A Renewable Energy Assessment Model Considering the Effect of Frequency Regulation

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Abstract. Under the background of energy Internet, a high proportion of renewable energy is connected to the power system, and its volatility and randomness make the flexibility of the power system itself increasingly important in dealing with the fluctuation of net load. In order to evaluate the limit capacity of renewable energy consumption under the given power structure and the future absorption prospect of regional power grid, a renewable energy evaluation model considering the effect of frequency regulation is proposed in this paper. This method fully considers the role of frequency regulation in dealing with the uncertainty of renewable energy, establishes the absorption index from the perspective of absorption capacity and absorption efficiency, and comprehensively evaluates the absorption capacity of renewable energy from the perspective of frequency modulation, slope climbing and other time scales. Finally, the model is verified by a ten-machine system.

1. Introduction

In the context of energy Internet, renewable energy generation has become the main power generation form of the future power system. China proposes to achieve the goal of 85% renewable energy generation by 2050 [1], and Europe even proposes the idea of 100% renewable energy [2]. A high proportion of renewable energy is connected to the power system, and its volatility and randomness break the power balance mode of conventional unit tracking load, making it difficult for conventional unit to track the fluctuation of net load, and generating the limit of renewable power supply and load cutting capacity, which run counter to the purpose of developing renewable energy. Therefore, it becomes an important subject to evaluate the absorption capacity of renewable energy under the current power structure and provide references for the planning of renewable power.

Most existing studies evaluate the absorption capacity of the system from the perspective of operation simulation, which is mainly divided into two categories: (1) time-series simulation method [3-5]: it mainly conducts scene simulation through unit combination and economic scheduling, and evaluates the absorption capacity according to whether there is load loss and the limit of renewable power supply; (2) flexibility evaluation [6-9]: evaluate the receptivity of renewable energy from the perspective of flexibility. Such studies tend to consider the abundance of system flexibility in a given time profile considering the existing renewable energy capacity.

All the above studies are analyzed from one point or one section, and it is difficult to find the internal law of the proportion of installed capacity and power generation of renewable energy, so the
absorption potential of the system for renewable energy cannot be obtained intuitively. In this regard, this paper first analyzes the absorption mechanism of renewable energy with different capacities after being connected to the system, and sets up three absorption scenarios according to the measures to deal with the uncertainty of renewable energy: natural absorption, standby absorption and auxiliary absorption. The absorption capacity of renewable energy was evaluated comprehensively from different time scales, such as frequency modulation and slope climbing.

2. UC model considering frequency regulation effect
Existing wind farms and photovoltaic farms are equipped with a prediction system, which reports the prediction information in real time. Based on this, the dispatching department arranges the starting and stopping plan of the next day's conventional units. Variables to be optimized include: 1) starting and stopping variables of conventional units (controllable units of thermal power, hydropower, etc.) at all times \( I = \{ t_i | i = 1 \ldots N, t \in 1 \ldots T \} \) (0 represents shutdown, 1 represents opening); 2) the output base point of conventional units \( i \) at \( t \), \( P_i^t \); 3) the output base point of the renewable power source at \( t \), that is \( P_r^t \), the maximum output value of renewable energy that the system can absorb.

2.1 Evaluation indicators
This paper studies the relationship between the proportion of renewable energy capacity and the actual operation proportion. Therefore, this section establishes an evaluation index system from the two aspects of absorption capacity and absorption efficiency to evaluate the saturated capacity and economic saturated capacity of renewable energy that can be accessed in the future years under the current power supply structure of the system.

2.1.1 Absorption ability
The principle of analyzing this index is that, regardless of economy and operating efficiency, conventional units give way to renewable energy and give full play to the absorption potential of the system.

System access to a certain amount of renewable energy, due to its output volatility and randomness, cause system can't fully accepting renewable energy output value, abandon the abandoned light phenomenon is inevitable. The electricity will be renewable power and cutting load phenomenon is referred to as rejection, therefore absorption ability can use renewable energy to reject rate meet certain signs of maximum capacity threshold.

\[
\alpha = \frac{\sum \Delta P_r^t}{\sum P_{r,f}^t} + \frac{\sum \Delta P_l^t}{\sum P_{l,f}^t}
\]  

(1)

\( \Delta P_r^t \) and \( \Delta P_l^t \) are respectively the limit of renewable power supply and the cutting load in the period \( t \), respectively, \( P_{r,f}^t \) and \( P_{l,f}^t \) are the predicted values of renewable power supply and load; \( \alpha_1 \) and \( \alpha_2 \) respectively represent the weight coefficient of the influence of wind and light abandoning and load cutting on the rejection rate.

2.1.2 Absorption efficiency
This paper mainly measures the absorption efficiency from the economic perspective. The main purpose of renewable energy access to the power grid is to replace thermal power, reduce the cost of power generation, in order to achieve the effect of energy conservation and emission reduction; But at the same time, the addition of fans, photovoltaic panels and other devices will increase the fixed cost, and the operation process will also cause the decline of the operation efficiency of conventional units, and increase the operation cost. Therefore, reasonable evaluation of the value of renewable energy is a core problem of high proportion of renewable energy grid connection.
This paper studies the relationship between renewable power capacity and absorption efficiency, so the contribution rate of unit capacity $\eta$ is defined to characterize the emission reduction efficiency of renewable energy to the system under different access capacities.

$$\eta = \frac{C_o - C_r}{W_t \cdot C_r}$$  \hspace{1cm} (2)

$$C_i = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[ f(P'_i) \cdot I'_i + f(I'_i) \right] + f(C_r)$$  \hspace{1cm} (3)

$$C_0 = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[ f(P'_i) \cdot I'_i + f(I'_i) \right]$$  \hspace{1cm} (4)

$$f(P'_i) = a_i(P'_i)^2 + b_i P'_i + c_i$$  \hspace{1cm} (5)

$$f(C_r) = C_r \cdot d \cdot (1 - \gamma \%)$$  \hspace{1cm} (6)

$C_o, C_r$ is the total power generation coal consumption of the system before and after the access of renewable energy, $W_t$ is the total power generation, and $C_r$ is the installed capacity of renewable energy; $f(P'_i)$ is the power generation cost of conventional units, $f(I'_i)$ is the start-stop cost, $f(C_r)$ is the fixed cost of renewable power converted to the cost of each day, the straight-line depreciation method for simple calculation; $a_i, b_i, c_i$ are the coefficients of each part of the power generation cost function respectively; $d$ is the unit capacity cost, $\gamma \%$ is the expected net residual value rate, and $D_i$ is the expected number of days of use.

2.2 Evaluation UC model

The optimization is carried out on the principle of "maximum acceptance of the output value obtained from the prediction of renewable energy $P'_r$", to ensure the minimum power limit of renewable energy, and the optimization objective is

$$\min \sum_{t=1}^{T} (P'_{r,t} - P'_t)$$  \hspace{1cm} (7)

Including constraints:

1) power balance:

$$\sum_{i=1}^{N} P'_i = (P'_o + \Delta P'_o) - P'_t$$  \hspace{1cm} (8)

In order to ensure that the model has a solution, the relaxation quantity is added, that is, the load loss $\Delta P'_i$ in the period $t$ is satisfied

$$0 \leq \Delta P'_i \leq P'_i$$  \hspace{1cm} (9)

2) climbing constraints of conventional units:

$$P'_o - P'_i - \Delta P'_i \leq [1 - I'_o \cdot (1 - I'_i)] \cdot r_i \cdot \Delta t + I'_o \cdot (1 - I'_i) \cdot R \cdot \Delta t$$  \hspace{1cm} (10)

$$P'_i - P'_o \leq [1 - I'_i \cdot (1 - I'_o)] \cdot r_i \cdot \Delta t + I'_i \cdot (1 - I'_o) \cdot R \cdot \Delta t$$  \hspace{1cm} (11)

$r_i$ is the regulating speed of the conventional unit, $R$ is the starting and stopping speed of the conventional unit, and $\Delta t$ is the interval of time.

3) reserve range:

$$\Delta P'_{up} \geq \Delta P'_{r,i,j} + \Delta P'_i - \Delta P'_o$$  \hspace{1cm} (12)

$$\Delta P'_{down} \leq \Delta P'_{r,i,j} + \Delta P'_o - \Delta P'_i$$  \hspace{1cm} (13)

$\Delta P'_{up}, \Delta P'_{down}$ are the up-regulation and down-regulation. The left side of the above equation is the power regulation effect of the system, and the right side is the net load fluctuation.

Scenario 1:
Natural absorption: For the regions with high load level, the unbalance that can be adjusted by primary frequency modulation is large, and the system shows great flexibility. In the early stage of the development of renewable power supply, namely, the access capacity is small, the intermittent characteristics are not obvious, the short-term fluctuation is small, and only one frequency modulation can meet the rejection rate requirements.

\[
\Delta P_{EP} = -\sum_{i=1}^{N} (K_{G} + K_{L}) \cdot \Delta f_{down}^i
\]  

(14)

\[
\Delta P_{DOWNY} = -\sum_{i=1}^{N} (K_{G} + K_{L}) \cdot \Delta f_{up}^i
\]  

(15)

\[0 \leq \Delta f_{up}^i \leq \Delta f_{max}^i \]  

(16)

\[\Delta f_{min}^i \leq \Delta f_{down}^i \leq 0\]  

(17)

\[K_{G}\] is the frequency regulation effect coefficient of the unit \(i\); \(K_{L}\) is the frequency regulation effect coefficient of load; \(\Delta f_{up}^i, \Delta f_{down}^i\) are the upward and downward variation of the frequency; \(\Delta f_{max}^i, \Delta f_{min}^i\) respectively are the maximum upward and downward changes.

**Scenario 2:**

Reserve absorption: With the increase of the access capacity of the renewable power supply, the standby demand cannot be met only by primary frequency modulation.

\[
\Delta P_{EP} = -\sum_{i=1}^{N} (K_{G} + K_{L}) \cdot \Delta f_{down}^i \]  

(18)

\[
\Delta P_{DOWNY} = -\sum_{i=1}^{N} (K_{G} + K_{L}) \cdot \Delta f_{up}^i - \sum_{i=1}^{N} \Delta P_{up,i}^r
\]  

(19)

4) reserve response speed:

up-regulation \(\Delta P_{up,i,j}, \) down-regulation \(\Delta P_{down,i,j}\)

\[0 \leq \Delta P_{up,i,j} \leq \tau \cdot \Delta \tau \]  

(20)

\[0 \leq \Delta P_{down,i,j} \leq \tau \cdot \Delta \tau \]  

(21)

5) conventional unit output constraint:

\[P_i^r + \Delta P_{up,i,j} - K_{G} \cdot \Delta f_{down}^i \leq P_{max,i} \cdot I_i \]  

(22)

\[P_i^r - \Delta P_{down,i,j} - K_{G} \cdot \Delta f_{up}^i \geq P_{min,i} \cdot I_i \]  

(23)

\(\Delta \tau\) is the standby response time, which depends on the fluctuation speed of renewable energy; \(P_{max,i}, P_{min,i}\) are the maximum , minimum output of the first unit.

6) other constraints:

In addition to the above constraints, there are conventional unit output constraints, renewable energy output value constraints, minimum start-stop time constraints, and conventional unit start-stop status constraints [10].
3. Example

In this paper, 10 conventional units are taken as examples for simulation, and the parameters of the units are shown in literature\(^{[10]}\).

Three typical days were taken and the exclusion threshold was set as \(\alpha = 10\%\), \(\alpha_1 = \alpha_2 = 0.5\), that is, the power limit ratio and load cut ratio of permissible renewable energy were 10%.

(1) Absorption ability

In the case of different renewable power access capacity, the expected value of the total power generation proportion and the expected value of the rejection rate in three typical days can be obtained through simulation operation, as shown in figure 2 and figure 3.

![Figure 2. Renewable energy capacity and operating ratio](image)

As can be seen from figure 2, when the installed capacity reaches 1820MW, the operation proportion reaches saturation, but at this time, the exclusion rate reaches 40.24%, exceeding the set threshold \(\alpha = 10\%\). As shown in figure 3, the corresponding saturation capacity is 1150MW, which has been marked out in figure 2, and the corresponding operation proportion is about 30.14%.
Natural given scenario: the installed capacity of more than 400 mw, due to its limited ability to cope with uncertainty, resulting in a large number of abandoned discard wind, when the installed capacity of 2800 mw, the running of saturated, but the rejection rate is 62.05%, more than half of the renewable energy output has been abandoned. Figure 3 shows, the saturated capacity corresponding to $\alpha = 10\%$ is 650MW, and the operation proportion in figure 3 is 18.63%.

(2) absorption efficiency
Calculating the contribution rate of unit capacity $\eta$, the absorption efficiency under the two absorption scenarios can be obtained, as shown in figure 4.

In the case of natural absorption, the benefit of emission reduction is the best when the capacity reaches 790MW. However, based on the analysis in figure 3, the exclusion rate exceeds 10%. Therefore, based on good absorption, that is, before 650MW, the benefit of energy saving and emission reduction of renewable power increases with the increase of installed capacity. In the case of reserve absorption, when the capacity reaches 1850MW, the benefit is the highest, which is much larger than the economic saturation capacity in the case of natural absorption, that is, the system can more economically accept renewable energy.

4. Summary
This paper establishes a renewable energy assessment model that takes into account the frequency regulation capability. The internal law between renewable energy capacity and operation ratio is obtained through operation simulation. Based on the indexes of absorption capacity and absorption efficiency, this paper evaluates the current situation and potential of absorption of renewable energy at the present stage, and provides a reference for the planning of renewable energy.

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