Planning method for joint operation of integrated energy storage system considering reliability

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Abstract: A joint operation planning method for integrated energy storage systems considering reliability is proposed. Firstly, the planning of the power exchange level of the energy storage system is achieved by calculating the optimal power exchange level of the supercapacitor, constructing a model for the optimal configuration of the two-layer energy storage, and using an algorithm for the solution of the model to optimise it. In the experiments, the joint operation planning performance of the proposed method is verified. The experimental results show that the model prediction accuracy is high when the proposed method is used for the joint planning of the integrated energy storage system, and has a more satisfactory joint operation planning performance.

1. Introduction

Integrated Energy Systems (IES) break through the barriers of separate management of traditional energy systems and realise the unified dispatch of multiple energy sources such as electricity, gas, cooling and heat, which can effectively improve the dispatchability confidence level of wind power, thus increasing the economic operation benefits of the system[1].To optimize the operation strategy of the energy storage system in IES, the synergistic operation of other devices and energy storage must be considered.There are some intuitive drawbacks to the phase change energy storage - supercapacitor composite energy storage system[2] . From the perspective of game, the user load model, user benefit model, and operator revenue and cost model can be constructed. The operator as the dominant player in the game is responsible for regulating the energy supply price, while the user as the follower regulates its own energy demand according to the supplier price, and achieves a balanced distribution of benefits through the game between the operator and the user; for the game problem of capacity side, system and user benefits, the The first stage of the model is to optimize the operation of the system, using the price to mobilize users to respond to the economic optimization of the system, while the second stage is to optimize the interests of the capacity side and the users, using the method of contractual incentives to build the model of the interests of the users and the capacity side, and the balance of interests between the subjects is realized by the method of coalition game to realize the joint optimization of three different subjects.[3]After the configuration of energy storage system in IES, the energy storage system can store energy when IES has excess energy and release energy when there is energy shortage by storing and releasing energy, which effectively enhances the system flexibility and thus improves the operational efficiency of the system. The optimal operation of IES needs to meet the balance of energy supply and demand, from this perspective, based on multi-energy coupling and energy supply and demand balance, an optimal configuration model of energy storage can be established to make the supply and demand of IES more stable. Based on this, various energy storage systems can be established for the whole life cycle of IES to improve the operational efficiency of the system. By establishing a technology acceptance model to measure users' willingness to use demand-side response technology for EVs, the configuration capacity of energy storage can be optimized based on the EV load demand response; the use of electricity-to-gas technology can effectively improve the flexibility of system operation, and considering electricity-to-gas technology in IES to configure energy storage systems can make the configuration scheme more in line with the system demand, through IES The use of electric-to-gas technology in IES can effectively improve the system operation efficiency[4] .

2. Planning of power exchange level of integrated energy storage system considering reliability

The energy storage and release processes of phase change energy storage systems can be decoupled and controlled, therefore, when combined with

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supercapacitors, phase change energy storage systems can switch between energy storage and power generation at will, with a much higher degree of freedom than battery storage and pumped storage[5] . This section will match the two based on the characteristics of various energy storage types and the characteristics of the integrated energy storage system. The physical energy storage technology characteristics of the integrated energy storage system are shown below.

(1) The scale of phase change energy storage is comparable to that of battery storage and is suitable for deployment at the outlet of wind farms; the power exchange level of phase change energy storage is low and should be considered in engineering practice for parallel operation of multiple machines to match the power regulation of large-capacity wind turbines; the control accuracy and response speed of phase change energy storage are at an intermediate level, and if a composite energy storage system is formed with power-type energy storage of appropriate capacity, the power tracking and regulation capability can easily be Significant improvement [6] .

(2) compressed air energy storage compressed air storage compressed air and stored in the low load hours, when the power system into the peak load hours, and then release the compressed air to push the turbine power generation, is another very potential large-scale energy storage system after the pumped storage power plant. Due to high technical maturity, its energy storage cost is only 3 000-5000 yuan / kW; and long life, through maintenance can reach 40-50 years; large capacity, single capacity in 100-300 MW, small can also do 10 MW[7]. However, the start-up time is slow, about 5-10 minutes, slower than the response time of batteries, capacitors, flywheel energy storage, etc. Small compressed air energy storage is the storage of air into the ground and a smaller capacity container, which is still immature and has low conversion efficiency and high technical costs.

(3) Flywheel energy storage Flywheel energy storage refers to the use of electric motors to drive the flywheel to rotate at high speed, and then use the flywheel to drive the generator to generate electricity when needed.In recent years, its research has focused on superconducting magnetic levitation technology to reduce losses, and composite technology to improve energy density and reduce the size and weight of the system. Flywheel energy storage is suitable for short time (such as less than 1 min) rapid energy storage and release, at present, there are cases of comprehensive energy storage system using flywheel energy storage to assist lead-acid battery to calm the new energy volatility. However, if in a longer time range, flywheel energy storage is extremely expensive to operate and difficult to achieve continuous power supply, and cannot adapt to the demand of integrated energy storage system alone[8] .

Through the above analysis of the physical characteristics of the composite energy storage system, it is clear that the initial capacity setting of the supercapacitor is the main factor affecting the coordinated control effect of the composite energy storage system. Assuming that the supercapacitor always starts discharging from full load or charging from empty load, the initial capacitance setting of the capacitor and the rated capacity can reach conceptual unity. In addition, through an in-depth analysis of the linearized charging and discharging energy management approach of supercapacitor, the rated exchange power of supercapacitor should be matched with the installed capacity of series expansion generator set under the satisfaction of external constraints, as shown in the following expressions.

$$P_{sc\_rate} = P_{asm\_rate} \quad (1)$$

Where P_{sc_rate} represents the optimal power exchange level of the supercapacitor and P_{asm_rate} represents the optimal power exchange level of the series expansion generator set. The above steps will complete the level planning for the power exchange of the integrated energy storage system.

3. Constructing an optimal configuration model for the energy storage double layer

In this paper, we adopt the idea of hierarchical optimization, propose a two-layer decision model, put the long time-scale planning problem in the outer optimization layer to solve, and put the short time-scale operation problem in the inner optimization layer to solve, select different optimization algorithms to solve the problem according to the specific performance of different optimization problems, and after several numerical simulation experiments, finally conclude a set of numerical optimization algorithms based on genetic algorithm, the algorithm The process and analysis will be reflected in the subsequent chapters.

The electric storage configuration model for purely electric industrial users established in this chapter is a two-layer planning model, where the upper planning model mainly solves the configuration capacity and power of energy storage, while the lower operation model mainly solves the operation strategy of energy storage and the load management strategy.In this paper, IES is modelled and analysed using the model of an energy hub.

Uncertainty is widely present in the load side and power side of IES. Using historical data of large-scale new energy and load for reasonable data pre-processing, uncertainty parameter modelling and scenario generation/reduction, a model of IES uncertainty can be established. The historical data of new energy generation and multi-energy loads are screened for gaps and clustering analysis, and can be combined with regional climate characteristics and other selected complete feature data.

The upper optimization model is a planning model for energy storage, which mainly solves the capacity planning problem of purely electric industrial user electric energy storage system. After analysing the pre-processed feature data, if the uncertain parameters are difficult to portray with multiple scenarios, RO can be used to build the model shown in equation (2), and parameters such as the upper and lower bounds of the uncertain parameters need to be calculated in combination with the feature data; if the uncertain parameters can be described by a certain number of representative scenarios, SO can be used to build the uncertain parameter model by calculating the distribution of the data in combination with the feature data, the expression of the upper model objective function is shown below .

$$\max C_{\sup} = C_{inc} + C_{traninc} - C_{inv} - C_{op} \quad (2)$$

Where, C_{inc} represents the benefit of electricity bill reduction due to the synergy of load impact management and energy storage optimization operation, and the benefit of maximum demand electricity bill reduction. $C_{traninc}$ represents the benefit of electricity bill reduction for load response management and optimal operation of energy storage, C_{inv} represents the inflation rate, and C_{op} represents the power investment cost of the energy storage system. If the above model is used, a large number of typical scenarios for uncertain parameters will need to be generated using Monte Carlo simulations based on the uncertain parameter distribution model, and appropriate scenario reduction methods will need to be considered based on the need for computational efficiency, reliability and economy.

The synergy between the optimal operation of energy storage system and load response management can obtain the peak-valley spread arbitrage and the reduction of the monthly maximum demand charge. The lower level optimization model aims at maximizing the comprehensive benefits in the daily dispatch cycle, including the reduction of daily electricity charges, the reduction of monthly maximum demand charges, and the benefits of electricity sales to small customers brought by load response management and energy storage optimization. In addition, the benefits from the reduction of electricity charge and the sale of electricity to small users are on a daily basis, and the reduction of maximum demand charge is on a monthly basis. For the scenario generation process in SO, the Monte Carlo method is used to simulate the generation of the required number of SO scenarios based on the information obtained on the mean values, deviations and distributions of the thermal/electrical load uncertainty parameters, which can subsequently be substituted into the second stage of the two-stage SO model for calculation. The expression of the lower objective function can be obtained as follows.

$$\max C_{low} = C_{pv} + \frac{C_{ba}}{30} + C_{co} \quad (3)$$

Where, C_{pv} C_{ba} C_{co} represents the reduced electricity cost, the reduced maximum demand cost, and the revenue of the electricity sales customer, respectively.

When using prices to manage electricity consumption of small users, the overall electricity price cannot be too high to prevent excessive electricity prices from reducing the motivation of small users to use electricity. The average electricity price change rate is the average change rate of electricity prices of small users in a day, which can characterize the overall electricity prices of small users to a certain extent, and in order to control the overall electricity prices of small users, it is necessary to constrain the overall electricity price change rate of small users. The overall rate of change of electricity price cannot exceed the set average rate of change of electricity price.

4. Design of mixed integer programming solution algorithm

This paper uses a genetic algorithm to optimise the solution process for the above model. The genetic algorithm is partially improved according to the computational requirements of the model proposed in this paper, and the algorithm steps are as follows:

(1) Algorithm initialization, obtaining the network parameters and system parameters of the system, etc.

(2) The decision variables for the outer layer optimization are coded, the energy storage installation location is coded in Gray code, the energy storage power and capacity are coded in binary, and M initial individuals are randomly generated.

(3) The randomly generated initial individuals are tested for feasibility, the initial individuals outside the feasible domain are eliminated, and the same number of initial individuals are randomly generated again until all M initial individuals are in the feasible region. Among them, the feasibility detection contains two steps, and the operation of the genetic algorithm to generate new individuals arbitrarily later requires feasibility detection of new individuals, including:① Inverse coding of individuals, substituting the energy storage capacity and power into the inner layer, performing optimization calculation, and judging whether the inner optimization is solvable. If it is not solvable, the individual is not feasible; otherwise, the corresponding operation optimization solution is recorded and ②; ② The operation optimization solution is used as the boundary condition for the tide calculation, and the tide solution of the current section of the system is calculated to judge whether the tide is solvable. If it is not solvable, the individual is not feasible; otherwise, the corresponding tidal solution is recorded and the feasibility test ends.

(4) For the power blockage scenario, the line tide is checked to see if the unit output is over shut down, recalculated, and the operational suboptimal solution for the inner layer optimization is obtained and recorded. Then perform the tide calculation and record the tide solution. For the power peaking scenario, this step can be omitted.

(5) Calculate the value of the fitness function using the feasible individual operation optimization solution and the tide solution.

(6) Perform selection, crossover and mutation operations on populations to form the next generation of populations.

① The selection operation is performed on feasible individuals using the values of fitness functions of different individuals. Since the selection operation does not generate new individuals, no feasibility testing is required after the selection operation;

② Perform cross-sense operations on the populations generated by selection operations and perform viability tests on the newly generated individuals;

(iii) Perform variation operations on the populations generated by the crossover operation and perform viability testing on the newly generated individuals;

④ Based on the results of ①-③ in step 6, a new generation of populations is formed.

(7) determine whether the maximum genetic generation is reached, if yes, the calculation is finished and the calculation result is output; otherwise, return to step 4.

The design of the mixed-integer programming algorithm can be completed by the above steps, and the design of the joint operation planning method of the integrated energy storage system considering reliability is now completed.

5. Experiment and analysis

5.1 Experimental preparation

In order to prove that the planning effect of the joint operation planning method of the integrated energy storage system considering reliability is better than the conventional joint operation planning method of the integrated energy storage system, an experimental session is constructed to test the planning effect of this paper after the theoretical part of the design is completed.

To verify the effectiveness and adaptability of the model proposed in this paper, pumped storage and battery storage are used in the power peaking scenario and power blocking scenario, respectively, to explore the planning and operation of the energy storage system under different application scenarios and different optimization objectives. Among them, the pumped storage data come from a pumped storage power station in the north, with an installed capacity range of 50,400 MW, a maximum working depth of 45 m in the reservoir, and a total capacity of 2,400 MW/h available for continuous power generation. the battery data come from an energy storage technology development company, with a modular battery assembly that can provide 5-50 MW power output and a storage capacity of 500 MW/h maximum and 50 MW/h minimum.

5.2 Analysis of test results

The specific measure of the planning performance of the standard algorithm selected for this experiment is the degree of fit between the predicted wind power output and the actual output curve under the same power peaking scenario, and the higher the degree of fit represents the better the joint planning performance of the algorithm for the energy storage system, and the specific experimental results are shown in the following figure. The thick line represents the actual output curve of the risk.

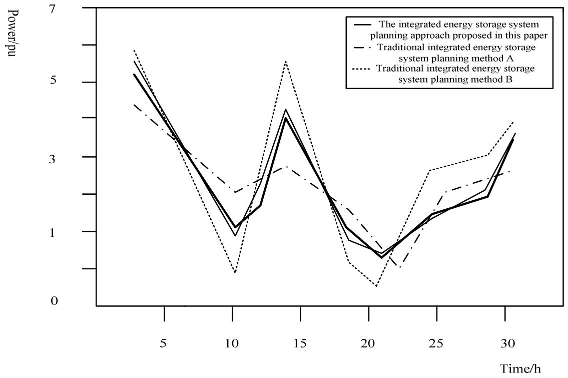

Figure 1 Fitting curve of actual and predicted wind power output under power peaking scenario

From the experimental results, it can be seen that there are differences in the effectiveness of different planning models for predicting unit output under power peaking scenarios as time increases. The fitted curves show that the prediction curves of the joint planning algorithm proposed in this paper are closer to the actual situation, which proves that the method in this paper can predict the wind turbine output more accurately and thus achieve a more scientific planning configuration.

6. Concluding remarks

This paper proposes a joint planning-operation optimisation method with a two-stage optimisation for calculating the optimal planning scheme and operation strategy for IESs such as energy hubs when uncertainties are accessed, and the flexible configuration of electric/thermal energy storage is fully considered in the model to improve the economy and load carrying capacity of the IES.

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