Demand Analysis of Wind Turbine System Based on MBSE

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Abstract. Because the wind turbine system is complex and involves a wide range of disciplines, the model-based system engineering (MBSE) method is used to effectively process demand analysis, system function analysis, and system logic architecture design synthesis and verification in a graphical manner, forming a standard Sequential design process reduces costs and improves design efficiency. Requirement analysis is the key to system design and the key to the forward design process of MBSE system architecture model. It is of great significance to the entire system and subsequent development. This article mainly describes the application of MBSE in wind turbine system demand analysis.

1. Preface
System engineering is a science and technology that studies the design, establishment, testing and operation of complex systems. As systems in various fields become more and more complex and social inforbility, and improving the efficiency of communication.

The wind turbine system includes seven subsystems including the pitch system, power generation system, main drive system, yaw system, controlmation technology becomes more and more developed, the traditional way of designing and developing based on documents can no longer meet the requirements of complex systems [1]. Therefore, in 2007, the International Committee for Systems Engineering (INCOSE) put forward the concept of MBSE: the formal application of modeling to support system requirements, design, analysis, verification, and validation activities. These activities start at the conceptual design stage continues to the entire development and later life cycle stages; and the MBSE vision plan was first proposed at the meeting, and it is planned that the MBSE theory will gradually mature from 2007 to 2020. It aims to use the MBSE method to achieve the effects of design unambiguity, design integration, ensuring reusa system, braking system, and wind measurement system. It is a comprehensive system engineering. Involving many disciplines, using traditional document-based design methods to read information can easily lead to inconsistencies in understanding, and repeated iterative modifications often occur in the product design process. The use of the MBSE method can promote the cooperation between the subsystems, which is the key to ensuring the efficient operation of the wind turbine system [2].

2. Significance of needs analysis
The INCOSE System Engineering Manual defines requirements as descriptions that identify the characteristics or constraints of systems, products, or processes, which are clear, clear, unique, consistent, independent (not grouped), and verifiable, which is very acceptable to stakeholders. necessary. The United States is conducting follow-up investigations on 8,000 projects nationwide. When analyzing the reasons for project failure, it was found that the reasons related to the demand process accounted for 45%, and the lack of end-user participation and incomplete demand were the...
two primary reasons, each accounting for 13% and 12% [3]. There are a large number of requirements, a wide range of sources, intricate levels, and large changes. Without efficient and orderly management, it is difficult to achieve the design results corresponding to the needs of stakeholders.

3. Model-based system engineering

Model-based system engineering is to design the target system according to the process using modeling methods and graphical expressions, which is mainly realized through specific modeling languages, modeling methods, and modeling tools. The unified modeling language removes the inconsistencies in the modeling process and promotes the association between the various subsystems [4]. The modeling method stipulates the design process, from requirements to function analysis to architecture model, modeling in an orderly manner. Modeling tools provide guarantee for the establishment, storage and reuse of models.

3.1. Modeling method

This article uses SysML modeling language, Magic Draw modeling software, and Magic grid modeling method introduced by no magic company, as shown in Figure 1. The modeling method includes three main parts: problem domain, solution domain and physical layer.

Among the problem domains, the black box part is the first to be solved. In the black box part, stakeholders first propose requirements, use SysML to analyze the requirements, and then classify the requirements. This process requires the use of nine types of diagrams in the SysML language. The package diagram, demand diagram, and use case diagram in the package diagram; then the black-box architecture design derived from the functional requirements is gradually analyzed until the white-box model architecture is generated, and then the black-box discrete functional requirements architecture is subjected to the white-box continuous function through numerical simulation Requirement analysis to improve functional requirements and capture new requirements, and finally use the state machine simulation in the MBSE architecture to verify the completeness and rationality of the requirements. This process completes the distribution of system requirements to all functional levels and decomposes the functions to the next hierarchy, definition of functional interfaces and functional architecture and other goals [4,5], this process involves sequence diagrams, activity diagrams, and state machine diagrams.

Then in the solution domain, with the help of the white box model, the possible logical architecture of the system can be weighed and analyzed, and system functions can be allocated to the subsystem architecture.

Finally, the physical layer needs to achieve the goals of transforming the functional architecture into the physical architecture, defining alternative system solutions, configuration items and system elements, selecting the preferred product or process solution, and defining internal and external physical interfaces.

In summary, the design process of a wind turbine mainly includes 3 steps and 4 loops, as shown in Figure 2.
The first step is to draw a demand map according to the parameters and classification of the wind turbine system to obtain the development requirements, transform the user's needs and external environment constraints into system requirements, and generate demand maps, use case maps and package maps.

The second step is to perform system functions Analyze and draw the system functional architecture, generate sequence diagrams, activity diagrams and state machine diagrams, output use case models and operating protocols, and operating protocols describe the logic and interface specifications of the system's interaction with the outside world. Through the consistency analysis of the use cases, the use case collaboration model is established, and the use case diagrams are merged together to form an all-round investigation of the system functions and complete the logical verification of the system architecture model. Then define the function of the subsystem according to the requirements of the subsystem development.

The third step is to "map" the functional architecture to the physical architecture based on the existing products and technical conditions, establish physical models of each sub-system, and generate module definition diagrams, internal module diagrams and parameter diagrams. Use the output operating protocol to simulate to verify the correctness. The 4 loops are responsible for comparing the outputs and inputs of the 3 steps to see if they match. This process is called verification, so that the model can meet the requirements of the overall and sub-system development [6,7].

![Figure 2. Magic grid modeling method diagram.]

### 3.2. Advantages of model-based systems engineering (MBSE) modeling

According to the previous design process, it can be concluded that Traditional System Engineering has the following problems [8].

- It is the lack of simulation and verification of the system-level architecture, resulting in product defects that cannot be corrected by later changes, and there are many product design iterations.
- The document size is large, the version is many, and the technical status is not easy to control.
- There is a lack of multi-physics coupling simulation analysis. Simulation verification is carried out independently in each field, and it is only carried out in the detailed product design stage. System function and behavior simulation is rarely carried out in the requirements analysis and preliminary design stages.
- In the optimization design of software and hardware, only the optimization of its own parameters is considered, and the mutual influence relationship among electronic, software, control and other parameters is difficult to realize in the later optimization design. Therefore, this method has been unable to meet market needs.

Model-based systems engineering methods are mainly due to visual and easy-to-understand design results, more accurate engineering data, more accurate engineering data, easy integration of different types of engineering data, data consistency across engineering activities and work products, easier management and The seven advantages of maintenance engineering data, early verifiable engineering data, and easy-to-use design results have gradually replaced the traditional document-based design methods.
4. Demand modeling
The main functions of requirement modeling include the expression of requirements in various requirements development stages and the conversion of user requirements into system requirements by means of import, editing, association and item management, etc., with the help of MBSE method [9,10]. Requirements are mainly divided into five categories: target requirements, business requirements, functional requirements, performance requirements, constraints and restrictions. Among them, performance requirements and constraints and restrictions are non-functional requirements, and constraints and restrictions are set for the realization of functional requirements.

4.1. Demand for wind turbine systems
In the demand analysis stage, the needs of stakeholders are mainly divided into appearance technical features, basic parameters, external conditions and pitch system, power generation system, main drive system, yaw system, control system, braking system, wind measurement system, etc. Each subsystem, as shown in Figure 3, shows the basic original requirements such as appearance and technical features in Magic Draw software. Various types of requirements in Magic Draw can be set and differentiated, mainly divided into non-functional requirements and functional requirements.

![Figure 3. Basic original requirements such as appearance and technical features.](image)

4.2. Use case diagram
The behavior performed by the system is called a use case, and the use case diagram expresses the use case performed by the system and the participants of the behavior. Create a use case in the use case diagram and add participants for the use case. This participant covers the person or external system of the use case behavior process, so as to truly and comprehensively reflect the externally visible functions provided by the system. At the same time, it is the basis for the information interaction and interface creation between the system and the external system.

The pre-requirements are incomplete and need to be converted into use cases, so as to complete the requirements through the modeling process. The use case diagram of the system is shown in Figure 4.

![Figure 4. Use case diagram.](image)

For the entire system, the external participants that may be involved include the controller, the external environment, and so on. These external participants all come from the behavioral process of system functions and have a greater impact on subsequent modeling. Therefore, all possible external participants need to be added to the use case diagram. When creating a use case diagram, you need to include all relevant stakeholders.
4.3. Activity diagram

Activity diagram is an intuitive representation of system functional behavior, which can vividly reflect the designer's idea of a certain use case. The activity diagram shows the behavior process of a certain use case of the brake system in the form of process control, which can explain the continuous behavior of the system. In Magic Draw, an activity diagram is created directly in the created use case diagram element to facilitate later tracking. The overall activity diagram of the design process is shown in Figure 5. First, the "Start" button, and then the wind turbine system starts to debug under the action of the wind, if there is no problem, it will start to run, and it will run without exceeding the set limit; If there is any problem, check and debug again, and start running until there is no problem.

![Figure 5. Activity diagram.](image)

4.4. State machine diagram

The state machine diagram is used to specify a series of states of the module and the possible transitions between states in response to events. The state machine diagram is concerned with how the structure of the system changes state with events that occur over time, and the behavior it displays often represents the classification behavior of the module. The state machine diagram can make precise and clear descriptions of the behavior of the braking system, for example, and can also be used as the output of the detailed design (input items for the next level of development). The operating results of the state machine can be used to verify whether the model meets the system requirements, and can also be used to initially confirm the system requirements. According to the previous activity diagrams, etc., after the state machine diagram can be automatically generated, the designer needs to complete the state information of the system and construct a reasonable state machine diagram. If there is an error in the construction of the system behavior model, the state machine diagram will not operate normally, which requires the design team to re-verify the behavior logic and requirements of the system and make changes to the unreasonable system behavior. Therefore, the state machine diagram is more to test the accuracy of the built model, which also shows a big advantage of MBSE which is different from the traditional system model: it can achieve continuous verification during the process, thereby avoiding the discovery after the entire model is built. An irreversible error occurred midway.

5. Conclusion

- In summary, the following conclusions are obtained.
- For complex and multi-disciplinary systems, the use of model-based systems engineering methods for design has become an increasingly trend.
- There are many subsystems of the wind turbine system, and the interrelationships between the subsystems are complicated. The model-based system engineering method used in the design of the wind turbine system can not only achieve the purpose of consistent and correct data and clear interrelationship, but also realize the effect of design reuse, saving a lot of time and energy for future design.
- However, the domestic use and understanding of MBSE has just started. How to save the workload of pre-model building and popularize this method in the tight project plan needs to be continuously explored.
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References
[1] Yang Hong, Xiao Yang, Li Bing. The application of MBSE in the demand analysis of civil aircraft brake system[J]. Civil Aircraft Design and Research, 2018, 000(004): 104-108.(in Chinese)
[2] Wu A, Sun W L, Wang P P. Large Wind Turbine Dynamic Modeling and Simulation[J]. Applied Mechanics & Materials, 2010, 34-35: 1098-1103.
[3] IBM Watson IoT. IBM Rational DOORS Workshop. 2017.
[4] Ramos A L, Ferreira J V, Barcelo J. Model-Based Systems Engineering: An Emerging Approach for Modern Systems[J]. IEEE Transactions on Systems Man & Cybernetics Part C, 2011, 42(1):101-111.
[5] Cao Y, Liu Y, Paredis C J J. System-level model integration of design and simulation for mechatronic systems based on SysML[J]. Mechatronics, 2011, 21(6):1063-1075.
[6] Mouratidis H, Jurjens J. From goal-driven security requirements engineering to secure design[J]. International Journal of Intelligent Systems, 2010, 25(8):813-840.
[7] Cao Y, Liu Y, Fan H, et al. SysML-based uniform behavior modeling and automated mapping of design and simulation model for complex mechatronics[J]. Computer-Aided Design, 2013, 45(3):764-776.
[8] Cloutier, R, Sauser, et al. Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models[J]. Systems Man & Cybernetics Systems IEEE Transactions on, 2014.
[9] Holt J, Perry S, Payne R, Bryans J, Hallerstedt S, Hansen FO, et al. A Model-Based Approach for Requirements Engineering for Systems of Systems[J]. IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC, 2015, 9(1):252-262.
[10] Bernard Y. Requirements management within a full model-based engineering approach[J]. Systems Engineering, 2012, 15(2):p.119-139.