Power and Energy Management: A User-Centered System-of-Systems Engineering Approach

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Abstract. Energy is considered a resource for survival. The demand and supply of natural resources used to generate, transmit, and consume the power make the puzzle for the human race even more complex. Other physical elements like water, copper wiring, electric cars, nuclear power plants, oil platforms, consumer tablets, and buildings to name a few are attached to the energy ecosystem adding mass confusion to a system failing to keep up with the global changes. This paper deals with a methodology for designing a smarter power and energy management system, following the V-cycle. It focuses on building a model using systems modeling language (SysML). The application of systems engineering process in power and energy is presented in this paper as well as the devices in the systems which are going to have a software component enveloping the digitization and proliferation of better, faster, and more effective ways of reusing our best practices in systems engineering. This paper introduces a system-of-systems engineering approach codified in client power management software needed for the urgent transformation of global power systems.

Keywords: Systems engineering, energy, power management.

1 Introduction

By creating sustainable cities, the planet could become smarter. As a matter of fact, an urbanizing world means that cities are “gaining greater control over their development, economically and politically. Cities spread wider and wider but at the same time they are becoming overcrowded and polluted while energy consumption increases exponentially. Cities are also being empowered technologically, as the core systems on which they are based become instrumented and interconnected, enabling new levels of intelligence. In parallel, cities face a range of challenges and threats to their energy sustainability across all their core systems that they need to address

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holistically. To seize opportunities and build sustainable prosperity, cities need to become efficient in utilizing power and energy resources. The evolution of technology and communication can allow the inhabitants to live a better and easier life. Nowadays, high-technology can be employed by the users daily. An effective energy management initiative is going to answer this tradeoff dilemma of technology and environment. In this paper, the main focus will be about how to implement a system-of-systems engineering approach design efficient energy and power management system for smarter cities.

2 Systems Engineering

A system is defined by the International Council on Systems Engineering (INCOSE) [22], as an artifact created by humans consisting of components that pursue a common goal unattainable by each of the single elements. This definition can lead to very broad generalizations or in-depth plans for an element. The engineering part of systems engineering represents the practice of employing tools and structured approaches to develop a product. Putting these two words together describes the SE practice of defining and documenting requirements for a product or process, preparing or choosing amongst design alternatives, assuring requirements have been met, and finally deploying, maintaining and disposing the system. The process is iterative, all the while employing optimization and streamlining the various elements to ensure that cost, schedule, and operational requirements are met.

Forsberg et al. [1] describe the "Vee" model relating systems engineering to the project cycle (see Figure 1). Design explorations and analyses are conducted at the start of the system development, ending with the complete integration and qualification of the finished system. The left side of the "Vee" model describes decomposition and definition activities; the center base represents the complete specification of system components, while the right side describes the quantitative verification activities assuring that requirements were met.

According to Ahram et al. [24], the contemporary SE process is an iterative, hierarchical, top down decomposition of system requirements [24,2]. The hierarchical decomposition includes Functional Analysis, Allocation, and Synthesis. The iterative process begins with a system-level decomposition and then proceeds through the functional subsystem level, all the way to the assembly and program level. The activities of functional analysis, requirements allocation, and synthesis will be completed before proceeding to the next lower level. Modeling SE Process Activity is performed using Systems Modeling Language (SysML). SysML is a general-purpose visual modeling language for specifying, analyzing, designing, and verifying complex systems which may include hardware, software, information, personnel, procedures, and facilities (http://www.omgsysml.org). SysML provides visual semantic representations for modeling system requirements, behavior, structure, and parametrics, which is used to integrate with other engineering analysis models [3]. SE teams along with system designers are responsible for verifying that the developed systems meet all requirements defined in the system specification documents.

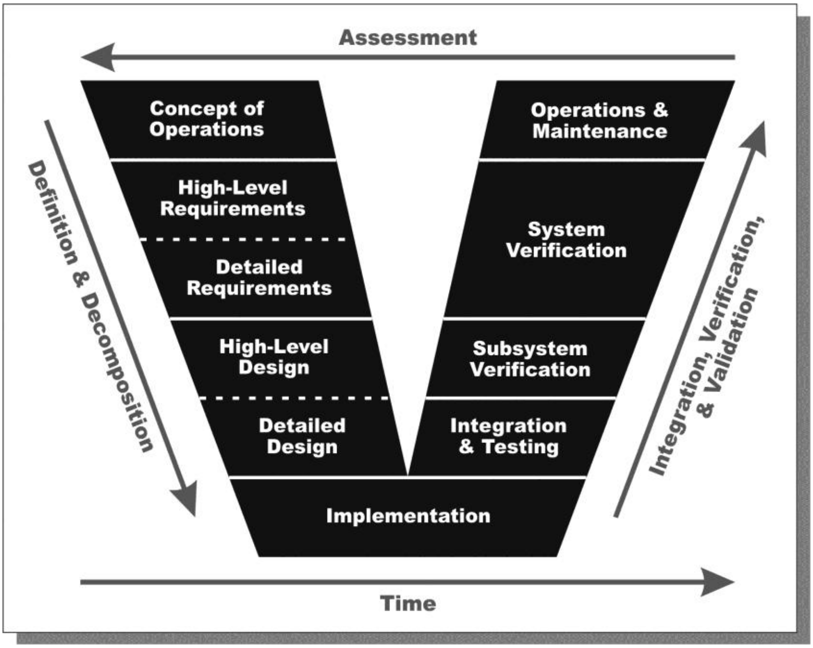

Fig. 1. Systems Engineering Vee Model [4]

The system-of-systems engineering approach for design and modeling of power generation systems differentiate between performance and effectiveness criteria [24]. These criteria determine a total system mission performance level and acceptability that is directly attributable to specific actions allocated to performance and efficiencies metrics. These are indicators measure which performance effectiveness criteria are met [5, 6]. The SE framework (see Figure 2) can be used to develop a system where the users and machine synergistically and interactively cooperate to conduct the mission of efficient power management and sustainability, and the "low hanging fruit" of performance improvement lies in the human–system interaction block.

As systems engineering (SE) practices unfold, problems inherently develop. These challenges are addressed using the systematic approach integral to SE practices and, once sufficiently addressed as defined by the agreed-upon requirements, the process moves on to the next phase and next problem [26]. The current standard used in industry and military applications is the EIA-621 standard. It applies to the product life cycle starting from the user needs to the final delivery. It outlines thirteen related processes divided into five functional groups.

Following systems engineering practices affords a formal design approach that attempts to cover all aspects of design. This includes a robust risk management portion that, given good requirements, will yield a safe design. Safety is not the only benefit of following this approach. Past performance on projects and previous research in systems engineering indicated that there is a positive correlation between utilizing formal systems engineering practices and the degree of success in an engineering undertaking, especially in return on investment (ROI) [7,5,8]. Today's difficult economy mandates a positive ROI on practically all undertakings and systems engineering practices assure that safety is not compromised.

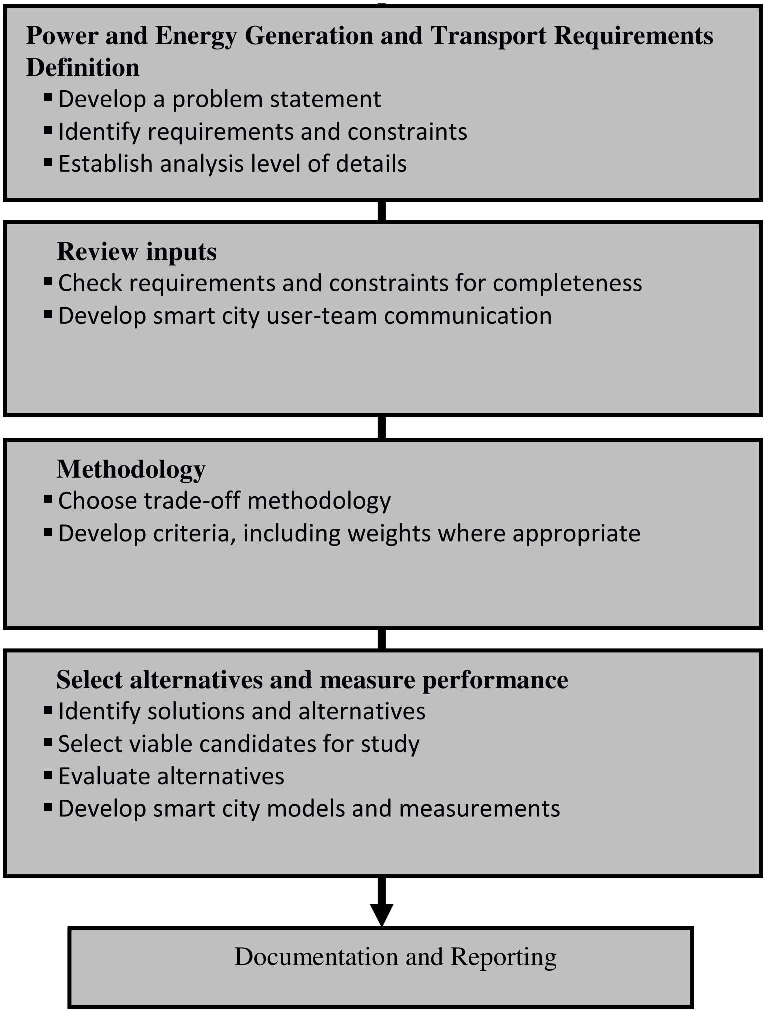

Fig. 2. The SE knowledge integration framework [24]

Profitability or on time delivery should never take priority over system safety and having a detailed plan based on systems engineering practices assures this does not happen. Ensuring a high ROI with a detailed plan on how to execute the design reassures management and moves projects forward [9].

Systems engineering also manages complexity. It is no secret that hardware and software is growing more complex with each passing year. New features are added, additional functionalities are created, and overall system complexity increases accordingly. Baumgart et al. [10] state that the implementation of new functions can actually lead to "inconsistent" systems. Their rationale is that in order to accommodate new functionalities technical architectures must be modified to compensate for these changes. Having a continuous, robust, reproducible design approach simplified matters greatly. This traceable, repeatable approach can increase overall levels of system safety through explicit visualization of system operations and identify possible breakdowns before they occur.

Another added benefit of a rigorous design framework is enabling concurrent design, where multiple projects proceed in parallel. These methods can also enable reuse of system components in new functions. These components can find new life by re-instantiation. This is especially true of software projects, however many modular physical components demonstrate this property as well. Systems engineering support identifying and assessing risk and help system designers and program managers develop proactive, cost-effective loss prevention programs that protect against loss, safeguard systems and operational continuity. Systems engineering assures that a life-critical support system behaves as needed even when components fail.

This merging of system components and functions was not possible until recent times. The design process must evolve to keep up with these new practices. The systems engineering practice comprises the following chain of artifacts: Processes → Methods → Tools. Processes are identified based on previous studies and general design heuristics, or from standards such as the EIA-632 standard. Methods can either be developed from scratch or recycled from past programs if they are applicable. The third item, tools, is concerned with methods involved in conceptual and detailed design; the tools are defined, acquired, or created once a viable method exists [11].

The overall goal of systems engineering is to convert user or stakeholder requirements into technical engineering requirements that drive design. Safety is always an important part of the requirement process, and is supported by the systems engineering framework through both validation of said requirements as well as verification that they have been met. Safety requirements generally set constraints on any given system. For example, safety requirements may mandate fall protection provisions, or set touch temperature on surfaces, or limit shift lengths. Safety requirements are hierarchical in nature with the most attention and consideration given to those of a critical nature or those needed even when components fail. Stakeholders, regulatory bodies, governing policies, or certification and quality standards may specify safety requirements. These requirements safety and loss prevention engineering may also be ordered and managed by a set of attributes. Software tools such as Systems Modeling Language (SysML) may aid in this venture [11].

3 Benefits of System Engineering for Energy Management

Systems engineering (SE) concepts and principles are an integral part of the contemporary engineered world [2] Such concepts are also used to create smarter consumer systems, protect human health, enable travel over great distances, and allow for instant and ubiquitous communication. These principles are also used to build energy efficient houses and transportation solutions, design workplaces, develop an infrastructure that society relies upon for smarter cities. The SE principles are used to make services and systems cheaper, more functional, and get them to the market faster. Systems engineers apply and integrate concepts and rules derived from math and science to create and apply such principles [12, 14, 15]. For example, the energy used to heat, cool, and light residential or industrial dwellings is typically generated hundreds of miles away from where it is used and needs to be transferred over long distances.

4 Power and Energy Smart Grid Revolution

Today, electricity is primarily generated at large, central fossil fuel plants and hydroelectric dams. It then travels hundreds of miles along complex network of transmission and distribution lines and devices that criss-crosses vast landscapes - called simply the grid. The electricity that powers everything from a single appliance to vast, intricate national systems is such an integral part of our daily lives that we rarely think about where it's made or how it's delivered.

In the near future, power generation and transmission need an even more complex and sophisticated infrastructure that will continue to power the digital economy but in a cleaner, more reliable, and more affordable way - a smart grid. Smart cities provide major economical and technological benefits to the nation and boost economy and jobs creation by implementing smart grid innovations [17]. According to the handbook for assessing smart grid projects [17,19], a smart grid will provide the following major benefits:

- Reduce peak demand by actively managing consumer demand
- Balance consumer reliability and power quality needs
- Mine energy efficiency opportunities proactively
- Improve overall operational efficiency
- Seamlessly integrate all clean energy technologies

5 Integration of Systems Engineering and Human Factors Knowledge Management into Energy and Power Generation and Transport

Knowledge management for smart cities and energy management is challenging [24], especially for large organizations with complex projects involving multiple disciplines. Despite the increasing ability to communicate and share knowledge, it seems that many designers and engineering groups do not share their findings outside of their own group [18, 26]. An often-encountered phenomenon is that of a "*Tribal Knowledge*", where a certain group or individual acquires a skill or trade and keeps it, employing it when called upon. Such groups rarely leave a legacy or ability to transfer this knowledge to their replacements, forcing the organization to relearn and human factors engineering groups and SE practitioners have realized the limitations and coined the term recreate that which it already knew [12].

The commercial market has already realized the importance of SE & human factors knowledge management, and thus a few software systems such as the *IBM Rational Focal Point*™ have been created to assist organizations and governments managing complex projects involved in designing and optimizing cities systems & infrastructure [26]. Figure 3 illustrate two *Focal Point*™ portfolios for smarter cities and smart energy and utility projects management. *Focal Point*™ supports SE, human trade-off analysis, data integration to optimize energy usage and maximize distribution efficiency.

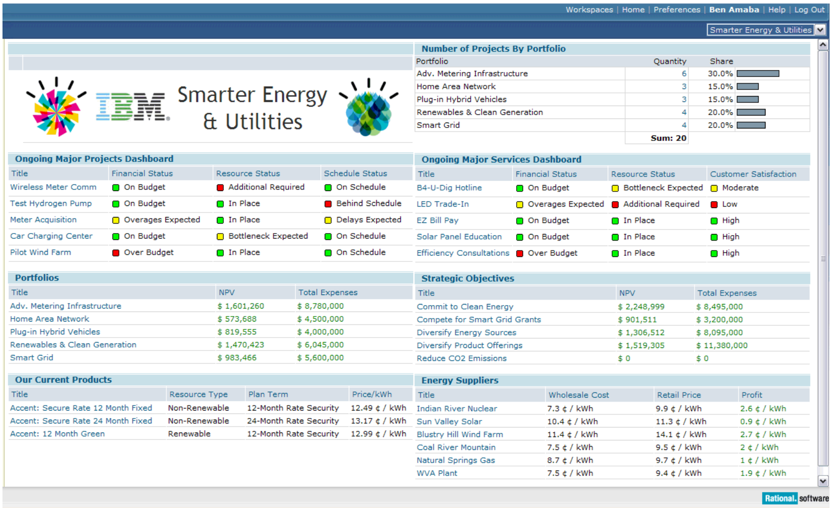

Fig. 3. Smarter Energy & Utilities network distribution projects management workspace. (Source: IBM Rational Focal Point™)

Successful practices for smart cities (software based on these practices) require the following features [6]:

- *Ease of use* – it is unlikely that something awkward or difficult to use will continue to be used in the long term
- *Varied format input* – aside from scribbling on notebook paper, the software should accept many document and file formats
- *Traceability* – inputs should be traced to their owner
- *Security* – all users may not require access to all elements of the knowledge database; proprietary, secret, and competitiveness concerns must be addressed
- *Routine* – inputs should be encouraged while the idea, solution, or process is still fresh in the creator's mind

- *Organization* – without a structured method of entry or effective indexing method, acquired knowledge is meaningless; it should be viewable top-down, or searchable as browsable on varied related topics

6 Conclusions

Having a strong energy infrastructure changes how nations innovate, prosper, suffer or fade. Given the urgency of the situation, societies have to reuse, modify and apply best practices and technology to accelerate our ability to solve the energy famine on the horizon. History calls on an effective and battle tested systems engineering discipline that has supported putting people on the moon, space exploration, medical devices, airplanes, cellular telephones, nuclear reactors, and defense systems. This paper provides a motivation and quest for integrated systems engineering smart energy management approach. While a large number of disciplines and research fields must be integrated towards development and widespread use of smarter systems, considerable advancements achieved in these fields in recent years indicate that the adaptation of these results can lead to highly sophisticated yet widely useable collaborative user-centered applications for smart cities sustainability's. The SE and human engineering approach to design and modeling of smarter energy generation and transport systems prove critical l in supporting and facilitating the development and applications of future sustainable cities.

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