OPTIMAL SIZING OF A BATTERY ENERGY STORAGE SYSTEM USING PARTICLE SWARM OPTIMIZATION FOR MICROGRID

TỐI ƯU KÍCH CỠ CỦA HỆ THỐNG PIN LƯU TRỮ NĂNG LƯỢNG SỬ DỤNG TỐI ƯU BẦY ĐÀN CHO MICROGRID

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ABSTRACT

Nowadays, the rapid penetration of renewable energy sources causes instability in the grids, especially in the microgrids. Battery Energy Storage System (BESS) with an optimum size when integrating into a microgrid can prevent it from instability as well as system collapse. The installation of BESS whose size is arbitrary or not optimal might result in higher cost, system losses, and larger BESS capacity. Therefore, this research provides a novel technique for determining an optimal BESS size at a low total BESS cost based on particle swarm optimization (PSO) using MATLAB in a standalone microgrid. The Loss of Power Supply Probability (LPSP), Loss of Load Expected (LOLE), and Loss of Energy Expected (LOEE) indices are also considered in this paper. The result reveals that with the optimum BESS size achieved, it can dramatically improve the stability of the microgrid and simultaneously maintain a high level of economic viability.

Keywords: *BESS, PSO, Loss of Power Supply Probability (LPSP), Loss of Load Expected (LOLE), Loss of Energy Expected (LOEE).*

TÓM TẮT

Ngày nay, sự xâm nhập nhanh chóng của các nguồn năng lượng tái tạo gây ra sự mất ổn định trong lưới điện, đặc biệt là trong các lưới điện siêu nhỏ. Hệ thống pin lưu trữ năng lượng (BESS) với một kích cỡ tối ưu khi được tích hợp vào một lưới điện siêu nhỏ có thể ngăn chặn lưới khỏi sự mất ổn định cũng như sự cố sụp đổ hệ thống. Việc lắp đặt BESS với kích cỡ ngẫu nhiên hay không được tối ưu sẽ dẫn đến chi phí cao hơn, tổn thất hệ thống và dung lượng BESS lớn hơn. Do đó, nghiên cứu này cung cấp một kỹ thuật mới để xác định kích thước BESS tối ưu với tổng chi phí BESS thấp dựa trên tối ưu bầy đàn (PSO) bằng MATLAB trong một lưới điện siêu nhỏ độc lập. Các chỉ số xác suất mất nguồn cung cấp điện (LPSP), Mất phụ tải dự kiến (LOLE) và mất năng lượng dự kiến (LOEE) cũng được xem xét trong bài báo này. Kết quả cho thấy rằng với kích thước BESS tối ưu đạt được, nó có thể cải thiện đáng kể tính ổn định của lưới điện siêu nhỏ và đồng thời duy trì mức độ khả thi kinh tế cao.

Từ khóa: *BESS, PSO, xác suất mất nguồn cung cấp điện (LPSP), mất phụ tải dự kiến (LOLE), mất năng lượng dự kiến (LOEE).*

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1. INTRODUCTION

The penetration of renewable sources into the grid can cause many problems for the grid, especially the microgrid. The intermittent of renewable energy sources causes voltage and frequency problems, affects grid reliability, and even leads to system collapse. One of the most effective, modern methods to reduce that is the battery energy storage system (BESS) technology. BESS can balance systems, regulate voltage and frequency and smooth the fluctuation of the voltage and frequency caused by renewable energy which is unstable and interruptible. Figure 1 illustrates the structure of distributed renewable energy with BESS installation. However, BESS with the wrong size will lead to an increase in costs and system losses. And sizing for BESS provides those benefits shown in [1].

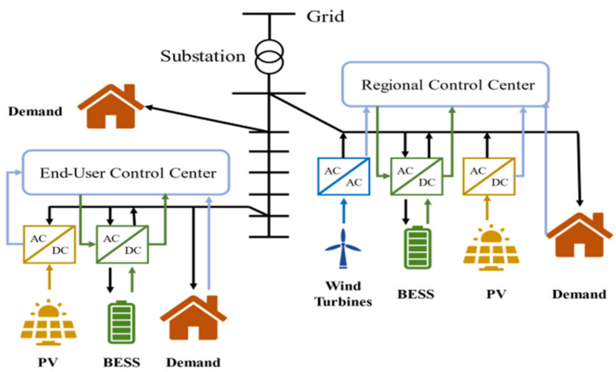

Figure 1. The structure of distributed renewable energy with BESS

One of the popular approaches for solving optimization size problems is to use soft computing such as meta-heuristic. L.A. Wong et al proposed a method using the Whale Optimization Algorithm (WOA) to find the optimal size and placement of BESS [2]. This study aims to reduce the power losses with and without the duck curve phenomenon. In [3], the author proposed a method for optimal placement and sizing of the BESS in a distribution system using the Improved Coyote Optimization Algorithm (ICOA) to minimize the total loss reduction. This study also analyzed different scenarios and noticed that the total loss of the distribution decreased by increasing the number of

BESS. Besides, a simple and effective method for sizing BESS based on energy balance was proposed in [4]. The results showed that the calculated deviation between the real and simulated battery sizes was found to be lower than 5%. Moreover, in [5-6], Loss of Power Supply Probability (LPSP), Loss of Load Expected (LOLE), and Loss of Energy Expected (LOEE) indices had been considered to ensure reliability. The main purpose of the present work is to determine the optimal sizing of BESS at minimal cost by applying PSO. This method is tested in a 13-node microgrid using MATLAB environment. Moreover, this work also considers the reliability indices LPSP, LOLE, and LOEE. The rest of this paper is arranged as follows: Section 2 briefly demonstrates the system configuration. Section 3 presents the method to optimize the size of BESS using PSO and considers three reliability indices. Section 4 reveals the results and analytics. Finally, the concluding remarks are illustrated in Section 5.

2. SYSTEM CONFIGURATION

The system used in this study is an IEEE 13 bus, which is simple and usually used in previous research, as can be seen in Figure 2. The data of the grid is illustrated in [7]. The grid contains a slack bus at Node 632, a PV at Node 675, and a BESS at Node 633.

Because of environmental factors such as clouds, dust, the output power of PV is uncertain and intermittent. Therefore, the effect of solar irradiation and environmental temperature is designed to show the PV characteristics in the operational state. The power of the PV array is calculated as follows:

$$P_{PV} = Y_{PV} \cdot \frac{G_{bar}}{G_{bar,STC}} \cdot \left(1 + \alpha_P \left(T_C - T_{C,STC}\right)\right) \quad (1)$$

where Y_{PV} (MW) is the output power of the PV array under standard test conditions, G_{bar} (MW/m^2) is the solar irradiation incident on the PV array in the current time, $G_{bar,\ STC}$ (MW/m^2) is the incident radiation at standard test conditions, α_P (%/^{0}C) is the temperature coefficient of power, T_C (^{0}C) is the PV cell temperature in the current time, $T_{C,STC}$ (^{0}C) is the cell temperature under standard test conditions.

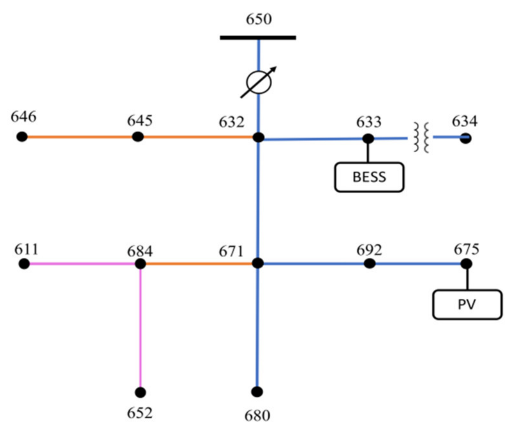

Figure 2. The microgrid system

The capital cost of BESS is shown as:

$$C_{cap} = C_P P_{BESS} + C_W C_{BESS} \quad (2)$$

where P_{BESS} (MW) and C_{BESS} (MWh) are BESS power and capacity respectively.C_P (\$/MWh) and C_W (\$/MWh) is the specific power and capacity cost of BESS respectively.

The operating and maintenance cost of BESS can be written as:

$$C_{OM} = C_{MF} P_{BESS} + W_{ann} C_{MV} \quad (3)$$

where, C_{MF} (\$/MW/year) is the fixed cost of BESS, and C_{MV} (\$/MW/year) is the variable operating and maintenance cost of BESS. W_{ann} (MW/year) is the energy storage system's annual discharge energy.

The BESS technology, used in this study is the Vanadium Redox battery. The BESS technology is shown in Table 1. These parameters are referenced from [8].

Moreover, the reliability indices can be calculated by following equations:

$$LPSP = \frac{\left|P_{Load} - P_{PV}\right|}{P_{Load}} \quad (4)$$

$$LOLE = \frac{\left|P_{Loss} - P_{Load} - P_{PV}\right|}{T} \quad (5)$$

$$LOEE = \frac{P_{Loss}}{T} \quad (6)$$

where P_{Load} (MW) is the total load, P_{Loss} (MW) is the total power losses, P_{PV} (MW) is the total power of PV and T (h) is the data collecting period.

Table 1. Parameter of Vanadium Redox BESS

Parameter	Value	Unit
C_P	426	\$/MW
C_W	100	\$/MWh
C_{MF}	9	\$/MW/year
C_{MV}	0	\$/MW/year
W_{ann}	1	MW/year
Lifetime	15	years
Efficiency	70	%

To optimize the size and the total cost of BESS, the objective functions are selected and written as follows:

$$f_1 = Opt(P_{BESS}) \quad (7)$$

$$f_2 = \min(C_T) = \min(C_{cap} + C_{OM}) \quad (8)$$

$$f = f_1 + f_2 + \sum_{t=1}^{T} P_{Loss}(t) \quad (9)$$

The constraints attached to this optimization are expressed as follows:

$$P_{BESS}^{min} \le P_{BESS} \le P_{BESS}^{max} \quad (10)$$

$$C_{BESS}^{min} \le C_{BESS} \le C_{BESS}^{max} \quad (11)$$

where P_{BESS} (MW) and C_{BESS} (MWh) are the rated power capacity and rated energy capacity, respectively. P_{BESS}^{min},

P_{BESS}^{max}, C_{BESS}^{min}, C_{BESS}^{max} are respectively the minimum and maximum rated power capacity, the minimum and maximum rated energy capacity.

3. METHODOLOGY

In this study, the optimal BESS sizing can be calculated using PSO. This is one of the most effective methods because of its simplicity, ease of use, high convergence rate, and so on. Further information can be found in [9]. PSO is an approach for evaluating the optimal parameters in the search spaces. Firstly, PSO initializes a group of random particles to search for the optimal parameters. It updates two values in each iteration, which are P_{best}, the best solution of its particle acquired and G_{best}, the best value adopted by any particle in all previous iterations. Each particle upgrades its position and velocity by using equations (12) and (13):

$$v_{i+1} = v_i + c_1 r_1 (P_{best} - x_i) + c_2 r_2 (G_{best} - x_i) \tag{12}$$

$$x_{i+1} = v_{i+1} + x_i \tag{13}$$

where, r_1, r_2 are arbitrary in [0,1], $c_1 = 0{,}022$, $c_2 = 0{,}023$. In this work, the number of iterations is $N_i = 50$ and the number of the particle is $N_p = 10$.

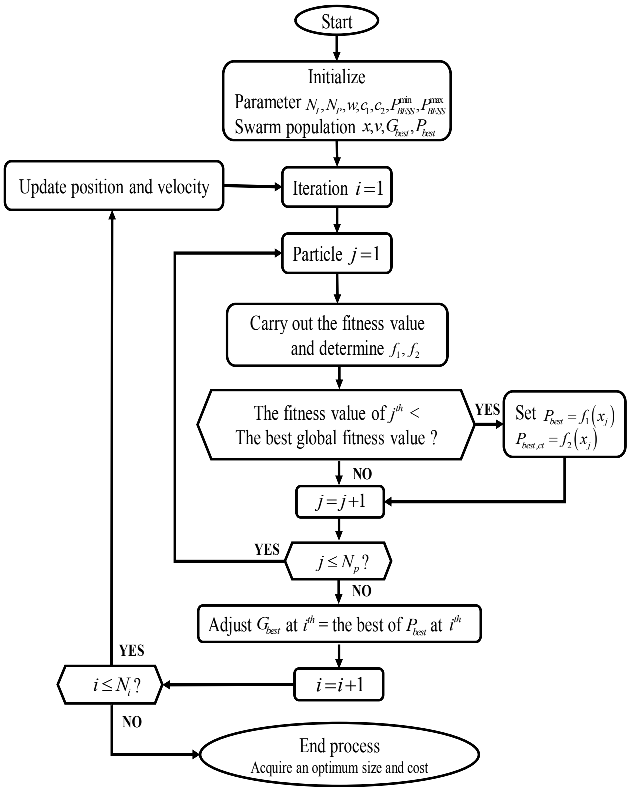

Figure 3. A flow chart determines the optimal sizing of BESS using PSO

The flow chart of the proposed optimal sizing of BESS by using PSO is shown in Figure 3, which is clarified as follows:

Step 1: Initialize the parameters and iteration with random position and velocity.

Step 2: Start the particle j = 1 in the swarm.

Step 3: Carry out the objective functions for the particle j^{th} in iteration i^{th}.

Step 4: Find P_{best} and G_{best} for a particle j^{th} of iteration i^{th}. If the value of j^{th} is smaller than the best global fitness value, set $P_{best} = f_1(x_j)$ and the best total cost $P_{best,ct} = f_2(x_j)$.

Step 5: Increase j by 1 and check if $j+1 \le N_P$, go back to **Step 3**.

Step 6: Adjust G_{best} at i^{th} iteration equals the best of P_{best} at i^{th} iteration.

Step 7: Increase i by 1 and if $i+1 \le N_i$, update position and velocity using Equations (4) and (5) and go back to **Step 2**. Conversely, end the process and acquire an optimum size and cost.

4. RESULTS AND ANALYTICS

The method is tested in an IEEE 13 bus microgrid with the data collected in a year. The parameter used in this study is described in Table 2.

The total power generated, which is PV power, is shown in Figure 4 and Figure 5 illustrates the load power measured in one year. The performance of the PSO algorithm to show the total objective functions is illustrated in Figure 6. The total objective function after 50 iterations is 8.809×10^7. The optimal size of BESS, which is acquired using this method, is 3.8698MW, and the battery capacity is 3.3900×10^4 MWh. The minimum total cost including capital cost, operating and maintenance cost is 2840$. The graph also shows how effective the PSO performs with a high convergence rate.

Table 2. Parameter of model PV

Parameter	Value	Unit
T	8760	h
Y_{PV}	0.255	MW
$G_{bar,STC}$	0.001	MW/m^2
α_p	0.001	
$T_{C,STC}$	25	^{0}C

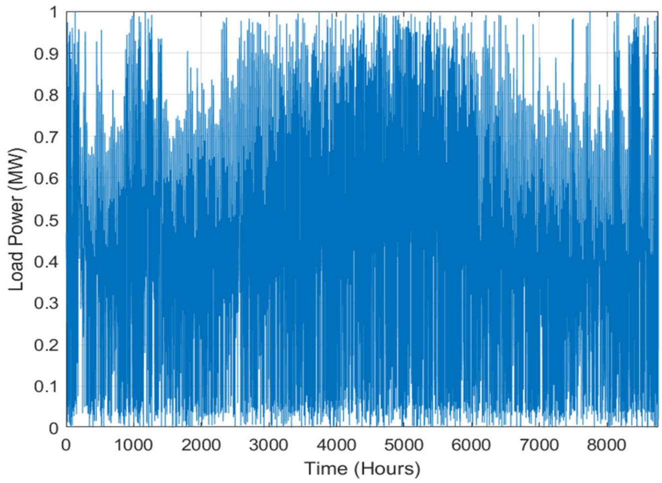

Figure 4. PV power in one year

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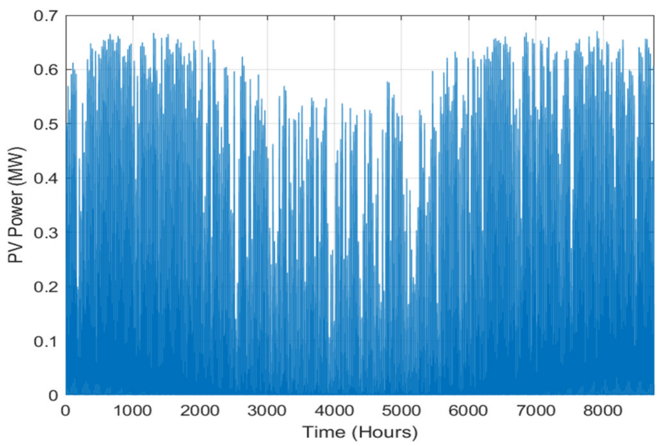

Figure 5. Load power in one year

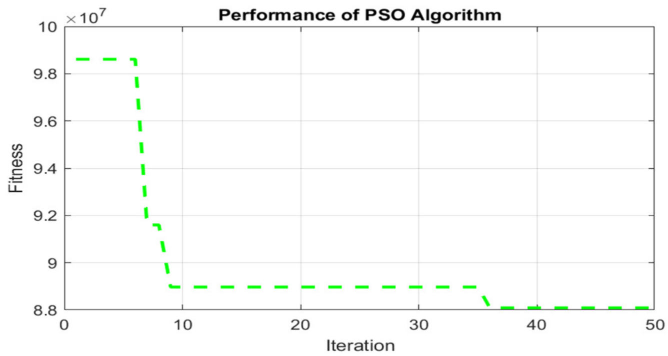

Figure 6. Performance of Particle Swarm Optimization

Figure 7 and Figure 8 show the SOC and the power of BESS in 720 hours. The highest SOC of the battery is set to 70% and the lowest one is approximately 65%. The SOC of the BESS corresponds to the power of the battery, which can be shown by the similarity between the two figures. It illustrates that when the SOC of the BESS decreases (BESS is in discharging mode), the power of BESS will increase an amount, which is the power discharged from BESS to balance with the demand and vice versa, the power of BESS will decrease the amount equal the charging power at this period. The power loss over 720 hours is described in Figure 9. From those results and using Equations (4), (5) and (6), the values of the reliability indices can be determined as follows: LPSP = 0.0363, LOLE = 51.5884 and LOEE = 51.3058.

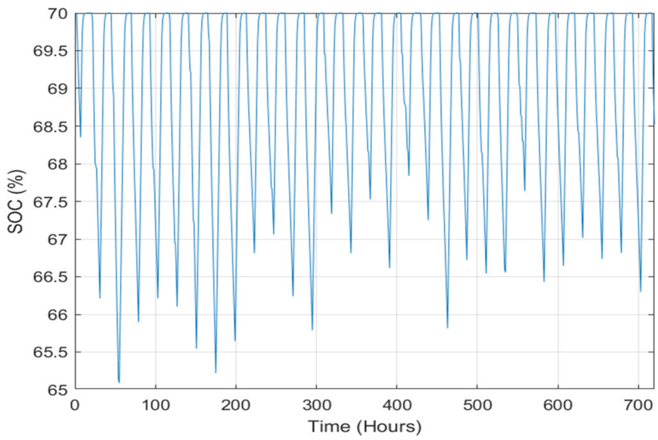

Figure 7. SOC of BESS in 720 hours

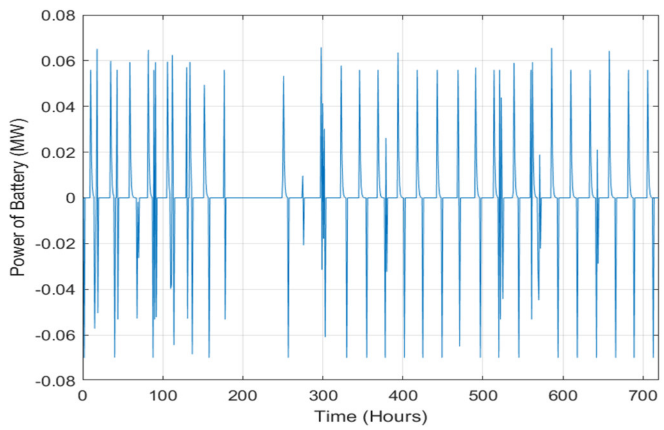

Figure 8. Power of battery in 720 hours

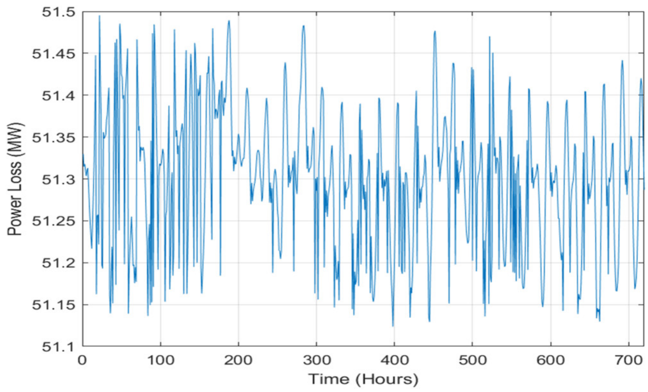

Figure 9. Power loss in 720 hours

5. CONCLUSIONS

On the first hand, this study proposed a method to determine the optimal size of BESS at minimal BESS cost by using a meta-heuristic optimization is PSO in a microgrid with renewable sources to regulate the voltage within an acceptable range and prevent the microgrid from instability and system collapse. The objective function of the method is the minimization of the total cost and optimal size of BESS. The result shows that by setting BESS with the acquired optimal size of BESS, the economic problem can be improved and the voltage of the system does not exceed the boundary as well as decreasing total power losses. Moreover, this study also considered the reliability indices LPSP, LOLE, and LOEE to ensure the result precisely.

On the other hand, a larger grid with more renewable sources in number and type should be considered and carried out over a longer period. The comparison between this optimization and others also needs to be considered to find the more effective and precise algorithm to find the optimal size of BESS.

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THÔNG TIN TÁC GIẢ

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