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Net-Zero Power Productions with Microgrid Control Incorporated with Small Modular Reactor (SMR) in UIUC: One More Step to Zero-Energy School Construction

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1. Introduction

The United States Department of Energy commenced the development of its microgrid program strategy in 2020 [1]. Projections suggest that microgrids will constitute a critical component of future electricity supply systems by the year 2035, contributing significantly to enhanced resilience, decarbonization efforts, and affordability. Presently, the University of Illinois Urbana-Champaign (UIUC) campus derives its power from the Abbott Generating Station, a combined heat and power facility capable of supplying peak loads of 77 MW of electricity and 550,000 lb/hr of steam, with a maximum capacity of 85 MW of electricity and 1,235,000 lb/hr of steam. The energy system includes a chilled water system, several solar farms, and purchases from the Rail Splitter Wind Farm, with the remaining electricity demand met through partnerships with the local grid [4]. This paper models the microgrid project at the University of Illinois, Urbana-Champaign (UIUC) (Table 1), and proposes a microgrid strategy incorporating Small Modular Reactors (SMRs) to achieve a broader spectrum of power generation capabilities. Beyond simplified configurations, SMRs facilitate the design of energy grids wherein interconnected load and generation systems are tightly integrated, functioning as a cohesive operational unit. The implementation of microgrids augments end-user autonomy over energy resources, resulting in significant enhancements in operational flexibility, safety, security, and economic efficiency. Fig. 1, as presented in Cui et al. [5], depicts a representative microgrid architecture within a campus setting. This framework integrates a diverse portfolio of distributed energy resources, including nuclear, renewable (solar and wind), and combined heat and power generation, all interconnected with the utility grid. The generated energy serves a multitude of on-site loads, such as classrooms and laboratories, thereby meeting the energy requirements of various campus facilities.

2. Methods

The implementation of microgrids, leveraging a diverse array of power generation sources, within university campus environments necessitates sophisticated analytical methodologies. This requirement stems from the inherent variability in the operational characteristics of each constituent variable within the modeling framework. Furthermore, the dynamic analysis, which demands the concurrent execution of multiple computational processes, is effectively addressed through the application of the System Dynamics (SD) methodology [6,7].

To facilitate the implementation of complex algorithms, a SD model was developed, spanning a 60-year temporal horizon. This period is deemed suitable for the integration of nuclear energy into the microgrid system, and can be adjusted in future research to reflect evolving energy consumption patterns. Fig. 2 presents the SD model architecture, encompassing (a) Microgrid Control, (b) Distributed Resources, and (c) SMR-based Nuclear Energy. Within Fig. 2(a), Microgrid Control is depicted as a network connecting Distributed Power to Load Following, with weighting factors employed to calibrate the model. In the Vensim coding environment, the modeling formula is expressed as INTEG (rate, initial value), where Rates (also referred to as Flows) represent variables that directly modify the level. These Rates signify the accumulation of values computed at each discrete time step, as detailed in Table 2 [8].

In essence, the summation of values from all preceding temporal events culminates in the determination of the final time-dependent value. Consequently, Microgrid Control can be represented as follows,

Microgrid Control = INTEG ((W1-W2) * Microgrid Control, 1) (1)

In this context, the initial value is assigned a value of 1, and the cumulative value of (W1-W2) is determined by the summation of all values, each multiplied by Microgrid Control, across each discrete time step. Analogously, Load Following is represented as follows,

Load Following = INTEG (W2/Load Following, 1) (2)

Moreover, Distributed Power is as follows,

Distributed Power = INTEG ((-W1 + Distribution Network Managements)/Distributed

Power, 1) (3)

Furthermore, the model incorporates several parametric elements. Specifically, directed arrows represent the trajectory of event flow, while positive (+) and negative (-) symbols denote the additive and subtractive nature of events, respectively. Additionally, valve representations signify the application of weighting factors to events transitioning from source to sink.

3. Results

In this investigation, simulation outcomes are presented as availability, a dimensionless metric representing relative value. Fig. 3 illustrates simulation results for (a) Nuclear Energy, (b) Marketing & Power Plants, (c) Load Following, and (d) Microgrid Control. In Fig. 3(a), the availability of nuclear energy exhibits oscillatory behavior over the initial three decades, indicative of dynamic interactions among nuclear, renewable, combined heat and power, and utility grid energy sources. Subsequent to this period, the prioritization of nuclear energy significantly increases, attributable to its non-carbon emitting and high-efficiency characteristics. In this context, negative values are devoid of physical significance, and only relative values are considered meaningful. The remaining simulated components (Distributed Resources, Distributed Power, Load Following) demonstrate upward trends, signifying a gradual enhancement in availability. Specifically, Marketing & Power Plants and Microgrid Control display an oscillating upward trajectory. In this analysis, the graphical morphology is deemed more informative than the magnitude of the values.

4. Conclusions

The imperative of energy efficiency within university campus environments is paramount, as associated costs directly influence educational and research expenditures. Consequently, judicious energy production can serve as a corollary to successful educational and research endeavors. Furthermore, the outcomes derived from this model possess a broad applicability to educational institutions globally, thereby demonstrating substantial potential impact. Net-zero carbon emissions production is possible through nuclear power, and zero-energy school cities can be created through microgrids (Fig. 4). These microgrids also offer operational efficiency, flexibility, reliability and security by allowing users to manage their own energy systems [4]. In the context of online-based education, this model can also serve as a critical energy provisioning mechanism, particularly if universities establish dedicated data centers. The establishment of energy-intensive data centers constitutes a salient concern. As a university town, this area can bring about innovation in the use of electric energy, and it has great potential for application in Korea. For example, Seoul National University is the largest demander of electricity in the Seoul area, so utilizing a microgrid with nuclear power generation can alleviate the excessive demand for electricity.

Acknowledgments

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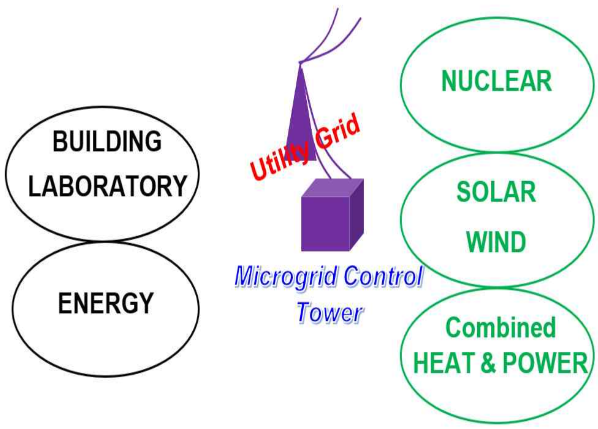
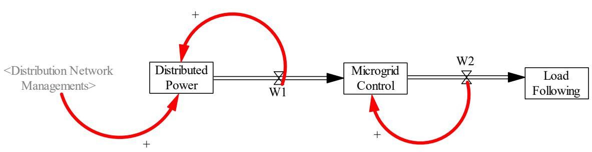
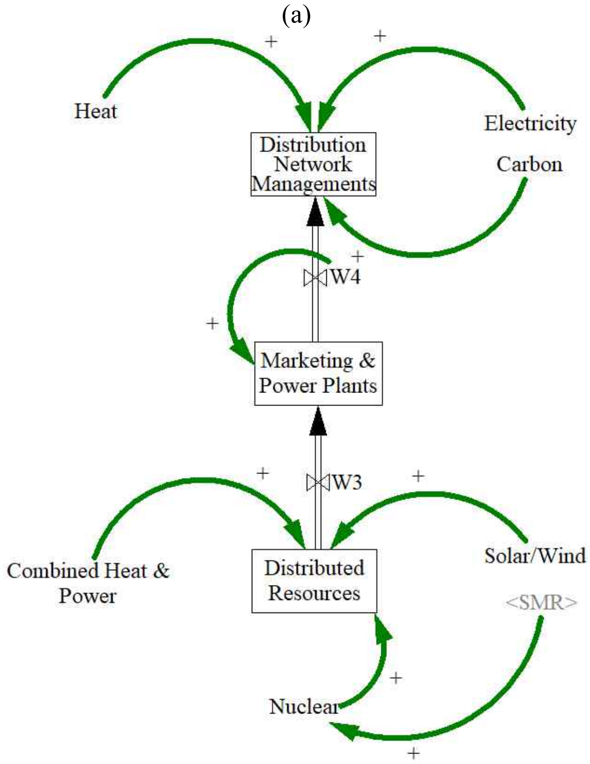


Fig. 1. Basic configuration of microgrid in the campus.

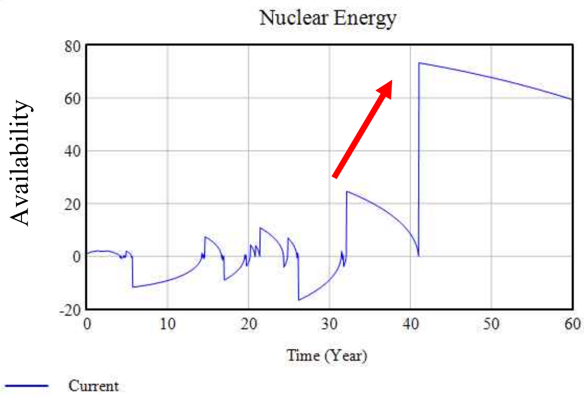


(a)



(b)

Fig. 2. SD modeling for modeling (a) Microgrid Control and (b) Distributed Resources.



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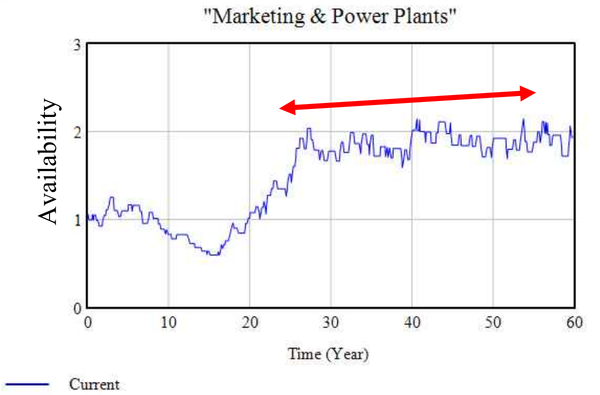

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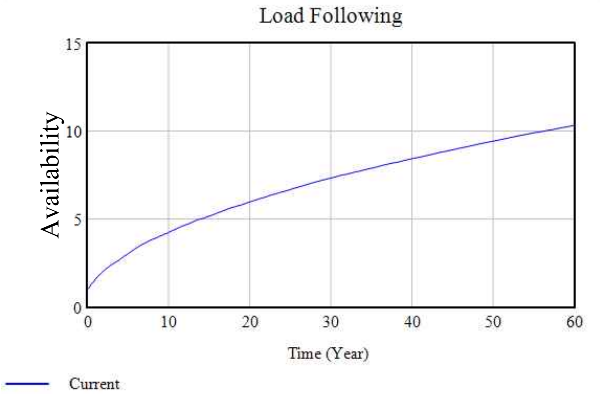

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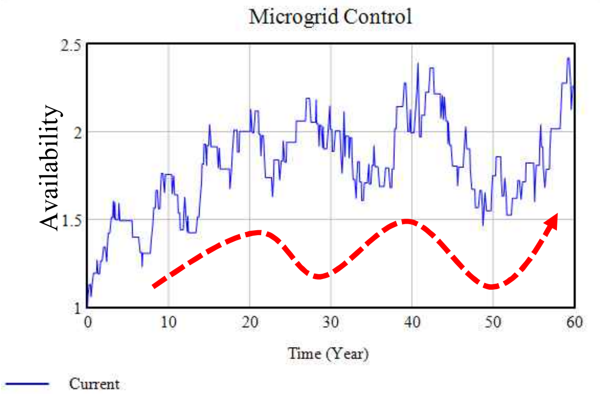

(d)

Fig. 3. Simulation results (a) Nuclear Energy, (b) Marketing & Power Plants, (c) Load Following, and (d) Microgrid Control.

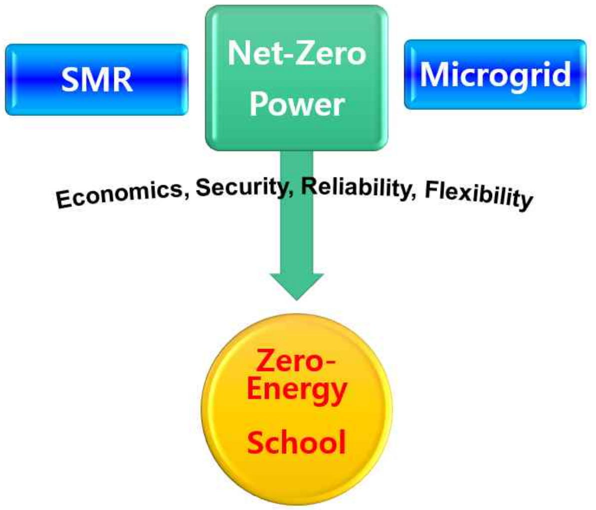

Fig. 4. Strategy for zero-energy school by SMR-based net-zero power.

Table I: Overview of the city [2,3].

Variable	Urbana	Champaign
Pop. Density	1,251.15/km^2	1,482.97/km^2
Population	38,336(2020)	88,302(2020)
Avg. Temp. (^{o}C)	16.5(High), 5.4(Low)	16.7(High), 5.9(Low)
Elevation	222 m	233 m

Table II: List of modeling parameters [8]

Variable	Content
Distributed Resources	INTEG (-W3 + Nuclear +"Solar/Wind" + "Combined Heat & Power", 1)
W1	if then else (random 0 1 () < 0.1, 0, 1)
W4	if then else (random 0 1 () < 0.1, 0, 1)
Distribution Network Managements	INTEG ((W4 + Electricity + Heat + Carbon) / Distribution Network Managements, 1)