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Strategies for Commercializing Neighboring SMRs (N-SMRs): Groundbreaking Service Quality Improvement of Data Centers

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1. Introduction

With the recent rapid development of the Artificial Intelligence (AI) industry, demand for data center power has exploded. By analyzing operational cases of nuclear-based data centers, a key energy source in the AI era, we identified an efficient power supply model and proposed ways to utilize nuclear power and sustainable future connectivity strategies to meet the rapidly increasing power demand of the IT industry [1]. The use of small modular reactors (SMRs) near cities is emerging as a key strategy to simultaneously address both energy shortages and carbon neutrality [2,3]. The value analysis of Neighboring SMRs (N-SMRs) is the subject of this paper. Unlike large nuclear power plants, SMRs offer greater flexibility in location, allowing them to be deployed directly near data centers. This reduces the burden on the national power grid and dramatically reduces energy loss during transmission. While renewable energy sources like solar and wind power are subject to significant fluctuations in power generation due to weather conditions, SMRs serve as a 24/7, uninterrupted baseload, making it practically possible to achieve the real-time carbon-free energy goals pursued by global tech giants like Google and Microsoft.

Furthermore, SMR-based data centers can be located near cities, making them highly advantageous for building ultra-low latency edge computing infrastructure essential for autonomous driving and real-time AI computing [4]. While large-scale nuclear power plants in the past required large amounts of cooling water and had to be built near coastlines, SMRs can be easily installed inland near urban centers due to their air-cooling capabilities. This structure goes beyond simply consuming electricity; it recycles waste heat generated during the power generation process to provide heating for nearby areas or industrial hot water, creating a virtuous energy cycle. Consequently, SMRs will maximize data center operational efficiency while simultaneously serving as a core energy hub for smart cities that thrive with local communities. Fig. 1 illustrates the above points.

SMRs are a next-generation core energy source that offer groundbreaking flexibility and safety compared to existing large-scale nuclear power plants, thanks to their compact design of less than 300 MWe. Their modular construction method, in which key components are manufactured in factories and assembled on-site, significantly reduces construction time and costs. This makes them ideal for customized deployment near power demand centers, such as data centers and industrial complexes. In particular, their passive safety system, which cools the reactor using natural principles like gravity and convection without requiring external power or manual intervention, is a key factor in lowering the psychological and technical barriers to installation near densely populated areas. These features open up the possibility of multipurpose use as a customized "neighborhood-level" energy hub that supplies heat and energy for diverse purposes, such as district heating, hydrogen production, and seawater desalination, beyond simply generating electricity. They are becoming an essential element in the realization of future smart cities.

2. Methods

This study utilizes the system dynamics (SD) method. Developed at MIT, this method has been used to quantitatively analyze not only humanities and social science issues but also sensitive scientific and technological issues [5-7]. Furthermore, it can provide low-performance conditions and regulatory proposals based on this approach. Data center availability using SMR is analyzed under a 60-year scenario. A graphical model is created using Vensim software [8,9]. Fig. 2 shows the modeling of an SMR-based data center, showing (a) an SMR and (b) a data center. The content shown in Fig. 1 is expressed as an SD model. Here, W1 represents the weight, and its value is as follows.

if then else(random 0 1 () < 0.2, 0, 1) (1)

This means the following formula:

$$\text{Value} = \begin{cases} 0 & \text{if random number} < 0.2 \\ 1 & \text{if random number} \geq 0.2 \end{cases} \tag{2}$$

So, this value creates a Boolean value that is 0.0 if the random sample is less than 0.2, and 1.0 otherwise. Table 1 shows the list of variables. Fig. 3 shows the causal loop of modeling, representing (a) SMR and (b) Data Center. This demonstrates the causal relationships within the model, making it easier to understand the meaning of complex models.

3. Results

Fig. 4 shows the results of modeling, showing the unavailability of (a) SMR, (b) passive safety, (c) on-site power, and (d) energy efficiency. Here, SMR and On-Site Power gradually decrease, while Passive Safety gradually increases. This means that while SMR aging increases, the impact of passive safety increases. Furthermore, energy efficiency fluctuates due to not only technical issues but also socioeconomic and social factors. Fig. 5 shows the results of the Data Center. Current 1 shows the impact of SMRs, while Current 2 shows the absence of SMRs. Current 1 shows that the effect is significantly greater from around 25th year onward. This implies that SMRs, with their stable electricity supply, have a minimal impact on energy price and policy fluctuations. Table 2 shows the modeling statistics, with Current1 showing a larger standard deviation, indicating the volatility of SMR.

4. Conclusions

The N-SMR commercialization strategy involves deploying small nuclear reactors near data centers to reduce transmission losses and provide uninterrupted power 24/7. This will compensate for the variability of renewable energy sources and achieve real-time carbon-free energy, dramatically improving data center service quality and operational stability. The following are important points in this study:

- It can be deployed near data centers, minimizing grid strain and transmission losses.
- It supports global companies' carbon-free goals by providing 24-hour power regardless of weather conditions.
- Passive safety systems become increasingly important with aging, and energy efficiency fluctuates depending on technological and social factors.
- Its effectiveness is maximized after 25th year of operation, providing stability unaffected by external policies or price fluctuations.

Overall, N-SMR-based data centers near cities will be an innovative alternative that overcomes the limitations of existing suburban data centers, which increase grid load and incur massive transmission losses. Establishing data centers in non-urban areas incurs the costs and delays associated with expanding long-distance transmission networks, and relying on renewable energy sources like solar and wind power inevitably leads to power instability due to weather conditions. In contrast, N-SMRs provide 24/7, uninterrupted baseload, enabling global companies to achieve their real-time carbon-free goals. They also maximize location flexibility by freeing them from the physical constraints of national power grids.

Modeling analysis results show that while the SMR-based system (Current 1) may exhibit volatility during the initial operation phase, it demonstrates overwhelming stability and efficiency over the long term compared to the outlying power supply system (Current 2). This serves as a powerful defense mechanism that protects data center operations from external energy price fluctuations and policy changes. Although availability changes due to aging SMRs may occur, the expanding influence of the technology will compensate for this, making N-SMR a key strategic model for building a sustainable data infrastructure for future intelligent cities.

Acknowledgments

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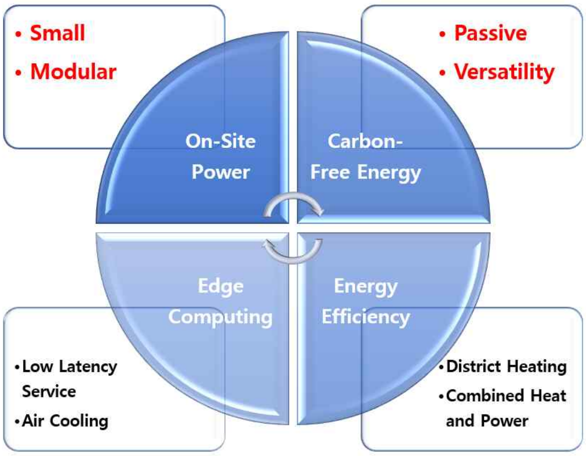
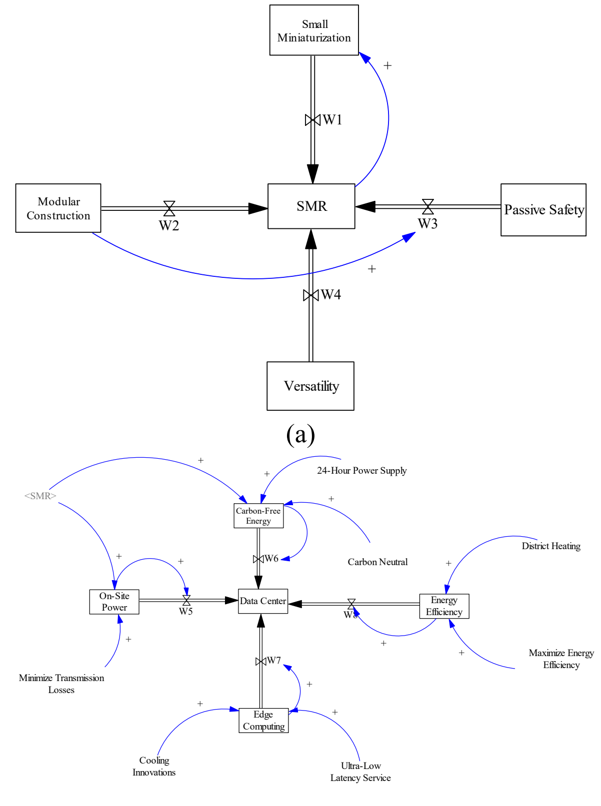


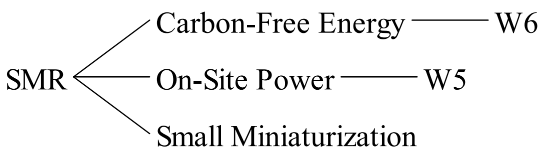
Fig. 1. SMR-based data center characteristics.



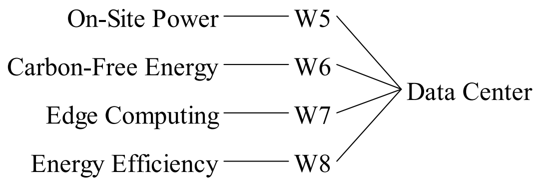
(a)

(b)

Fig. 2. Modeling of SMR-based data center (a) SMR and (b) Data Center.

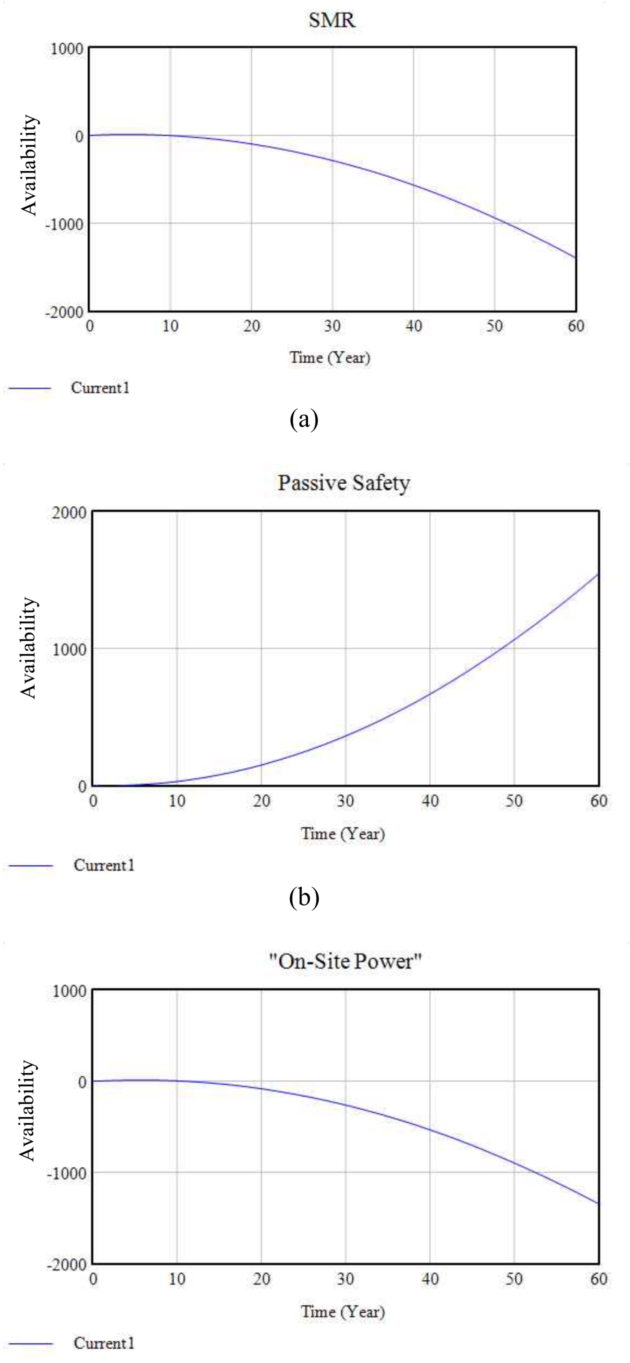


(a)



(b)

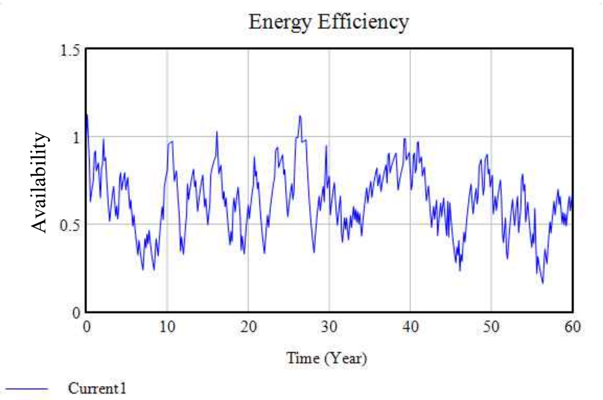
Fig. 3. Causal loop of modeling (a) SMR and (b) Data Center.



(a)

(b)

(c)



(d)

Fig. 4. Results of modeling (a) SMR, (b) Passive safety, (c) On-site power and (d) Energy Efficiency.

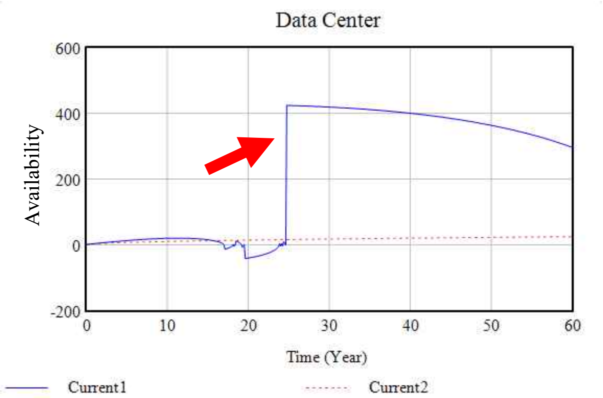


Fig. 5. Result of Data Center.

Table I: List of variables

Variable	Content
Carbon Neutral	if then else(random 0 1 () < 0.3, 0, 1)
24-Hour Power Supply	if then else(random 0 1 () < 0.4, 0, 1)
W2	if then else(random 0 1 () < 0.1, 0, 1)
W5	if then else(random 0 1 () < 0.1, 0, 1) + On-Site Power
W6	if then else(random 0 1 () < 0.4, 0, 1) + Carbon-Free Energy
W7	if then else(random 0 1 () < 0.3, 0, 1) + Edge Computing
W8	if then else(random 0 1 () < 0.1, 0, 1) + Energy Efficiency
Modular Construction	INTEG(-W2), Initial Value = 1.0
Energy Efficiency	INTEG(-W8 + District Heating + Maximize Energy Efficiency), Initial Value = 1.0
Data Center	INTEG((W5+W6+W7+W8)/Data Center), Initial Value = 1.0

Table II: Statistics of modeling

	Min.	Max.	Mean	St. Dev.
Current1	-40.91	424.30	227.29	336.39
Current2	1.00	25.237	16.99	5.85