Optimization configuration and operation strategy of energy storage for microgrid considering external power transmission

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Abstract. In the context of the evolving power system landscape, the proliferation of microgrid systems anchored on large-scale new energy generator sets is advancing rapidly. Nonetheless, the inherent instability of new energy generation introduces substantial unpredictability into the power transmission process, thereby escalating the challenges in power system dispatch and elevating transmission costs. To address these issues, optimizing energy storage configurations emerges as a pivotal strategy, capable of effectively mitigating the fluctuations in new energy output, bolstering the stability and reliability of external power supplies, curbing transmission expenses, and enhancing the economic feasibility of new energy power generation.This paper endeavors to devise an optimal energy storage allocation framework for microgrids, aiming to maximize transmission efficiency. An objective function tailored to this pursuit is formulated, followed by the construction of constraints that encompass system power balance, as well as the safe operational prerequisites of generators, new energy sources, energy storage units, and other integral equipment. Subsequently, a comprehensive optimal energy storage allocation model tailored specifically for microgrids is formulated.To validate and demonstrate the efficacy of this model, a simulation testbed leveraging MATLAB is established, incorporating real-world data from a designated locale. This platform facilitates the realization of optimal energy storage configuration and scheduling within the microgrid. The optimized configuration outcomes indicate a rated power capacity of 113kW and a rated energy capacity of 169kWh. This proposed model not only underscores a tangible enhancement in the economic viability of microgrids but also presents a viable blueprint for optimizing energy storage configuration and operational scheduling strategies within microgrids.

Keywords: Microgrid, new energy, optimal configuration, operation strategy.

1. Introduction

As a new energy system, the new energy microgrid system has the advantages of rich resources, local utilization, pollution-free, wide distribution, low cost, and easy maintenance of distributed energy system, and at the same time uses energy storage technology to avoid the shortcomings of randomness and volatility of distributed energy output, and can achieve stable, economical and reliable output. New energy power stations considering the power transmission can effectively reduce the waste of energy by sending surplus power to meet the needs of local users. The optimal configuration and operation scheduling strategy of energy storage in microgrid directly affect the operation efficiency of the system, so it is urgent to study the energy storage configuration and scheduling strategy of new energy microgrid.

Zhao put forward a hybrid energy capacity allocation approach that incorporates the bidirectional demand of wind power and users, and developed an optimization model aimed at minimizing hybrid energy storage system's (hybrid energy storage system, HESS) cost, reducing curtailment rate, and ensuring power satisfaction [1]. Chen introduced an optimized model for distributed energy storage capacity in a microgrid utilizing an improved whale algorithm, which can achieve optimal allocation through constrained planning, and this model has effectively demonstrated its capability in allocating energy storage capacity within the tested microgrid [2]. With consideration of the power interaction between the DC transmission system and the upstream grid, Zhao devised an optimization method that takes into account the HESS capabilities, and the findings reveal that this proposed HESS configuration method can significantly mitigate fluctuations in the contact line and bolster system stability, as evidenced by a case study on the enhanced IEEE-14-node DC distribution network [3]. To minimize overall power generation costs, curb frequent charging and discharging state changes in the energy storage system, mitigate thermal power fluctuations, and adhere to system operation constraints, Wang presented a convex optimization technique for the coordinated scheduling of thermal, wind, and solar energy storage systems, enabling coordinated optimal day-ahead scheduling in a thermal-wind-solar hybrid power system integrated with an energy storage system (energy storage system, ESS) [4]. Verma crafted and chose an optimal microgrid (microgrid, MG) rooted in renewable energy systems tailored for rural India's power system. Introducing a novel pheasant bird optimization algorithm (pheasant bird optimization algorithm, PBOA), he demonstrated its superiority in convergence time and iteration speed over PSO, ACO, GA, and CSA algorithms. This advancement offers policymakers and investors invaluable insights for deploying MG systems in rural regions [5]. Addressing the resource wastage stemming from the chaotic interplay between prosumer charging-discharging activities and microgrid energy interactions, Li proposed a game theory-based MG optimization scheduling strategy. This strategy facilitates orderly ES charging and discharging, leveraging the complementary nature of prosumer ES utilization and energy generation. Additionally, it optimizes energy scheduling among constituent units, minimizing overall costs [6]. Liang F presented a stochastic optimal scheduling approach for the wind-solar-storage-hydrogen-water system within independent island zero-carbon microgrids. This strategy effectively mitigates wind power scenario uncertainties and reduces system operating costs [7]. To optimize the scale of hybrid solar-wind microgrids interconnected with Chile's main grid, Merino harnessed genetic algorithms, considering local meteorological conditions, aggregate loads, and Chilean electrical regulations, to determine the optimal PV module and wind turbine counts [8]. To efficiently incorporate flexible resources in the optimal scheduling process of multi-energy microgrids, Xinyu X augmented the optimal scheduling problem with an analysis of flexible resource aggregation. This was followed by the validation of the effectiveness of the aggregation model and control algorithm through numerical illustrations, ultimately enhancing the efficiency and precision of multi-energy microgrid control [9]. Furthermore, addressing the challenge of computational optimization in distributed microgrids, Fan introduced a blend of chaos mechanism, differential evolution, and random inertia weights, thereby refining the conventional PSO algorithm and formulating a mathematical model aimed at minimizing the operational costs of microgrids [10].

This paper introduces an energy storage optimization system tailored for new energy power stations, accounting for transmission power dynamics. By optimizing energy storage arrangements, the system captures surplus energy during new energy troughs and discharges it during peaks, mitigating output fluctuations and bolstering transmission stability and reliability. Furthermore, optimal storage configurations amplify transmission channel efficiency, decrease costs, and bolster the economic viability of new energy power. We construct an objective function tailored to transmission-aware energy storage optimization and establish constraints that ensure system operational safety. Utilizing this framework, we formulate an optimization model. Lastly, we apply the model to real-world data from a specific locale, achieving optimal configurations for new energy power stations.

2. Structure of a new energy microgrid

Microgrid can not only enhance the efficiency of renewable energy utilization, but also ensure the stability of the power system through flexible regulation, making them crucial for energy structure transformation. The microgrid configuration analyzed in this paper is illustrated in Figure 1. In the figure, Wind is a wind turbine, Solar is a photovoltaic unit, Gen is a thermal power generator, E_s is an energy storage unit, Local is a local load, and Ps is the power transmitted by the microgrid.

Wind power generation in areas with high wind speeds and photovoltaic modules on the roofs of buildings form a renewable clean energy system. In addition, diesel generators are used to supplement the indirectness and uncertainty of renewable energy.To balance power supply and demand and improve system stability, the microgrid is equipped with a battery pack to act as an energy storage device. In addition to meeting the local load requirements, any excess energy is fed into the grid and transmitted externally.

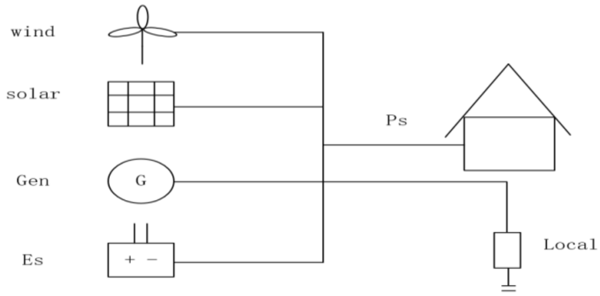

Figure 1. Microgrid Architecture.

3. Energy storage optimization configuration and scheduling model of microgrid considering the export power

This section establishes an objective function to optimize the configuration and dispatch of energy storage within a new energy microgrid system, aiming to maximize export power. Constraints are then formulated, considering factors such as system power balance and safety operation requirements for generators, new energy sources, and energy storage equipment. Based on this, an energy storage optimization and dispatch model for the microgrid is developed, with a focus on maximizing export power.

3.1. Objective function

The objective function for energy storage capacity configuration in a microgrid with an energy storage system aims to maximize the daily output power transmission while minimizing the daily operation cost. This operation cost encompasses the costs associated with wind, solar, heat generation, and energy storage operations. It also includes the daily cost of building and maintaining the energy storage facilities, which is equivalent to the annual cost distributed over a daily basis.

3.1.1. Operation cost

The operation cost of the microgrid primarily consists of three components: the operation costs of the generator, wind power, and solar power. The daily operation cost of the generator can be represented by formula (1).

$$C_g = \sum_{t=1}^{24}\left(P_g(t) * C_{g1}\right) \tag{1}$$

Where $P_g(t)$ represents the generator's output power during period *t*, C_{g1} represents the operation cost per unit of generator power.

The operation cost of wind power in period *t* is determined by multiplying the difference between generated power and abandoned wind power by the operation cost per unit of wind power. Consequently, the daily operation cost of wind power can be represented by formula (2).

$$C_{wind} = \sum_{t=1}^{24}\left(\left(P_{w\_g}(t) - P_{w\_c}(t)\right)C_{w1}\right) \tag{2}$$

Where $P_{w\_g}(t)$ represents the wind power generation in period *t*, $P_{w\_c}(t)$ represents the abandoned wind power in period *t*, C_{w1} represents the operation cost per unit of wind power.

The operation cost of solar power in period *t* is determined by multiplying the difference between generated power and abandoned solar power by the operation cost per unit of solar power. Consequently, the daily operation cost of solar power can be represented by formula (3).

$$C_{solar}=\sum_{t=1}^{24}\left(\left(P_{s\_g}(t)-P_{s\_c}(t)\right)C_{s1}\right) \tag{3}$$

Where $P_{s\_g}(t)$ is the solar power generating power in period *t*, $P_{s\_c}(t)$ is the abandoned power of solar power in period *t*, C_{s1} is the operation cost per unit of solar power.

3.1.2. Construction cost of energy storage

The construction cost of energy storage mainly comprises two components: the investment cost for constructing the energy storage power plant and the investment cost for building energy storage capacity. The annual cost of energy storage construction is distributed evenly across each day of the year, resulting in the daily construction cost of energy storage, which can be represented by formula (4).

$$G_3=\frac{\left(c_{p\_es}P_{es}+c_{s\_es}S_{es}\right)}{365} \tag{4}$$

Where P_{es} the rated power of the energy storage is, S_{es} is the rated capacity of the energy storage, c_{p_es} is the construction cost per unit of power, c_{s_es} and is the construction cost per unit of capacity.

By integrating operation cost and energy storage construction cost, formula (5) can be used to represent the total cost of a day of new energy microgrid.

$$C=C_g+C_{wind}+C_{solar}+G_3 \tag{5}$$

Based on this, a multi-objective optimization function, as shown in aormula (7), is formulated. This function incorporates the daily output power of the new energy power station, represented by formula (6), and combines weighting variables and to minimize operation cost and maximize output power.

$$S_{song}=\sum_{t=1}^{24}P_{song}(t) \tag{6}$$

Where $P_{song}(t)$ is the output power of the microgrid in period *t*

$$Min \quad b_1C-b_2S_{song} \tag{7}$$

3.2. Constraint condition

The constraints of the microgrid primarily encompass four aspects: power balance constraint, generator constraint, wind and solar power constraint, and energy storage constraint.

3.2.1. Power balance constraint

By defining $P_l(t)$ as the load power, the power balance constraint can be expressed as fomula (8). Specifically, each term in the power balance equation represents the corresponding power of the new energy microgrid for each period of the day. The sum of $P_l(t)$ and $P_{song}(t)$ represents the output power of the microgrid, $\left(P_{es\_d}(t)-P_{es\_c}(t)\right)$ represents the difference between the charging power and discharge power of the energy storage facility, that is, the output net power of the energy storage; $\left(P_{w\_g}(t)-P_{w\_c}(t)\right)$ represents the difference between the power generated by wind power units and the power abandoned by wind power, signifying the actual power utilized by wind power; $\left(P_{s\_g}(t)-P_{s\_c}(t)\right)$ represents the difference between the generation power of the solar unit and the abandoned solar power, indicating the actual power utilized by solar power generation.

$$\begin{aligned} P_l(t)+P_{song}(t) = P_g(t) &+\left(P_{es\_d}(t)-P_{es\_c}(t)\right) \\ &+\left(P_{w\_g}(t)-P_{w\_c}(t)\right) \\ &+\left(P_{s\_g}(t)-P_{s\_c}(t)\right), \forall t \end{aligned} \tag{8}$$

3.2.2. Generator constraint

Defining $P_{g\_\min}$ as the minimum output power of the generator and $P_{g\_\max}$ as the maximum output power of the generator, constraint condition (9) is derived, considering the maximum and minimum limits of the generator's output power.

$$P_{g\_\min} < P_g(t) < P_{g\_\max} \tag{9}$$

Additionally, to ensure the safe operation of the generator and maintain microgrid stability, the generator's ramp rate constraint must be considered. This constraint limits the rate of change in the generator's output power and can be represented by formula (10).

$$\left|P_g(t) - P_g(t+1)\right| < P_{g\_p} \tag{10}$$

Where $P_g(t)$ and $P_g(t+1)$ are the output powers of the generator in the *t* and *t*+1 period, respectively, P_{g_p} is the climbing power of the generator.

3.2.3. Wind and solar power constraint

In any given period, the abandoned power of wind power or solar power generation must be less than the power generation, and this constraint can be represented by fomula (11) and fomula (12).

$$P_{w\_c}(t) < P_{w\_g}(t) \tag{11}$$

$$P_{s\_c}(t) < P_{s\_g}(t) \tag{12}$$

3.2.4. Energy storage constraint

Constraints on the energy storage facility primarily encompass capacity constraint, output power constraint, and state of charge (SOC) constraint. The energy storage facility's capacity has a maximum limit, which can be represented by formula (13).

$$C_{es}(t) < C_{es\_\max} \tag{13}$$

Where $C_{es}(t)$ represents the capacity of the energy storage facility in the new energy power microgrid, $C_{es\_\max}$ represents the maximum permissible capacity of the energy storage.

As the energy storage facility's charging and discharging power have both maximum and minimum limits, the output power constraint can be represented by formula (14).

$$P_{es\_\min} < P_{es}(t) < P_{es\_\max} \tag{14}$$

Where $P_{es\_\min}$ represents the lower limit of charge and discharge power of the energy storage, $P_{es\_\max}$ represents the lower limit of charge and discharge power of the energy storage.

The SOC variation rule of the energy storage unit can be represented by fomula (15).

$$\begin{cases} SOC(t) = SOC(t-1) - \dfrac{P_{es\_d}(t)}{P_{sb} \times \eta_{sb}} \times 100\% \\ SOC(t) = SOC(t-1) + \dfrac{P_{es\_c}(t) \times \eta_{sb}}{P_{sb}} \times 100\% \end{cases} \tag{15}$$

Where $SOC(t)$ and $SOC(t-1)$ are the charging states of the battery in *t* and *t-1* periods, respectively, $P_{es\_c}(t)$ and $P_{es\_d}(t)$ are the charging and discharging amount of the battery in *t* period, respectively, P_{sb} represents the capacity of the energy storage facility, η_{sb} represents the conversion efficiency of charge and discharge.

The lower limit of SOC is defined as $SOC_{\min}$, and the upper limit of SOC is defined as $SOC_{\max}$. To ensure the efficient and stable operation of the energy storage facility, the SOC constraint, shown in Formula (16), is introduced.

$$SOC_{\min} \le SOC(t) \le SOC_{\max} \tag{16}$$

4. Simulation analysis

4.1. Model parameter

Define the price per kW of the generator as C_{g1}, the price per kW of wind power is C_{w1}, the price per kW of photovoltaic power generation is C_{s1}. They are taken as 1, 0.5, and 0.4. Energy storage construction costs c_{p_es} =800, c_{s_es}=1800. Use of parameters: b_1=1, b_2=1. Adoption of constraint parameters: $P_{g\_\min}$ =0 kW, $P_{g\_\max}$ =300 kW. P_{g_p} Is the climbing power of the generator, Combined with generator rating 300 kW, it can be taken as 30kW. The upper limit of energy storage capacity $C_{es\_\max}$ is 500 kWh. The absolute value of $P_{es\_\max}$ is 300 kW. $SOC_{\min}$ =0.1, $SOC_{\max}$ =0.9. The data for wind power and PV used in this paper come from measured data at one location.

4.2. Analysis of the simulation results

Simulation in MATLAB shows that the optimized energy storage rated power is 113kW, and the optimized energy storage capacity is 169kWh. Figure 2 shows the typical daily scheduling obtained from the optimization. During each time period, the system's power consumption can be balanced with the output power of the power generation unit. The total outgoing power of the new energy microgrid in a day is 4882.6436kW. At *t*=13h, the maximum output power of PV is 720kW, exceeding the local load demand, resulting in approximately 620 kW being exported from the microgrid at that time. In the time period from *t*=9h to *t*=16h, the output power of the power generation unit is significantly higher than that of other time periods thanks to the PV power generation. The thermal generators steadily take up a part of the load in all time periods. The wind generation does not vary much with time.

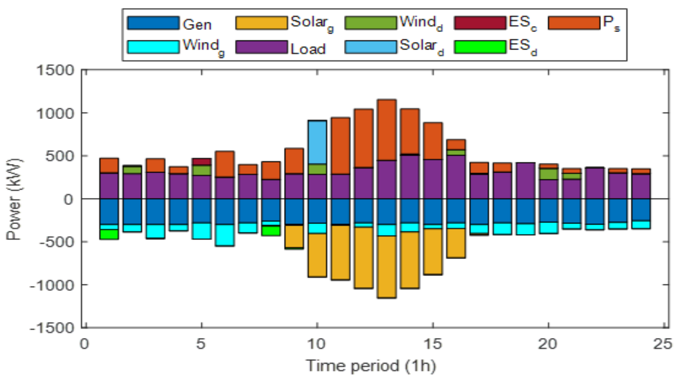

Figure 2. Typical daily scheduling situation.

Figure 3 illustrates the consumption of wind power and PV. The figure shows that, in a day, overall, the consumption rate of wind power and PV is high, and there are only a few moments of the phenomenon of wind and light abandonment, which indicates that the proposed strategy effectively enhances the utilization of renewable energy within the system, reduce the abandonment of wind and light, improve the comprehensive operational efficiency of the system, and help to reduce carbon emissions.

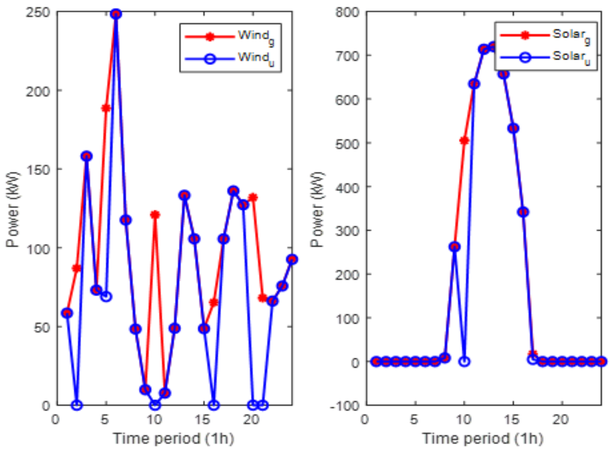

Figure 3. Photovoltaic and wind power utilization.

Meanwhile, the variation of energy storage SOC in a typical day is shown in Figure 4. Due to the instability of the new energy source, the energy storage system is constantly charging and discharging to smooth out the new energy system. Throughout the process, the SOC of the energy storage unit is between 0.1 and 0.9, i.e., it is able to satisfy the set SOC constraints.

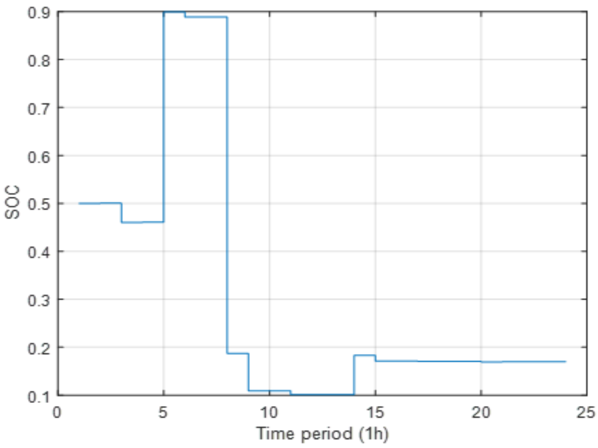

Figure 4. Typical daily energy storage SOC changes.

5. Conclusions

In this paper, a microgrid with wind power, photovoltaic (PV), thermal generator and energy storage system is designed to meet the demand of local loads and power transmission. The simulation environment is built based on MATLAB, and the strategy is simulated under typical day conditions. The optimized rated power of the energy storage is 113kW, the optimized rated capacity of the energy storage is 169kWh, and the export power in a day is 4882.6436kW. This strategy effectively balances supply and demand while optimizing power efficiency.

Future work will consider the effects caused by wind and light uncertainties such as grid frequency and voltage instability due to power fluctuations, pressure on power peaking from uncertain generation, etc. through data augmentation, regularization techniques, and adversarial training techniques.

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