An improved scheduling curve of wind power with the help of energy storage in micro grids

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Abstract. In a Micro grid, the distributed power sources are near to the customers, so the load may be sensible to the power fluctuation caused by power sources such as wind power generators. In the case where higher power quality is required, wind power often suffers restraints which will lead to loss coming from abandoned wind power. This paper proposes a novel dispatching scheme in which considerations are given to both power supply quality and sufficient wind power utilization, and then schedule a new power reference value obtained by calculating the Confidence level of wind power. The proposed scheme smooth the wind power curve injected into the micro grid with the help of energy storage, and then promotes the confidence level of wind power output by rolling correction, which is helpful to raise the dispatch curve in order to reduce wind power curtailment. Corresponding energy storage needed is calculated also, whose economy is taken into consideration for balance between energy storage investment and benefit from the reduction of wind power curtailment. Case analysis shows the effect of the proposed scheme.

1. Introduction

Due to the reasonable plan of different kinds of new energy power generation in the Micro grid, these resources can be made maximum use in the premise of ensuring the quality of power use\cite{1-2}. However, because the penetration of new energy power generation in micro grid is higher than in the traditional grid, the volatility of new energy power generation has greater influence in micro grid. Moreover, the micro grid always connected to the end of the traditional grid and the capacity of its output load is often small, with the result that the micro grid is relatively sensitive to power fluctuations. It is necessary to propose strategies for reducing the volatility of new energy power generation.

In China, most large-scale wind power generators has been integrated to power system at present. Nevertheless, because of the low credibility of wind power capacity and the power quality of consumers should be taken into account by the dispatching centre, the phenomenon of wind power curtailment is serious. Now, on the one hand, the penetration of new energy power generation in micro grid is high and the kinds of power supplies and customers in micro grid are relatively simple. On the other hand, most modes of micro grids are self-sufficient mode, so the dispatch mechanisms of different kinds of energy are much more flexible, thus balances the comprehensive benefits of the power supplies and customers and reduces the phenomenon of wind power curtailment.

In recent years, some scholars have paid more attention to the problem of abandoning the wind. Literature\cite{3} proposed evaluation methods to effectively evaluate the wind power curtailment in.
power grid and literatures [4, 5] proposed some ways to solve the problem of abandoning the wind. Due to the continuous development of energy storage technology, the use of energy storage technology to reduce the fluctuation of wind power output and meet the Power supply requirement standards has been applied. Literature [6, 7] proposed a Model by using the energy storage to reduce the fluctuation of wind, but did not take into account the situation that it can not meet the expected requirements because of the wind power prediction error in real-time dispatch, so there are still greater fluctuation. Proposed in the literature [8-10], the best reservoir capacity is optimized by optimizing function , but not on the basis of historical data, through statistical methods with these data the comprehensive benefits for capacity reservoir and the other economic impact on other factors can be get.

This paper presents a novel dispatch strategy of wind power generation in micro grid. Energy storage technologies are used to reduce the volatility of new energy power generation. At the same time, the dispatching requirement of grid corporations, which is the wind power generation can be dispatched, is satisfied. In this way, the credibility of wind power can be improved and the loss of wind power generation can be decreased.

2. The formulation of wind power scheduling curve
   The purpose of the ideal wind power scheduling is try to send more wind power to the user, but due to the fluctuation of wind power, there is a certain limit to the wind power dispatch. Then it is necessary to develop a novel dispatching scheme, which can reduce the loss and the fluctuation of wind power.

   In order to make day-ahead generation scheduling curve of the wind power similar to the general form of generation scheduling curve, the concept of "time window"[6] is introduced in this paper. The time window is in the scope of the scheduling cycle $T$, including $N$ times $\Delta t$, which is the minimum interval of wind power prediction. Within each time window, wind power output is formulated to a constant value. All the reference values of wind power output within the scheduling cycle form a staircase waveform which is in line with the general form of the generation scheduling curve [7].

   Firstly, set the minimum variance of power output as the target in a given time window to obtain the basic reference value of each dispatch cycle:

   $$\min \sum_{i=1}^{T} \frac{1}{N \Delta t} \sum_{t_{i}, t_{i}+N \Delta t} (\Delta P)^2$$

   In the formula, $i$ means the No.$i$ time window, $t_{i}$ means the time corresponding to the No.$i$ time window. The $\Delta P$ is the difference between the prediction power $P_{ref}(t)$ and the power reference value $P_{i}$ in the time window, that is, $\Delta P = P_{ref}(t) - P_{i}$.

3. Generate scheduling curves considering confidence level of wind power capacity

3.1. Confidence level of wind power output capacity

In practical cases, basically the actual capacity of all power supply is smaller than its installed capacity. Therefore, the concept of power confidence level is often introduced to express the reliability of power supply capacity[11]. Due to the fluctuation of wind resources, wind power generation capacity is less reliable than thermal power and other energy sources. Because of this property of wind power, the traditional power confidence level has been unable to fully meet the further optimization of the above generation scheduling curve. Therefore, the confidence level of wind power output Coe, which is a new concept required to propose based on the scheduling curve above.

   Within each time window, it can be seen as that the wind power provides a fixed output, and the actual generating capacity of the period is the effective load bearing capacity, the new confidence level of output reference is obtained:

   $$C_{oe} = \frac{C_{eff}}{C_{w}}\times100\% = \frac{P_{i}}{P_{ref}}\times100\%$$
In the formula, $C_{efw}$ means the payload capacity of wind farm, $C_w$ means the capacity of the wind farm connected in the power system. $\bar{P}_{i}^{\text{pre}}$ is the average prediction power of the No. $i$ time window.

3.1.1. Introduction of confidence level of wind power capacity. The basic reference value of each dispatch time window is obtained on the wind power prediction curve, but there is still a large error in current power prediction, the average level of wind power prediction is 25%–40%. In the preliminary generation scheduling curve, fluctuation of ideal output of wind power can be as small as the thermal power. But due to the existence of power prediction error, the power of the actual output is still fluctuating. So the power prediction error is the main factor that affects the reliability of wind power capacity.

Based on the literature [12], the assumption that the prediction error follows the normal distribution is obtained by analyzing the actual data, and the mean value of the normal distribution is set as 0, and the estimation formula is given by:

$$P_{\text{cap}} - P_{\text{pre}} \sim N(0, \sigma^2) \quad (3)$$

In the formula, $P_{\text{cap}}$ means total capacity of all the working wind power generators, $\mu$ means the expectation to be assessed, $\sigma$ means the standard deviation to be assessed.

Referring the method of power prediction and error calculation, confidence level of wind power output is calculated based on the history of the scheduling process. According to the regulation of dispatch, when the value of actual generation power is higher than the one in the generation scheduling curve, the part of higher power must be abandoned. Therefore, the error value greater than 0 is set as 0. For error less than 0, the average error $\mu$ is obtained by calculating the errors of each time interval based on historical data. The confidence level of wind power output of corresponding time of the day is calculated based on the follow equation.

$$\bar{P} = \mu P_{\text{cap}} + \bar{P}_{i}^{\text{pre}} \quad (4)$$

$$C_{oe} = \frac{\mu P_{\text{cap}} + \bar{P}_{i}^{\text{pre}}}{\bar{P}_{i}^{\text{pre}}} = \mu + \frac{P_{\text{cap}}}{\bar{P}_{i}^{\text{pre}}} \quad (5)$$

4. Storage configuration

Due to the uncertainty of wind power, the final generation scheduling curve may fluctuate. Large-capacity storage system possesses the characteristics of absorbing and releasing dynamic energy at any time [11], which achieves the translation of power and energy in terms of time. So these energy that exceed the generation scheduling curve can be saved into the storage devices, and be released when the output power is lower than the scheduling value.

4.1. Energy storage selection

Battery energy storage is a common kind of energy storage form in wind energy storage, and its technology is quite mature. The advantages include free space, wide power range, faster response time, high energy density and charge/discharge efficiency and low cost of material, etc[13]. Besides, battery energy storage is suite for rapid charge/discharge process, and is beneficial to stabilize and supplement the short-term power of date-planned output power.

4.2. Battery mathematical model

Due to the battery voltage boundary constraints, the impact of battery capacity and maximum power of charge/discharge must be taken into account. The storage capacity of storage battery $C_{\text{ban}}(t)$ at moment $t-1$ and $C_{\text{ban}}(t-1)$ at moment can be calculated at two stages which are charging and discharging stage[10].
When wind energy exceed the generation scheduling value, those exceeding energy should be stored into battery. However, it will be stopped when the charged energy exceeds the rated capacity of the battery $C_{\text{batt}}(t-1)$, because the battery capacity is limited. The charging power at moment $t$ can be calculated as follows:

$$
\begin{align*}
P_{\text{ch}}(t) &= \frac{1}{\eta_{\text{ch}}} (C_{\text{batt}}(t) - C_{\text{batt}}(t - \Delta t)) \\
\text{or} \\
P_{\text{ch,max}}(t) &= \frac{1}{\eta_{\text{ch}}} (C_{\text{batt,max}} - C_{\text{batt}}(t - \Delta t))
\end{align*}
$$

In these equations, $\eta_{\text{ch}}$ is the charging efficiency of battery, and generally is set as 0.65 to 0.85; $P_{\text{ch}}(t)$ is the charging power of battery at moment $t$ considering the maximum capacity and the maximum charging power limit and it is positive. $\Delta t$ is wind power sampling interval.

When the wind energy is less than required, it needs energy discharged by battery. Since the amount of battery is limited, it will maintain the output power of battery as rated value $C_{\text{batt}}N$ when the release energy can not make up the battery capacity requires.

The discharging power at moment $t$:

$$
\begin{align*}
P_{\text{dis}}(t) &= \frac{1}{\eta_{\text{dis}}} (C_{\text{batt}}(t) - C_{\text{batt}}(t - \Delta t)) \\
P_{\text{dis,max}}(t) &= \frac{1}{\eta_{\text{dis}}} (C_{\text{batt,max}} - C_{\text{batt}}(t - \Delta t))
\end{align*}
$$

In these equations, $\Delta t$ is wind power sampling interval; $P_{\text{dis}}(t)$ is the discharging power of battery at moment $t$ considering the maximum capacity and the maximum charging power limit and it is negative. $\eta_{\text{dis}}$ is the discharging efficiency of battery, and generally is 1.

4.3. The economy of storage configuration

Battery energy storage system power costs are mostly divided into power investment costs and energy investment costs, and the power investment costs are related to the input or output power, and energy investment costs are related to the battery capacity[14], beside, the battery life is related to the number of discharging times and depth of discharging[15], and thus affecting the cost of operation. It is necessary to reduce the fluctuation of output power curve in order to reduce energy storage costs.

The selection of energy storage capacity is based on the historical data, which must meet demands at the majority time. First, record the power to add at each time, and select the amount of the charge which appears at higher probability. And then put the selected charge capacity into equation (1)-(2) to obtain the amount of abandoned wind due to the reduce of the storage configuration, finally compare its economy comprehensively.

Example analysis

The calculation example is based on the wind power data of a small micro grid model with the control room, it is scheduled according to the plan presented above, and its feasibility and effectiveness are calculated and analyzed.

4.4. Formulation of scheduling curve

Selecting the micro grid data for a period of time, the basic reference value of each dispatch time window is determined preliminarily based on the prediction curve of the fifth day. The simulated annealing algorithm is used to optimize the objective function (1), and the preliminary scheduling curve as shown in figure 1 is obtained.

Based on the preliminary generation scheduling curve, confidence level of wind power output of the first three days of the historical data is calculated and making generation scheduling curve with its confidence level.

According to the novel dispatching strategy presented in this paper, the generation scheduling curves can be determined on the basis of selected historical data. Count the required power capacity of every time period. The results are shown in figure 2, figure 3 and figure 4.
Figure 1. Preliminary generation scheduling curve.

Figure 2. Scheduling curve with confidence level.

Figure 3. Comparison of different generation scheduling curves.
Figure 4. The actual output power curve under the scheduling rules.

It can be seen from this that the scheduling strategy of wind power proposed in this paper in the micro grid to some extent stabilizes the fluctuation of wind power output power.

4.5. Allocation of energy storage
From the statistical results, it is obvious that most of the required power capacity is less than 250kW•h. Therefore, select this range of data (as shown in figure 5) to analyze.

After that, choose the appropriate capacity of energy storage according to the appearing probability of each capacity range and put them into (10) and (11). Then we can get the decrement of abandoned wind power because of the allocation of energy storage.

If the electrovalence is 0.3¥/kWh, the cost of the capacity of energy storage is 640¥/kWh [16]. Choose a reasonable capacity of energy storage based on the result of the comprehensive economic benefit analysis. The results are shown in table 1, table 2.

| The probability range | The capacity of energy storage (kWh) | The decrement of abandoned wind power (kWh) |
|------------------------|--------------------------------------|--------------------------------------------|
| >0.8%                  | 70                                   | 6949.583                                   |
| >1.2%                  | 30                                   | 4792.117                                   |
| >1.6%                  | 20                                   | 3712.867                                   |

| The capacity of energy storage (kWh) | The cost of energy storage (¥) | Cost of the decrement of abandoned wind power (¥) | Comprehensive cost (¥) |
|-------------------------------------|-------------------------------|-----------------------------------------------|-----------------------|
| 70                                  | 44800.00 ¥                   | 2084.88 ¥                                   | 42715.12 ¥           |
| 30                                  | 19200.00 ¥                   | 1437.64 ¥                                   | 17762.36 ¥           |
| 20                                  | 12800.00 ¥                   | 1113.86 ¥                                   | 11686.14 ¥           |

Because the cost of the capacity of energy storage is high, it is obviously that with smaller capacity, the comprehensive cost is lower. Therefore the capacity of energy storage we can choose is 20 kWh.
Figure 5. The amount of electricity needed for a period of time.

As a result, the proposed method of energy storage capacity formulation can reduce the comprehensive cost of the wind farm.

5. Conclusions
A novel dispatching scheme for wind power in micro grids is proposed in the paper, in which considerations are given to both power supply quality and sufficient wind power utilization. The strategy calculates the basic reference value of each dispatch time window by simulated annealing algorithm first, and then promotes the confidence level of wind power output by rolling correction, which is helpful to raise the generation scheduling curve in order to reduce abandoned wind power. The proposed strategy smooth the wind power curve injected into the micro grid with the help of energy storage, at the same time, energy storage can also save part of the energy sliced off that may be provided by wind power exceed the generation scheduling curve. Corresponding energy storage needed is calculated also, whose economy is taken into consideration for balance between energy storage investment and benefit from the reduction of abandoned wind power. Case analysis shows that the proposed scheme is helpful to reduce the abandoned wind power and can promote the economy of the micro grid.

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