J. Automation & Systems Engineering 11-1 (2017): 27-36

Regular paper

Using Systems Modeling Language SysML for analysis of Wind Power System

K. Nasraoui, M.N. Lakhoua and L. El Amraoui

Research Unit Signals, and Mechatronic Systems, SMS, UR13ES49,
National Engineering School of Carthage, ENICarthage,
University of Carthage, Tunisia

JASE
Journal of Automation & Systems Engineering

Abstract- This paper presents an analysis and modeling of a wind turbine using the systems modeling language SysML in order to achieve a functional, structural, and behavior description. Nowadays, our energy production is the primary culprits behind environmental issues including global warming, greenhouse gases, CO_2 emissions and climate change. Therefore, we need to move to renewable sources of our energy generation to further help the environment and to sustain our increasing demand. One of the alternative ways to generate electricity is wind turbine. Since it appearance at the beginning of the last century, wind turbine technology system has improved step by step. Actually, wind turbine has a complicated structure, a set of heterogeneous components that interact in an organized manner to accomplish a common goal which is harnessing the wind to produce electrical power. We start with introducing wind turbine generator systems. Next, we describe the systems modeling language SysML. Subsequently, a graphical description of the functionality of a wind turbine system based on SysML diagrams are shown here. Finally, some conclusions are presented.

Keywords: Wind power system, analysis and modeling, SysML

1. INTRODUCTION

Nowadays, increasing dependency over electricity has led to the increasing unabated of the energy demand observed worldwide. Meanwhile, the fossil fuels which still the dominant source of energy production draw on finite and non-renewable resources, which they will be finished someday. Moreover, they are already dwindling and thus becoming more expensive or their retrieval is becoming ever more environmentally damaging. To further help the environment by diminishing of fossil fuel sources [1-2] and to sustain our increasing demand, we need to move to renewable sources of our energy generation. It may come as a surprise to learn that the harnessing of natural phenomena such as sunlight, wind, for same form of productivity use has always been part of the human activity for centuries.

One of the alternative ways of generating electricity is harvesting wind power [3]. However, this latter has been used since early history to provide mechanical power to pump water or to grind grain. However, windmills and water driven mills were the only the only power generators for over 1.200 years predating the 18^{th} Industrial Revolution. Later, evolution and perfection of these systems was performed step by step in s in Denmark, France, Germany, and the United Kingdom [4].

Although, harvesting wind power isn't exactly a new idea, contemporary societies are essentially based on fossil fuels for covering their increasing electrical energy demand. But actually, during the last decade of the twentieth century, security of energy supply, increasing demand and environmental issues has captivated the interest for renewable sources of energy such as wind turbine system.

In order to understand the overall operation of the wind turbine system, we propose in this paper a high level graphical description based on SysML diagrams.

The outline of this paper is as follows. An overview of wind turbine generator systems is given in section II. Systems modeling language SysML is presented in section III. Functional, structural, and behavior description of a wind turbine using SysML diagrams is shown in section VI. Finally, section V concludes this paper with some prospects.

2. WIND POWER SYSTEM

Wind energy has reemerged as one of the most important sustainable energy resources, partly because it is free from pollution as there are no greenhouse gas or heat emissions. Moreover, the wind is a clean, sustainable, free and renewable source of energy, so it will never run out [5-6].

Wind turbine is a device that converts the wind's kinetic energy into electrical power [7]. It falls into one of two basic categories: Horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). HAWTs, is the more common type currently used [9].

Today's wind turbines are manufactured in a wide range of small and large types [10-11]. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

Regardless of the type of design, the main components that can and often times will be found in wind turbine systems [12] are a nacelle which contains the key components of the wind turbine, including the gearbox, and the electrical generator which uses electromagnetic to generate electricity, propellers-like blades rotates when wind is blown over them, causing the rotor to spin. Most turbines have either two or three blades, a tower which carries the nacelle and the rotor.

Generally, it is an advantage to have a high tower, because winds are stronger higher from the ground. All those components serve a purpose in delivering electricity where it is intended to go. Thus it is clearly that the wind turbine has a complicated structure. However, not only by a large number of components, but also by the diversity of these components, their relationships and interactions in an organized manner to accomplish a common goal which is harnessing the wind to produce electrical power, wind turbine system has the characteristics of complex systems. Moreover, the introduction of such a renewable energy sources and system decentralization in what we called now smart grids has increased its degree of complexity in terms of interactions and communications [13].

In the aims of better understand and analyze the complex structure of wind turbine system we present in the next section one of the tools for modeling complex system: SysML.

3. SYSTEM MODELING LANGUAGE WITH SYSML

In order to master the understanding, development and exploitation of complex systems, approaches such as system engineering have proposed methodological approaches associated with tools that give simplified representations of reality. These simplified visions are called models which are based on graphical languages.

Structured Analysis Design Technique (SADT), classic tools of fundamental analysis (APTE, FAST...) and GRAFCET are already part of these languages. However, all these disparate tools, powerful they are, will never give a coherent overall description of the thing represented. So, the idea is to feeder several specialized languages within a meta-language giving a pertinent vision to the system. That is what we are always looking for by using SysML language [14].

In a manner similar to how UML unified the modeling languages used in the software industry, the OMG defines a general-purpose modeling language for systems engineering applications, called SysML, which is intended to unify the diverse modeling languages currently used by systems engineers. SysML supports the specification, analysis, design, verification and validation of a broad range of complex systems. These systems may include hardware, software, information, processes, personnel, and facilities.

SysML diagrams can be divided into three types [15-17]:

- Diagrams that capture system requirements (requirements diagram) and physical constraints (parametric diagram).
- Diagrams that describe the structure of the system (internal block diagram and block definition diagram).
- Diagrams that describe the behavior of the system (use case diagrams, sequence diagram, activity diagram, and state machine diagrams).

Figure 1presents the SysML diagram architecture [18].

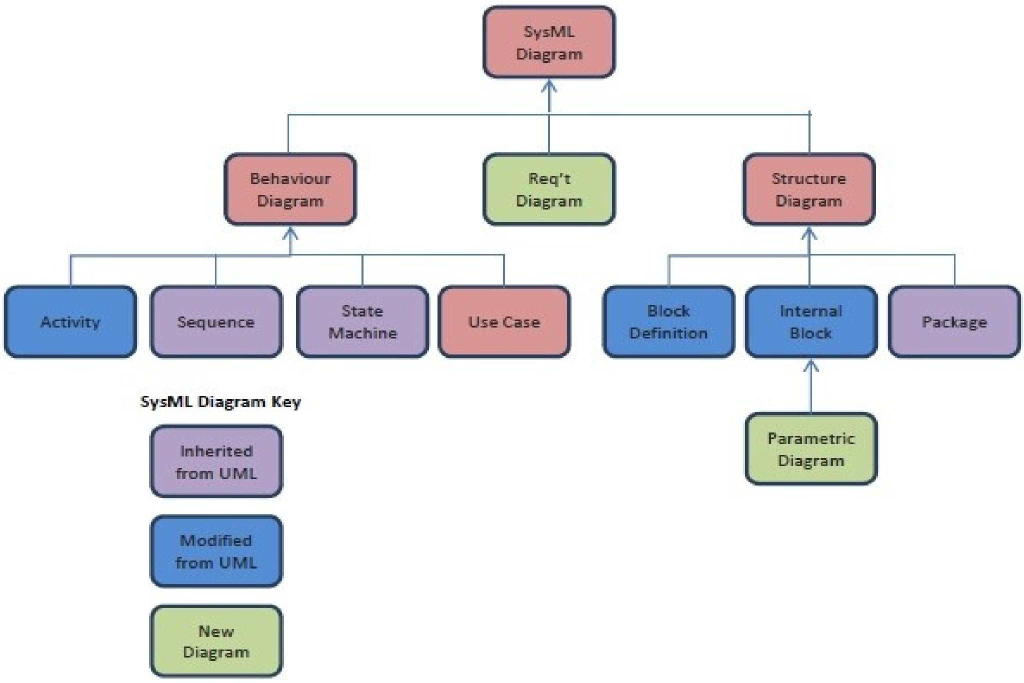

Fig. 1. SysML 1.0 diagram architecture.

In the literature, we find many applications that have been used to develop design of renewable systems. We present here some studies that have been presented in various researches:

Researcher Kaitovic and al. [19], have explained how economical and environmental concerns push toward novel solutions for sustainable, renewable and intelligent energy power grid - the Smart Grid. Such complex system, or better aggregation of systems, involve a number of various stakeholders coming from different areas of expertise, requires novel ICT solutions, etc [20-21]. Even so, on-going projects do not apply unique formal design methodology and language. In order to better correlate the projects, improve understating of system requirements and simplify system design by decomposing its complexity a model-driven methodology (MDM) and SysML could be applied. Applying MDM should give a possible referent model for aggregations in future Power Grid.

Researchers Hodgson and al. [22], have discussed the principal mechanism for achieving the policy goal of the diminution of greenhouse gas emissions is the widespread electrification of transport and heating coupled with the parallel de-carbonization of electricity generation. This requires a main expansion of renewable generation (principally wind) jointly with new nuclear and clean fossil.

This paper reviews both the policy position inside the UK and the implications for system balancing that large-scale intermittent generation, such as wind, presents to the System Operator (SO). One suggestion for helping to preserve system balance is the use of Demand Response (DR) by the SO. It is by no means clear whether the existing industrial structure can provide the right incentives for the realization of significant DR capacity. This paper presents a method of classifying barriers and describes experience in developing a Systems Engineering methodology, using SysML, as an approach to modeling the structural and operational aspects of the British system with the objective of considerate barriers to the execution of DR.

Researchers Neureiter et al. [23], have explained that the current integration of decentralized, renewable energies is a main challenge for today's power system. In order to control the volatile behaviour of these Distributed Energy Resources (DER), the electricity system has to develop towards a Smart Grid. The development of this critical and complex System-of-Systems involves different stakeholder from different disciplines. Thus, domain specific engineering concepts on system level are wanted. To foster the interdisciplinary development, the proposed approach presents a standards-based architecture framework, implemented as Domain Specific Language (DSL). Moreover, the DSL is used to develop a reference architecture on basis of the NIST Logical Reference Model. To evaluate the applicability of the reference architecture model it is used for instantiation of a particular system solution.

Researchers Gezer et al. [24], have described a methodology and a case study through which system architecture and dynamic models of related system components are gathered in order to design and simulate the SCADA system of a new hydro turbine test laboratory. System architecture model is prepared in SysML, a system modeling language based on UML, while the dynamic model of the laboratory is formed in Matlab/Simulink. Some simulations are performed in order to verify the preliminary system design studies and system requirements.

Researchers Gutierrez et al. [25], have presented a methodology for modeling photovoltaic systems in embedded hardware. This methodology uses the HiLeS platform to transform SysML models in Petri nets and generate VHDL code. The proposed methodology is intended for Hardware-in-the-Loop simulations of power converters and PV panels in microgrids. In addition, this methodology allows the design of MPPT controllers for their direct implementation in FPGA.

Researcher Gutierrez et al. [26], have described a methodology for implementing in FPGA models of photovoltaic panels for Hardware-in-the-Loop (HIL) and real-time simulations. The proposed methodology integrates numerical solutions, SysML diagrams and Petri nets for structural design and formal validation. In this study, photovoltaic cells have been modeled using the single diode circuit. The photovoltaic panel model is solved by the Newton-Raphson method, and the Lagrange remainder is employed to limit the iteration number. Results show suitable accuracy and performance of the proposed methodology.

After showing an overview of SysML, this language is chosen, in section VI in order to obtain high level graphical description of the functionality of a wind turbine system. These descriptions identify interactions and flow of data and control between parts of the system which is necessary to understand the overall operation of the wind turbine.

4. RESULTS OF WIND TURBBINE MODELING

In this section, SysML is used to provide simple but powerful description for modeling wind turbine system. In fact, we present a functional modeling with use case diagram. Next, a complement to functional modeling with requirements diagram. Then, we present a modeling the behavior with sequence diagram and a structural modeling with BDD and IBD. Finally, we present a modeling with state machine diagram.

A. *Functional modeling with use case diagram*

A use case diagram lists the usage functions that the system offers to each of its user actors in order to satisfy their needs. It represents the external functional behavior of the system (Fig.2). In other words, a use case represents a service offered by the system to one or more actors in its environment. It is defined by a function in an ellipse connected to the actor concerned.

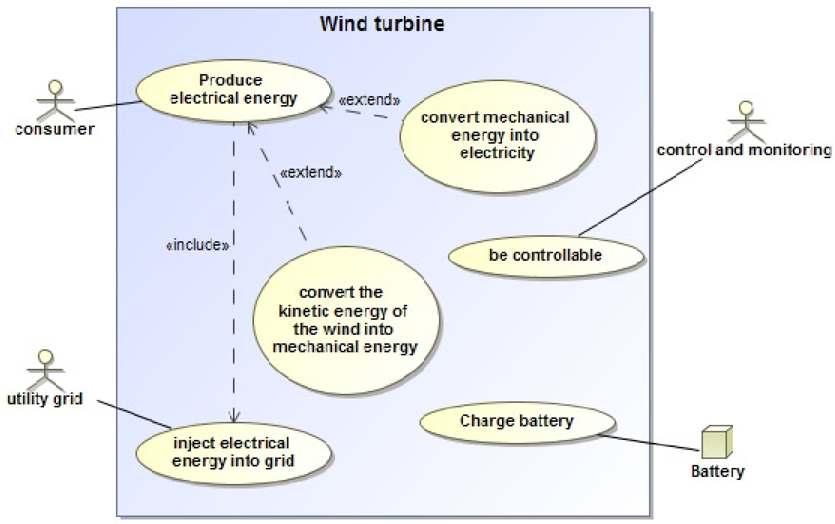

Fig. 2. Use case diagram.

B. Compliments to functional modeling with requirements diagram

Remember that a requirements diagram is a new diagram and it is different type of behavior diagrams and structure diagrams. Its role is to specify the needs of the system.

Figure 3 presents the functional requirement diagram figure 4 presents the performance requirement diagram.

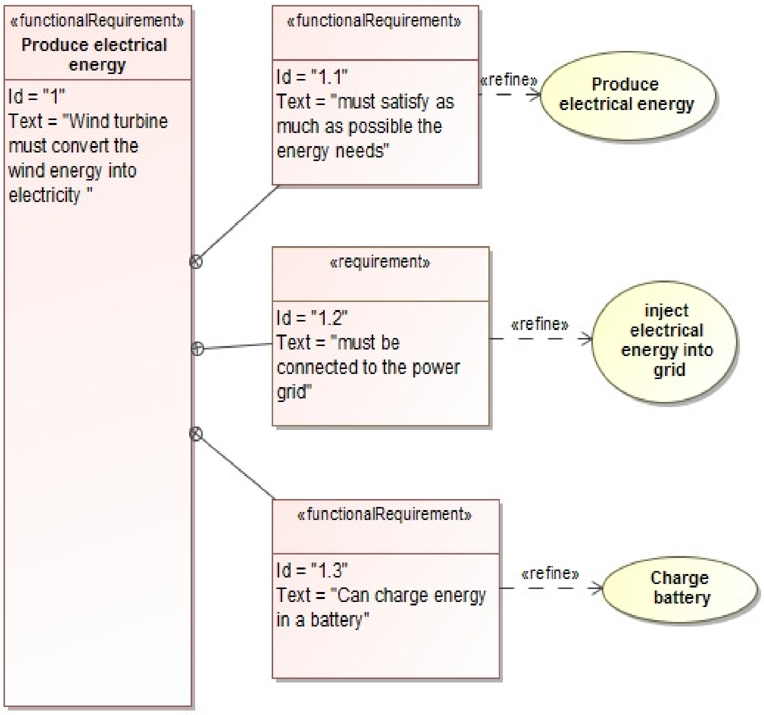

Fig. 3. Functional requirements diagram

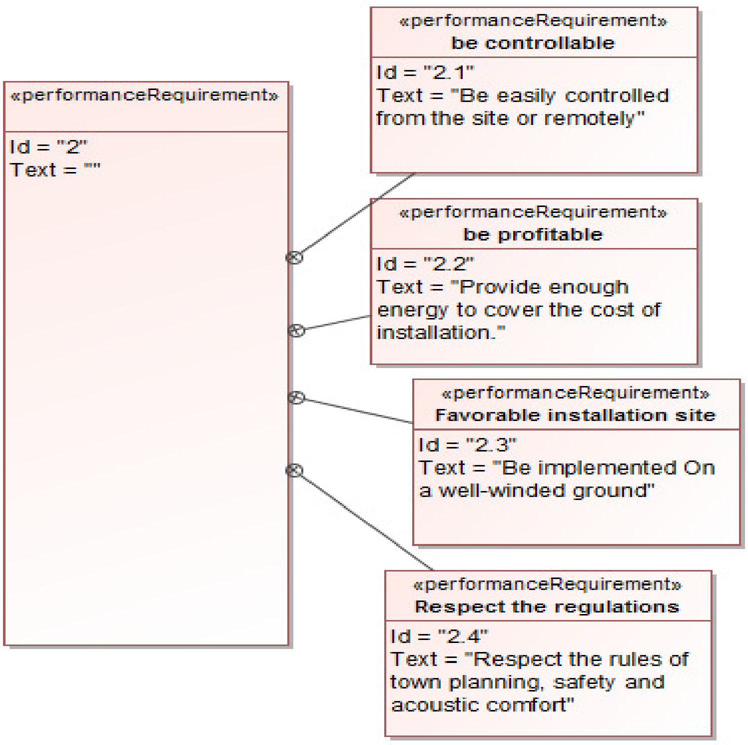

Fig. 4. Performance requirements diagram

C. Modeling the behavior with sequence diagram

A sequence diagram lets you map the interactions arranged in chronological order among system components or among actors and the system (Fig.5).

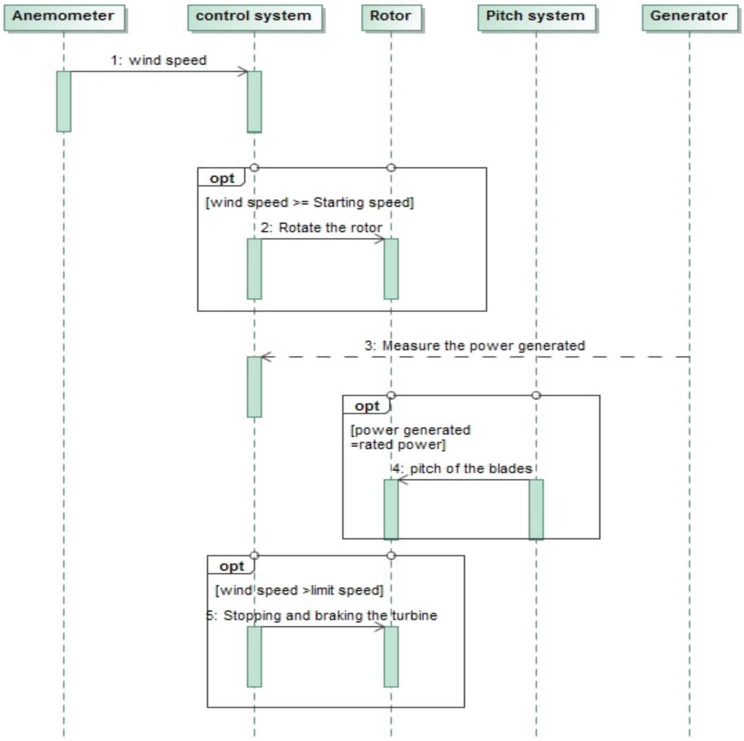

Fig. 5. Performance requirements diagram

D. Structural modeling with BDD and IBD

SysML block definition diagram (BDD) represents structural elements called blocks, and their composition and classification (Fig.6).

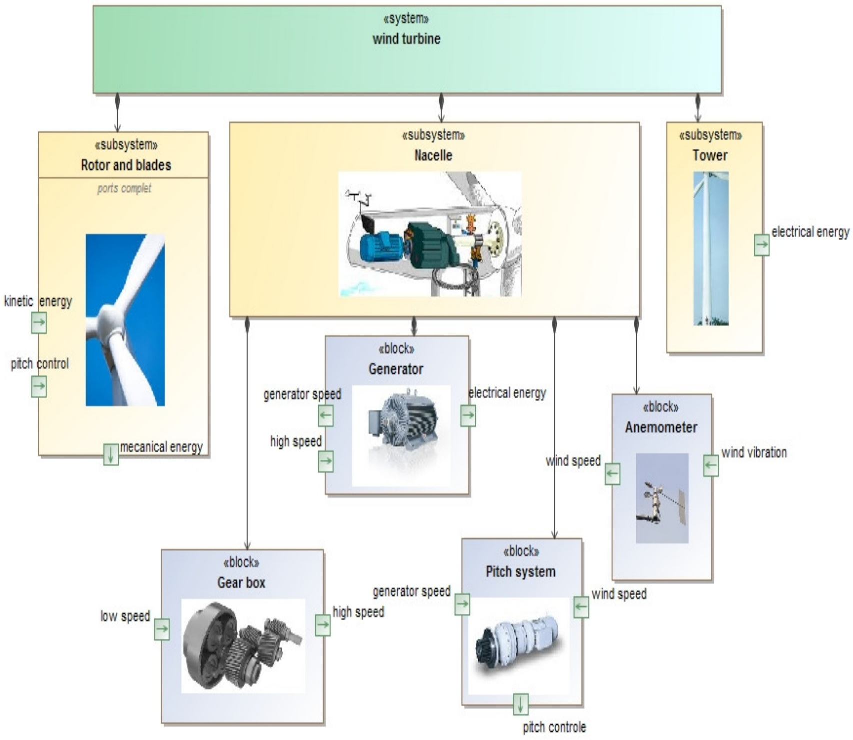

Fig. 6. Block defenition diagram

A SysML internal block diagram (IBD) describes the internal structure of a block, its properties and connectors (Fig.7).

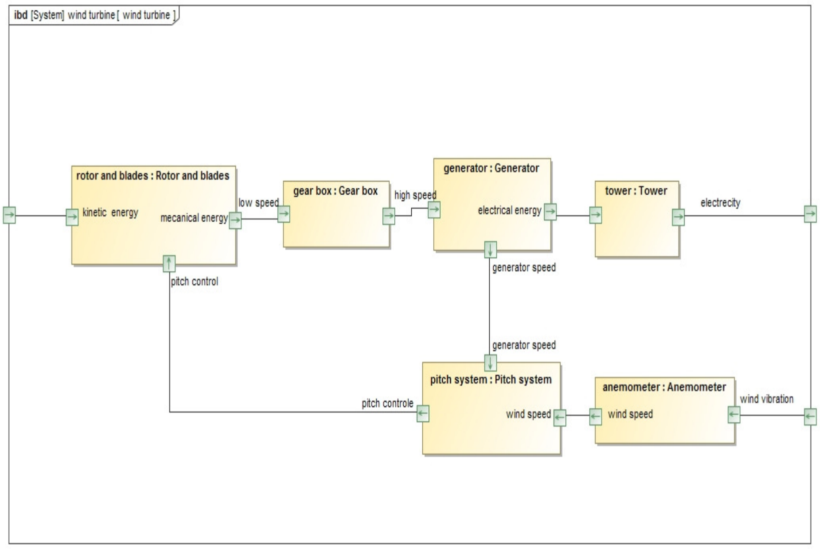

Fig. 7. Internal block diagram

E. Modeling with state machine diagram

SysML state machine diagrams represents behavior of an entity in terms of its transitions between states triggered by events (Fig.8).

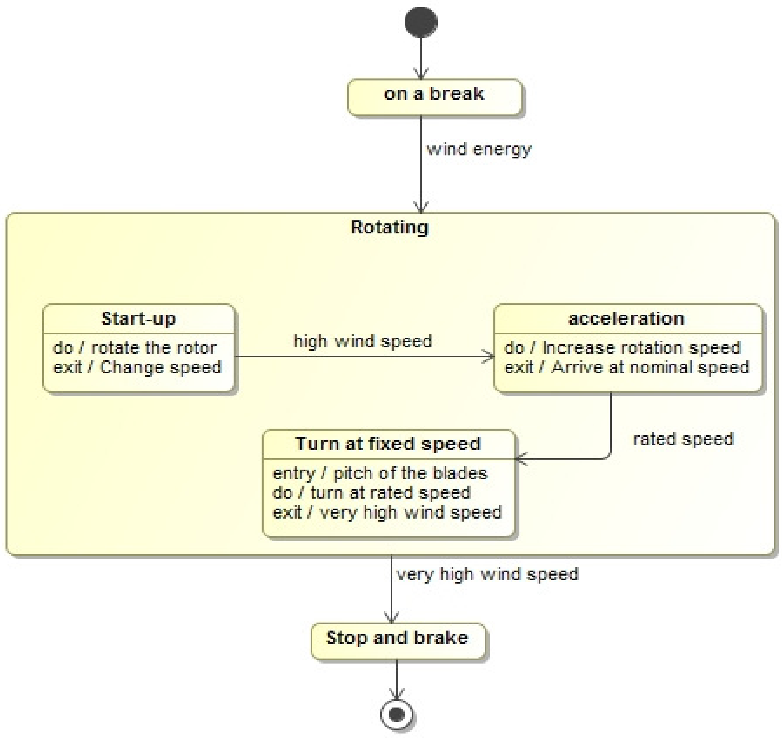

Fig. 8. State machine diagram

5. CONCLUSION

In this paper, a high level description of a wind turbine system using the graphical modeling language SysML for systems engineering is shown. Starting with the structure of the system, followed by the behavior of the system (dynamic modeling) and finishing with the novelties of SysML (requirements diagram), these descriptions allows identifying interactions, flow of data and control between parts of the system. We show here the interest and the potential of such a complex systems approach to make it possible to master the complexity of the system studied, wind turbine, because each model gives access to an abstract representation of different aspects of the wind turbine system.

Staring from this case study of analysis and modeling of wind turbine based on the systems modeling language SysML discussed in this paper, work is in progress to develop simulations of wind system using Matlab and SyML diagrams.

REFERENCES

[1] H. Aroussi1, E. Ziani and B. Bossoufi, “Robust Control of a Power Wind System Based on the Double Fed Induction Generator (DFIG),” J. Automation & Systems Engineering 9-3, 2015, pp. 156-166.
[2] G. Boukattaya, L. Krichen and A. Ouali, “Sensorless Control of a fly wheel Energy Storage System Associated to an Isolated Hybrid Energy Production, ” J. Automation & Systems Engineering, December 2008.
[3] Z. Lubosny, “Wind Turbine Operation in Electric Power Systems, Berlin: Springer, 2003.
[4] J. Kaldellisa and D. Zafirakis, “Lab of Soft Energy Applications & Environmental Protection, TEI of Piraeus, Greece,‘The wind energy (r)evolution: A short review of a long history, ” Renewable Energy, Elsevier, February 2011.
[5] A. Schaffarczyk, “Introduction to Wind Turbine Aerodynamics, 7 Green Energy and Technology,” Springer 2014.
[6] L. Yongqiang et al., “Wind Power Technology: State of the Art,” IEEE Canadian Review, December 2007, pp.10-17.
[7] C. Lakshmi and M.R. Sindhu, “Novel Ising Controller Based Three Phase Reactive Power Compensator For Wind Electric Generator,” J. Automation & Systems Engineering 9-4 (2015): 266-281.
[8] S. Ashish Ingole, S. Bhushan Rakhonde, “Hybrid Power Generation System Using Wind Energy and Solar Energy,” International Journal of Scientific and Research Publications, Vol.5, Issue 3, March 2015.
[9] C. Lewis and J. Muller, “A direct drive wind turbine HTS generator, Power Engineering Society Meeting, IEEE, 2007.
[10] A. Tummala, “A review on small scale wind turbines,” Renewable and Sustainable Energy Reviews 56 (2016): 1351-1371.
[11] F. Ben Amara & al., “Energy assessment of the first wind farm section of Sidi Daoud, Tunisia,” Renewable Energy 33, 2008, pp.2311-2321.
[12] S. Belfedhal, “Modeling and Control of Wind Power Conversion System with a Flywheel Energy Storage System and Compensation of Reactive Power,” International journal of renewable energy research, Vol.2, No.3, 2012.
[13] A. E. Kremers, “Modeling and simulation of electrical energy systems through a complex systems approch using agent models,” Karlsruher institut for technology (KIT), KIT scientific publishing, 2013.
[14] J. Lamy, “SysML un langage modèle,” Journal Technologie, 179, Avril 2012.
[15] E. Hart, “Introduction To Model-Based System Engineering (MBSE) and SysML,” Delaware Valley INCOSE Chapter Meeting, July 30, 2015.

[16] F. Mhenni, “SysML extensions for safety critical mechatronic systems design,” IEEE International Symposium on Systems Engineering, 2015.
[17] P. Patwari, S. Chaudhuri, A. Banerjee, S. Natarajan, S Pandey, “A complementary domain specific design environment aiding SysML,” IEEE International Symposium on Systems Engineering, 2016.
[18] Website, accessed January,10, 2017, https://www.specinnovations.com/the-basics-of-sysml/
[19] I. Kaitovic and S. Lukovic, “Adoption of model-driven methodology to aggregations design in Smart Grid,” 9th IEEE International Conference on Industrial Informatics, 2011.
[20] E. I. Gergely, Laura Coroiu, Helga Maria Silaghi, “Dependability Analysis of PLC I/O Systems Used in Critical Industrial Applications, ” V.E. Balas et al. (Eds.), New Concepts and Applications in Soft Computing, Studies in Computational Intelligence 417, Springer-Verlag Berlin Heidelberg 2013, pp. 201-217.
[21] G. Husi, C. Szász and H. Hasimoto, “Application of reconfigurable hardware technology in the development and implementation of building automation systems,” Environmental Engineering and Management Journal, 13: (11), 2014, pp. 2899-2905.
[22] G. Hodgson, M. Thomson, C. Clifford, “A systems engineering approach to resolving structural barriers to the implementation of demand response,” 8th International Conference on the European Energy Market, 2011.
[23] C. Neureiter, M. Uslar, D. Engel and G. Lastro, “A standards-based approach for domain specific modelling of smart grid system architectures,” 11th System of Systems Engineering Conference, 2016.
[24] D. Gezer, H. Ozgur, Y. Tascioglu, K. Celebioglu, S. Aradag, “Design and simulation of a SCADA system using SysML and Simulink,” International Conference on Renewable Energy Research and Applications, 2013.
[25] A. Gutierrez, H. R. Chamorro, J. F. Jimenez, L. F. Villa and C. Alonso, “Hardware-in-the-loop simulation of PV systems in micro-grids using SysML models,” IEEE 16th Workshop on Control and Modeling for Power Electronics, 2015.
[26] A. Gutierrez, H. R. Chamorro, L. Villa, J. F. Jimenez and C. Alonso, “SysML methodology for HIL implementation of PV models,” 17th European Conference on Power Electronics and Applications, 2015.