects both the topology of the grid and the IT-infrastructure, leading to various heterogeneous systems, data models, protocols, and interfaces on an enterprise level. The discipline of EA proposes the use of models to support decision-making on enterprise-wide information system issues. The challenges arise when a company's information systems need integration. Therefore, a comprehensive model and systematic assessment is necessary to select the most suitable EA development or integration project from many alternatives. In this paper, the new analysis tool for the selection of optimal EA for the Smart Grid implementation has been presented. EA analysis of complex Smart Grid solutions has been carried out using Fuzzy Influence Diagrams. They differ from the conventional ones in their ability to cope with the uncertainty associated with the use of language and in their ability to represent multiple levels of abstraction. The contribution of this paper is the successful implementation of the probabilistic inference mechanism of Bayesian networks and Fuzzy influence diagrams to the Smart Grid conceptual model. This kind of modeling allows the analysis of a wide range of important properties of EA models, which is illustrated on an example of risk analysis of different Smart Grid solutions.

II. EA Model Analysis Using Fuzzy Influence Diagrams

The development of Smart Grid raises many economic questions. The impact of Smart Grid on the development of the economy, market regulation of electricity sales, reduction of the risk for investors and increase of competitiveness is processed in [2]. Also, the issue of increasing the use of renewable energy sources and their optimization within the system of Smart Grid in order to increase the economy competitiveness is considered.

To fulfill these requirements, EA should be model-based, in the sense that diagrammatic descriptions of the systems and their environment constitute the core of the approach. A number of EA initiatives have been proposed, including The Open Group Architecture Framework, Zachman Framework, Intelligrid, and more [3], [4], [5]. Employing the probabilistic inference mechanism of Bayesian networks, extended influence diagrams are also proposed for the analysis of a wide range of important properties of EA models [6]. However, although the concept of influence diagram has been successfully applied to different areas, different Smart Grid architectures have not been modeled in such a way.

A. EA for the Smart Grid Requirements

Smart grid EA encompasses all four levels according to Zachman terminology:

- Conceptual - models the actual business as the stakeholder conceptually thinks the business is, or may want the business to be; defines the roles/services that are required to satisfy the future needs.
- Logical - models of the "services" of the business uses, logical representations of the business that define the logical implementation of the business.
- Physical - the specifications for the applications and personnel necessary to accomplish the task.
- Implementation - software product, personnel, and discrete procedures selected to perform the actual work.

Achieving interoperability in such a massively scaled, distributed system requires architectural guidance, which is provided by the Smart Grid architectural model based on influence diagrams. In this conceptual model of an enterprise, the information represented in the models is normally associated with a degree of uncertainty. The EA model may be viewed as the data upon which the algorithm operates. The result of executing the algorithm on the data is the value of the utility node, i.e. how “good” the model is with respect to the assessed concept (information security, availability, etc.) [6]. Therefore, EA analysis, as the application of property assessment criteria on enterprise architectural models, is the necessary step in the EA model evaluation.

Furthermore, in the field of EA, it is necessary to make decisions about different alternatives on information systems. Making of rational decisions concerning information systems in an organization should be supported by conducting risk analyses on EA models. Dependencies and influences between different systems are not obvious, and for the support of decision making in such complex environments, the concept of a model-based EA analysis is used.

Generally, a conceptual architecture defines abstract roles and services necessary to support Smart Grid requirements without delving into application details or interface specifications. It identifies key constructs, their relationships, and architectural mechanisms. The required inputs necessary to define a conceptual architecture are the organization’s goals and requirements. In influence diagrams, decision nodes represent a choice between alternatives. In EA analysis, these alternatives are concretized by different EA scenarios. The risk calculation of different scenarios is performed using fuzzy influence diagram.

III. Smart Grid Scenario Risk Assessment

The overall risk is calculated with exhaustive enumeration of all possible states of nature, and their expected value of risk. Let suppose a system in which risk value node has X_n parent nodes, with different number of discrete states. Fuzzy probability of the chance node X_i being in the state j is expressed as $FP(X_i = x_{ij})$. Fuzzy value of possible consequences in the state x_{ij} is represented by $FD(X_i = x_{ij})$. The expected value of risk is then calculated:

$$R \cong \sum_j \sum_i FP(X = x_i) \otimes FD\left(X = x_{ij}\right). \qquad (1)$$

EA analysis is the application of property assessment criteria on EA models. One investigated property might be the information security of an information system and a criterion for assessment of this property might be the estimated risk level of such an intrusion.

In the following example, Fuzzy Influence Diagram will be used for the risk assessment of two different Smart Grid scenarios. Decision about the introduction of two alternative vendors of Smart Grid application has to be brought, having in mind different constraints, stakeholders, their goals and interdependencies between them. The conceptual model is presented on Figure 1. Decision node (1) presents two possible scenarios of Smart Grid technology introduction (S1 and S2). The chance node (2) depicts the possible impact on information security of these scenarios, with three possible states: Information security low (ISL), medium (ISM) and high (ISH). Appropriate fuzzy conditional probabilities are presented in Table I. Two different stakeholders are presented in this model, including network owner and customers, with their particular goals: profit and satisfaction, presented in chance nodes (3) and (4) respectively.

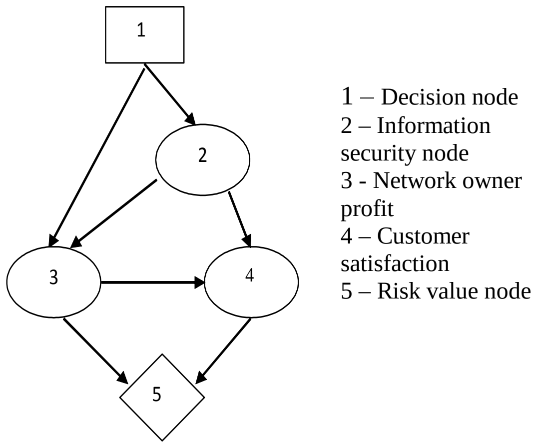

Figure 1. Fuzzy influence diagram for the conceptual model of Smart Grid risk assessment

TABLE I.
FUZZY CONDITIONAL PROBABILITIES FOR THE INFORMATION SECURITY NODE (2)

	Scenario 1 (S1)	Scenario 2 (S2)
Information security low (ISL)	H	EL
Information security medium (ISM)	VL	L
Information security high (ISH)	EL	MH

Network owner profit depends on both: selected scenario and the level of information security and encompasses three possible states (low (PL), medium (PM) and high profit (PH). Fuzzy conditional probabilities for this node are presented in Table II.

TABLE II.
FUZZY CONDITIONAL PROBABILITIES FOR THE NETWORK OWNER PROFIT NODE (3)

States of node 3	States of nodes 1 and 2					
	S1 ISL	S1 ISM	S1 ISH	S2 ISL	S2 ISM	S2 ISH
Low profit (PL)	L	EL	EL	M	L	EL
Medium profit (PM)	MH	VL	EL	ML	M	MH
High profit (PH)	EL	H	VH	EL	VL	L

On the other hand, customer satisfaction is inversely related to the state of network owner profit (the bigger the profit, the customer satisfaction is lower). Three possible states of customer satisfaction are Customer satisfaction is also depending on the state of information security, and conditional probabilities for this node are presented in Table III.

TABLE III.
FUZZY CONDITIONAL PROBABILITIES FOR THE CUSTOMER SATISFACTION NODE (4)

States of node 4	States of node 2 and 3		
	PL ISL	PL ISM	PL ISH
CL	VL	EL	EL
CM	L	VL	EL
CH	M	H	VH
States of node 4	States of node 2 and 3		
	PM ISL	PM ISM	PM ISH
CL	L	VL	EL
CM	MH	M	ML
CH	EL	L	M
States of node 4	States of node 2 and 3		
	PH ISL	PH ISM	PH ISH
CL	M	L	EL
CM	ML	M	MH
CH	EL	VL	L

Using the expressions (1), values of fuzzy risk for both alternatives are calculated and presented on Figure 2 [7].

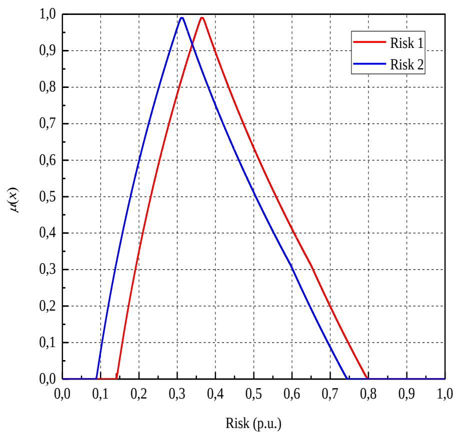

Figure 2. Fuzzy risks for two Smart Grid alternatives

It is obvious that the alternative with low information security risk (S1), and moderate customer satisfaction dominates the alternative with higher profit for the utility.

IV. CONCLUSION

Investments made in Smart Grid technologies are faced with risk that the diverse Smart Grid technologies will become prematurely obsolete or, worse, be implemented without adequate security measures. Furthermore, a Smart Grid cyber security strategy must include requirements to mitigate risks and privacy issues pertaining to Smart Grid customers and uses of their data.

The implementation of Smart Grid requires an overarching architecture to accommodate regulatory, societal and technological changes in an uncertain environment. Utilities are managing much more data and information in real time, using completely "of the shelf" applications requiring internal and external interoperability. A critical step in this integration is the development of the EA semantic model enabling data and information services. In this paper, fuzzy influence diagrams are proposed for the conceptual modeling of Smart Grids and the decision making support in the assessment of different Smart Grid alternatives and integration framework. The probabilistic inference mechanism of Bayesian networks and influence diagrams with linguistic probabilities is adequate to the EA model viewed as the data upon which the algorithm operates. Therefore, EA analysis as the application of property assessment criteria on enterprise architectural models is the necessary step in the EA model evaluation.

The advantage of this kind of modeling is the consistent representation of the Smart Grid conceptual level, consisting of several domains, each of which containing many applications and roles that are connected by associations, through interfaces. A vast range of properties on enterprise architectural model can be assessed using this model. Furthermore, this kind of modeling allows the analysis of a wide range of important properties of EA models, which is illustrated on an example of risk analysis of different Smart Grid solutions

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