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A Study on Flexibility Modeling of Nuclear-Renewable Hybrid Energy System

Youngsuk Bang[a*], Haneul Kim[a], JaeSeon Cho[a], Byongsup Kim[b] and Chulyong Paik[b]
[a] *FNC Technology Co., Ltd.,*
[b] *SMART Power Co., Ltd.,*
[*] *Corresponding author: ysbang00@fnctech.com*

1. Introduction

Nuclear-Renewable Hybrid Energy System(NRHES) is a conceptual system that integrates the nuclear, fossil, renewables, energy storage and industry customers.[1] Conventionally, nuclear energy has been utilized as a baseload unit and mostly operated in constant power. Pursuing minimization of environmental effects and maximization of economical competiveness, the penetration of renewable energy has been increased significantly, which demands an increased flexibility in energy system.

Flexibility demand mainly results from the nature of renewable energy. Renewable energy is the intermittent energy source of which the power output cannot be predicted accurately. It depends on installation location, weather, time of day and so forth. Fluctuation in power generation would make it difficult to have a market plan for stable electricity supply and may result in excessive energy generation which has to be sold in a loss.

Flexibility in NRHES can be provided in the followings ways.[2] First, the power generation could be flexible. For nuclear energy, this could be the load following operation. According to load demands, the power of nuclear plant could be varied in pre-defined or automatic manners. Secondly, the energy storage could be integrated. At times of low electricity demands or high renewable generation, the excess energy could be stored. Then, it can be discharged later in the electrical form or thermal energy form to industry or buildings. Third, the large connectivity of transmission lines would dilute the fluctuation in energy system. For example, the connection to several wind turbines separated in far distance would reduce the effects of weather. Fourth, the electricity demand could be controlled. Charging the electric vehicle at night or operating the machines in factory at holiday could lower the electricity demand peak.

In order to examine the flexibility compliance, a proper simulation tool would be essential, which can provide the information of net-load demand for nuclear reactors, required operation mode of nuclear reactor or energy storage system and boundary conditions for component design. For the purposes, there are a lot of energy system modeling and analyzing tools[3] and in particular for NRHES, INL and ORNL have developed the simulation tool based on Modelica language[4]. On the other hands, a tool for Korean NRHES has not been investigated extensively.

In this study, the tools for energy system modeling are briefly reviewed and the basic aspects required for NRHES modeling and system are identified. As a demonstration, numerical tests with Modelica language are presented.

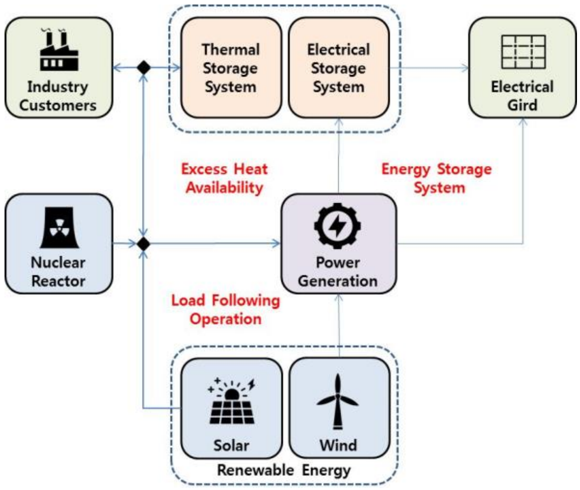

Fig. 1. Schematics of Nuclear-Renewable Hybrid Energy System and Flexibility Feature

2. Energy System Modeling

Originally, energy system modeling has been introduced firstly after 1970s oil-crisis to maintain energy stability.[5] Since then, the emphasis has moved to environmental issues related to global climate changes. Meanwhile, a lot of modeling tools has been developed for their specific purposes which can be categorized as in Table I.[3]

For engineering purposes (e.g., component/system design or safety analysis), tools for power system analysis and operation decision support would be useful. Those can be used to generate the physical boundary condition for further engineering analysis in details. On the other hands, tools for investment decision support and scenario would be more appropriate for economic analysis and policy makers, in which many societal factors are considered like population growth, market price changes and etc.

It is important to note that the tools may be highly sensitive with respect to assumptions and used data, while the internal models, source-code, assumptions and data are not accessible in many tools[3]. Especially, for

NRHES, non-accessibility for internal model (source code) might be serious limitation because of the rapid advances in renewable technologies and improved design for nuclear reactors.

Table I: Energy System Modeling Tools[3]

	Purpose	Time Step	Time Horizon
Power System Analysis	power flow, dynamic stability	sub-sec. ~ seconds	short term (hours)
Operation Decision Support	system optimization, unit commitment	hour ~ week	mid term years
Investment Decision Support	investment optimization	hour ~ month	long term (years~ decade)
Scenario	policy impact evaluation	hour ~ month	long term (years~ decade)

3. Numerical Test

As a numerical demonstration of economic dispatch, a simple supply/demand model consisted of nuclear and renewables has been modeled by using Modelica language and its Standard Library. The Modelica Language is a non-proprietary, object-oriented, equation based language to model complex physical systems.[6] Modelica community has been actively improved the generic features and shared the verified and validated libraries. Especially, the open source Modelica Standard Library contains about 1600 model components and 1350 functions from many domains[7] and TRANSFORM library developed by INL and ORNL for NRHES are opened available online[8].

4.1. Wind Turbines

For wind turbines, WindPowerPlants1.1.1[9] in Fig. 2 have been used. Thanks to object-oriented nature, user can use the wind turbine component simply by connecting the terminals of input and output. Hourly wind speed for a year[10] in Fig. 3 is put into wind turbine model as an input and calculated energy generation output is presented in Fig. 4.

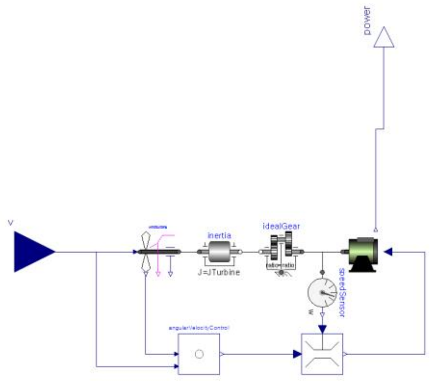

Fig. 2. Schematics of Wind Turbine Modelica Model

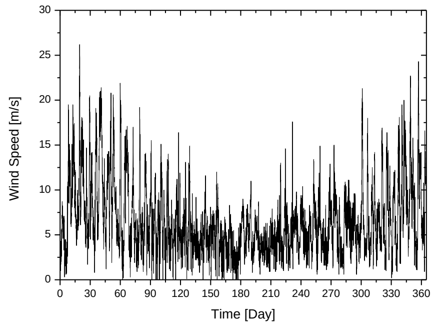

Fig. 3. Wind Speed Yearly Profile

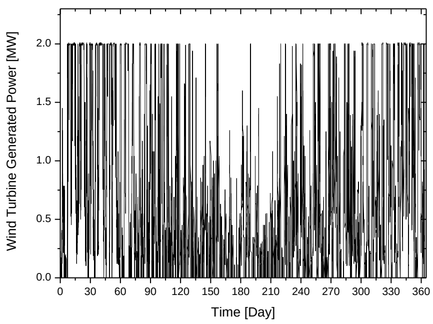

Fig. 4. Wind Turbine Energy Generation

4.2. PhotoVoltaics

For photovoltaics, PhotoVoltaics1.3.1[11] in Fig. 5 have been used. In the library, the specification data of several companies' photovoltaic panel are available as an option. Like wind turbine model, photovoltaic model can be used simply by connecting terminals of input and output. In Fig. 6, hourly-based irradiation profile for a year is shown and calculated output is depicted in Fig. 7.

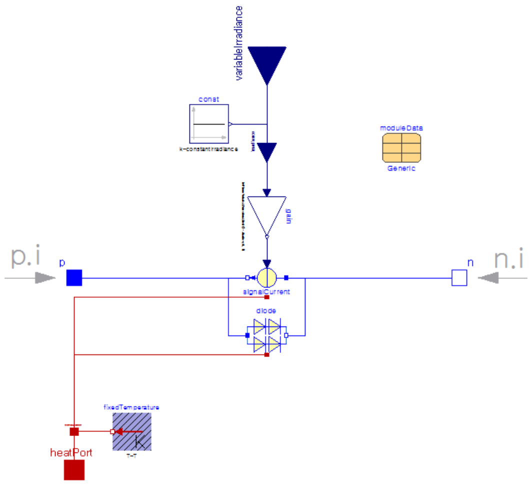

Fig. 5. Schematics of PhotoVoltaics Modelica Model

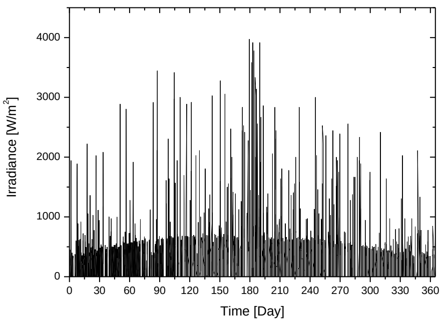

Fig. 6. Irradiation Yearly Profile

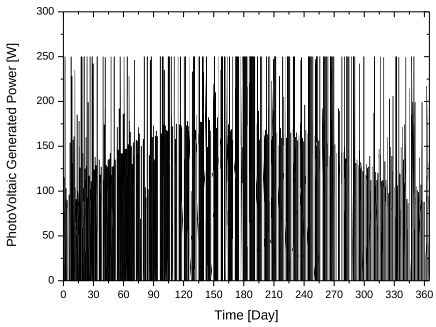

Fig. 7. PhotoVoltaic Energy Generation

4.3. NRHES Modeling

For a demonstration of NRHES modeling, a simple microgrid consists of photovoltaic, wind turbines and nuclear power plant has been configured as shown in Fig. 8. As a basic modeling frame, PowerSystems0.6.0 has been used[12]. For nuclear power plant, a reactor has been modeled by point kinetics equation with delayed precursor and RCS/NSSS have been modeled simply by Turbine component and Generator component as shown in Fig. 9. In a reactor model, the reactivity variable is added as an input to control the reactor power and mimic the load following operation. Ideally, it is assumed that the net load (total electricity demand – renewable energy generation) is balanced solely by nuclear power plant.

With the NRHES Modelica model, numerical tests can be conducted by varying the number of nuclear power plants, number of nuclear power plants in load following operations, power change constrains, total electricity demand profile and etc. In Fig. 10, the example of nuclear power plant energy generation is presented.

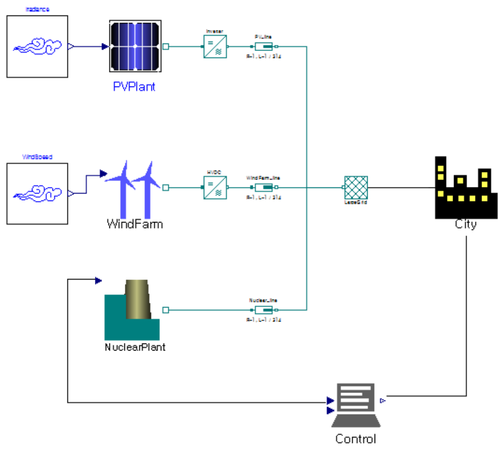

Fig. 8. Schematics of NRHES Modelica Model

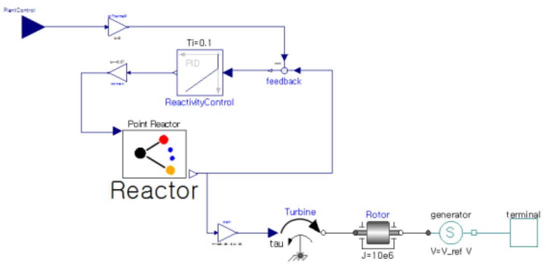

Fig. 9. Schematics of Nuclear Power Plant Modelica Model

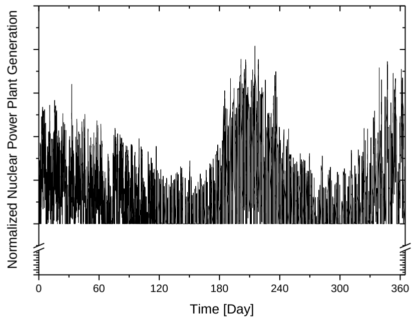

Fig. 10. Nuclear Power Plant Energy Generation

5. Conclusion

Increasing renewable energy penetration is a world-wide trend and the energy system has been transforming to require more flexibility. NRHES is a promising candidate for clean and sustainable energy system. In order to facilitate NRHES R&D, the proper modeling tool would be necessary. Especially, research related to NRHES modeling tools for the purpose of engineering support have not been studied yet in Korea; thus, related R&D would be pressing. In this study, a simple modeling and numerical tests by using Modelica and its library available publicly has been demonstrated. It is found that the libraries for NRHES have been well-developed and opened by former researchers and foreign national laboratories, which makes Modelica modeling easy and convenient.

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