Reliability Assessment of the Wind-solar-battery Storage System Based on Optimized Configuration

Yuan Wang[1*], and *Haojie* Liu [2]

[1]Xi'an Aeronautical University, 710077 Xi'an, Shaanxi Province, China
[2]State power grid Baoji power supply company, 721004 Baoji, Shaanxi Province, China

Abstract. In order to analyze the impact of new energy power generation on the power grid system, the reliability evaluation of the wind-solar-battery storage system is carried out. Proposed to wind power, solar, thermal power, different sodium-sulfur battery storage combined optimal dispatch of scenery. The shortest variance of the net load and the maximum variance of the wind storage system are taken as the objective function. The short-term optimal scheduling model of the power grid is established based on the characteristics of the wind farm, the characteristics of the solar field and the electric field of the sodium flow battery. Multi-objective particle swarm optimization The algorithm solves the model and obtains the output power of wind, light, storage and fire under different new energy strategies. The reliability is evaluated by Monte-Carlo method. Taking the IEEE-30 node as an example, it is proved that the proposed model is reasonable and the new energy can improve the clean energy consumption ability and minimize the impact on the power grid under the optimal scheduling strategy.

1 Introduction

In recent years, wind and solar energy with their wide distribution, abundant resources, clean and renewable energy, have been widely used and developed. However, the counter-peak load regulation of wind power indirectly widen peak-valley difference of load, leading to thermal power depth peak shaving or shutdown[1-2]. The substantial, frequent fluctuations of solar power will have serious impact on the active balance of system, influencing active power economic dispatching, increasing the risk of frequency quality cross-border[3]. Therefore, the study of how to maximize the acceptance of wind power and solar power generation, while minimizing its impact on the system is of great importance.

Aiming at this problem, researches focus on energy storage system and hybrid systems consisting wind power plant and photovoltaic power plant, by controlling the charging and discharging of the energy storage system, the fluctuation of wind power and solar power generation is reduced. Literature [4] established a multi-objective energy storage

*Corresponding author: 578101618@qq.com

optimization configuration model based on the minimum cost, the best power matching and the smoothest output power. Literature [5] proposed micro-grid storage margin calculation method based on scene generation and reduction technology, battery charge and discharge optimization technology chord method. Grid system is complex and diverse, not just consider the energy storage system. Only when the energy storage system is operated in a complex power grid can we better reflect the impact of energy storage optimization on the power grid. Therefore, this paper simulates complex power grids based on recent loads, wind power and solar power generation forecast, and the energy storage impact is evaluated by reliability.

Based on daily load forecast, wind power and solar power generation output forecast, combined with Na/S battery storage system and TOU, a wind-solar-battery hybrid system which can declare next day output plan was proposed. The wind-solar-battery hybrid system maximum profit and minimum net load were set as objectives, considering the Na/S battery storage internal characteristics. A 96-period all-day optimal dispatch model was established. Multi-objective Particle Swarm Optimization (PSO) is used to solve the model. The output power of wind, light, storage and fire under different new energy strategies is obtained. And the reliability of the model is evaluated by Monte-Carlo method. the correctness and feasibility of model and algorithm were verified by an example.

2 Wind-solar-battery hybrid system dispatching process

2.1 Wind-solar-battery hybrid system operation mode

The wind-solar-battery hybrid system operation mode mainly including the following steps:
Step1: Power grid dispatching center, wind power plant and solar power plant will forecast the next day load output curve, as well as wind and solar power curve.
Step2: Wind-solar-battery hybrid system jointly considers TOU, reducing abandoned wind, abandoned light, punishment assessment and other factors, the improved ratio method is adopted to declare next day output plan to the dispatching center.
Step3: The dispatching center will arrange the output of regular power unit according to the declaration of wind-solar-battery hybrid system.

2.1 Batteries, wind power and solar power generation dispatching strategy

The real time predicted power of wind power and solar power is compared with declaration planning output.

(1) If the predicted power of wind power and solar power is smaller than declaration planning output, as shown in following formula:

$$P_p^*(t) + P_w^*(t) < L(t) \tag{1}$$

Then wind power and solar power are connected to power grid:

$$P_w(t) + P_p(t) = P_w^*(t) + P_p^*(t) \tag{2}$$

Wherein: $P_w(t)$ and $P_p(t)$ is wind power and solar power grid electricity at time t.

Battery power plant is discharging to meet the energy state and the maximum power constraints:

$$P_x(t) \in (0, P_{rate}) \tag{3}$$

$$P_x(t)\Delta t \le E_{bat}(t) - E_{bat.\min} \tag{4}$$

Wherein: $P_x(t)$ is dispatching output of battery power plant at time t, P_{rate} is the rated power of battery plant, $E_{bat}(t)$ is the energy state of battery plant at time t, $E_{bat.\min}$ is the minimum energy state of battery plant, meeting the following formula:

$$(1-\eta)L(t) \le P_w(t) + P_p(t) + P_x(t) \le (1+\eta)L(t) \tag{5}$$

Wherein: η is the deviation parameter, its value equals 10%.

(2) If the predicted power of wind power and solar power is larger than declaration planning output, as shown in following formula:

$$P_p^*(t) + P_w^*(t) \ge L(t) \tag{6}$$

Then wind power and solar power are connected to power grid:

$$P_w(t) + P_p(t) = L(t) \tag{7}$$

When the remaining electricity of wind power and solar power is smaller than the maximum charging power of battery plant, as shown in the following formula:

$$(P_w^*(t) + P_p^*(t)) - (P_w(t) + P_p(t)) < 1.2P_{rate} \tag{8}$$

The charging power of battery plant is:

$$P_X(t) \in (0, (P_w^*(t) + P_p^*(t)) - (P_w(t) + P_p(t))) \tag{9}$$

When the remaining electricity of wind power and solar power is larger than the maximum charging power of battery plant, as shown in the following formula:

$$(P_w^*(t) + P_p^*(t)) - (P_w(t) + P_p(t)) \ge 1.2P_{rate} \tag{10}$$

The charging power of battery plant is: $P_x(t) = 1.2P_{rate}$. Meeting the following formula is $P_x(t)\Delta t \le E_{bat.\max} - E_{bat}(t)$.

Wherein: $E_{bat.\max}$ is the maximum energy state of battery plant.

It has to be noticed that during load peak, when the wind and solar power generation predicted power is larger than the declared plan, wind power and solar power generation grid power can be increased within the deviation of planning declaration output, maximizing the use of wind power and solar power generation.

3 Wind-solar-battery hybrid optimal dispatching model

3.1 Objective function

The paper considers the revenue of electricity sale under the TOU, the punishment costs of declaration planning output deviation in wind-solar-battery hybrid system. The amount of abandoned wind and the amount of abandoned light and other factors is reduced, the maximum expected revenue under the constraints of the system is set as objective. In addition, the variance of net load may reflect the degree of flatness of wind-solar-battery hybrid output, the smaller of net load variance, the more flat net load curve, on the one hand, thermal power depth peak shaving or shutdown can be avoided, on the other hand, hydro-thermal frequent adjustment times can be reduced, therefore, the minimum net load variance is set another objective.

Objective 1: The maximum revenue of wind-solar-battery hybrid system

$$\max f_1 = \sum_{t=1}^{96} \frac{1}{M} [\rho_{pri.t} (P_w(t) + P_p(t) + P_x(t)) - \rho_{pen.t} \left| P_w(t) + P_p(t) + P_x(t) - L(t) \right| \\ - \rho_{dro.t} (P_{dro.w}(t) + P_{dro.p}(t))] \tag{11}$$

Wherein: M is 1h the number of time units,this article is 4; $\rho_{pri.t}$, $\rho_{pen.t}$, $\rho_{dro.t}$ is respectively joint system sell electricity prices,deviating from the plan output punishment prices, abandoned wind power and abandoned solar power punishment prices at time t ; $P_{dro.w}(t)$, $P_{dro.p}(t)$ is abandoned wind power and abandoned solar power at time t .

Objective 2:The minimum net load variance

$$\min f_2 = \frac{1}{96} \sum_{t=1}^{96} (P_j(t) - P_{jt.av})^2 \tag{12}$$

Wherein: $P_j(t)$ is net load variance value at time t , $P_{jt.av}$ is net load variance average at time t .

Net load value $P_j(t)$ can be represented as at time t :

$$P_j(t) = L_S(t) - P_w(t) - P_p(t) - P_x(t) \tag{13}$$

The average of the net load is $P_{jt.av} = \frac{1}{96} \sum_{t=1}^{96} P_j(t)$

3.2 Constraint condition

The wind farm output constraint is $0 \le P_w(t) \le P_w^*(t)$;The solar field output constraint is $0 \le P_p(t) \le P_p^*(t)$.

3.2.1 Na/S battery electric field characteristics and constraints

Because the Na/s battery has high specific energy, adaptation of wide and has realized the advantages of the batch production, this article selects Na/S battery energy storage system as the research object. This article discharge $u_{disch}(t)$ and recharge $u_{ch}(t)$ to Na/S battery energy storage system is two kinds of running state.

$$u_{disch}(t), u_{ch}(t) \in \{0,1\} \tag{14}$$

Na/S battery through power converter can control the charging and discharging. When Na/S battery converter capacity is large enough, the instantaneous charging and discharging power of the sodium sulfur batteries can reach 1 ~ 5 times the rated power, but based on the internal temperature, its output has certain limitation, this limit is called pulse limit Na/S battery N_{pulse}, based on the relationship between sustainable battery discharge time T_{dur} and N_{pulse} [3] :

$$T_{dur}(t) = -3.4497N_{pulse}^{3}(t) + 21.5962N_{pulse}^{2}(t) - 45.7961N_{pulse}(t) + 34.7117 \tag{15}$$

Na/S battery energy storage E_{bat} within changing over time, E_{bat} expression is as follows:

When charging:

$$E_{bat}\left(t+1\right) = E_{bat}\left(t\right) + \frac{1}{M} P_x\left(t\right)\Delta t \bullet \eta_c \tag{16}$$

When discharging:

$$E_{bat}(t+1) = E_{bat}(t) - \frac{1}{M} P_x(t)\Delta t / \eta_f \tag{17}$$

Wherein: η_f , η_c is Na/S Battery discharge and charging efficiency.

According to the operation characteristics of Na/S battery energy storage unit, as they are in the Wind-Solar-Battery system to satisfy the constraint conditions are as follows:

A)For running state constraints

$$u_{disch}(t) + u_{ch}(t) = 1 \tag{18}$$

Two kinds of state of a Na/S battery storage system is mutually exclusive .

B) For pulse factor constraints

$$0.8 \le N_{pulse}(t) \le 1 \tag{19}$$

$$N_{pulse}(t) = N_{pulse}(t+1) \tag{20}$$

C) For the charging and discharging power constraints

$$0 \le P_x(t) \le N_{pulse}(t) P_{rate} \tag{21}$$

$$-1.2P_{rate} \le P_x(t) \le 0 \tag{22}$$

Wherein: P_{rate} is Na/S battery power rating, for maximum power Na/S battery charging, the charging power of the selected generally slightly greater than the rated power, 20% higher than the rated power of the numerical value.

D) Status of Na/S battery energy constraints

$$E_{bat\min} \le E_{bat}(t) \le E_{bat\max} \tag{23}$$

E) A scheduling cycle of Na/S battery charge and discharge frequency constraints

$$Y_{dis} + Z_{ch} \le N \tag{24}$$

Wherein: Y_{dis}, Z_{ch} is Na/S Battery discharge total conversion and charging conversion plant.

4 Wind-solar-battery hybrid optimal dispatching model solving

The particle swarm algorithm is adopted to solve multi-objective optimization problem, the conventional method is transferring multi-objectives problem into single objective problem, but the non-dominant characteristic of various objectives determines that multiple objectives can't simply linear weighted. The Pareto optimal and particle swarm algorithm are combined in the paper, the optimal individual and optimal global are obtained through Pareto optimal mechanism, the flight direction of particles can be guided, the optimal solution can be searched concurrently. The above method is introduced to solve the wind-solar-battery hybrid optimal dispatching model, and the specific flow chart is shown as follows:

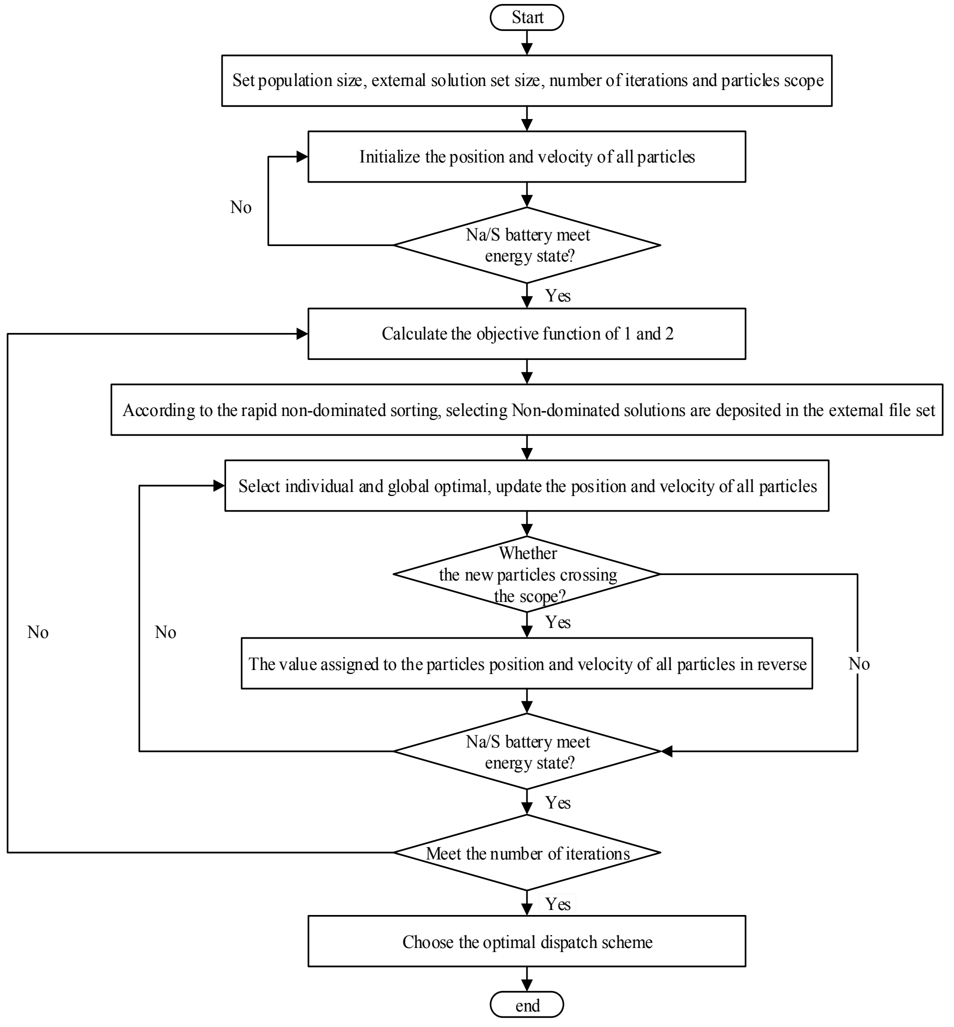


Fig. 1. The flow chart of Wind-Solar-Battery joint optimization scheduling model

5 Reliability assessment process

In this paper, non-sequential Monte Carlo method for system state selection.

This article uses the two state model. It is assumed that each component has only two states of failure and operation, and that the failure of the components is independent of each other. If the failure rate and repair rate of the components i are λ_i and μ_i, respectively, and the forcing-out rate of the components is $for_i = \frac{\lambda_i}{\lambda_i + \mu_i}$, then the status of the components is:

$$s_i = \begin{cases} 0 & (failure \quad state) \quad r_i \le for_i \\ 1 & (normal \quad state) \quad r_i > for_i \end{cases} \tag{25}$$

Where, r_i is the component i in the [0,1] interval evenly distributed random number.

Such a system state with d elements can be denoted as $s = (s_1, s_2, \ldots, s_i, \ldots, s_d)$.

Non-sequential Monte Carlo state of all components of the system after the election, the system may make a great change in the network topology, so the need for network topology analysis. In this paper, depth-first algorithm for network topology analysis to determine whether the system is unfolded, and then its power flow analysis, get the voltage of each node, the line active, reactive power value. Then cut the load calculation, the system reliability index calculation required data.

After the system state selection and state analysis, calculate the system reliability index.

(l) LOLP (Loss of load probability) is $LOLP = \frac{N_{fi}}{N_s}$, Where: N_{fi} said the number of power failures or nodes; said the number of samples.

(2) EPNS (Expected power of not supplied) is $EPNS = \left(\sum_{j=1}^{N_{fi}} P_{fij}\right) / N_{fi}$, Where: P_{fij} is the power failure power of node i in the jth sampling state of the system.

(3) EENS (Expected energy of not supplied) is $EENS = EPNS * t = \left(\sum_{j=1}^{N_{fi}} E_{fij}\right) / N_{fi}$, Where: E_{fij} is the node j in the system the first j sampling state of the power outage.

6 The result of example and analysis

6.1 Basic data and parameters

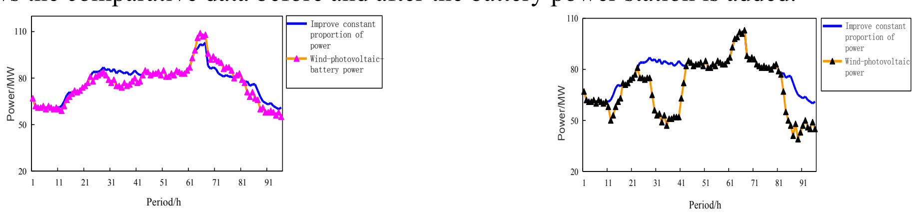
With IEEE-30 system simulation, the wind-solar-battery hybrid system and typical daily load predicted curve constructed system in a region in Northwest China was analyzed. Wherein: the installed capacity of wind power and solar is 150MW and 100MW respectively, the maximum discharge power of the Na/S battery energy storage system is 30MW, the rated power is 96MW • h, the initial energy state is 50%, the market price of electricity based on TOU is shown in Table 1, in order to reduce the deviation from the planning output, the output deviation punishment coefficient of the hybrid system is 1.5 times of electricity price, the punishment cost of abandoned wind and light is 0.05 yuan MW • h.

Table1. Market sale of electricity TOU

Period of time	**Time interval range**
Peak period 0.8yuan/ MW • h	11:00-15:00;19:00-21:00
Ordinary period 0.5yuan/ MW•h	8:00-10:00;16:00-18:00 ;22:00-23:00
Valley period 0.2 yuan/ MW • h	0:00-7:00

6.2 Result analysis of the wind-solar-battery storage system

When the battery is not added to power stations, the deviation curve of wind-solar-battery from planning output is shown in Figure2 (a), when the battery power station is added, the deviation curve of wind-solar-battery from planning output is shown in Figure2(b). Table 2 shows the comparative data before and after the battery power station is added.



(a) (b)

Fig. 2 Join the deviating from the plan before and after the battery output curve

Table.2 Join the battery power station before and after the contrast data

Project	**Total revenue /10^4 yuan**	**Penalty cost/10^4 yuan**	**Total abandon energy of Wind-PV/MW.h**	**Relative to maximum offset/%**	**Net load variance**
Wind-PV	664.6	230.7	239	39.5	2493
Wind-PV-battery	796.4	83.4	52	6.2	1759

It can be concluded from Figure.2 and Table.2 that:

1) Before the battery power plant is added, the total revenue of wind-solar-battery is 6.646 million Yuan, and after the battery power plant is added, since the battery stores the wind power and solar power at low price, and feeds back to power grid at peak price, so the total revenue of wind-solar-battery has significantly increased, reaching 7.964 million Yuan.

2) Before the battery power plant is added, due to the uncontrollable output of wind-solar-battery, leading to the output curve of wind-solar-battery deviates significantly from the planning output curve, the punishment cost, maximum deviation, and the maximum relative deviation percentage is 2.307 million Yuan, 32MW, 39.5 % respectively. And after the battery power plant is added, the wind-solar-battery hybrid system becomes controllable, it can be found that the output power of the hybrid system is significantly consistent with the planning output curve, the punishment cost, the maximum deviation and the maximum relative deviation percentage has significantly reduced, which are 834 thousand Yuan, 5MW, 6.2% respectively. In addition, through rational control of the battery charge and discharge strategy, the wind power and solar power can be used to the maximum extent, the total amount of abandoned wind decreases from the original 239MW • h to 52MW • h.

3) After the battery power plant is added, wind-solar-battery hybrid system transfers into stable, adjustable power supply, obtaining smooth net load curves, the net load variance decreases from the original 2493 to 1759, thus ensuring the safe and stable operation of the system.

6.3 Reliability evaluation

Through the optimal system configuration obtained in Section 6.2, the amount of power generated by wind power, solar, energy storage and thermal power generation. This and the typical daily load curve quantity is brought into the IEEE-30 node system, and the reliability assessment is carried out to obtain the reliability index of the system.

Table.3 Reliability evaluation comparison

System reliability index	**No new energy system**	**the wind-solar-system**	**the wind-solar-battery storage system**
LOLP(10^{-2})	0.66390	0.66390	0.63233
EPNS(10^{-1})/MW	0.34491	0.34491	0.29881
EENS/(MW.h).a^{-1}	676.259	676.259	633.634

As can be seen from Table 3, the reliability of the power system without new energy is better. However, due to the random fluctuation of the scenery, the scenery becomes less accessible, the power shortage becomes larger and the reliability deteriorates after the scenery is connected to the system. The charge-discharge characteristics of the sodium flow battery, smooth access to the system after the net load curve, making the system reliability.

7 Conclusion

The paper combines wind power, solar power and battery power, through reasonable control of the battery charge and discharge strategy, the wind-solar-battery hybrid system turns into a stable and adjustable power supply. The constraint of Na/S battery storage system charge and discharge times and the deviation of wind-solar-battery hybrid system output from the planning power output constraint are considered in the paper. And the reliability of the model is evaluated. It can be concluded from the example that: wind-solar-battery hybrid system can stores surplus wind power and solar power during low load period and feeds back into peak load period lacking of electricity, the output power of the hybrid system is significantly consistent with the planning output curve, obtaining smooth net load curves, tracking the variation curve of load, improving the overall economic profit and system stability.According to the different new energy optimal allocation of the reliability of the power grid, to achieve the best reliability of the grid.

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