

ECONOMIC DISPATCH OF A MICROGRID INTEGRATING SMALL MODULAR REACTOR

Sang Nguyen Thanh¹, Chau Le Thi Minh^{2*}, Trong Nghia Le¹

¹*HCMC University of Technology and Engineering, Ho Chi Minh City, Vietnam*

²*Hanoi University of Science and Technology, Ha Noi, Vietnam*

*Corresponding author: chau.lethiminh@hust.edu.vn

(Received: June 29, 2026; Revised: September 04, 2026; Accepted: September 14, 2026)

DOI: 10.31130/ud-jst.2026.24(9).455E

Abstract - This study develops an Economic Dispatch (ED) model for a microgrid integrating Small Modular Reactors (SMRs) to analyze the impact of SMR participation on the operational and economic efficiency of the system. The SMR used in this study is the NuScale 60 MW design, combined with diesel, PV, wind, and BESS. Three operating scenarios are simulated using PSO and GWO, including one SMR, two SMRs, and no SMR. The results show that the two-SMR scenario achieves the lowest total cost of 6032.47 USD, representing a reduction of 2.65% compared with the one-SMR scenario and 6.33% compared with the no-SMR scenario. The results confirm that SMRs have the potential to improve the economic efficiency and reliability of microgrids.

Key words - BESS; Economic Dispatch; GWO; Microgrid; PSO; SMR.

1. Introduction

Microgrids are considered a promising solution for improving power supply reliability, enhancing the capability for independent grid operation, and facilitating the integration of renewable energy sources such as solar and wind power [1], [2]. However, due to the uncertainty and intermittency of renewable energy sources, maintaining power balance and ensuring the economic operation of the system remain major challenges. To address this issue, small modular reactors (SMRs), with advantages such as compact size, passive safety, modular capacity, and flexible load-following capability, have emerged as a potential carbon-free generation source [3], [4]. In addition, SMRs can be scaled up in a modular manner, making them suitable for systems with medium and small loads, particularly microgrids located on islands, in industrial zones, or in areas requiring high reliability. Many studies have suggested that integrating SMRs into microgrids can improve stability, reduce emissions, and enhance operational and economic efficiency [5], [6]. However, most existing studies mainly focus on the integration capability or technical analysis of SMRs, whereas the evaluation of economic dispatch under different levels of SMR participation remains limited.

The economic dispatch problem aims to determine the output power of generating units such that the operating cost is minimized while satisfying technical constraints. Since microgrid problems are often nonlinear, involve multiple constraints, and include renewable energy sources, metaheuristic algorithms such as PSO and GWO are selected because of their ability to effectively search for solutions to complex optimization problems [7] – [13].

Recent studies published in The University of Danang - Journal of Science and Technology have addressed optimization issues in power systems and renewable-energy-based microgrids. For example, Le used the Whale Optimization Algorithm for optimal power flow in a wind-integrated power system [21], while Nguyen et al. developed an optimal operation model for a microgrid with renewable energy sources and hydrogen fuel cells [22]. Although these studies provide useful references for microgrid operation and optimization, the economic dispatch of microgrids under different levels of SMR participation remains insufficiently investigated. Accordingly, the main contribution of this study is the scenario-based assessment of different levels of SMR participation within a unified economic dispatch framework integrating SMRs, diesel generators, PV, wind generation, and BESS. The study quantifies the resulting changes in generation allocation, diesel-generator utilization, and total operating cost, while PSO and GWO are employed as optimization solvers rather than as methodological novelties.

2. SMR Power Plant and Microgrid System

2.1. SMR Nuclear Energy Source

According to the International Atomic Energy Agency, SMRs are advanced nuclear reactors with an electrical power capacity of up to 300 MWe [14]. In essence, the reactor core of an SMR is smaller than that of a large-scale nuclear power plant and is designed based on a standardized modular configuration, which can help shorten construction time and reduce the initial investment cost.

In this paper, NuScale's 60 MW SMR is selected as the subject of the study because it represents a design with an advanced licensing status and has a considerable amount of publicly available technical data [15]. The selected module capacity is compatible with the scale of the investigated microgrid and enables the effects of one- and two-module SMR participation to be evaluated. The SMR parameters adopted in the dispatch model are representative literature-based values synthesized from the technical and economic-dispatch studies cited in this work [20], [23] and are used within the scope of the static economic dispatch formulation. This study considers only the electricity generation function of the SMR and does not examine auxiliary applications such as desalination, heat supply, or hydrogen production. Figure 1 illustrates the main energy-conversion process of the single-module SMR, from the reactor and steam-generation section through the turbine-generator unit to the electrical power output.

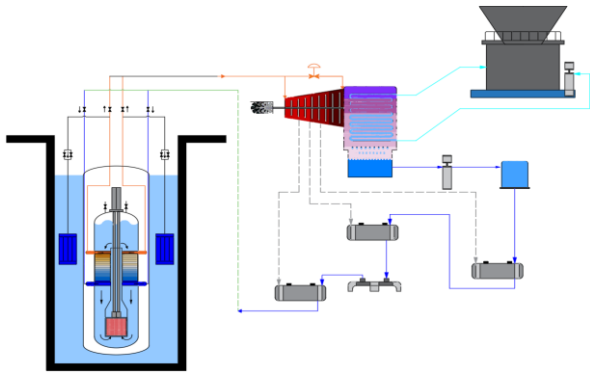


Figure 1. Schematic diagram of a single-module SMR nuclear power plant

Recent thermodynamic analysis of the NuScale 60 MWe SMR shows that its secondary power-conversion system is based on the Rankine steam cycle, in which nuclear heat is converted into mechanical energy through the steam turbine and subsequently into electrical energy [23]. This thermodynamic similarity provides a physical basis for representing the SMR as a turbine-generator unit at the power-system dispatch level. In this study, the quadratic cost function is therefore adopted only as an equivalent operational cost approximation for the static economic dispatch problem and does not imply that the fuel-cost structure or life-cycle economics of an SMR are identical to those of a conventional fossil-fueled thermal generating unit. However, the advantage of SMRs lies in their low variable cost and their capability to provide stable baseload power over an extended period.

2.2. Proposed Microgrid System

Microgrid systems are widely adopted on remote islands, in industrial zones, and at critical facilities to ensure energy autonomy. In principle, such systems integrate distributed generation sources, including diesel, PV, wind, and BESS, through an energy management system to maintain power balance, power quality, and reasonable operating costs.

The proposed model in this study consists of two SMR plants, two diesel generating units, a PV system, a wind system, a BESS, and a 250 MW load. The two SMR plants serve as baseload generation sources and are capable of load-following operation within their design limits; the BESS supports instantaneous power balancing; and the diesel units act as backup sources and compensate for power shortages when renewable generation decreases.

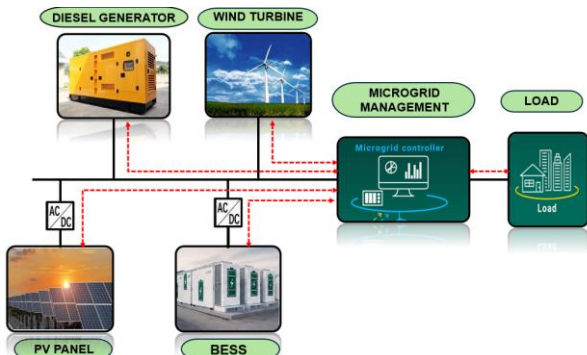


Figure 2. Schematic diagram of the microgrid

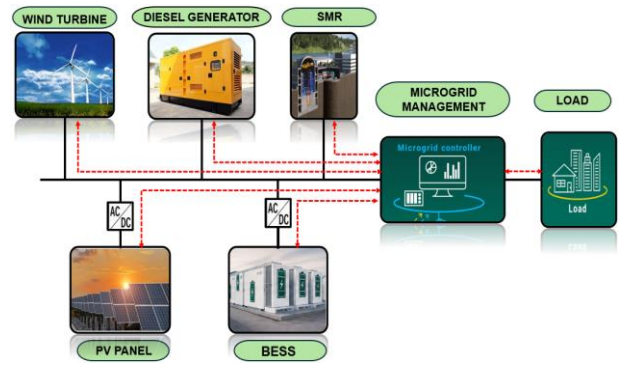


Figure 3. Schematic diagram of the microgrid integrated with SMR plants

Figures 2 and 3 respectively illustrate the microgrid configurations before and after SMR integration. Figure 2 presents the conventional microgrid comprising diesel generation, PV, wind power, BESS, and load, whereas Figure 3 shows the extended configuration with two SMR plants integrated into the system.

3. Formulation of the Economic Dispatch Optimization Problem

3.1. Objective Function and Cost Components

The main objective of the economic dispatch problem is to optimally allocate the power outputs of generation units so as to minimize the total operating cost of the system while satisfying technical constraints. In the considered microgrid configuration, PV and wind generation have nearly zero marginal fuel costs; therefore, they are prioritized for utilization based on their available power. Accordingly, PV and wind outputs are treated as available renewable generation rather than freely dispatchable decision variables, whereas SMRs, diesel generators, and the BESS are optimized within their respective operating limits.

The objective function used in the optimization algorithm considers controllable sources, including SMRs, diesel generators, and the BESS. The costs of PV and wind generation do not directly affect the dispatch decision-making process but are still included in the reported total system cost [17].

$$C_{\text{obj}} = \sum_{i=1}^{n_{\text{SMR}}} C_{\text{SMR}} + \sum_{k=1}^{n_{\text{DG}}} C_{\text{DG}} + C_{\text{BESS}} \rightarrow \text{Minimum} \quad (1)$$

Where, C_{obj} is the objective cost function of the system; C_{SMR} is the cost function of the (i)-th SMR; C_{DG} is the cost function of the (k)-th diesel generating unit; C_{BESS} is the operating cost of the battery energy storage system; n_{SMR} and n_{DG} denote the numbers of SMRs and diesel generating units, respectively.

$$C_{\text{Total}} = C_{\text{obj}} + C_{\text{PV}} + C_{\text{Wind}} \quad (2)$$

Where, C_{Total} is the total operating cost of the entire system; C_{PV} is the converted cost of the photovoltaic power system; C_{Wind} is the converted cost of the wind power system.

The costs of the SMR and diesel generators are

represented by quadratic cost functions that describe the nonlinear relationship between the dispatched power output and the operating cost:

$$C_{SMR}(P_{SMR}) = a_{SMR}P_{SMR}^2 + b_{SMR}P_{SMR} + c_{SMR} [USD/h] \quad (3)$$

Where, P_{SMR} is the power output of the SMR; a_{SMR} , b_{SMR} and c_{SMR} are the characteristic cost coefficients of the SMR.

$$C_{DG}(P_{DG}) = a_{DG}P_{DG}^2 + b_{DG}P_{DG} + c_{DG} [USD/h] \quad (4)$$

Where P_{DG} is the power output of diesel; a_{DG} , b_{DG} and c_{DG} are the characteristic cost coefficients associated with the fuel consumption and operation of the diesel generating unit.

The converted costs of PV and wind generation are determined based on investment capital, operation and maintenance costs, discount rate, and equipment lifetime. The cost coefficient conversion factor is calculated as follows [17]:

$$C_{PV}(P_{PV}) = aI_{PV}^p P_{PV} + G_{PV}^E P_{PV} \quad (5)$$

Where, P_{PV} is the power output of the PV system; I_{PV}^p is the initial investment rate of the PV system; G_{PV}^E is the converted operation and maintenance cost of PV; a is the capital recovery factor.

$$C_{Wind}(P_{Wind}) = aI_{Wind}^p P_{Wind} + G_{Wind}^E P_{Wind} \quad (6)$$

Where, P_{Wind} is the power output of the wind source; I_{Wind}^p is the initial investment rate of the wind power system; G_{Wind}^E is the converted operation and maintenance cost of wind power; a is the capital recovery factor.

$$a = \frac{r}{1 - (1 + r)^{-N}} \quad (7)$$

Where, r is the discount rate; N is the investment lifetime or the economic operating years of the equipment.

The operating cost of the BESS is composed of the degradation cost during discharge, as expressed in (8), and the charging cost, as expressed in (9). According to [18], the degradation cost depends on the state of charge, depth of discharge, discharge rate, and the characteristic coefficients of the storage system.

$$C_{BESS,dis,t} = a_b SOC_t^{dis} + b_b SOC_{t-1}^{dis} + c_b DCR_t + d_b \quad (8)$$

Where, $C_{BESS,dis,t}$ is the discharge cost of the BESS; SOC_t^{dis} is the state of charge of the BESS during discharge at time t ; SOC_{t-1}^{dis} is the state of charge of the BESS at the previous time step; DCR_t is the discharge rate at time t ; a_b , b_b , c_b and d_b are the characteristic degradation coefficients of the BESS.

$$C_{BESS,ch} = c^{ch} E^{ch} \quad (9)$$

Where, $C_{BESS,ch}$ is the charging cost of the BESS; c^{ch} is the charging cost coefficient or charging electricity price; E^{ch} is the amount of energy charged into the BESS.

$$C_{BESS,t} = C_{BESS,dis,t} - C_{BESS,ch} \quad (10)$$

3.2. Constraint Equations

3.2.1. Power Balance Constraint

At each operating time interval, the power balance between the total power generated by the distributed generation sources and the load demand must consider the charging power of the BESS. The power balance constraint is expressed as follows:

$$\sum_{k=1}^{n_{DG}} P_{kt}^{DG} + \sum_{i=1}^{n_{SMR}} P_{it}^{SMR} + P_t^{PV} + P_t^{Wind} + P_t^{BESS,dis} - P_t^{BESS,ch} = P_t^{Load} + P_t^{Loss} \quad (11)$$

Where, P_{kt}^{DG} is the output power of the (k)-th diesel generating unit at time t ; P_{it}^{SMR} is the output power of the (i)-th SMR at time t ; P_t^{PV} and P_t^{Wind} are the output powers of the photovoltaic and wind power sources, respectively; $P_t^{BESS,dis}$ is the discharge power of the BESS; $P_t^{BESS,ch}$ is the charging power of the BESS; P_t^{Load} is the load demand; P_t^{Loss} is the system power loss.

3.2.2. Diesel and SMR Constraints

The power output of the diesel generator must not exceed its maximum rated value and must not be lower than the minimum operating value to ensure equipment efficiency and durability. For the SMR, the output power is kept within the range of 9–60 MW and is subject to ramping constraints according to the operating characteristics of nuclear power sources.

$$P_{DG}^{min} \leq P_{DG,t} \leq P_{DG}^{max} \quad (12)$$

Where, $P_{DG,t}$ is the output power of the diesel generating unit at time t ; P_{DG}^{min} and P_{DG}^{max} are the minimum and maximum output power limits of the diesel generator.

$$P_{SMR}^{min} \leq P_{SMR,t} \leq P_{SMR}^{max} \quad (13)$$

Where, $P_{SMR,t}$ is the output power of the SMR at time t ; P_{SMR}^{min} and P_{SMR}^{max} are the minimum and maximum output power limits of the SMR.

$$P_{g,t} - P_{g,t-1} \leq RU_g \quad (14)$$

Where, $P_{g,t}$ is the output power of unit g at time t ; $P_{g,t-1}$ is the output power of unit g at the previous time step; RU_g is the allowable ramp-up limit of unit g .

$$P_{g,t-1} - P_{g,t} \leq RD_g \quad (15)$$

Where RD_g is the allowable ramp-down limit of unit g .

3.2.3. BESS Constraints

The BESS is subject to limits on the charging power, discharging power, and state of charge. To ensure

equipment lifetime, the SOC must remain within the allowable range, and the BESS must not be charged and discharged simultaneously.

$$SOC^{min} \leq SOC_t \leq SOC^{max} \quad (16)$$

Where, SOC_t is the state of charge of the BESS at time t ;

SOC^{min} and SOC^{max} are the minimum and maximum state-of-charge limits of the BESS.

$$0 \leq P_{ch,t} \leq P_{ch}^{max} \quad (17)$$

$$0 \leq P_{dis,t} \leq P_{dis}^{max}$$

$$P_{ch,t} \cdot P_{dis,t} = 0 \quad (18)$$

Where, $P_{ch,t}$ is the charging power of the BESS at time t ;

$P_{dis,t}$ is the discharging power of the BESS at time t ;

P_{ch}^{max} and P_{dis}^{max} are the maximum charging power and maximum discharging power of the BESS.

4. Power Supply Scenarios and Simulation Data

To evaluate the role of SMRs, this study develops three operating scenarios: Scenario 1, in which only one SMR plant is in operation; Scenario 2, in which both SMR plants are in operation; and Scenario 3, in which SMRs do not participate. PV, wind, BESS, and diesel sources are considered in all cases. To ensure a consistent basis for comparison, the three scenarios are formulated using the same economic dispatch framework, 250 MW load demand, and mathematical models for the resources common to all cases, while differing in the level of SMR participation.

The problem is solved using PSO and GWO in the MATLAB environment. The input data are synthesized from scientific publications related to microgrid economic dispatch models, renewable energy costs, BESS characteristics, and the flexible operating capability of SMRs [16] – [20].

Tables 1 and 2 summarize the cost coefficients and operating constraints of the SMR and diesel generating units, respectively. The SMR parameters reported in Table 1 are based on [20], [23], whereas the diesel-generator cost coefficients and generation limits in Table 2 are adopted from [16].

Table 1. Parameters of the two SMR plants

Unit	a [USD/MW ² .h]	b [USD/MW.h]	c [USD/h]	Pmax [MW]	Pmin [MW]
SMR1	0.00386	14.652	15.33	60	9
SMR2	0.00386	14.652	15.33	60	9

Table 2. Parameters of the two diesel generating units

Unit	a [USD/MW ² .h]	b [USD/MW.h]	c [USD/h]	Pmax [MW]	Pmin [MW]
DG1	0.0029	20.16	992	160	40
DG2	0.0210	20.40	600	190	50
DG1: RU [MW/h] = 60; RD [MW/h] = 100					
DG2: RU [MW/h] = 50; RD [MW/h] = 50					

Tables 3 and 4 present the principal technical and economic parameters of the renewable generation sources

and the BESS considered in the simulations. The renewable-energy economic parameters in Table 3 are based on [17], while the BESS degradation-cost coefficients and selected operating parameters in Table 4 are based on [18].

Table 3. Parameters of PV and wind

Unit	Pmax [MW]	I [USD/kW]	r (p.u)	G [USD/kW]	N [year]
PV	40	1630	0.09	0.016	20
Wind	30	1400	0.09	0.016	20

Table 4. Main parameters of the BESS

Parameter	Value	Parameter	Value
a_b [USD]	-36.23	$P_{ch}^{ch,max}$ [MW]	25
b_b [USD]	34.80	$P_{dis}^{dis,max}$ [MW]	25
c_b [USD]	2.77	η [%]	90
d_b [USD]	-2.45	DOD [%]	90
c^{ch} [USD/MWh]	44.607	SOC^{min} [p.u]	0.1
DCR^{max} [p.u]	1	SOC^{max} [p.u]	0.9

5. Simulation Results and Discussion

In this study, the economic operation problem of the MG is solved using two algorithms, PSO and GWO, to search for the optimal solution. The simulation is implemented in MATLAB 2024a on a Nitro AN515-57 laptop equipped with an 11th Gen Intel(R) Core (TM) i5-11400H 2.70 GHz processor, 12 CPUs, approximately 2.7 GHz, and 24 GB RAM. Based on the previously collected data, the PSO and GWO algorithms are applied to search for the optimal solution for all three scenarios.

5.1. Results of Scenario 1

Figure 4 presents the convergence behavior of PSO and GWO for Scenario 1, where both optimization solvers approach comparable objective-function values during the iterative search process.

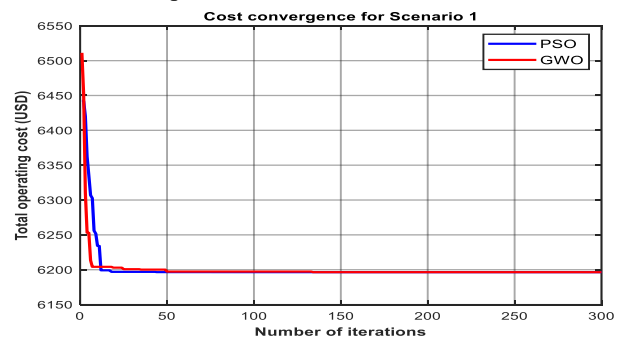


Figure 4. PSO and GWO convergence curves for Scenario 1

Table 5. Dispatch results for Scenario 1

Generation source	P (MW)	Cost
SMR1	60.00	908.35
SMR2	0.00	15.33
DG1	61.90	2251.02
DG2	50.00	1672.50
PV	40.00	815.42
Wind	30.00	525.28
BESS discharge	8.10	8.68
Total	250.00	6196.57

The resulting generation dispatch and the corresponding source-wise operating costs for Scenario 1 are summarized in Table 5.

In Scenario 1, SMR1 generates 60 MW, corresponding to approximately 24% of the load demand. The two diesel generators supply a total output of 111.9 MW, indicating that they still play an important role together with traditional generation sources. The total cost is 6196.57 USD. The BESS only contributes 8.1 MW, which reflects its role in supporting power balance rather than serving as the main generation source.

5.2. Results of Scenario 2

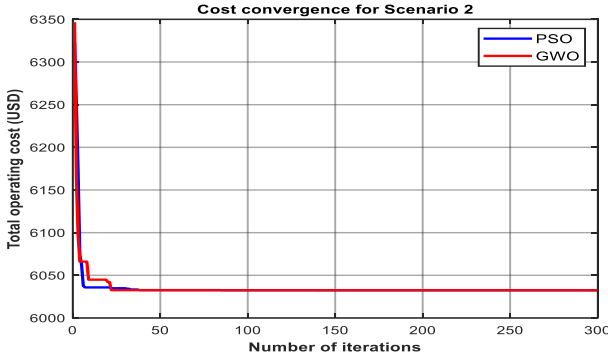


Figure 5. PSO and GWO convergence curves for Scenario 2

For Scenario 2, Figure 5 indicates that PSO and GWO converge to comparable objective-function values, while Table 6 summarizes the associated generation dispatch and source-wise operating costs.

Table 6. Dispatch results for Scenario 2

Generation source	P (MW)	Cost
SMR1	30.72	469.05
SMR2	48.48	734.75
DG1	40.00	1803.04
DG2	50.00	1672.50
PV	40.00	815.42
Wind	30.00	525.28
BESS discharge	10.80	12.44
Total	250.00	6032.47

Scenario 2 provides the most favorable results when both SMRs participate, with a total output of 79.2 MW. The diesel output decreases to 90 MW, and the total cost reaches 6032.47 USD. Compared with Scenario 1, the cost is reduced by approximately 2.65%; compared with Scenario 3, the cost decreases by about 6.33%. This demonstrates the clear economic effectiveness of increasing the participation level of SMRs.

5.3. Results of Scenario 3

Figure 6 shows that PSO and GWO converge to closely comparable objective-function values for Scenario 3. In Scenario 3, neither SMR is in operation; therefore, diesel generation must increase to 166.5 MW, accounting for approximately 66.6% of the load demand. The total cost is 6440.05 USD, which is the highest among the three scenarios. This result shows that, in the absence of SMRs, the system becomes more dependent on diesel generators, leading to higher operating costs and lower economic efficiency.

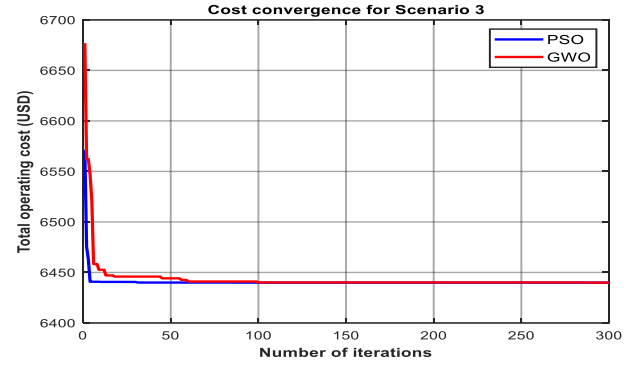


Figure 6. PSO and GWO convergence curves for Scenario 3

Table 7. Dispatch results for Scenario 3

Generation source	P (MW)	Cost
SMR1	0.00	15.33
SMR2	0.00	15.33
DG1	116.50	3380.00
DG2	50.00	1672.50
PV	40.00	815.42
Wind	30.00	525.28
BESS discharge	13.50	16.19
Total	250.00	6440.05

Table 7 summarizes the corresponding Scenario 3 dispatch, including the higher diesel output and total cost. Based on the three scenarios, it can be observed that SMRs help reduce the dependence on diesel generation, support the provision of stable baseload power, and improve the economic performance of the microgrid. The BESS maintains a flexible supporting role, while PV and wind generation continue to be prioritized to reduce marginal costs and emissions.

5.4. Comparison and Discussion

When the three scenarios are compared, the most significant difference is observed in the amount of diesel generation that must be dispatched. In the scenario without SMR participation, the total diesel output increases to 166.5 MW, which is considerably higher than 111.9 MW in the one-SMR scenario and 90 MW in the two-SMR scenario. This indicates that SMRs not only reduce operating costs but also alleviate the operating burden on conventional generating units. From a technical perspective, the increased contribution of SMRs allows a larger share of the load to be supplied by stable baseload generation, thereby reducing the loading requirement on the diesel units. Operationally, the diesel generators remain available as controllable and backup resources, while their contribution to the total power supply decreases as SMR participation increases.

The results also show that the role of the BESS varies according to the level of baseload power shortage. When SMRs are not involved, the BESS has to discharge 13.5 MW, which is higher than 8.1 MW in the one-SMR scenario. However, the BESS still serves only as a short-term balancing support due to its limited storage capacity and charge/discharge power. Therefore, the BESS cannot fully replace a continuous baseload generation source such as an SMR.

From an algorithmic perspective, PSO and GWO provide nearly equivalent solutions across the scenarios,

indicating that the solution space of the proposed model is stable. PSO generally reaches convergence faster in the early iterations, whereas GWO tends to reduce the objective function more smoothly. Since the objective of this study is to evaluate the operational effectiveness of SMRs rather than to compare optimization algorithms, PSO and GWO are used as independent solvers to verify the consistency of the obtained dispatch solutions.

Table 8. Summary comparison of costs among the scenarios

Scenario	Total cost (USD)	Reduction compared with Scenario 3	Comment
1	6196.57	3.78%	Diesel generation is reduced but not yet optimal
2	6032.47	6.33%	Lowest cost
3	6440.05	0%	High dependence on diesel generation

From Table 8, Scenario 2 is the most economically reasonable option because it both reduces the operating cost and maintains the capability to supply baseload power. When both SMRs are in operation, the system can utilize generation sources with lower costs than diesel generators while still maintaining PV and wind generation at their available levels to take advantage of renewable energy.

The proposed framework can be adapted to other islanded microgrids or large-scale industrial power systems by updating the system-specific load, generation, storage, cost, and operating parameters. However, the quantitative results reported in this study are specific to the investigated 250 MW microgrid configuration and should not be directly generalized to other systems.

6. Conclusion

This paper has developed and formulated an economic dispatch model for a microgrid system integrated with SMRs, diesel generators, PV, wind power, and a BESS. The model simultaneously considers the optimization objective function for controllable sources and the reported total cost of the overall system, thereby reflecting more clearly the impact of each generation component on the operating cost.

The simulation results show that SMR integration provides significant benefits. The two-SMR scenario achieves the lowest total cost of 6032.47 USD, which is 2.65% lower than that of the one-SMR scenario and 6.33% lower than that of the scenario without SMR participation. At the same time, diesel generation is considerably reduced, demonstrating the role of SMRs in decreasing dependence on conventional generation sources.

The results obtained from PSO and GWO exhibit only minor deviations, indicating that the dispatch solution is stable. Therefore, SMRs can be considered a potential solution for improving economic efficiency, enhancing reliability, and supporting renewable energy integration in modern microgrids. In future research, the model can be extended to a 24-hour cycle, considering detailed network losses, start-up and shut-down costs, and more in-depth dynamic constraints of SMRs.

REFERENCES

- [1] R. H. Lasseter, "Microgrids", in *Proc. IEEE Power Engineering Society Winter Meeting*, vol. 1, 2002, pp. 305–308.
- [2] N. Hatziaargyriou, *Microgrids: Architectures and Control*. Hoboken, NJ, USA: Wiley-IEEE Press, 2014.
- [3] G. Locatelli, M. Mancini, and N. Todeschini, "Generation IV nuclear reactors: Current status and future prospects", *Energy Policy*, vol. 61, pp. 1503–1520, 2013.
- [4] G. Locatelli, S. Boarin, and M. E. Ricotti, "Load following with small modular reactors", *Energy*, vol. 48, pp. 41–55, 2015.
- [5] D. Michaelson and J. Jiang, "Review of integration of small modular reactors in renewable energy microgrids", *Renewable and Sustainable Energy Reviews*, vol. 152, p. 111638, 2021.
- [6] B. Poudel et al., "Small reactors in microgrids: Technology modeling and analysis", Idaho National Laboratory, Idaho Falls, ID, USA, Tech. Rep., 2021.
- [7] J. A. Momoh, M. E. El-Hawary, and R. Adapa, "A review of selected optimal power flow literature", *IEEE Transactions on Power Systems*, vol. 14, no. 1, pp. 96–111, 1999.
- [8] S. Mishra, D. Das, and S. Paul, "A comprehensive review of optimization techniques in microgrid", *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 1292–1310, 2018.
- [9] M. Basu, "Economic environmental dispatch using multi-objective differential evolution", *Applied Soft Computing*, vol. 11, no. 2, pp. 2845–2853, 2011.
- [10] A. Soroudi, *Power System Optimization Modeling in GAMS*. Cham, Switzerland: Springer, 2017.
- [11] X. S. Yang, *Nature-Inspired Optimization Algorithms*. Oxford, U.K.: Elsevier, 2014.
- [12] J. Kennedy and R. Eberhart, "Particle swarm optimization", in *Proc. IEEE International Conference on Neural Networks*, 1995, pp. 1942–1948.
- [13] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer", *Advances in Engineering Software*, vol. 69, pp. 46–61, 2014.
- [14] International Atomic Energy Agency, "What are small modular reactors (SMRs)?" *IAEA.org*. [Online]. Available: <https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs> [Accessed: Apr. 17, 2026].
- [15] D. Claudio, "NuScale power overview—Energiforsk nuclear seminar 2021", NuScale Power, LLC, Jan. 20, 2021. [Online]. Available: https://energiforsk.se/media/29017/claudio_nuscale.pdf [Accessed: Apr. 17, 2026].
- [16] B. Dey, B. Bhattacharyya, and F. P. G. Márquez, "A hybrid optimization-based approach to solve environment constrained economic dispatch problem on microgrid system", *Journal of Cleaner Production*, vol. 307, p. 127196, 2021.
- [17] N. Augustine, S. Suresh, P. Moghe, and K. Sheikh, "Economic dispatch for a microgrid considering renewable energy cost functions", in *Proc. 2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, Washington, DC, USA, 2012, pp. 1–7.
- [18] N. Padmanabhan, M. Ahmed, and K. Bhattacharya, "Battery energy storage systems in energy and reserve markets", *IEEE Transactions on Power Systems*, vol. 35, no. 1, pp. 215–226, Jan. 2020.
- [19] R. Ingersoll et al., "Integration of NuScale SMR with renewable energy sources", *Nuclear Technology*, vol. 191, no. 1, pp. 22–31, 2015.
- [20] S. Alhadhrami, G. J. Soto, and B. Lindley, "Dispatch analysis of flexible power operation with multi-unit small modular reactors", *Energy*, vol. 280, p. 128107, 2023.
- [21] L. D. Luong, "Optimal power flow in wind power integrated systems using Whale Optimization Algorithm", *The University of Danang - Journal of Science and Technology*, vol. 22, no. 10, pp. 58–63, 2024.
- [22] Q. M. Nguyen, D. L. Nguyen, D. H. Do, H. V. A. Nguyen, T. T. M. A. Tran, and T. H. L. Nguyen, "Optimal operation of microgrid integrated with renewable resources and hydro fuel cell", *The University of Danang - Journal of Science and Technology*, vol. 21, no. 10, pp. 78–84, 2023.
- [23] N. Kasińska, A. Mielcarek, J. Sierchula, R. Szczerbowski, and B. Ceran, "Technical and Economic Comparative Analysis of Nuclear Power Plants: AP1000 and SMR", *Energies*, vol. 18, no. 17, p. 4749, 2025, doi: 10.3390/en18174749.