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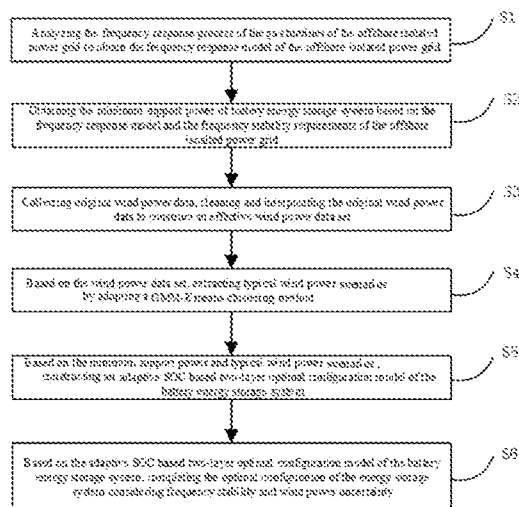
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OPTIMAL CONFIGURATION METHOD OF BATTERY ENERGY STORAGE SYSTEM CONSIDERING FREQUENCY STABILITY AND WIND POWER UNCERTAINTY.

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The invention provides an optimal configuration method of battery energy storage system considering frequency stability and wind power uncertainty, which comprises the following steps: obtaining a frequency response model of an isolated offshore power grid; based on the frequency response model and the frequency stability requirements of offshore isolated power grid, the minimum support power of battery energy storage system is obtained; collecting original wind power data to construct an effective wind power data set; GMM-Kmeans clustering method is used to extract typical wind power scenarios. Based on the minimum support power and typical wind power scenarios, an adaptive SOC based two-layer optimal configuration model of battery energy storage system is constructed. Based on the two-layer optimal configuration model of battery energy storage system, the optimal configuration of energy storage system considering frequency stability and wind power uncertainty is completed.



DESCRIPTION

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OPTIMAL CONFIGURATION METHOD OF BATTERY ENERGY STORAGE SYSTEM CONSIDERING FREQUENCY STABILITY AND WIND POWER UNCERTAINTY**TECHNICAL FIELD**

The invention belongs to the technical field of optimal configuration of battery energy storage system, and particularly relates to an optimal configuration method of battery energy storage systems considering frequency stability and wind power uncertainty.

BACKGROUND

Offshore isolated power grid relies on generators to operate independently from the main power grid, so its frequency adjustment ability is poor and its anti-interference ability is weak. With the high penetration level of offshore wind power, the frequency stability problem of offshore isolated power grid has become prominent. Voltage stability can be improved by connecting reactive power compensator, while frequency stability is an important factor that hinders the penetration level of offshore wind power. Therefore, offshore isolated power grid is more prone to frequency stability problems. Battery energy storage system has excellent active and reactive power characteristics, and can adjust the frequency of power grid, so it is considered as the most effective means to improve the wind power penetration level of power grid. However, the configuration of battery energy storage system in the offshore isolated power grid is difficult due to the uncertainty of wind power. Accurate offshore wind power characteristics are crucial for enhancing the reliability of battery energy storage system configuration. In many researches, the SOC of battery energy storage system is fixed. The invention proposes a battery energy storage system configuration model with adaptive SOC, in which SOC is not fixed but an optimized variable. Meanwhile, due to the high cost of battery energy storage system, how to optimize its size while ensuring the stability of offshore isolated power grid frequency is an urgent problem to be solved.

SUMMARY

Aiming at the shortcomings of the prior art, the invention provides an optimal configuration method of battery energy storage system considering frequency stability and wind power uncertainty, thereby reducing the operating cost of an offshore isolated power grid.

In order to achieve the above objectives, the present invention provides the following scheme:

an optimal configuration method of battery energy storage system considering frequency stability and wind power uncertainty comprises the following steps:

analyzing the frequency response process of gas turbines in offshore isolated power grid, and obtaining the frequency response model of offshore isolated power grid;

based on the frequency response model and the frequency stability requirements of the offshore isolated power grid, the minimum support power of the battery energy storage system is obtained;

collecting original wind power data, and cleaning and interpolating the original wind power data to construct an effective wind power data set;

based on the wind power data set, a gaussian mixture model-Kmeans (GMM-Kmeans) clustering method is adopted to extract typical wind power scenarios;

based on the minimum support power and the typical wind power scenarios, an adaptive SOC (state of charge) based two-layer optimal configuration model of the battery energy storage system is constructed;

based on the two-layer optimal configuration model of the battery energy storage system, the optimal configuration of battery energy storage system considering frequency stability and wind power uncertainty is completed.

Preferably, the method for obtaining the frequency response model of the offshore isolated power grid comprises the following steps:

obtaining an equivalent dynamic equation of the gas turbine, and obtaining a rotor motion equation of the gas turbine based on the equivalent dynamic equation;

obtaining the frequency response model based on the rotor motion equation;

wherein, the frequency response model comprises a frequency response model of offshore isolated power grid without battery energy storage system and a frequency response model of offshore isolated power grid with battery energy storage system.

Preferably, the method for extracting typical wind power scenarios by using GMM-Kmeans clustering method is as follows:

collecting original wind power data, and cleaning and interpolating the original wind power data to construct an effective wind power data set;

training a gaussian mixture model (GMM) based on the wind power data set;

generating massive wind power scenarios based on the trained gaussian mixture model GMM;

clustering the wind power scenarios based on Kmeans method, and combining elbow method and silhouette value to obtain the best clustering number;

based on the optimal cluster number and cluster center, the typical wind power scenarios in the massive wind power scenarios are extracted.

Preferably, the method for constructing the adaptive SOC (state of charge) based two-layer optimal configuration model of the battery energy storage system is as follows:

based on the carbon capture cost, wind power curtailment cost, life cycle cost of battery energy storage system, fuel and operation and maintenance cost of gas turbines and the probability of typical wind power scenarios in a preset number, the total operation cost of offshore isolated power grid is obtained, and the total operation cost is taken as an objective function of a two-layer optimal configuration model of battery energy storage system;

evaluating the life of the battery energy storage system based on the discharge depth of the battery energy storage system to obtain the battery life;

based on the objective function, the battery life and constraints, an adaptive SOC based two-layer optimal configuration model of the battery energy storage system is obtained.

Preferably, the constraints include power balance constraints, adaptive SOC constraints, frequency stability constraints, battery energy storage system operation constraints and other constraints.

Preferably, the adaptive SOC constraint is SOC_{min}, and SOC_{min} is the SOC lower limit of the battery energy storage system, and the constraint formula is as follows:

$$SOC_{\min} \geq \max \left\{ SOC_{\min, N}, \frac{P_{s, \min} T_{\sup}}{E_{bat}} \right\},$$

$SOC_{\min, N}$ is the lower limit of SOC of battery energy storage system at rated discharge depth, $P_{s, \min}$ is the minimum support power of battery energy storage system to meet the frequency stability requirements of offshore isolated power grid, E_{bat} is the minimum capacity of battery energy storage system, and $T_{\sup}$ is the duration for battery

energy storage system to provide power support to maintain the frequency stability of offshore isolated power grid. LU507732

Preferably, genetic algorithm is used to solve the upper model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system, and CPLEX is called to solve the lower model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system.

Compared with the prior art, the invention has the beneficial effects that the frequency stability of offshore isolated power grid can be improved, the problem of wind power uncertainty can be solved, and the reliability of battery energy storage system configuration results can be improved. Compared with other fixed SOC methods, the adaptive SOC method can reduce the total operating cost of offshore isolated power grid on the premise of ensuring the frequency stability of offshore isolated power grid.

BRIEF DESCRIPTION OF THE FIGURES

In order to explain the technical scheme of the present invention more clearly, the drawings needed in the embodiments are briefly introduced below. Obviously, the drawings in the following description are only some embodiments of the present invention. For ordinary people in the field, other drawings can be obtained according to these drawings without paying creative labor.

Fig. 1 is a flowchart of an optimal configuration method of energy storage system considering frequency stability and wind power uncertainty in an embodiment of the present invention.

DESCRIPTION OF THE INVENTION

In the following, the technical scheme in the embodiment of the invention will be clearly and completely described with reference to the attached drawings. Obviously, the described embodiment is only a part of the embodiment of the invention, but not the whole embodiment. Based on the embodiments in the present invention, all other embodiments obtained by ordinary technicians in the field without creative labor belong to the scope of protection of the present invention.

In order to make the above objects, features and advantages of the present invention more obvious and easier to understand, the present invention will be further described in detail with the attached drawings and specific embodiments.

Example 1

As shown in Figure 1, the optimal configuration method of battery energy storage system considering frequency stability and wind power uncertainty includes the following steps:

S1, analyzing the frequency response process of the gas turbines of the offshore isolated power grid to obtain the frequency response model of the offshore isolated power grid;

A further embodiment is that the method for obtaining the frequency response model of the offshore isolated power grid comprises the following steps:

obtaining the equivalent dynamic equation of the gas turbine, and obtaining the rotor motion equation of the gas turbine based on the equivalent dynamic equation;

based on the rotor motion equation, the frequency response model is obtained.

Among them, the frequency response model includes the frequency response model of offshore isolated power grid without battery energy storage system and the frequency response model with battery energy storage system.

S2, obtaining the minimum support power of the battery energy storage system based on the frequency response model and the frequency stability requirements of the offshore isolated power grid;

S3, collecting original wind power data, cleaning and interpolating the original wind power data to construct an effective wind power data set; A further embodiment is that the method for cleaning the wind power raw data comprises the following steps:

according to the physical characteristics of the wind turbines, cleaning rules are formulated, and the bottom stacked abnormal data of the original wind power data are eliminated to obtain first cleaning data;

Using the density-based noise space clustering method, the discrete abnormal data, LU507732 part of the bottom stacked abnormal data with low stacking density and the central stacked abnormal data in the first processing data are removed to obtain the second cleaning data;

Using the quartile method, the remaining abnormal data in the second cleaning data are removed to obtain the wind power data set.

S4, based on the wind power data set, extracting typical wind power scenarios by adopting a GMM-Kmeans clustering method;

A further embodiment is characterized in that the method for extracting typical wind power scenarios by using GMM-Kmeans clustering method comprises the following steps:

training gaussian mixture model GMM based on wind power data set;

generating massive wind power scenarios based on the trained gaussian mixture model (GMM);

clustering wind power scenarios based on Kmeans method, and combining elbow method and silhouette value, the optimal clustering number is obtained;

based on the optimal cluster number and cluster center, the typical wind power scenarios in the massive wind power scenarios are extracted.

S5, based on the minimum support power and typical wind power scenarios, constructing an adaptive SOC based two-layer optimal configuration model of the battery energy storage system;

in a further embodiment, the method for constructing the adaptive SOC based two-layer optimal configuration model of the battery energy storage system comprises the following steps:

based on the carbon capture cost, wind curtailment cost, life cycle cost of battery energy storage system, fuel and operation and maintenance cost of gas turbine and the probability of typical wind power scenarios in a preset number, the total operation cost of offshore isolated power grid is obtained, and the total operation cost is taken as the objective function of the two-layer optimal configuration model of battery energy storage system;

evaluating the life of the battery energy storage system based on the discharge depth of the battery energy storage system to obtain the battery life;

based on the objective function, battery life and constraints, an adaptive SOC based two-layer optimal configuration model of battery energy storage system is obtained.

A further embodiment is that the constraints include power balance constraints,^{LU507732} adaptive SOC constraints, frequency stability constraints, battery energy storage system operation constraints and other constraints.

A further embodiment is that the adaptive SOC constraint is SOC_{min} , and SOC_{min} is the SOC lower limit of the battery energy storage system, and the constraint formula is as follows:

$$SOC_{min} \geq \max \left\{ SOC_{min,N} \quad \frac{P_{s,min} T_{sup}}{E_{bat}} \right\},$$

$SOC_{min,N}$ is the lower limit of SOC of battery energy storage system at rated discharge depth, $P_{s,min}$ is the minimum support power of battery energy storage system to meet the frequency stability requirements of offshore isolated power grid, E_{bat} is the minimum capacity of battery energy storage system, and T_{sup} is the duration for battery energy storage system to provide power support to maintain the frequency stability of offshore isolated power grid.

Frequency stability constraint:

$$P_{PCS} \geq P_{s,min}$$

Where P_{PCS} is the power conversion system (PCS) of battery energy storage system, which determines the upper limit of output power. P_{PCS} should be greater than $P_{s,min}$, so that battery energy storage system has enough capacity to output power to resist the lower frequency limit even under the most severe power disturbance.

S6, based on the two-layer optimal configuration model of the battery energy storage system, completing the optimal configuration of the energy storage system based on frequency stability and wind power uncertainty.

The further implementation is to use genetic algorithm to solve the upper model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system, and call CPLEX to solve the lower model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system.

Specifically, the solution process is as follows:

Step I: The minimum support power of battery energy storage system constitutes a part of the frequency stability constraint of the upper model. The typical wind power scenarios are obtained by GMM-Kmeans method which are input to the lower model.

Step II: Randomly generate the initial population, and each individual in the population represents the PCS power and capacity of battery energy storage system

StepIII: The population consists of binary numbers, which need to be decoded to obtain the PCS power and capacity of battery energy storage system. LU507732

StepIV: The PCS power and capacity of battery energy storage system are input into the lower model, and CPLEX solves the lower model. Determine the best operation plan and SOC of battery energy storage system through the lower model. The life cycle of battery energy storage system, fuel and operation and maintenance cost of generator, carbon capture cost and wind power curtailment cost will be input into the upper model.

StepV: The upper model calculates the life cycle cost of battery energy storage system and the total operating cost of offshore isolated power grid.

Step VI: If the evolution does not reach the upper limit, the upper model will evolve the population according to the total operating cost of offshore isolated power grid.

StepVII: Repeat StepsIII-VI–VI until the evolutionary upper limit is reached.

The above-mentioned embodiment is only a description of the preferred mode of the invention, and does not limit the scope of the invention. Under the premise of not departing from the design spirit of the invention, various modifications and improvements made by ordinary technicians in the field to the technical scheme of the invention shall fall within the protection scope determined by the claims of the invention.

CLAIMS

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1. An optimal configuration method of energy storage system considering frequency stability and wind power uncertainty, comprising the following steps:

analyzing the frequency response process of gas turbines in offshore isolated power grid, and obtaining the frequency response model of offshore isolated power grid;

based on the frequency response model and the frequency stability requirements of the offshore isolated power grid, the minimum support power of the battery energy storage system is obtained;

collecting original wind power data, and cleaning and interpolating the original wind power data to construct an effective wind power data set;

based on the wind power data set, a GMM-Kmeans clustering method is adopted to extract typical wind power scenarios;

based on the minimum support power and the typical wind power scenarios, an adaptive SOC based two-layer optimal configuration model of the battery energy storage system is constructed;

based on the two-layer optimal configuration model of the battery energy storage system, the optimal configuration of the energy storage system considering frequency stability and wind power uncertainty is completed.

2. The optimal configuration method of energy storage system considering frequency stability and wind power uncertainty according to claim 1, characterized in that the method for obtaining the frequency response model of offshore isolated power grid comprises:

obtaining an equivalent dynamic equation of the gas turbine, and obtaining a rotor motion equation of the gas turbine based on the equivalent dynamic equation;

obtaining the frequency response model based on the rotor motion equation;

wherein, the frequency response model comprises a frequency response model without battery energy storage system of an isolated offshore power grid and a frequency response model with battery energy storage system.

3. The optimal configuration method of energy storage system based on frequency stability and wind power uncertainty according to claim 1, characterized in that the method for extracting typical wind power scenarios by using GMM-Kmeans clustering method comprises:

training a gaussian mixture model GMM ; based on the wind power data set;

generating massive wind power scenarios based on the trained gaussian mixture model (GMM);

clustering the wind power scenarios based on Kmeans method, and combining elbow method and silhouette value to obtain the best clustering number;

based on the optimal cluster number and cluster center, the typical wind power scenarios in the massive wind power scenarios are extracted.

4. The optimal configuration method of energy storage system considering frequency stability and wind power uncertainty according to claim 1, characterized in that the method for constructing an adaptive SOC based two-layer optimal configuration model of battery energy storage system comprises:

based on the carbon capture cost, wind curtailment cost, life cycle cost of battery energy storage system, fuel and operation and maintenance cost of gas turbine and the probability of typical wind power scenarios in a preset number, the total operation cost of offshore isolated power grid is obtained, and the total operation cost is taken as an objective function of a two-layer optimal configuration model of battery energy storage system;

evaluating the life of the battery energy storage system based on the discharge depth of the battery energy storage system to obtain the battery life;

based on the objective function, the battery life and constraints, an adaptive SOC based two-layer optimal configuration model of the battery energy storage system is obtained.

5. The optimal configuration method of energy storage system considering frequency stability and wind power uncertainty according to claim 4, wherein the constraints include power balance constraints, adaptive SOC constraints, frequency stability constraints, battery energy storage system operation constraints and other constraints.

6. The optimal configuration method of energy storage system considering frequency stability and wind power uncertainty according to claim 5, wherein the adaptive SOC constraint is SOC_{min} , SOC_{min} is the lower limit of SOC of battery energy storage system, and the constraint formula is as follows:

$$SOC_{min} \geq \max \left\{ SOC_{min,N} \quad \frac{P_{s,min} T_{sup}}{E_{bat}} \right\},$$

$SOC_{min,N}$ is the lower limit of SOC of battery energy storage system at rated discharge depth, $P_{s,min}$ is the minimum support power of battery energy storage system to meet the frequency stability requirements of offshore isolated power grid, E_{bat} is the minimum capacity of battery energy storage system, and T_{sup} is the duration for battery energy storage system to provide power support to maintain the frequency stability of offshore isolated power grid.

7. The optimal configuration method of energy storage system considering frequency stability and wind power uncertainty according to claim 5, characterized in that genetic algorithm is used to solve the upper model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system, and CPLEX is called to solve the lower model of the adaptive SOC based two-layer optimal configuration model of battery energy storage system.

PATENTANSPRÜCHE

1. Ein Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft, das die folgenden Schritte umfasst:

Analysieren des Frequenzgangprozesses von Gasturbinen in einem isolierten Offshore-Stromnetz und Erhalten des Frequenzgangmodells des isolierten Offshore-Stromnetzes;

basierend auf dem Frequenzgangmodell und den Anforderungen an die Frequenzstabilität des isolierten Offshore-Stromnetzes wird die minimale Unterstützungsleistung des Batteriespeichersystems erhalten;

Sammeln der ursprünglichen Daten von Windkraft und Bereinigen und Interpolieren der ursprünglichen Daten von Windkraft, um einen effektiven Datensatz von Windkraft zu erhalten;

basierend auf dem Datensatz von Windkraft wird eine GMM-Kmeans-Clustermethode angewendet, um typische Windkraft-Senarien zu extrahieren;

basierend auf der minimalen Unterstützungsleistung und der typischen Windkraft-Senarien wird ein adaptives SOC-basiertes zweischichtiges optimales Konfigurationsmodell des Batteriespeichersystems erstellt;

basierend auf dem zweischichtigen optimalen Konfigurationsmodell des Batteriespeichersystems wird die optimale Konfiguration des Energiespeichersystems unter Berücksichtigung der Frequenzstabilität und der Unsicherheit von Windkraft abgeschlossen.

2. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 1, dadurch gekennzeichnet, dass das Verfahren zum Erhalten des Frequenzgangmodells eines isolierten Offshore-Stromnetzes Folgendes umfasst:

Erhalten einer äquivalenten dynamischen Gleichung der Gasturbine, und Erhalten einer Rotorbewegungsgleichung der Gasturbine auf der Grundlage der äquivalenten dynamischen Gleichung;

Gewinnen des Frequenzgangmodells auf der Grundlage der Rotorbewegungsgleichung; wobei das Frequenzgangmodell ein Frequenzgangmodell ohne Batteriespeichersystem eines isolierten Offshore-Stromnetzes und ein Frequenzgangmodell mit Batteriespeichersystem umfasst.

3. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 1, dadurch gekennzeichnet, dass das Verfahren zum Extrahieren typischer Windkraft-Szenarien unter Verwendung der GMM-Kmeans-Clustermethode Folgendes umfasst:

Trainieren eines Gaußschen Mischungsmodells GMM basierend auf dem Datensatz von Windkraft;

Erzeugen massiver Windkraft-Senarien basierend auf dem trainierten Gaußschen Mischungsmodell (GMM);

Clustering der Windkraft-Senarien basierend auf der Kmeans-Methode und Kombination von Ellbogenmethode und Konturenkoeffizienten, um die optimale Clusterzahl zu erhalten;

Extrahieren der typischen Windkraft-Senarien in den massiven Windkraft-Senarien basierend auf der optimalen Clusterzahl und dem Clusterzentrum.

4. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 1, dadurch gekennzeichnet, dass das Verfahren zur Erstellung eines adaptiven SOC-basierten zweischichtigen optimalen Konfigurationsmodells eines Batteriespeichersystems Folgendes umfasst:

basierend auf den Kosten für die Kohlenstoffabscheidung, den Kosten für die Windkraftbeschränkung, den Lebenszykluskosten des Batteriepeichersystems, den Kosten für Brennstoff und Betrieb und Wartung der Gasturbine und der Wahrscheinlichkeit typischer Windkraft-Senarien in einer vorgegebenen Anzahl, werden die Gesamtbetriebskosten des isolierten Offshore-Stromnetzes erhalten und die Gesamtbetriebskosten werden als eine Zielfunktion eines zweischichtigen optimalen Konfigurationsmodells des Batteriespeichersystems genommen;

Bewerten der Lebensdauer des Batteriespeichersystems auf der Grundlage der Entladetiefe des Batterie-Energiespeichersystems, um die Batterielebensdauer zu erhalten;

basierend auf der Zielfunktion, der Batterielebensdauer und der Beschränkungen wird ein adaptives SOC-basiertes zweischichtiges optimales Konfigurationsmodell des Batteriespeichersystems erhalten.

5. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 4, wobei die Beschränkungen Beschränkungen von Leistungsbilanz, adaptivem SOC, Frequenzstabilität, Batteriespeichersystem usw. umfassen.

6. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 5, wobei die adaptive SOC-Beschränkung SOC_{min} ist, SOC_{min} die untere Grenze des SOC des Batteriespeichersystems ist und die Beschränkungsformel wie folgt lautet:

$$SOC_{min} \geq \max \left\{ SOC_{min,N} \quad \frac{P_{s,min} T_{sup}}{E_{bat}} \right\}$$

$SOC_{min,N}$ ist die untere Grenze des SOC des Batteriespeichersystems bei Nennentladetiefe, $P_{s,min}$ ist die minimale Unterstützungsleistung des Batteriespeichersystems, um die Anforderungen an die Frequenzstabilität des isolierten Offshore-Stromnetzes zu erfüllen, E_{bat} ist die minimale Kapazität des Batteriespeichersystems, und T_{sup} ist die Dauer, für die das Batteriespeichersystem die Unterstützungsleistung zur Aufrechterhaltung der Frequenzstabilität des isolierten Offshore-Stromnetzes bereitstellt.

7. Das Verfahren zur optimalen Konfiguration eines Energiespeichersystems basierend auf Frequenzstabilität und Unsicherheit von Windkraft nach Anspruch 5, dadurch gekennzeichnet, dass ein genetischer Algorithmus verwendet wird, um das obere Modell des adaptiven SOC-basierten zweischichtigen optimalen Konfigurationsmodells des Batteriespeichersystems zu lösen, und CPLEX aufgerufen wird, um das untere Modell des adaptiven SOC-basierten zweischichtigen optimalen Konfigurationsmodells des Batteriespeichersystems zu lösen.

FIGURE

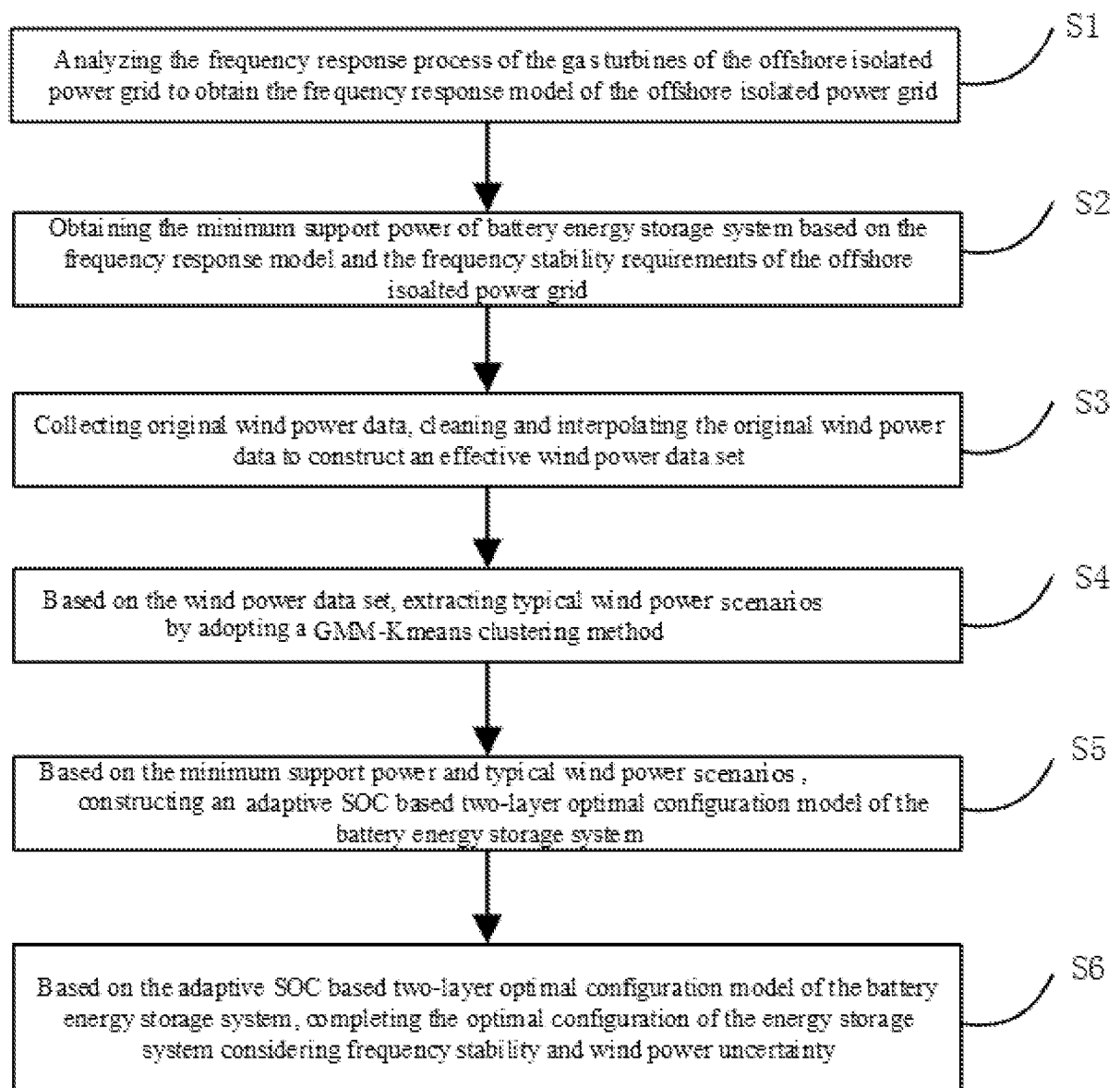


Fig. 1