

Architecting the Microgrid for Interoperability

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Abstract

This paper presents the Agile Enterprise and System Architecture design methodology (Agile EaSA) that Balance Energy uses on its Microgrid project. We define a Microgrid as a power grid, distribution, and customers that can be islanded under control and sustained with renewable power sources and energy storage. An overview of our Agile EaSA process along with its embedded Information Assurance templates are presented and applied to a Microgrid architecture.

Enterprise Architecture (EA) is a method for completely expressing the enterprise. It is the master plan which interconnects the business planning, business operations, organizational structures, processes and data, information systems, and the enabling infrastructures. The use of EA provides benefits in improved efficiencies of the business, improved quality and timeliness of critical information, incorporation of legacy systems and standard components, and maximized use of limited resources.

Agile EaSA enables multiple domains to be defined, related, and represented as artifacts using the UML 2.0. The use of UML facilitates the import of the Common Information Model (CIM). The Agile EaSA utilizes the Zachman Architecture Framework (ZAF) for system decomposition and includes an Information Assurance (IA) overlay that is pervasive across the entire architecture development. The ZAF is one of many that visualizes system of systems decomposition using a related of artifacts that encompass business processes, data, and functions [1]. The IA overlay includes cyber threats, vulnerabilities, attack types, defenses, and security audit trailing at all levels of the Microgrid. Interoperability with approved standards and legacy systems is part of the architecture process.

1. INTRODUCTION

Agile EaSA applies risk-based management and commercial best practices to achieve a best-value solution for the customer. The iterative and agile, incremental nature of the EaSA provides visibility into architecting and development progress while leveraging customer expertise to conduct

analysis and design activities that reduce risk during the execution of the engineering lifecycle. Iterative, incremental architecture development allows the team to focus on achieving objectives identified by Hard Technical Problems (HTP), Most Important Requirements (MIR), and Critical Success Factors (CSF) areas while managing other critical risk areas during each analysis cycle to prove the objective architecture, prototype design, and final product.

1.1. Definitions and Terminology

The use of a standard vocabulary is crucial in the architecture process. The use of the NIST Roadmap for interoperability facilitates this common terminology and definition. Section 8 of this report provides the definitions and terminology. [2]

For reference and context purposes, Balance Energy defines a Microgrid in the modern power grid as follows:

A Microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources capable of operating independent of the larger grid. Microgrid components include; distributed energy resources (including demand management, storage, and generation), control and management, secure network and communications infrastructure, and assured information management. When renewable energy resources are included, they usually are of the form of wind power, solar, hydro, geothermal, waste-to-energy, and combined heat and power systems. Microgrids perform dynamic control over energy sources enabling autonomous and automatic, self healing operations. During normal or peak loading or at times of power grid failure the Microgrid can operate independently from the larger grid and isolate its generation nodes and loads from the disturbance without affecting the larger grid's integrity. Independent Microgrid operation can offer higher reliability and cost efficiency than that provided by traditional grid control. The Microgrid is both an energy market consumer and provider of electrical power. Microgrids interoperate with existing power systems, information systems, and network infrastructure. The Microgrid may take the several forms, such as a utility metropolitan area, a shopping center,

industrial park, college campus or a small energy efficient community.

1.2. Enterprise Architecture Background

Enterprise Architecture represents many differing definitions and forms by many people. Until recently, this disparity resulted in slower adoption and general confusion amongst both practitioners and management. Today, most EA practitioners agree that architecture is a means to abstract and identify, form the enterprise, function, relationships, and integration points using frameworks, methods and artifacts to describe the design in its current and future states. Having a solid architecture establishes a foundation for executing business strategies because it relates the decisions business organizations make with business objectives and enterprise solutions. Although companies may adopt standards and best practices as a means for driving toward enterprise solutions, many efforts fall short because the business does not understand its maturity to employ enterprise architecture as a long range planning tool. EaSA establishes the method and approach for EA to align strategy, business, and technology elements across the entire enterprise

1.3. Benefits of EA

Model-Based – The methodology applied uses analysis and synthesis modes spanning enterprise and systems engineering activities to express a unified, holistic view of enterprise architecture.

Capabilities-Based – The process focuses on designing mission relevant capabilities by focusing on key used needs expressed through: Problems, Opportunities, and Directives (PODs), HTPs, MIRs, driving scenarios and change cases.

Linkage to Mission Needs – In the ZAF, the linkage between the Community (row 1), Business (row 2), System (row 3) and Technical (row 4) archetypes provide continuity from the business needs to the physical system design. This results in a “build-to-specification” architecture that is focused on the business, mission, and user needs.

Focus on Driving Scenarios – Driving Scenarios are high value, operational trends that are used as “think-space” drivers during the architecture development. In general, the threads should be selected using a design-of-experiments approach to ensure that they stress the architecture in different (i.e., orthogonal) ways.

Focus on PODs First – Problems, Opportunities and Directives (PODs) are motivating factors for a project based on current and future business and user needs. By focusing on the PODs, we ensure that the technical solutions are directly linked to the business and user needs.

Focus on HTPs First – Hard Technical Problems are early statements about the technical hurdles that must be

overcome to successfully deliver a system. By raising the architecting team’s awareness of these critical issues, we proactively require these issues to be addressed thereby reducing the overall system acquisition risk.

Focus on MIRs First – Most Important Requirements are driving requirements for the system acquisition. These requirements define the core capabilities of the system to be delivered and are linked to the critical success factors for the project.

Complete Project Lifecycle Coverage – The methodology spans the complete project lifecycle: requirements collection, requirements analysis, requirements allocation, architecture scoping, community design, business design, system design, technical design, implementation, verification, validation, deployment, operations and maintenance. Guidance on transition architecting is provided to addresses architecture evolution roadmapping, technology insertion, and refresh after initial operational capability is achieved.

Integration of Operations Analysis – Operations Analysis groups are involved in identifying current operational problems and proposing and evaluating architectural solutions to these problems. In conducting this analysis, operations analysts work with operations architects to create architecture products at the community (row 1) and business (row 2) level of the architecture description. The final set of architecture products defines the new levels of interoperability and integration that must be achieved to overcome current operational issues. These operational drivers provide critical context for system-level requirements and can form the basis for Problems, Opportunities, and Directive data. Requirements associated with key operational issues can be further categorized as Most Important Requirements to ensure they receive appropriate priority.

Integration of Requirements Management – To ensure that the architecture is designed to satisfy the requirements, we must have traceability between the requirements and the architecture designs. By allocating the requirements to ZAF cells, we can ensure that the architects are creating solutions in accordance with the requirements. This is a critical step in the verification and validation of the architecture description.

Integration of Architecture Development – The methodology defines a rigorous approach to architecture development with a modest sized team (i.e., 7 to 9 people).The ZAF provides guidelines and constraints to the architecture development and ensures that the architecture description is holistic and complete.

UML Integration – The selected product set can be pure UML products (for all rows) based on organizational

guidelines and the needs of the project. UML products can leverage specialized dialects such as SysML when practical to further and more completely express architecture concepts.

Integration of Architecture Modeling – Simulation is one of two direct approaches to verifying and validating an architecture description. However, in most simulation projects, only 50% of the data needed to build the simulation models are captured in the architecture and 50% must be derived through other means. *Simulatable Architecture* is an architecting technique in which the information needs of the simulation engineers are defined and explicitly linked into the architecture products. This leads to a dramatically improved ability to quickly create architecture models and simulations that are aligned with the proposed architecture.

Integration of Enterprise Technology Prototypes – The ability to create technology prototypes linked to the architecture description is another means of verifying and validating the architecture prior to committing to its implementation. Technology prototypes are usually focused at demonstrating the design approach to resolving the hard technical problems.

Change Case Integration/Analysis of Alternative – Most organizations claim that their architecture is open due to its compliance with established technology standards. Change cases allow us to prove that our architecture is open by demonstrating its ability to accommodate high likelihood changes in the community, business and system environments.

2. EA FOR MICROGRIDS

The direct relevance of EA for Microgrids is self-evident. The Microgrid is its own enterprise, representing a myriad of business functions. Figure 1.0 illustrates the NIST Conceptual Model for Smart Grid interoperability.[2] A Microgrid will have the function of the model below and/or interfaces to domains (markets) that are shown.

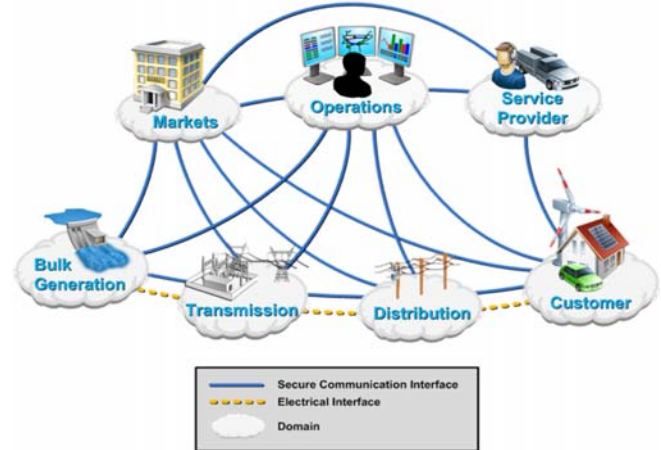


Figure 1.0 NIST Interoperability Conceptual Model [2].

2.1. Agile EASA Summary

Agile EaSA is a proven process and method for Enterprise Architecting and Systems Architecting for the last 8 years. Agile EaSA takes the traditional EaSA approach and tailors its associated activities and products to be generated in a more workshop-oriented, iterative fashion. Agile EaSA focuses on establishing the architecture and structure for development to implement test and integrate into the operational baseline. The agility in its approach drives the cost of doing architecture down significantly by producing only those artifacts needed to support capability development, design reviews, and meeting customer milestone gates. The iterative nature of Agile EASA allows analysis and products to be built up incrementally as the system matures alongside development activities, avoiding the typical waterfall pitfalls.

2.1.1. The Zachman Architecture Framework

The ZAF encompasses the common sense rules that we were given in grade school English class. In writing descriptive essays, we were taught to provide information about Who, What, When, Where, Why, and How in every story. This same common sense partitioning of knowledge occurs in the columns of the ZAF. This paper will not try to defend the ZAF over other frameworks. However, other architecture frameworks have been successfully mapped into the ZAF. In most cases, the coverage of these alternative architecture frameworks is incomplete when compared with that of the ZAF; however, the alternatives do have valid applications with the system engineering and IT communities. In any case, the framework that is adopted or developed should be easy to explain to management and the involved professionals.

According to Zachman, good information systems architecture is derived from the information system strategy, which, in turn, is determined by the business strategy. He implies, therefore, that the information systems should

support the business objectives of the enterprise, but he does not expand on a strategic planning process. His model describes the deliverables (*artifacts*) of a software engineering process. He identifies two different kinds of representations which, when used in combination, precisely describe the nature and purpose of these deliverables within the organizational context.































abstractions	DATA	FUNCTION	NETWORK	PEOPLE	TIME	MOTIVATION
perspectives	What	How	Where	Who	When	Why
SCOPE Planner contextual	List of Things - Important to the Business 	List of Processes - the Business Performs 	List of Locations - in which the Business Operates 	List of Organizations - Important to the Business 	List of Events - Significant to the Business 	List of Business Goals and Strategies 
ENTERPRISE MODEL Owner conceptual	e.g., Semantic Model 	e.g., Business Process Model 	e.g., Logistics Network 	e.g., Work Flow Model 	e.g., Master Schedule 	e.g., Business Plan 
SYSTEM MODEL Designer logical	e.g., Logical Data Model 	e.g., Application Architecture 	e.g., Distributed System Architecture 	e.g., Human Interface Architecture 	e.g., Processing Structure 	e.g., Business Rule Model 
TECHNOLOGY CONSTRAINED MODEL Builder physical	e.g., Physical Data Model 	e.g., System Design 	e.g., Technical Architecture 	e.g., Presentation Architecture 	e.g., Control Structure 	e.g., Rule Design 
DETAILED REPRESENTATIONS Subcontractor out-of-context	e.g. Data Definition 	e.g. Program 	e.g. Network Architecture 	e.g. Security Architecture 	e.g. Timing Definition 	e.g. Rule Specification 
FUNCTIONING ENTERPRISE	DATA Implementation	FUNCTION Implementation	NETWORK Implementation	ORGANIZATION Implementation	SCHEDULE Implementation	STRATEGY Implementation

Figure 2.0 Zachman Architecture Framework (ZAF) [1].

The ZAF is a commercial best practice that decomposes an information system's architecture into focused views, according to *scope* (rows) and *technology* (columns). The framework is shown in Figure 2.0. The scope dimension provides a coarse-to-fine view of the information system, with increasing levels of technical detail as a project progresses through the system/software engineering lifecycle. The technology dimension distinguishes different aspects of the system. These focus areas are used to classify relevant characteristics and emphasize different features of the system. Each focus area provides a different, product-centric view of the information system that highlights related characteristics and suppresses unrelated ones. Although each view describes the same system, they represent independent views of the system and tend to remain separate from each other.

2.1.2. Tenets of Agile

A key premise of Agile EaSA is to involve customers and stakeholders early and often into the design process. This is an adaptation of traditional software agile tenets, with the

exception that the right people are brought into the design process early at the appropriate times based on value and mission needs coupled with continuous development and integration, Agile EASA provides support to more agile, iterative engineering throughout the product development lifecycle. Architectures and designs are continuously updated and assessed through MSVA techniques to reduce risks associated with performance and requirements satisfaction.

A key benefit of using Agile EASA when applying agile concepts is the ability to assess, learn and apply feedback to ensure continuous product improvement. The nature of pure agile development practices is to rapidly develop capabilities, adjust requirements, and provide early prototyped capabilities as the customer and developer unfold the capability during real time interactions. This is the most extreme form of applying feedback and lessons learned. However, in a large program with complex capabilities and mission critical systems, requirements cannot be continuously redefined and capabilities cannot be developed on the fly and without structure and control mechanisms in place to manage risk.

When you apply the concepts of Agile EaSA with Iterative Design and Continuous Integration, you are placing more structure and rigor into the "agility" by which the team operates as they execute the lifecycle processes. Agile EaSA focuses on analyzing and developing only the necessary set of artifacts in a manner similar to peeling the layers off of an onion. Instead of drilling down into all areas of the four static views of engineering (network, data, functional, people), products are delivered in layers of maturation as engineers learn more about the system during its build-up an integration. After each pass at a particular set of analysis and its associated products, architects, engineers, developers and customer stakeholders have the opportunity to review, comment and provide feedback towards the next level of its design. This interaction is prevalent across the whole lifecycle of both architecture and product engineering activities. Not only does this interaction and iterative nature ensure higher end user advocacy and satisfaction with the final product, it also allows the team to negotiate changes in requirements as the design matures and alternatives are traded based on feedback in a controlled, structured manner. This form of feedback and early adoption in design through remaining flexible in the engineering approach through iterative design activities reduces risks associated with both pure agile applications as well as traditional waterfall development.

An additional consideration when applying agile methods to existing systems is to acknowledge that you will rarely begin with a clean sheet of paper. The key to applying structured-agile engineering approaches to programs or projects that have some design lineage or legacy is to be

able to work along side of the existing system to facilitate transition to the desired system.

2.2. EA Interoperability

It is critical that the organizations involved in the various efforts of Microgrid development utilize an EA process that allow for interoperability. Interoperability of system components may occur at different levels, such as applications, interfaces, and network layers. Interoperability processes are built-in to the ZAF to discover and define interfaces that needs translation to communicate. Legacy interfaces and systems represent most of the interoperability use cases. The generation of artifacts must be transportable amongst the various organizations involved. This facilitates a common understanding of the goals, scope, and solution spaces that the parties discuss and agree to.

2.2.1. Integrating the CIM

The native use of UML by Agile EaSA facilitates the integration of the Common Information Model (CIM) into a Microgrid project. The CIM describes how managed object in the Microgrid are represented as a common set objects with relationships. The notion of CIM is a core concept that any Microgrid and is defined by UML artifacts. The CIM allows for interoperability with a host of legacy and non-legacy systems. There maybe instances where multiple CIMs exist. Each CIM would be pervasive throughout a specific domain and interoperable a minimum set of interfaces to other domains.

2.2.2. Compliance with the GWAC Interoperability Framework

The Agile Framework can import other frameworks that perform specific functions and at different layers. The GridWise Architecture Council (GWAC) document on the GridWise Interoperability Context-Setting Framework, v1.1 describes a broad, conceptual, and layered framework in three categories [4]. The GWAC Framework allows a common ground for discussing of technical, organizational, informational and cross-cutting domain issues. A Microgrid and Smart Grid architecture effort may import the GWAC Framework as a starting point and use it for interoperability compliance.

2.3. How Standards are integrated into Agile EaSA

Standards essentially become constraints on the architecture. The standards define the bounds the potential solutions set for a Microgrid project. The standards incorporated by the architecture will dramatically increase the likelihood that early Microgrid projects will be “compliant” when the larger smart grid standards are put in place. Standards in the electric power industry and Microgrid describe interfaces, methods, and data formats that allow components to communicate.

2.4. The IA Overlay

Agile EaSA includes an approach to “defense-in-depth” security and information assurance architecting. This approach generates an architectural overlay that addresses the needs of security and IA at various levels in the architecture. Lessons learned show that the Security/IA (S/IA) requirements provide significant constraints on the overall system design. A perfectly implemented system is worthless if it cannot be accredited for operations. Agile EaSA implements S/IA design as an overlay across the entire framework. Each view of the architecture and design has security concerns that must be addressed! The IA overlay integrates Threat Analysis, Vulnerability Analysis, Risk Assessment, Control Placement, and Anti-Tamper activities and design into a cohesive S/IA package that is integrated into the core architecture.

3. CONCLUSION

The use of Agile EaSA with respect to Microgrids is a clear necessity. The Microgrid complexity and breadth of scope fame it as an enterprise system. The incredible amount of data that will be collected, analyses, and shared provide new IT challenges that only a conscious architecture can tackle. The use of standards and the ability to quickly react to changing conditions provide a clear need for an agile, yet rigorous approach. The ability to simulate that architecture and rapidly drive down risk will also be important aspects of the Microgrid enterprise architecture.

3.1. Agile EaSA in the SDG&E Microgrid Project

Agile EaSA is basis for architecture activities and design in the SDG&E Microgrid project. The Agile EaSA process incorporates several power grid components into new functions and interfaces with renewable energy sources. The processes include integration of legacy systems and standards in a pilot Microgrid connecting two distinct power areas with the SDG&E power grid.

3.2. Executable/Simulatable Architecture

Simulatable Architecture provides a ‘data bridge’ between Agile EaSA Models (i.e. artifacts) and Discrete Event Simulation. The Simulatable Architecture provides direct verification and validation of the architecture analysis and system design. It is 100% traceable to the architecture and design. The simulation scenarios are focused on addressing “Hard Problems First”

These simulations become part of the Modeling, Simulation, Visualization, and Analysis (MSVA) process. MSVA essentially brings the architecture “to life”. This facilitates risk reduction at an early stage in the project life-cycle. The MSVA models and simulations take of the form of messaging/data flow models or packet level representation of network protocols and stacks.

3.3. Interoperability Standards defined by NIST

NIST (National Institute of Standards and Technology) is working on the standards that will drive the Smart Grid. They have published a core set of standards that will be instrumental in defining the Smart Grid. An excerpt of these standards is provided in Figure 3.0. For any Microgrid project to be viable, compliance to most of these standards will be a necessity. These standards recommendations will define interoperability in the modern power grid in the future.

Initial Smart Grid Interoperability Standards Framework, Release 1.0

Standard	Application
AMI-SEC System Security Requirements	Advanced metering infrastructure (AMI) and Smart Grid end-to-end security
ANSI C12.19/MC1219	Revenue metering information model
BACnet ANSI ASHRAE 135-2008/ISO 16484-5	Building automation
DNP3	Substation and feeder device automation
IEC 60870-6 / TASE.2	Inter-control center communications
IEC 61850	Substation automation and protection
IEC 61968/61970	Application level energy management system interfaces
IEC 62351 Parts 1-8	Information security for power system control operations
IEEE C37.118	Phasor measurement unit (PMU) communications
IEEE 1547	Physical and electrical interconnections between utility and distributed generation (DG)
IEEE 1686-2007	Security for intelligent electronic devices (IEDs)
NERC CIP 002-009	Cyber security standards for the bulk power system
NIST Special Publication (SP) 800-53, NIST SP 800-82	Cyber security standards and guidelines for federal information systems, including those for the bulk power system
Open Automated Demand Response (Open ADR)	Price responsive and direct load control
OpenHAN	Home Area Network device communication, measurement, and control
ZigBee/HomePlug Smart Energy Profile	Home Area Network (HAN) Device Communications and Information Model

Figure 3.0 NIST Standards for Smart Grid (From: DOE) [3]

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5.0 Biography

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David Nemirow works for BAE Systems in San Diego CA. He is working on the Balance Energy initiative started by BAE Systems. He has 5 years of systems engineering and architecting experience and has been engaged on both DoD and DARPA projects. David received a Masters Degree in Systems Engineering from Johns Hopkins University.

Ralph Martinez

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