Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1027-1042
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 15 May 2022

Optimization of the Energy Storage System in ADN, Considering the Energy Storage Operating Strategy and Dynamic Characteristics of the System

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Abstract:

If you want your energy storage system to meet the needs of distributed power supply and active distribution network (ADN) operation, you need to improve the flow battery's dynamic capabilities (BESS). ADN energy storage operations should be implemented to stabilize the system's power fluctuation on this basis. As part of the energy storage configuration model, the dynamic programming algorithm is used to solve the model's decision variables of energy storage installation capacity, power, and installation position in order to maximize the BESS's fixed and operating costs, direct economic benefit, and environmental benefit over the course of the energy's life cycle. On the basis of the case 31 and 72 node instances, as well as the usual daily load and distributed generation output curves, a simulation research is carried out to reach the perfect design result. A tie-line power and dynamic characteristics may also be obtained from a pre-installed energy storage device, as well as after it is installed. Simulated results confirm the accuracy of the model.

***Keywords**: Energy storage system; Optimizing objectives; Dynamic programming algorithm; simulation demonstrate.*

I. INTRODUCTION

With expanding environmental concerns, high-tech energy has seen a surge in interest and implementation. Distributed generation (DG) system connections, on the other hand, have bad for electricity[1]. In the case of the consumption of DG, the concept of the active distribution network (ADN) [2-3] provides a realistic solution [2-3]. Distributed generation (DG), active load (AL), and battery energy storage systems (BESS) may all be integrated into a flexible network framework to create a distribution network that operates at peak efficiency. The BESS [4] may increase power supply capacity and improve grid security, therefore enhancing overall system performance, because of the ability to adjust the grid. The safe and effective operation of the ADN relies on the proper distribution of battery capacity.

Internationally and locally, there has been a surge in recent years in study appropriate. Smoothing the output power variations of wind and photovoltaic generation systems using a BESS using a fuzzy-based discrete Kalman filter method is proposed in [5-6]. An adaptive search algorithm is used to construct an optimization model. Because of this, in [7], we develop an analytical model for ADN network loss costs that takes into account the volatility of power prices, and we then investigate the most effective operational approach for each of these factors individually. Energy storage technology upgrade and development [8] is built with the purpose of achieving the least change in load and node voltage variation. Because it doesn't need any localization to reach the Pareto solution set for location and volume, modified particle swarm optimization may be used. An energy storage model using chance-constrained programming is presented in [9] by Xie et al., which is capable of dealing successfully with [10] the DG volatility, but only takes into consideration the load's volatility , among other things. Reduce power system losses and enhance voltage profiles among other things to increase energy efficiency.

It's also worth noting that none of the models above take into account battery system dynamic characteristics. Including the BESS's dynamic efficiency. When using wind turbine generators to produce alternating current (AC), researchers at Lei et al. [11] set out to figure out the best way to allocate the energy stored in a VRB energy storage system. The dynamic efficiency and long-term viability of VRB are considered in the proposed mathematical framework. Lead ‑ acid batteries have bring convenience to people. The lithium battery, despite there are many advantages is prohibitively expensive. Technology advancements for sodium sulfate batteries are still at an early stage. Due to its high energy efficiencies and multiple cycles as well as its long life, VRB is an excellent choice for distributed generation, peak load slashing and other similar applications. Because of its outstanding overall performance and wide variety of applications, the BESS with all-vanadium flow has received a lot of attention [12]. Moreover, VRB is the most popular and effective. This means that using VRB in energy storage design optimization is an intriguing study area.

As the preceding study shows, the BESS has undergone a significant amount of research in order to operate at its best. To stabilize power system oscillations and take into consideration battery dynamic charge ‑ discharge characteristics, however, is a rare phenomenon. In order to configure and operate , we'll provide a equipment to reducing system power fluctuations. With the aid of the dynamic programming method, set a stable price. The following compares the 31 and 72 samples.

II. THEORETICAL MODELS FOR DYNAMIC BATTERY CHARGING AND DRAINING

2.1 The ability to store energy in some form

The VRB's enormous capacity and power allow it to be designed to function at a variety of rated capacities. The energy economy, response time, number of cycles, and lifespan of this device are all excellent, and it can be set up in a variety of ways depending on the application. As a consequence, we'll put it to use in our system for optimizing energy storage. For batteries, the most important parameter to examine is their state of charge (SOC), which tells us how much power they have stored [13]. Modeling power change system requires taking into consideration its dynamic characteristics. The equation provided below may be used to estimate VRB's SOC in the BESS:

$$\mathrm{SOC}_t = \begin{cases} \mathrm{SOC}_{t-1} - \dfrac{P_{\mathrm{VRB},t}T}{\eta^{\mathrm{d}}E_{\mathrm{VRB}}^{\mathrm{rated}}}, & \text{discharge} \\ \mathrm{SOC}_{t-1} - \dfrac{P_{\mathrm{VRB},t}\eta^{\mathrm{c}}T}{E_{\mathrm{VRB}}^{\mathrm{rated}}}, & \text{charge} \end{cases} \tag{1}$$

Values may be stated in terms of time periods if t is known SOC_t and SOC, T how long are the intervals between them t, and E_{VRB}^{rated} is the amount of power the battery can hold. T how long does each menstruation last. η_c and η_d are, The equations below show the charging and discharging efficiency values derived using (2) and (3).. P_{VRB} calculate the energy storage system's output power over the time period indicated in the equation.

Voltage regulators (VRB) gain efficiency when charging or discharging power rises or falls on a rechargeable battery P_{VRB}.Because the electric energy fluctuates greatly, so VRB plays its role and the SOC, Charge and discharge efficiency of VRB are discussed in [14－16], as well as interact with each other (2) and (3) provide the fitting formulas. Table 1 in the Appendix contains the upshot of the fitting.

$$\eta_{\mathrm{c}} = \frac{(a_{\mathrm{c}}\mathrm{SOC} + b_{\mathrm{c}})P_{\mathrm{VRB}}(\mathrm{pu}) + c_{\mathrm{c}}\mathrm{SOC} + d_{\mathrm{c}}}{P_{\mathrm{VRB}}(\mathrm{pu})} \tag{2}$$

$$\eta_{\mathrm{d}} = \frac{P_{\mathrm{VRB}}(\mathrm{pu})}{a_{\mathrm{d}}P_{\mathrm{VRB}}(\mathrm{pu}) + b_{\mathrm{d}}\mathrm{SOC}(\mathrm{SOC} - 1) + c_{\mathrm{d}}} \tag{3}$$

In this equation, where η_c, η_d VRB's the terms and signify the charge- and discharge-efficiency measurements, respectively. In terms of VRB charging effectiveness, the coefficients a_c, b_c, c_c and d_c are two types , and the other for discharging. Table 1 displays the fitting results for the aforementioned parameters.

TABLE 1: According to equation, the parameters of charge－discharge efficiency may be determined

Parameters				
	a_i	b_i	c_i	d_i
c	-0.14	1.26	0.04	0.12
d	1.14	0.372	0.12	-----

2.3 BESS has a maximum charge-discharge power that isn't very high

By looking at things like when VRB's absorbed power gets too high, you can't let it go over the maximum amount that can be taken in. [14] Tu et al. came up with a model that could be used to figure out how the maximum absorbed power Pab and the surface oxygen concentration SOC were linked:

$$P_{\mathrm{ab}}(\mathrm{pu}) = \begin{cases} a_{\mathrm{ab}}^{\mathrm{c}}\mathrm{SOC}^2 + b_{\mathrm{ab}}^{\mathrm{c}}\mathrm{SOC} + c_{\mathrm{ab}}^{\mathrm{c}}, & \text{charge} \\ a_{\mathrm{ab}}^{\mathrm{d}}\mathrm{SOC}^2 + b_{\mathrm{ab}}^{\mathrm{d}}\mathrm{SOC} + c_{\mathrm{ab}}^{\mathrm{d}}, & \text{discharge} \end{cases} \tag{4}$$

The results of fitting are provided in Table 2, where ab, bb, cb, ab, bb, cb are the fitting coefficients.

TABLE 2 Parameters for calculating the charge–discharge absorption power P_{ab}

	a_{ab}^{i}	b_{ab}^{i}	c_{ab}^{i}
c	0.5715	0.4605	−1.0321
d	0.1686	0.8553	−0.0238

III. GREATEST EFFECTIVE USE OF ENERGY STORAGE RESOURCES WHILE TAKING INTO CONSIDERATION THE FLEXIBILITY OF BATTERY TECHNOLOGY

To simplify understanding, Fig. 1 depicts a two-part index system for energy storage system configuration [17-20]. These are: functionality and economics. Functional indicators include the average power fluctuation rate, peak shaving, valley filling, and valley filling. As well as the initial outlay, BESS has ongoing operating and maintenance expenses as well as environmental advantages. BESS has a wide range of operational strategies that take into consideration the system's optimization goals as well as the many different scenarios in which energy storage systems are put to use. Only seldom does it make sense to represent both the supply and demand sides of a power system at once. With the use of a model of BESS charge and discharge powers, we build a battery storage approach for controlling system power fluctuations and investigate dynamic battery properties.

3.1 Sample data from high-performance computers is pre-processed

In order to reduce the irregular change of electric energy, this paper realizes the irregular change by reducing the electric energy change.

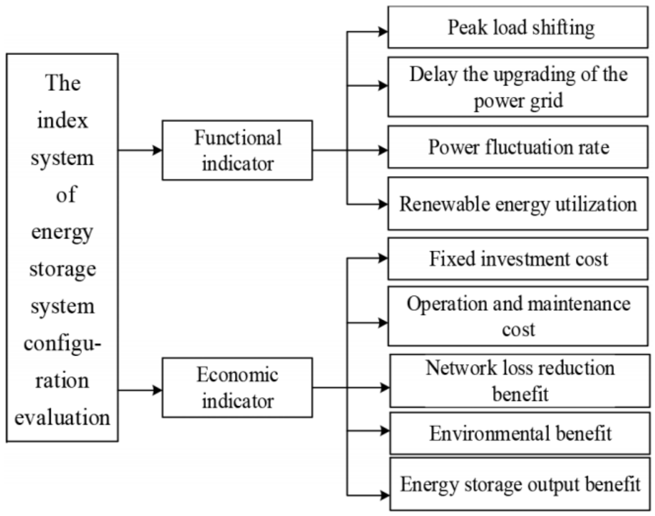

Fig. 1 Evaluating the energy storage system's indexing mechanism is crucial

3.1.1 Due of power fluctuations, there are limitations

With an eye toward reducing system-wide active power fluctuation, the upper power grid's Pt is being regulated such that it is less than a preset range in terms of power fluctuation rate.The energy change formula is as follows [5]:

$$F_t = \frac{\Delta P_t}{P_{\mathrm{grid}}} = \frac{P_{t\max} - P_{t\min}}{P_{\mathrm{grid}}} \tag{5}$$

$$P_t = \sum_{i=1}^{m_1} P_{\mathrm{load},\,i} - P_{\mathrm{DG}} \tag{6}$$

$$P_{\mathrm{DG}} = \sum_{j=1}^{m_2} P_{\mathrm{wind},\,j} + \sum_{k=1}^{m_3} P_{\mathrm{pv},\,k} \tag{7}$$

where P_{grid} is the average power value of grid-connected output, ΔP_t is represents the change in electrical energy over time t, $P_{t\max}$ is represents the maximum change in electrical energy in time t, $P_{t\min}$ is denotes the lowest equivalent load power, and Pt indicates the total equivalent load. Wind power P , which is the total output power generated by new energy. P wind is the output power of fresh energy generated by wind turbines.

The load fluctuation Ft satisfies the following formula and does not exceed the predetermined value F_t^{up}.

$$F_t \le F_t^{\mathrm{up}} \tag{8}$$

3.1.2 Analyses of samples

Maximum and lowest equivalent-load power are determined by power fluctuation constraints for each continuous time period T (assumed to be around 0.5 hours).

$$P_{T\max}(i) = \max\left[P(1:N_{\mathrm{s}})\right] \tag{9}$$

$$P_{T\min}(i) = \min\left[P(1:N_{\mathrm{s}})\right] \tag{10}$$

To determine the number of sampling points, we need a formula where we have two variables: T and Ts. Using the formulae (5)-(8).

It is possible to get the amplitude–frequency characteristics of the Pgrid by transforming it using the Fourier transform, as illustrated in (11). It is sufficient to maintain Pgrid,0 of Pgrid(n) in order to reduce the power fluctuation of ADN.

$$P_{\mathrm{grid},0}(k) = \sum_{n=0}^{N} P_{\mathrm{grid},0}(n)\mathrm{e}^{-\mathrm{j}(2\pi/N)kn},\ k = 0,\ 1,\ \ldots,\ N-1 \tag{11}$$

3.2 Strategic strategy for energy storage operations

Charge and discharge strategies for BESS may be devised in line with operational characteristics of VRB as well as DG and load power characteristics in order to limit power fluctuation at system junctions. Fig. 2 illustrates how this can be done. To maintain Pgrid,0 constant, the analysis in Section 3.1 demonstrates that the quantity of power obtained from the higher power grid must be kept within a specified range.

(i) Battery depletion occurs when the AND power Pt is less than Pgrid,0 at time t. This means that the battery has to be recharged before it is able to be utilized again.

$$P_{\mathrm{VRB},t} < 0 \quad \text{when } P_t < P_{\mathrm{grid},0} \tag{12}$$

(ii) For as long as the AND power Pt is greater than Pgrid0, then the battery's charge requirement is satisfied and it may be used.

$$P_{\mathrm{VRB},t} > 0 \quad \text{when } P_t > P_{\mathrm{grid},0} \tag{13}$$

(iii) When it comes to BESS charging and discharging capacities, certain formulae must be followed:

$$P_{\mathrm{VRB}}(t)=\begin{cases}\eta_{\mathrm{VRB}}P_{\mathrm{ab}}(\mathrm{pu})P_{\mathrm{VRB}}^{\mathrm{rated}}, & |P_{\mathrm{cx}}|>\eta_{\mathrm{VRB}}P_{\mathrm{ab}}(\mathrm{pu})P_{\mathrm{VRB}}^{\mathrm{rated}}\\ P_{\mathrm{cx}}, & |P_{\mathrm{cx}}|\le\eta_{\mathrm{VRB}}P_{\mathrm{ab}}(\mathrm{pu})P_{\mathrm{VRB}}^{\mathrm{rated}}\end{cases} \tag{14}$$

$$P_{\mathrm{cx}}=P_t-P_{\mathrm{grid},\,0} \tag{15}$$

In this equation, $P_{VRB}(t)$ represents the BESS's Indicates the actual power situation, η_{VRB} represents its efficiency, and P_{VRB}^{rated} is the BESS's rated . P_{cx} take the compensation power value.

Using this operating strategy, the BESS might lessen its reliance on the higher power grid while still releasing stored energy to meet demand, according to the company.

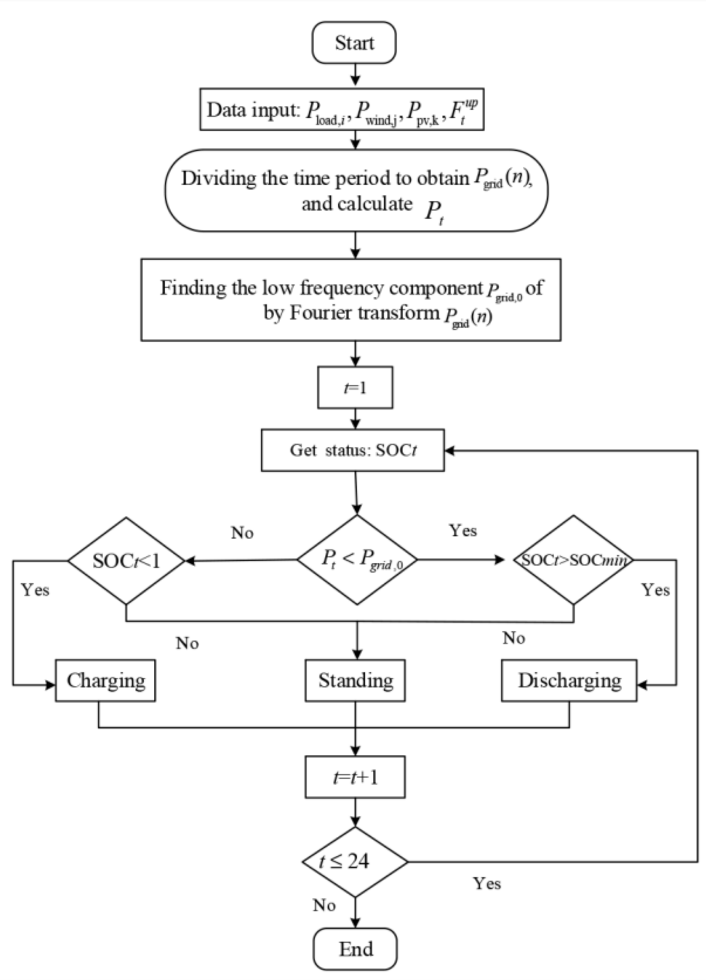

Fig. 2 a plan for the VRB battery system's optimal operation

3.3 Optimization of a certain function's performance

It is possible to determine the optimal BESS design based on the economic indicators available in the BESS's economic indicators.

A fixed investment and operational cost are two of the four components that make up the C_{tol}, B_{dir}, B_{env} from BESS and the B_{loss}.

The fixed investment costs and running costs comprise the first three components of the objective function F presented in this chapter C_{tol} , B_{dir}, B_{env} B_{loss}.

$$F(P_{\text{VRB}}^{\text{rated}}, E_{\text{VRB}}^{\text{rated}}, \boldsymbol{x}) = B_{\text{dir}} + B_{\text{env}} + B_{\text{loss}} - C_{\text{tol}} \tag{16}$$

P_{VRB}^{rated} and E_{VRB}^{rated} are the decision vectors for the VRB energy storage system. For the purpose of calculating the F, the calculation formulae for C_{tol}, B_{dir}, B_{env} and B_{loss} must be built individually.

3.4 Constraints on energy storage devices' functioning

As part of this research, we have defined the following conditions for the energy storage model's performance, which are described in this article.

(i) As indicated in the equation below, the BESS's maximum and minimum rated capacities are as follows:

$$\begin{cases} P_{\text{VRB}}^{\text{rated, min}} \le P_{\text{VRB}}^{\text{rated}} \le P_{\text{VRB}}^{\text{rated, max}} \\ E_{\text{VRB}}^{\text{rated, min}} \le E_{\text{VRB}}^{\text{rated}} \le E_{\text{VRB}}^{\text{rated, max}} \end{cases} \tag{17}$$

Because of this, lowering the decision vector energy storage system's rated power and capacity limitations is a simple but effective solution.

(ii) Below is an equation that depicts the voltage restriction at the node:

$$U_{\min} \le U_i \le U_{\max} \tag{18}$$

(iii) For emergency load distribution, the BESS must have a certain margin. There must be an answer to the following equation:

$$SOC_{\min} \le SOC_{VRB} \le SOC_{\max} \tag{19}$$

IV. A DYNAMIC PROGRAMMING APPROACH FOR IMPROVING THE DESIGN OF ENERGY STORAGE SYSTEMS

Section 3 shows the optimized configuration model of the VRB energy storage system, which has fewer options and more limitations, making it simpler to solve mathematically. Local optimal solutions are used to establish the ultimate optimisation result and the best option is selected. As a consequence, dynamic programming should be used to solve this issue[21- 23].

As shown in Figure 3, a dynamic programming approach to optimizing BESS design may be seen in action.

Because of this, while solving the BESS optimization configuration model using a dynamic programming technique, the values of incremental E and P are highly important in order to choose the values of incremental E and P reasonably. In this study, it is suggested that the issue of calculating quantity and accuracy be investigated thoroughly and that a problem with moderate E and P values be picked.

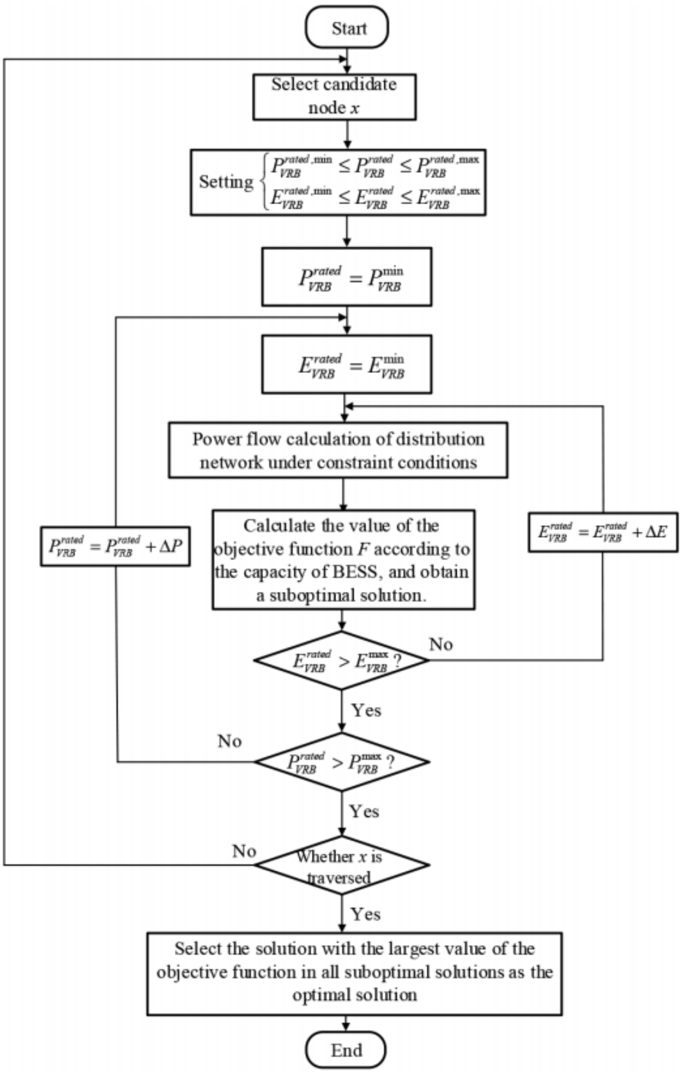

Fig. 3 The best configuration of BESS is solved using a dynamic programming approach

V. AN INVESTIGATION OF A SPECIFIC ISSUE

In this study, the use of DGs and BESS is used in order to analyze and enhance cases 42 and 57. There are nodes 9, 14, 18, 21 and 31 in instance 32 where DG systems like solar panels and wind turbines are erected; in case 72, nodes 9, 26, 31, 49 and 68 where DG systems like solar panels and wind turbines are installed. For the sake of this research, each node is given the same proportion of DG capacity.

To demonstrate the impact of adding energy storage at node 15, we've included Case 31 in Fig. 4.

As can be observed in the graph in Fig. 4, the system's tie line's power significantly varies, as can be seen. DG output and load have an unbalanced relationship, and there is a wide range of change between the two. For example, in instance 31, the overall system fluctuations were 29.13 percent before BESS

Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 15 May 2022

was installed, and the system fluctuations were reduced to 19.48 percent after BESS was installed. In the simulation, this was shown to be true. In general, it's critical to think about how energy storage technology reacts.

This is followed by an investigation of the influence of BESS dynamic characteristics on the functioning of an energy storage device access node 15. The charging and discharging efficiency is assumed to be a constant of 0.8 in both directions without taking into consideration the dynamic aspects of energy storage devices. The charging and discharging power is only relevant to the SOC when it is necessary to compensate. The following are the results of the optimization: PN is 250 kW, whereas EN is 1061 kWh. Figures 5－7 show the output curve, the SOC curve, and the efficiency curve for the energy storage system in case 31 before and after the dynamic elements of the BESS were included.

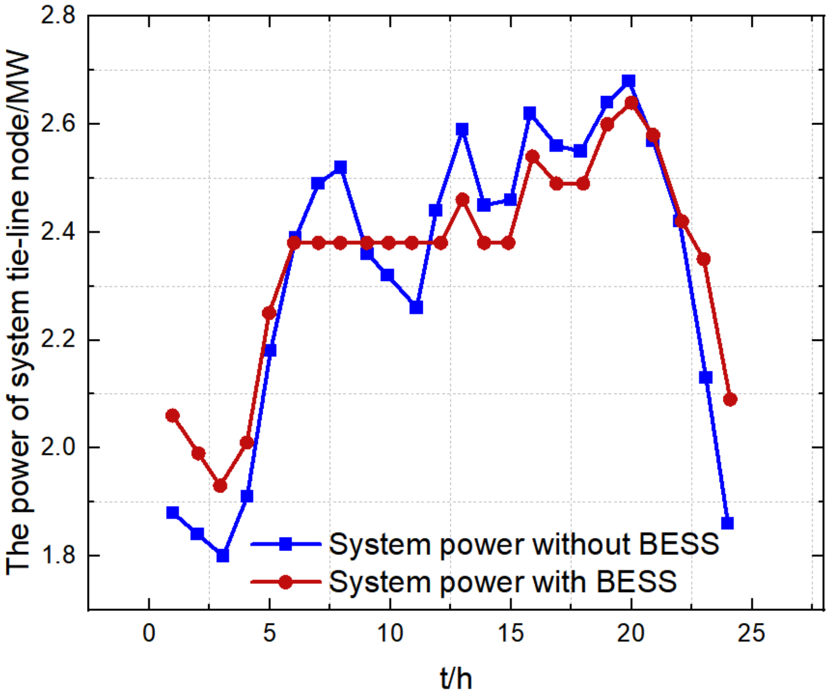

Fig. 4 Power measurements were taken before and after BESS was installed on a system tie-line node in instance 31

Optimal energy storage allocation without taking into consideration the dynamic aspects of BESS yields better results, as shown by the operation's outcomes and figures 5－7 (see below). Operation results are shown in Figure 5. There will be no limitations on charging and discharging power owing to the SOC or the maximum charges or discharges permitted by the battery. In other words, the simulation's outcome is greater when including both charging and discharging power, which is at odds with how the VRB energy storage system really works. The VRB model's completeness and accuracy may be better depicted in simulations if dynamic charging and discharging elements are taken into consideration.

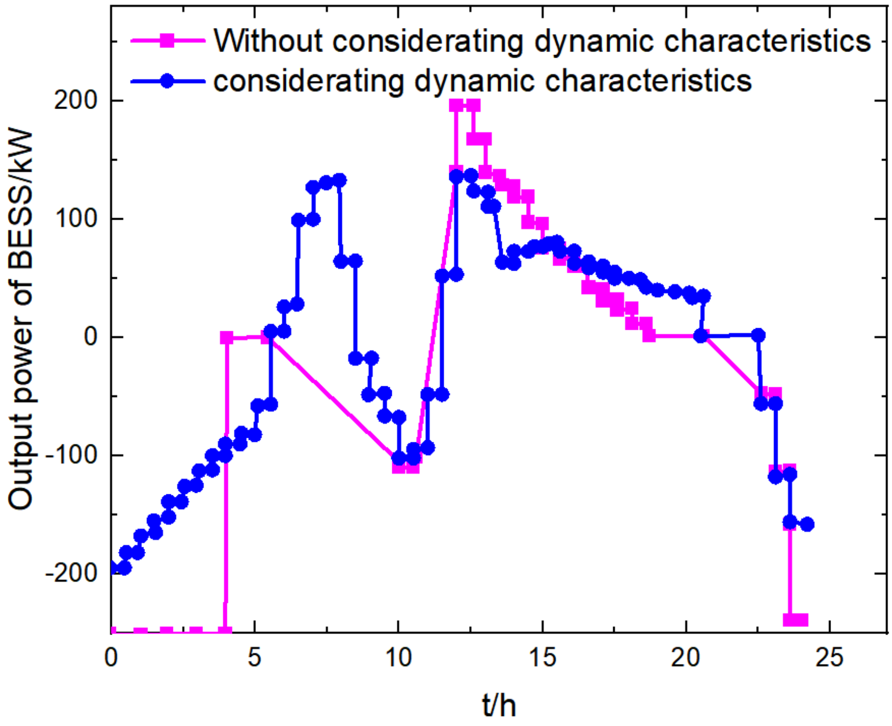

Fig. 5 In instance 31, the output curve of BESS was shown before and after taking into account dynamic features

Instance 72's optimal node allocation may also be determined using the dynamic programming technique, which is identical to the prior scenario. In this node, nodes 8, 25, 31, 51, and 65 earned the highest total revenue F total from the optimization results. In terms of overall revenue, the highest-ranking branch has the greatest total income, the highest-ranking branch.

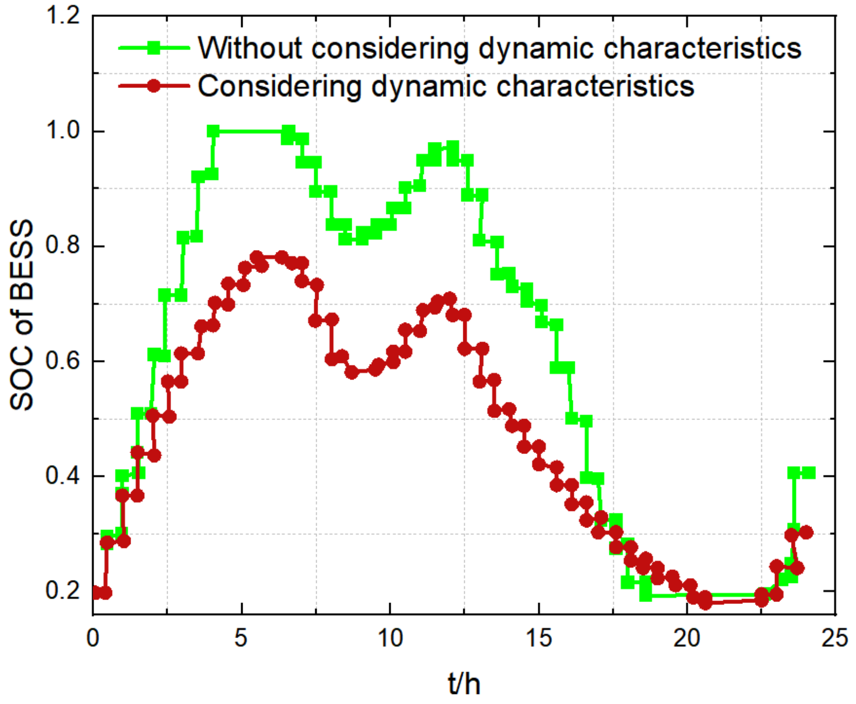

Fig. 6 Case 31 shows the SOC curve of BESS before and after taking into account dynamic features

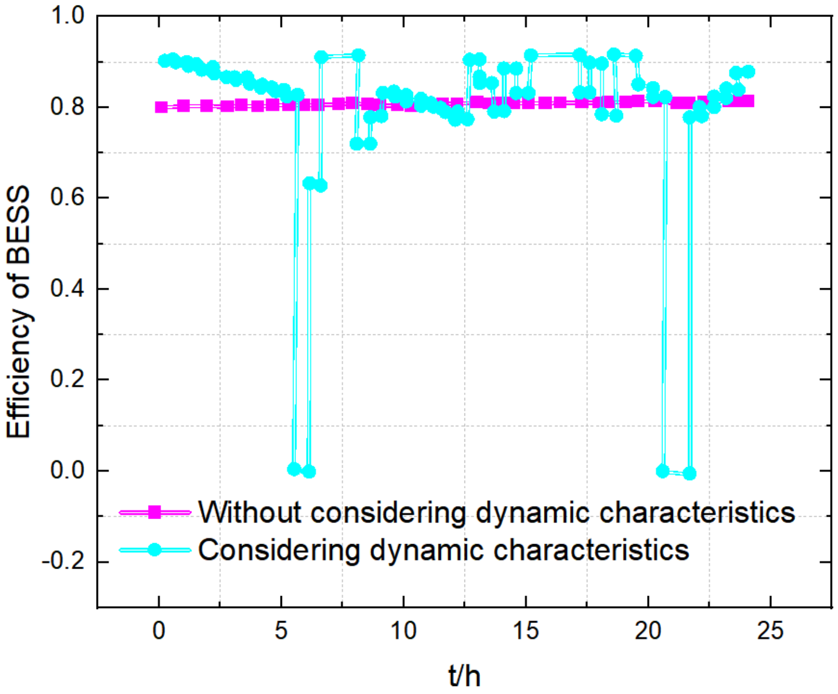

Fig. 7 In Case 31, the efficiency curve of BESS was shown before and after taking into account dynamic features

Figure 8 shows the changes before and after energy storage.After installing BESS, it can be seen in Figure 8 that, prior to BESS installation, the case 72 node system's connection line had more power than that of the case 31, and there was low power line fluctuation in the system after BESS. Total fluctuation rate before and after installing BESS were both determined using this method: The load fluctuation rate before and after installing BESS were used to calculate these rates in a computer simulation. This is heavily influenced by the overall attitude to energy storage technology.

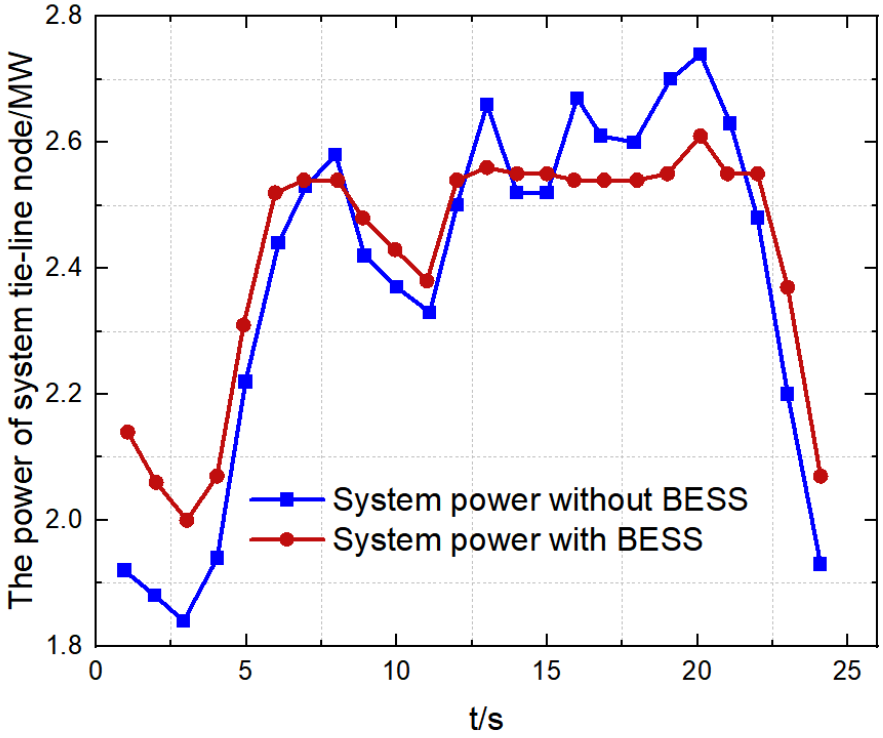

Figure 8 depicts the system tie-line node's pre-BESS and post-BESS power levels in case 72

VI. CONCLUSION

Research in this study examines the impact of energy storage operation strategy and dynamic features on the BESS setup and operation in a distributed generation network (DG). There is also an allocation model for the BESS's energy storage that takes into account the BESS's life cycle costs, operating costs (including capital expenditures), direct economic benefits (such as job creation), and environmental benefits (such as reduced greenhouse gas emissions). After running simulations in examples 33 and 72, the following findings are obtained:

(1) An energy storage allocation strategy that maximizes economic benefits while requiring little investment and ongoing maintenance is possible.

(2) The BESS, load, and generator may be coordinated to reduce power fluctuation on the connection line, which indicates that the energy storage approach can play a role in decreasing the power

fluctuation on the connection line.

(3) The VRB model is more accurate when the dynamic aspects of energy storage operations are taken into account.

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