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(54) **Titre : PROCEDE DE COMMANDE AUTOMATIQUE DU FLECHISSEMENT D'UN ONDULEUR DE MICRORESEAU BASE SUR L'ANALYSE DE LA STABILITE DES PETITS SIGNAUX**
(54) **Title: AUTOMATIC DROOP CONTROL METHOD FOR MICROGRIP INVERTERS BASES ON SMALL-SIGNAL STABILITY ANALYSIS**

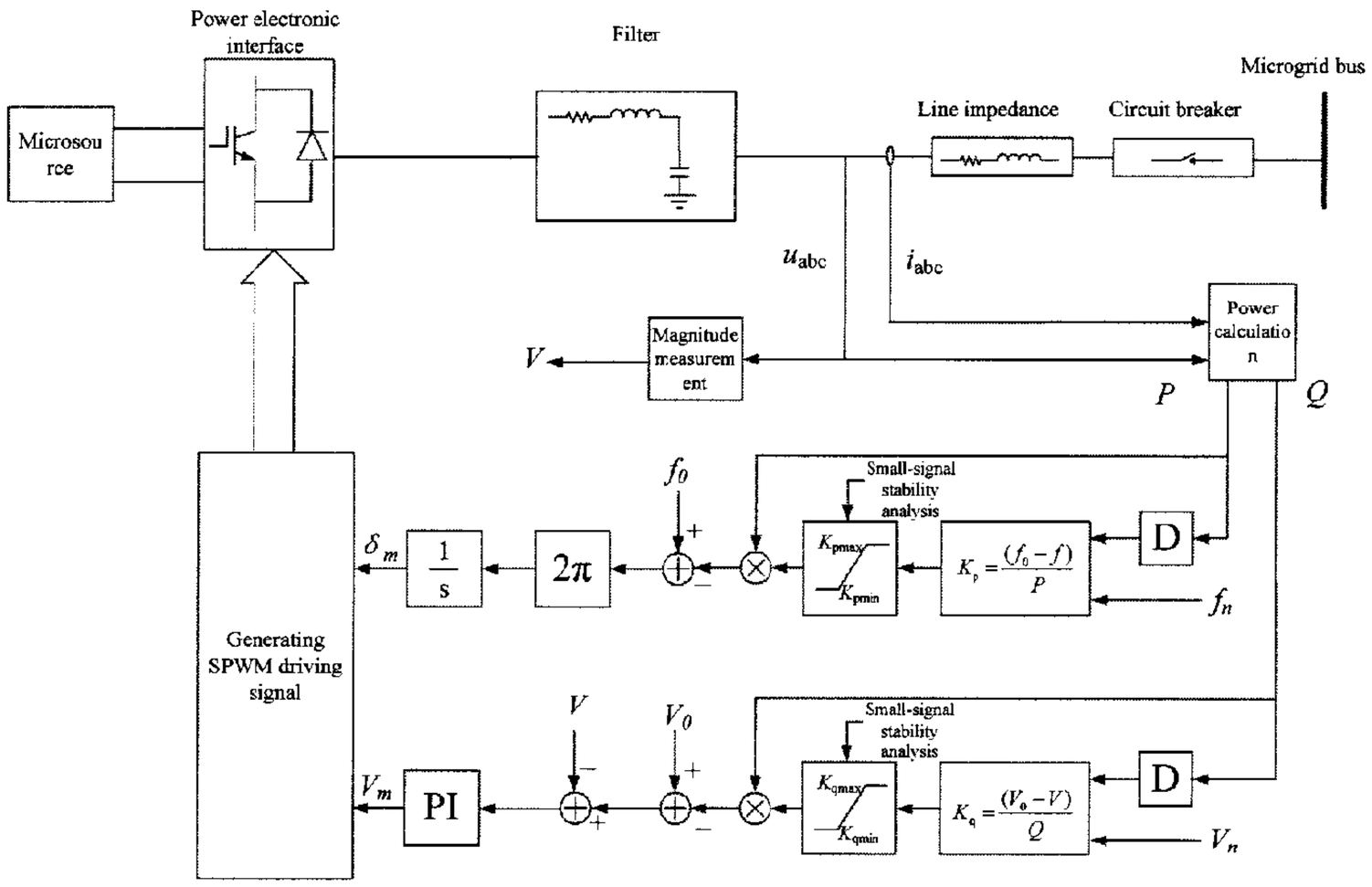

Fig. 8

(57) **Abrégé/Abstract:**
Disclosed is a microgrid inverter sagging automatic control method based on small-signal stability analysis. According to the control method, on the basis that the slope of a P-f sagging curve and the slope of the Q-V sagging curve are actively regulated, small-

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(57) **Abrégé(suite)/Abstract(continued):**
signal stability analysis is introduced, the feasibility of the slopes after the active regulation is verified, and no-deviating regulation of voltages and frequencies is implemented on the premise that the stability of a system is ensured. According to the present invention, for distributed generation under sagging control in an islanding state, the requirement of load changes is met by automatically regulating the slopes of the sagging curves and changing a reference active power value corresponding to a rated frequency in the sagging curves and a reference reactive power value corresponding to a rated voltage, and no-deviating frequency regulation and voltage regulation are implemented; the range of the slopes of the sagging curves allowed for stable operation of the system is obtained through the small-signal stability analysis, and when the sagging slopes are automatically regulated, the range needs to be met, and instability of the system caused by an operation of purely implementing the no-deviating frequency regulation and voltage regulation is avoided.

Abstract

The invention discloses an automatic droop control method for microgrid inverters based on small-signal stability analysis. On the basis of actively adjusting the slopes of P-f and Q-V droop curves, the control method introduces small-signal stability analysis to verify the feasibility of the actively adjusted slopes, thereby realizing no-deviating adjustment of voltage and frequency on the premise of guaranteeing system stability. For distributed power sources under droop control in an islanding status, the automatic droop control method for microgrid inverters based on small-signal stability analysis involves varying an active power reference value corresponding to a rated frequency and a reactive power reference value corresponding to a rated voltage in the droop curves by automatically adjusting the slopes of the droop curves, thus meeting the requirements of load changes and realizing no-deviating adjustment of frequency and voltage; besides, the slope ranges of the droop curves allowed by stable system operation are obtained through the small-signal stability analysis; the ranges should be satisfied during the automatic adjustment of the droop slopes so as to prevent system instability caused by unilateral realization of no-deviating adjustment of frequency and voltage.

AUTOMATIC DROOP CONTROL METHOD FOR MICROGRID INVERTERS BASED ON SMALL-SIGNAL STABILITY ANALYSIS

Field of the Invention

The invention relates to the field of microgrid control, and in particular to an automatic droop control method for microgrid inverters based on small-signal stability analysis.

Background of the Invention

With the advent of energy crisis and the development requirements of energy saving and emission reduction, microgrids using lots of renewable energy are developing rapidly. Distributed power sources in microgrids are connected to the power grid by means of power electronic devices. When the microgrids are decoupled from the large grid to be in an islanding status in case of failures of the large grid, the distributed power sources within the microgrid systems are required to provide voltage and frequency supports to the microgrid systems; this objective is achieved extensively by simulating synchronous power source characteristic droop control, such as P-f and Q-V droop control, P-V and Q-f droop control and the like. However, with regard to the determined droop curves, operating points vary correspondingly when loads change; thus, no-deviating adjustment of voltage and frequency cannot be realized.

The existing method involves actively adjusting the slopes of the droop curves when the load changes cause changes in voltage and frequency, i.e., changing the value of the rated power P_N corresponding to the rated frequency 50Hz in the P-f droop curve and the no-load voltage value in the Q-V droop curve, such that the voltage and the frequency of the system are recovered to the rated operating points to realize no-deviating adjustment. However, in this method, the limitations of constraint conditions of stable system operation to the droop slopes are not taken into account; therefore, the steady-state operating points after automatic adjustment may cause instability in system operation.

It is disclosed in invention patent (application No. 201210107053.4) an island power

grid control and optimization method based on coordinate-rotated virtual impedance, which intends to design, for complex impedance characteristics in actual microgrids, the coordinate-rotated virtual impedance by using coordinate-rotated orthogonal transformation to improve the impedance characteristics of the microgrids. However, this patent mainly aims at computational analysis on the steady-state operation of the microgrids and at optimization of the operation without considering the transient adjustment process of real-time fluctuation of new energy and loads of the microgrid systems within short time, and thus cannot realize no-deviating adjustment of voltage and frequency in the islanding microgrid systems.

Summary of the Invention

An objective of the present invention is to solve the above problem and provides an automatic droop control method for a microgrid inverter based on small-signal stability analysis. On the basis of actively adjusting the slopes of P-f and Q-V droop curves, the control method introduces small-signal stability analysis to verify the feasibility of the actively adjusted slopes, thereby realizing no-deviating adjustment of voltage and frequency on the premise of guaranteeing system stability.

In order to achieve the above objective, the present invention employs the following technical solutions:

An automatic droop control method for microgrid inverters based on small-signal stability analysis includes the following steps:

(1) providing voltage and frequency supports by distributed power sources: providing voltage and frequency supports by distributed power sources under droop control to an islanding microgrid, wherein the inverters are under P-f and Q-V control, i.e., adjusting a frequency of an output voltage of the inverters using active power and adjusting a magnitude of the output voltage of the inverters using reactive power; output characteristics of the inverters satisfy an active power-frequency droop characteristic curve and a reactive power-voltage droop characteristic curve;

(2) adjusting the droop curves: when a load change causes the frequency of the voltage to deviate from a rated value, automatically adjusting slopes of the droop

curves by an adjuster;

(3) analyzing and verifying: obtaining upper and lower limits of the slopes of the droop curves by means of small-signal stability analysis, and verifying whether the adjusted slopes are within an allowed range via calculation by a comparator;

(4) executing operations: if the adjusted slopes are between the upper and lower limits and fall into the allowed range, recovering a stable operating point of the inverters to a rated voltage by the adjuster; if the adjusted slopes exceed one of the upper and lower limits, setting the droop curves according to a limiting value closest to the adjusted slopes.

In the step (1), an equation of the active power-frequency droop characteristic curve, namely the P-f droop curve, is $f = f_0 - K_p P$, in which P represents the active power output by the inverters; f represents actual voltage frequency output by the inverters; f_0 represents a no-load system frequency; K_p represents the droop slope of the P-f curve. Besides, f_n is system rated frequency 50Hz and corresponds to an active power reference value P_n.

In the step (1), an equation of the reactive power-voltage droop characteristic curve, namely a Q-V droop curve, is $V = V_0 - K_q Q$, in which Q represents the reactive power output by the inverters; V represents the magnitude of an actual output voltage of the inverters; V_0 represents a no-load system voltage; K_q represents the droop slope of the Q-V curve.

In the step (2), the slope K_p of the P-f curve is derived from a curve equation: $K_p = (f_0 - f)/P$, and during working, K_p is changed to a coefficient K_{pi} generated in real time according to system operating parameters:

$$K_{pi} = \frac{f_0 - f_n}{P_{t-\Delta t}},$$

in which $P_{t-\Delta t}$ represents the active power output by the inverters at time (t-Δt).

When the active power of loads is invariant, a system frequency is $f=f_n$; when the active power of the loads increases at time t, the active power output by the inverters will increase to satisfy a system power balance; however, K_{pi} is calculated using the

active power $P_{t-\Delta t}$ of previous time Δt and thus kept unchanged, and the system frequency decreases; after a delay of time Δt, K_p starts to decrease until $P=P_n$. In other words, the active power reference value P_n corresponding to the rated frequency f_n in the P-f droop curve is increased by automatically decreasing the droop slope K_p, such that the frequency of the output voltage is still f_n even when the inverters generate more active power P. Nevertheless, the active power P output by the inverters cannot exceed a maximum P_{max} allowed by normal operation of the inverters.

In the step (2), the droop slope K_q of the Q-V curve is derived from a curve equation: $K_q = (V_0 - V)/Q$. When the reactive power of the loads is invariant, the voltage is within a system allowed range [V_{min}, V_{max}]; when the reactive power of the loads increases, the reactive power Q output by the inverters will increase to satisfy the system power balance; if the magnitude V of an outlet voltage exceeds [V_{min}, V_{max}], K_q is changed to a coefficient K_{qi} generated in real time according to the system operating parameters:

$$K_{qi} = \frac{V_0 - V_n}{Q_{t-\Delta t}}.$$

After a delay of time Δt, K_q starts to decrease until $Q=Q_n$. In other words, a reactive power reference value Q_n corresponding to a rated voltage V_n in the Q-V droop curve is increased by automatically decreasing the droop slope K_q, such that the magnitude of the output voltage is still kept within the range [V_{min}, V_{max}] even when the inverters output more reactive power Q. Nevertheless, the reactive power Q output by the inverters cannot exceed a maximum Q_{max} allowed by normal operation of the inverters.

In the step (3), the automatically adjusted slopes K_p, K_q of the droop curve satisfy the slope ranges [$K_{p\,min}$, $K_{p\,max}$], [$K_{q\,min}$, $K_{q\,max}$] of the droop curves obtained through the small-signal stability analysis. A microgrid system composed of the distributed power sources and the loads is described by n first-order nonlinear ordinary differential algebraic equations: , for an autonomous system: &y=f(x,u). Small disturbance is applied to the system and the equation is linearized into:

$$\&y = Ax + Bu, x(t_0) = x_0$$

$$y=Cx+Du,$$

in which A, B, C, D are coefficient matrices. By an automatic control theory, when the characteristic roots $\lambda=\sigma+j\omega$ of the matrix A have negative real parts, the system has damped oscillation and then recovers to be stable. When other variables of the system are determined, λ is a function of the droop coefficients K_p, K_q: $\lambda=f(Kp,Kq)$. The real part σ of λ is set below zero, and then the ranges $[K_{p\,min}, K_{p\,max}]$, $[K_{q\,min}, K_{q\,max}]$ of the slopes K_p, K_q of the droop curves are obtained.

The present invention has the following advantages:

for the distributed power sources under droop control in the islanding status, the active power reference value corresponding to the rated frequency and the reactive power reference value corresponding to the rated voltage in the droop curves are varied by automatically adjusting the slopes of the droop curves, thus meeting the requirements of the load changes and realizing no-deviating adjustment of frequency and voltage; besides, the slope ranges of the droop curves allowed by stable system operation are obtained through the small-signal stability analysis; the ranges should be satisfied during the automatic adjustment of the droop slopes so as to prevent system instability caused by unilateral realization of no-deviating adjustment of frequency and voltage.

Brief Description of the Drawings

Fig. 1 is a structure diagram of a microgrid system;

Fig. 2 is a Thevenin's equivalent circuit of two inverters connected in parallel;

Fig. 3 is a schematic diagram of a P-f droop curve;

Fig. 4 is a schematic diagram of a Q-V droop curve;

Fig. 5 is a schematic diagram of the P-f droop curve during K_p adjustment;

Fig. 6 is a schematic diagram of the Q-V droop curve during K_q adjustment;

Fig. 7 is a structure diagram of a microgrid example for small-signal stability analysis;

Fig. 8 is a control block diagram of the present control method;

Fig. 9 are result figures based on PSCAD/EMTDC simulation software.

In the drawings, a represents active power generated by distributed power sources in the microgrid; b represents reactive power generated by the distributed power sources; c represents the voltage of a microgrid bus; d represents the frequency of the microgrid system.

Detailed Description of the Embodiments

The present invention will be further described by combining the accompanying drawings with embodiments.

An automatic droop control method for microgrid inverters based on small-signal stability analysis comprises the following steps:

Step (1): distributed power sources under droop control provide voltage and frequency supports to an islanding microgrid. Specific operations are as shown in Fig. 1. As a general structure of the microgrid, the distributed power source DG1 is under droop control, while DG2 and DG3 are under PQ control. When the microgrid is in a grid-connected operation mode, DG1 is in a grid-connected constant power status under droop control. When the microgrid is decoupled from a power distribution network to be in an islanding status due to power distribution network failures or other reasons, DG1 provides the voltage and frequency supports to the microgrid system under droop control.

As shown in Fig. 2, the Thevenin's equivalent circuit of two inverters connected in parallel is illustrated. A relation between power and impedance transmitted on the line can be derived:

$$P_i = \frac{V_{0i}U_0}{Z_i}\cos(\theta_i - \delta_i) - \frac{U_0^2}{Z_i}\cos\theta_i \quad (1)$$

$$Q_i = \frac{V_{0i}U_0}{Z_i}\sin(\theta_i - \delta_i) - \frac{U_0^2}{Z_i}\sin\theta_i \quad (2)$$

The line impedance angle is very small and it thus can be considered approximately that $\sin\delta \approx \delta$ and $\cos\delta \approx 1$. If the output impedance of the inverters is controlled to

be inductive to keep the sum of the output impedance of the inverters and the line impedance still inductive, i.e., X□ R, Z≈jX, then the following equations can be obtained:

$$P_i = V_{0i}U_0\delta_i / X_i \quad (3)$$

$$Q_i = (V_{0i}U_0 - U_0^2) / X_i \quad (4)$$

Further, the droop characteristics of frequency and voltage may be obtained as follows:

$$f_i = f_0 - K_p P_i \quad (5)$$

$$V_i = V_0 - K_q Q_i \quad (6)$$

In other words, the frequency of the voltage across the ports of the inverters is approximately in a linear relation to active power, and the magnitude of the voltage is approximately in a linear relation to reactive power. Thus, P-f and Q-V droop characteristics are designed; the active power output by the inverters is adjusted to adjust the frequency, while the reactive power output by the inverters is adjusted to adjust the magnitude of the voltage.

As shown in Fig. 3, f_0 represents a no-load frequency; f_n represents the rated frequency 50Hz of the system and corresponds to the reference active power P_n in the *P-f* droop curve; f represents the frequency of the actual output voltage of the inverters and corresponds to the actual active power P output by the inverters; K_p represents the droop slope of the P-f curve:

$$K_p = \frac{(f_0 - f)}{P} \quad (7)$$

As shown in Fig. 4, V_0 therein represents a no-load voltage; V_{min} and V_{max} represent minimal and maximal voltages corresponding to the maximum reactive power output by the inverters and the maximum reactive power absorbed by the inverters, respectively; V represents the magnitude of the actual output voltage of the inverters and corresponding to the actual reactive power Q output by the inverters; K_q represents the droop slope of the Q-V curve:

$$K_q = \frac{(V_0 - V)}{Q} \quad (8)$$

Step (2): When a change of loads occurs, the slopes of the droop curves are adjusted to realize no-deviating adjustment of frequency and voltage.

When the active load of the microgrid increases, the active power P output by the DG1 will increase to satisfy power balance.

As can be seen from Fig. 3, when the active power output by DG1 increases, the frequency f of the output voltage will decrease. If the droop slopes are adjusted approximately, the operating point of DG1 can be translated back to the rated frequency f_n. Stated another way, as shown in Fig. 5, DG1 initially operates at point A in accordance with the droop curve 1; after the output active power increases, the frequency drops to f and DG1 operates at point B; the slope K_p of the droop curve is adjusted such that DG1 operates in accordance with the droop curve 2, and then the operating point turns to C and the output frequency is recovered to f_n.

When the reactive load of the microgrid increases, the reactive power Q output by DG1 will increase to satisfy power balance.

As can be seen from Fig. 4, the magnitude of the output voltage of DG1 will decrease and is prone to exceed the system allowed limit range [V_{min}, V_{max}]. If the droop slope is adjusted approximately, as shown in Fig. 6, DG1 initially operates in accordance with the droop curve 1, and has the minimal voltage value Vmin1 correspondingly when generating the maximum reactive power and the maximum voltage value V_{max1} correspondingly when absorbing the maximum reactive power. After the output reactive power increases, the magnitude of the output voltage decreases to exceed the system allowed range; then, the droop slope K_q is adjusted to result in an increase in the corresponding minimal voltage when the maximum reactive power is generated; as a result, the magnitude of the output voltage falls back into the allowed range.

Step (3): the above automatically adjusted slopes are verified using small-signal stability analysis.

Taking the microgrid shown in Fig. 7 as an example, the status equation of the system is established as follows:

$$\begin{bmatrix} & y_{INV} \\ i_{lineDQ} & \\ i_{loadDQ} & \end{bmatrix} = A_{mg} \begin{bmatrix} x_{INV} \\ i_{lineDQ} \\ i_{loadDQ} \end{bmatrix} (9),$$

in which

$$A_{mg} = \begin{bmatrix} A_{INV} + B_{INV} R_N M_{INV} C_{INVc} & B_{INV} R_N M_{NET} & B_{INV} R_N M_{load} \\ B_{1NET} R_N M_{INV} C_{INVc} + B_{2NET} C_{INV\omega} & A_{NET} + B_{1NET} R_N M_{NET} & B_{1NET} R_N M_{load} \\ B_{1LOAD} R_N M_{INV} C_{INVc} + B_{2LOAD} C_{INV\omega} & B_{1LOAD} R_N M_{NET} & A_{load} + B_{1LOAD} R_N M_{load} \end{bmatrix}$$

A_{mg} is the characteristic matrix of the system.

The characteristic roots of A_{mg} are solved with the real parts set to be negative, and then the stable ranges of the droop coefficients of the microgrid system are as follows:

$1.57\times10^{-5} < K_p < 1.90\times10^{-4}$

$3.17\times10^{-4} < K_q < 4.79\times10^{-3}$

Step (4): determination and adjustment setting: if the slopes are within the allowed ranges, no-deviating adjustment of frequency and voltage can be realized; or otherwise, the droop curves are set according to the allowed maximum or minimal slopes obtained through the small-signal stability analysis.

As shown in Fig. 8, a microsource is connected with a microgrid bus by means of the inverters, an LC filter and a line. The outlet voltage and current of the filter are measured to obtain the output active power, the output reactive power, and the magnitude and frequency of the voltage. D represents a delay link with a delay of a time interval t. The solving boxes of K_p and K_q are automatic solving processes for realizing no-deviating adjustment of frequency and voltage of the islanding microgrid; then, the small-signal stability analysis is performed to limit the magnitude. V represents the magnitude of the outlet voltage of the LC filter. PI represents a proportional-integral controller to improve the dynamic response characteristic of the magnitude of the voltage. V_m and δ_m represent a space vector magnitude of three-phase output phase voltage synthesis and a phase angle reference value required for SPWM (Sinusoidal Pulse Width Modulation), respectively.

During working, the active power and reactive power output by the inverters are measured. After a delay of time Δt, the automatically adjustable droop coefficients K_p,

K_q may be calculated. The system is modeled by the small-signal stability analysis, and then the slope ranges [$K_{p\ min}$, $K_{p\ max}$] and [$K_{q\ min}$, $K_{q\ max}$] of the droop curves capable of keeping the system stable may be calculated to limit the magnitudes of the previously calculated K_p, K_q. Reference voltage and frequency values for the inverters are calculated according to equations (5), (6) to further generate control pulses. As generation of the control pulses from the reference voltage and frequency is the prior art, it is not redundantly described herein.

PSCAD modeling is carried out on the microgrid as shown in Fig. 7, wherein DG1 is an energy storage system to which the automatic droop control method for the inverters with consideration to the small-signal stability analysis of the present patent is employed; DG2 is a photovoltaic power generation system to which constant power control may be employed within 12 seconds of simulation on the assumption of invariant illumination; DG3 is a wind power generation system to which constant power control may be employed within 12 seconds of simulation on the assumption of invariant wind speed.

At the fourth second, 10kW step pulse load is applied, and three distributed power sources output the active power, the reactive power, a bus voltage and a system frequency, as shown in Fig. 9.

As can be seen from Fig. 9, the automatic droop control method for the microgrid inverters based on the small-signal stability analysis has good adjustability: for the distributed power sources under droop control in the islanding status, the reference active power value corresponding to the rated frequency and the reference reactive power value corresponding to the rated voltage in the droop curves are varied by automatically adjusting the slopes of the droop curves, thus meeting the requirements of the load changes and realizing no-deviating adjustment of frequency and voltage; besides, the slope ranges of the droop curves allowed by stable system operation are obtained through the small-signal stability analysis; the ranges should be satisfied during the automatic adjustment of the droop slopes so as to prevent system instability caused by unilateral realization of no-deviating adjustment of frequency and voltage.

Although the specific embodiments of the present invention are described above in conjunction with the accompanying drawings, they are not limit to the protection scope of the present invention. It will be understood by those skilled in the art that various modifications or variations that can be made by those skilled in the art without creative work on the basis of the technical solution of the present invention still fall into the protection scope of the prevent invention.

Claims

1. An automatic droop control method for microgrid inverters based on small-signal stability analysis, comprising the following steps:

(1) providing voltage and frequency supports by distributed power sources: providing voltage and frequency supports by distributed power sources under droop control to an islanding microgrid, wherein the inverters are under P-f and Q-V control, i.e., adjusting a frequency of an output voltage of the inverters using active power and adjusting a magnitude of the output voltage of the inverters using reactive power; output characteristics of the inverters satisfy an active power-frequency droop characteristic curve and a reactive power-voltage droop characteristic curve;

(2) adjusting the droop curves: when a load change causes the frequency of the voltage to deviate from a rated value, automatically adjusting slopes of the droop curves by an adjuster;

(3) analyzing and verifying: obtaining upper and lower limits of the slopes of the droop curves by means of small-signal stability analysis, and verifying whether the adjusted slopes are within an allowed range via calculation by a comparator;

(4) executing operations: if the adjusted slopes are between the upper and lower limits and fall into the allowed range, recovering a stable operating point of the inverters to a rated voltage by the adjuster; if the adjusted slopes exceed one of the upper and lower limits, setting the droop curves according to a limiting value closest to the adjusted slopes;

wherein in the step (2), the slope K_p of a P-f curve is derived from a curve equation: $K_p = (f_0 - f)/P$, and during working, K_p is changed to a coefficient K_{pi} generated in real time according to system operating parameters:

$$K_{pi} = \frac{f_0 - f_n}{P_{t-\Delta t}},$$

in which $P_{t-\Delta t}$ represents the active power output by the inverters at time (t-Δt);

when the active power of loads is invariant, a system frequency is $f=f_n$; when the

active power of the loads increases at time t, the active power output by the inverters will increase to satisfy a system power balance; however, K_{pi} is calculated using the active power $P_{t-\Delta t}$ of previous time Δt and thus kept unchanged, and the system frequency decreases; after a delay of time Δt, K_p starts to decrease until $P=P_n$; in other words, an active power reference value P_n corresponding to a rated frequency f_n in the P-f droop curve is increased by automatically decreasing the droop slope K_p, such that the frequency of the output voltage is still f_n even when the inverters generate more active power P; nevertheless, the active power P output by the inverters cannot exceed a maximum P_{max} allowed by normal operation of the inverters.

2. The automatic droop control method for microgrid inverters based on small-signal stability analysis of claim 1, wherein in the step (1), an equation of the active power-frequency droop characteristic curve, namely the P-f droop curve, is $f = f_0 - K_p P$, in which P represents the active power output by the inverters; f represents an actual voltage frequency output by the inverters; f_0 represents a no-load system frequency; K_p represents the droop slope of the P-f curve; besides, f_n is system rated frequency 50Hz and corresponds to the active power reference value P_n.

3. The automatic droop control method for microgrid inverters based on small-signal stability analysis of claim 1, wherein in the step (1), an equation of the reactive power-voltage droop characteristic curve, namely a Q-V droop curve, is $V = V_0 - K_q Q$, in which Q represents the reactive power output by the inverters; V represents the magnitude of an actual output voltage of the inverters; V_0 represents a no-load system voltage; K_q represents the droop slope of the Q-V curve.

4. The automatic droop control method for microgrid inverters based on small-signal stability analysis of claim 1, wherein in the step (2), the droop slope K_q of the Q-V curve is derived from a curve equation: $K_q = (V_0 - V)/Q$; when the reactive power of the loads is invariant, the voltage is within a system allowed range $[V_{min}, V_{max}]$; when the reactive power of the loads increases, the reactive power Q output by the inverters will increase to satisfy the system power balance; if the magnitude V of an outlet voltage exceeds $[V_{min}, V_{max}]$, K_q is changed to a coefficient K_{qi} generated in real time

according to the system operating parameters:

$$K_{qi}=\frac{V_0-V_n}{Q_{t-\Delta t}}$$

after a delay of time Δt, K_q starts to decrease until $Q=Q_n$; in other words, a reactive power reference value Q_n corresponding to a rated voltage V_n in the Q-V droop curve is increased by automatically decreasing the droop slope K_q, such that the magnitude of the output voltage is still kept within the range $[V_{min}, V_{max}]$ even when the inverters output more reactive power Q; nevertheless, the reactive power Q output by the inverters cannot exceed a maximum Q_{max} allowed by normal operation of the inverters.

5. The automatic droop control method for microgrid inverters based on small-signal stability analysis of claim 1, wherein in the step (3), the automatically adjusted slopes K_p, K_q of the droop curve satisfy the slope ranges $[K_{p\,min}, K_{p\,max}]$, $[K_{q\,min}, K_{q\,max}]$ of the droop curves obtained through the small-signal stability analysis; a microgrid system composed of the distributed power sources and the loads is described by n first-order nonlinear ordinary differential algebraic equations: , for an autonomous system: &y=f(x,u); small disturbance is applied to the system and the equation is linearized into:

$$\&y = Ax + Bu, x(t_0) = x_0$$

$$y=Cx+Du$$

in which A, B, C, D are coefficient matrices; by an automatic control theory, when the characteristic roots $\lambda=\sigma+j\omega$ of the matrix A have negative real parts, the system has damped oscillation and then recovers to be stable; when other variables of the system are determined, λ is a function of the droop coefficients K_p, K_q: $\lambda=f(Kp,Kq)$; the real part σ of λ is set below zero, and then the ranges $[K_{p\,min}, K_{p\,max}]$, $[K_{q\,min}, K_{q\,max}]$ of the slopes K_p, K_q of the droop curves are obtained.

Drawings

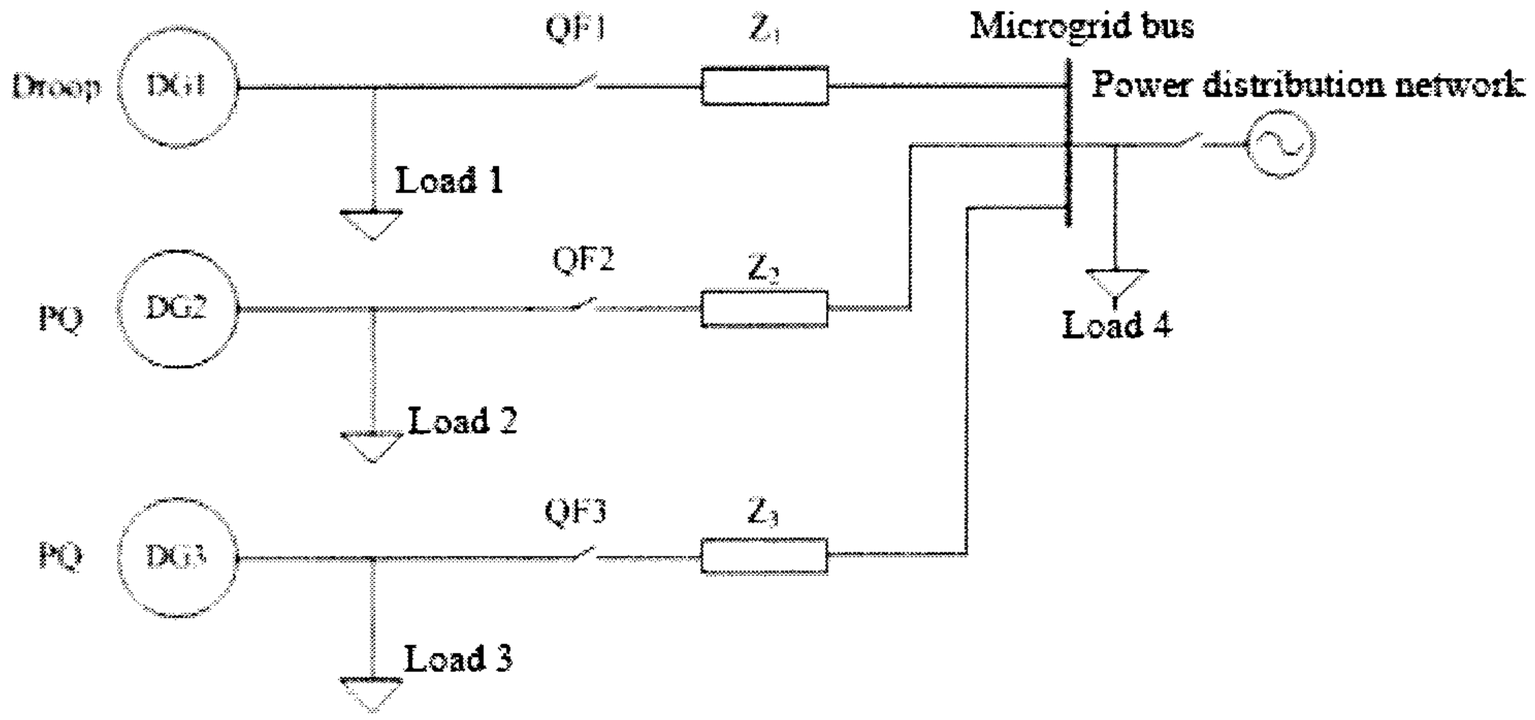

Fig. 1

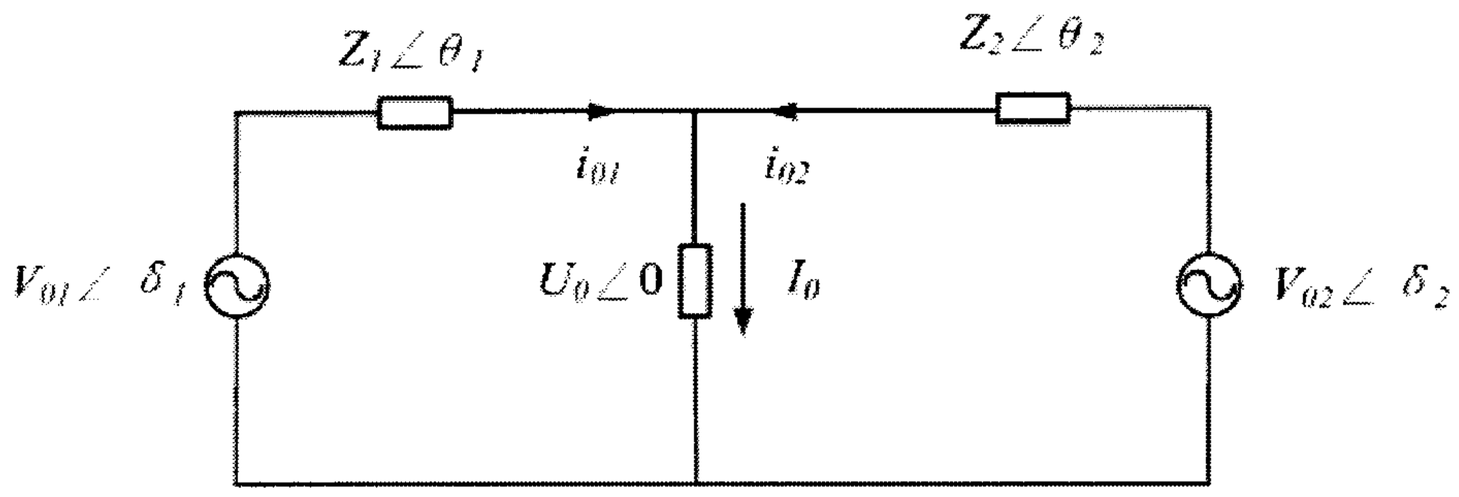

Fig. 2

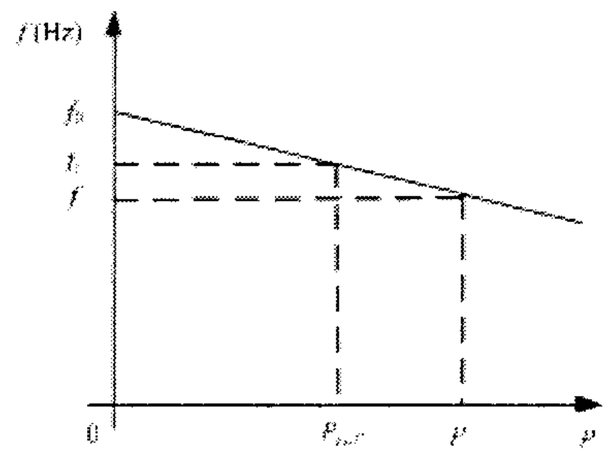

Fig. 3

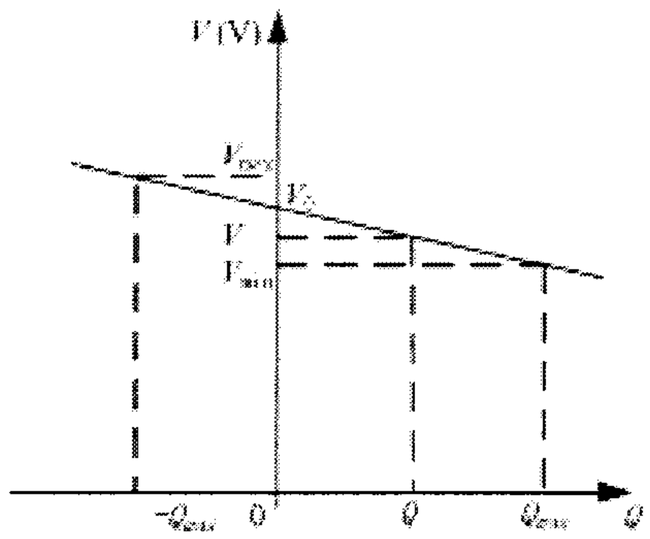

Fig. 4

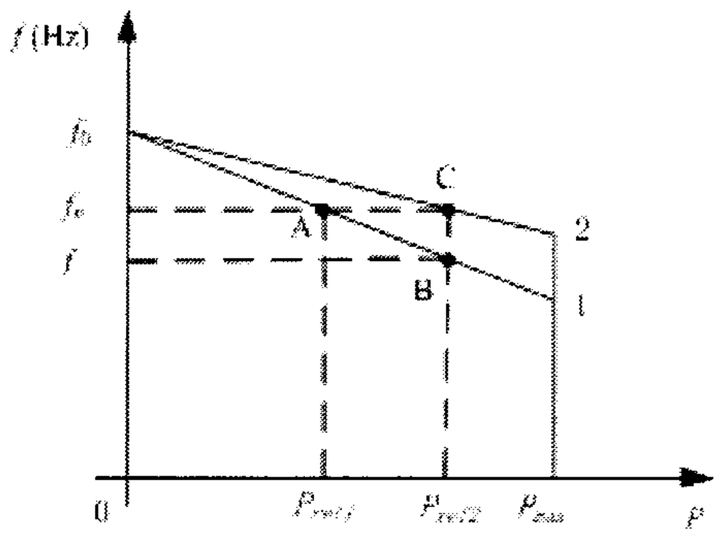

Fig. 5

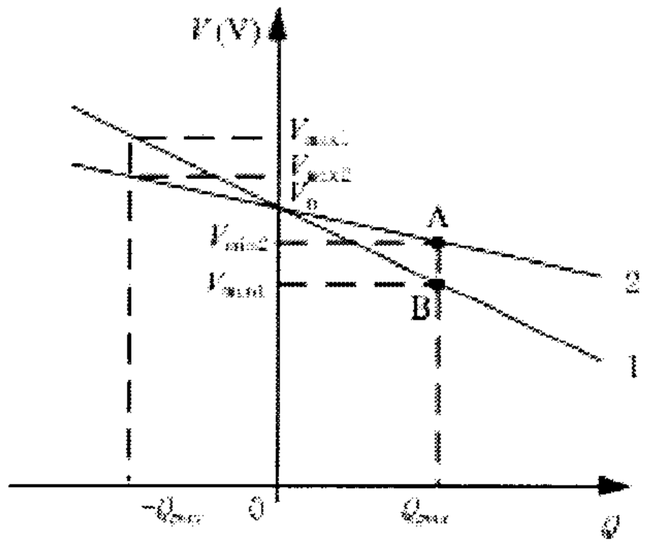

Fig. 6

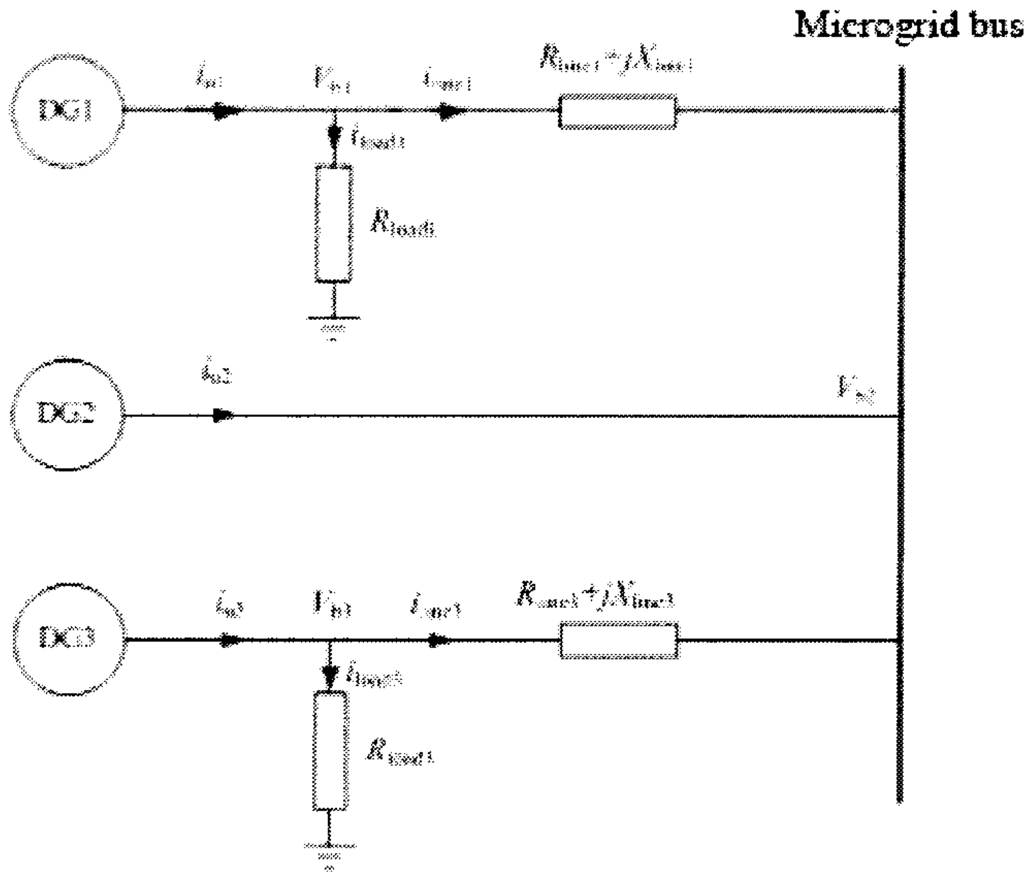
Microgrid bus
DG1
DG2
DG3

Fig. 7

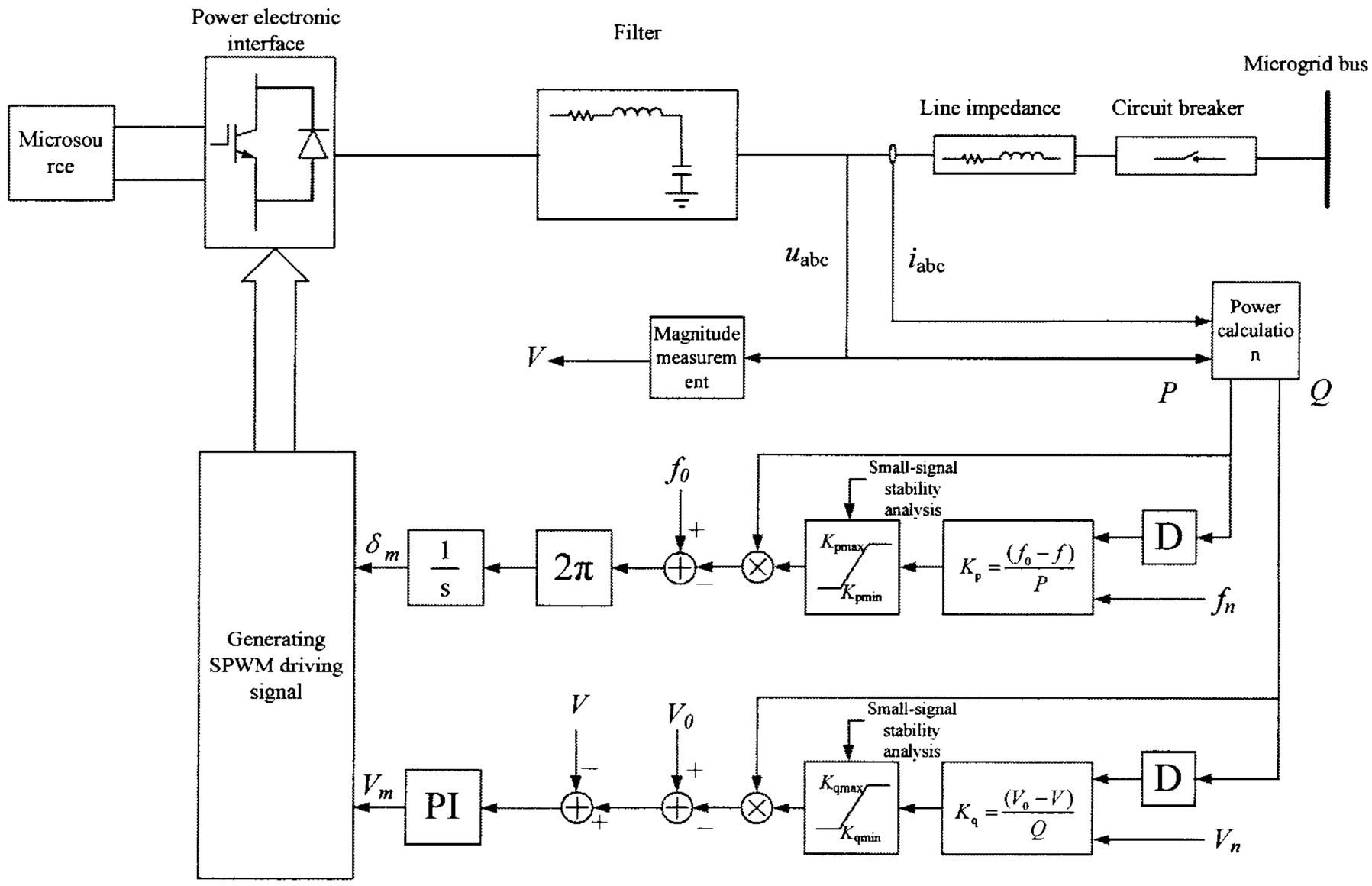
Power electronic interface
Filter
Microgrid bus
Microsou rce
Line impedance
Circuit breaker
u_{abc}
i_{abc}
Power calculatio n
Magnitude measurem ent
V
P
Q
f_0
Small-signal stability analysis
δ_m
1/s
2π
K_{pmax}
K_{pmin}
$K_p = \frac{(f_0 - f)}{P}$
D
f_n
Generating SPWM driving signal
V_0
K_{qmax}
K_{qmin}
$K_q = \frac{(V_0 - V)}{Q}$
V_m
PI
V_n

Fig. 8

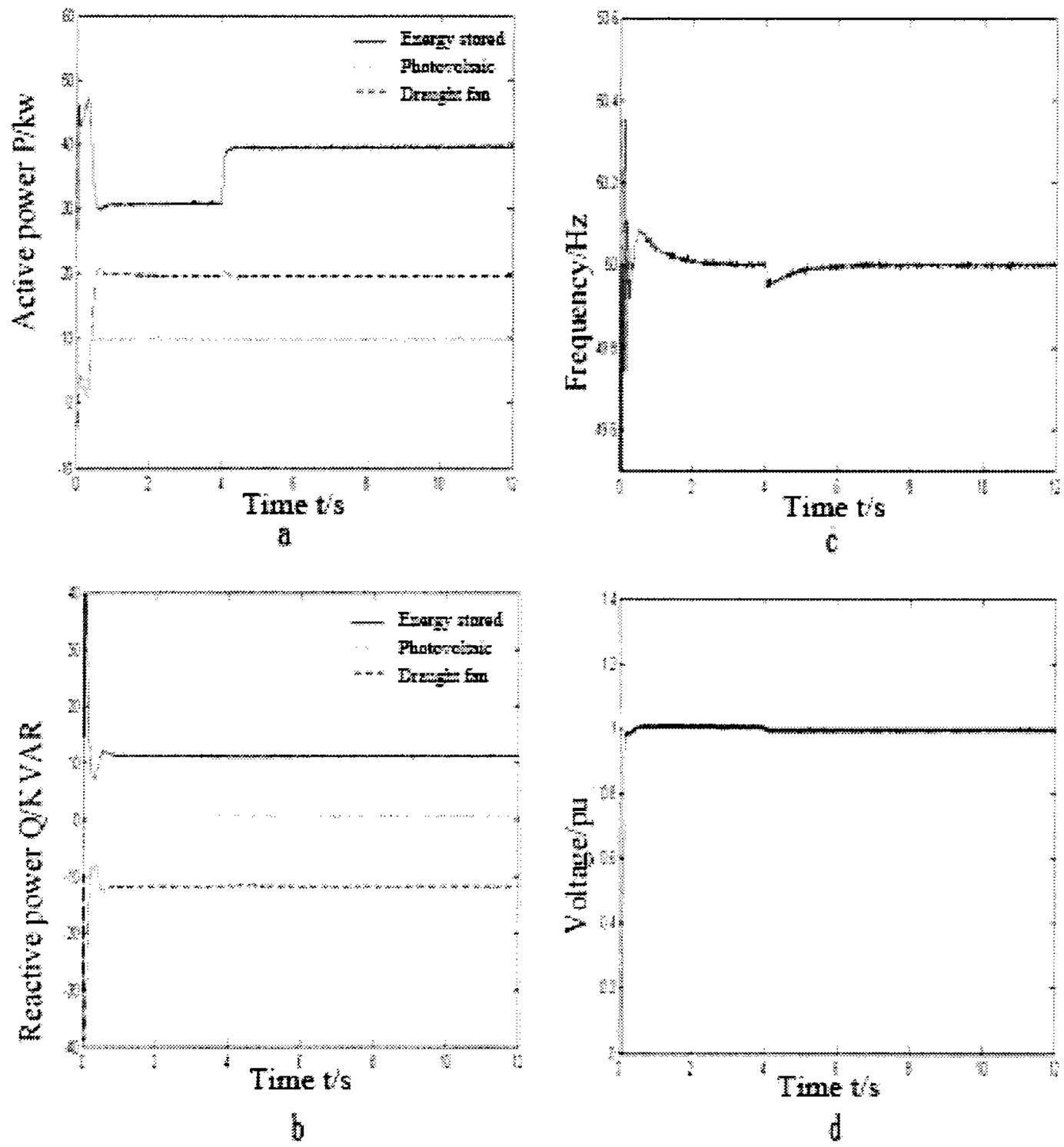
Energy stored
Photovoltaic
Draught fan
Active power P/kw
Time t/s
a
Frequency/Hz
Time t/s
c
Reactive power Q/KVAR
Time t/s
b
Voltage/pu
Time t/s
d

Fig. 9

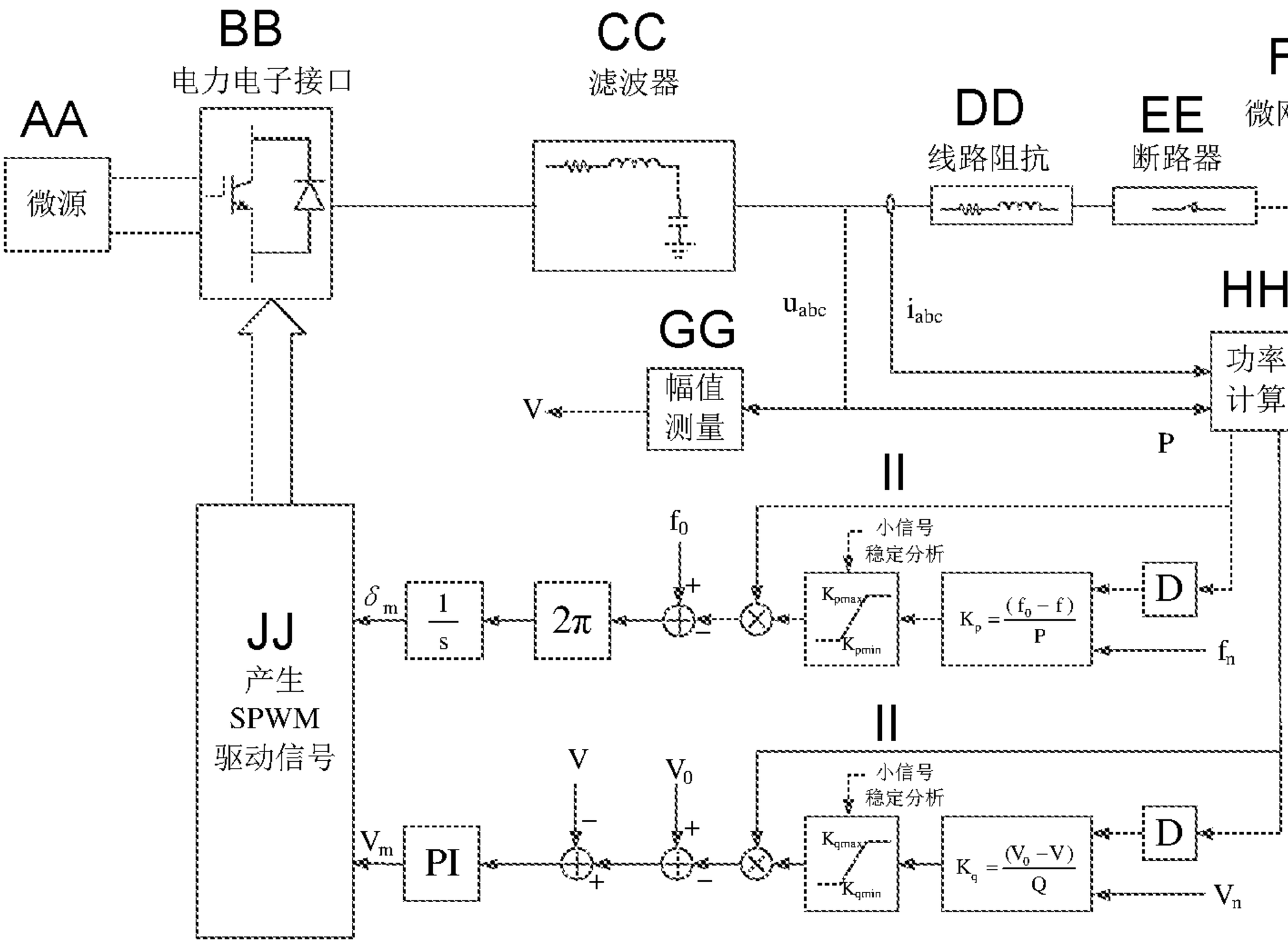

图 8 / Fig. 8

AA Microsource

BB Power electronic interface

CC Filter

DD Line impedance

EE Circuit breaker

FF Micronetwork bus

GG Amplitude measurement

HH Power calculation

II Small-signal stability analysis

JJ Generation of SPWM driving signal