

PHOTOVOLTAIC GRID-CONNECTED CONTROL DEVICE, SYSTEM, METHOD AND CONTROLLER

TECHNICAL FIELD

[0001] The present disclosure relates to the field of power electronics, and in particular, to a photovoltaic grid-connected control device, system, method and controller.

BACKGROUND

[0002] With the large-scale promotion of distributed photovoltaic power generation, photovoltaic power generation has caused severe challenges to the power and frequency stability of the power grid due to its shortcomings such as intermittent, random, and fluctuated power generation. In related technologies, the application of power springs to power systems can not only achieve voltage and frequency regulation, system power factor correction, and harmonic suppression to improve power quality, but also achieve objectives such as reducing power imbalance, reducing energy storage requirements, alleviating the three-phase unbalance of the power grid, and enhancing power system resilience.

[0003] Power springs can be widely distributed in any node in the power grid. As long as there is a noncritical load with a wide voltage range, it can be connected in series with a power spring

to form a smart load to ensure the stability of the critical load voltage.

[0004] However, in the related art, power springs are directly connected in series with noncritical loads, only having limited compensation capability or a limited range of compensation, and a poor effect of overvoltage suppression in the pure reactive power compensation mode. Moreover, the control goal of the existing power springs is to stabilize the grid-connected point voltage, which cannot adapt to the power regulation of photovoltaic grid-connected generation systems.

SUMMARY

[0005] A technical problem to be solved by the present disclosure is to provide a photovoltaic grid-connected control device, system, method and controller, which can ensure a relatively constant grid-connected active power of the entire topology.

[0006] According to an aspect of the present disclosure, there is provided a photovoltaic grid-connected control device, comprising a controller, and a voltage converter, an inverter and a low-pass filter that are cascaded in sequence, wherein: an input terminal of the voltage converter is configured to be connected to a photovoltaic device; an output terminal of the low-pass filter is configured to be connected to a grid, wherein a filter capacitor of the low-pass filter is configured to be connected in parallel with a noncritical load; and the controller is configured to control a switch driving signal of the inverter to adjust power of the noncritical load, so that a grid-connected active power output from the low-pass filter tracks a grid-connected active power reference value P_{g_ref} .

[0007] In some embodiments, the controller is configured to: control the switch driving signal of the inverter based on the grid-connected active power reference value P_{g_ref} , a first voltage signal v_g and a first current signal i_g at the output terminal of the low-pass filter, a second voltage signal V_{bus} and a voltage

reference value V_{bus_ref} on the DC bus side of the inverter, and an inductor value L_t of the low-pass filter.

[0008] In some embodiments, the controller is configured to: obtain a voltage component in a $\alpha\beta$ coordinate system based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g , the first current signal i_g , the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the inductor value L_t of the low-pass filter; obtain a feedforward component of grid voltage v_f according to the first voltage signal v_g and a feedforward function $G_{ff}(s)$; and obtain the switch driving signal according to the voltage component in the $\alpha\beta$ coordinate system and the feedforward component of grid voltage v_f .

[0009] In some embodiments, the controller is configured to: obtain a first current component I_d and a second current component I_q in a dq coordinate system according to the first voltage signal v_g and the first current signal i_g ; obtain a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system according to the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the grid-connected active power reference value P_{g_ref} ; obtain a first voltage component V_d and a second voltage component V_q in the dq coordinate system according to the first current component I_d , the second current component I_q , the first reference voltage value V_{d_ref} and the second reference

voltage value V_{q_ref} , and the inductor value L_t of the low-pass filter; and obtain a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system according to the first voltage component V_d and the second voltage component V_q .

[0010] In some embodiments, the controller is configured to: input the first voltage signal v_g to a phase locked loop (PLL) to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; obtain a β current component $i_{g_ \beta}$ in the $\alpha\beta$ coordinate system based on the β voltage component v_β , and the first voltage signal v_g ; and obtain the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g , the phase θ , and the β current component $i_{g_ \beta}$.

[0011] In some embodiments, the controller is configured to: input the first voltage signal v_g to a phase locked loop (PLL) to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; and obtain the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g and the phase θ .

[0012] In some embodiments, the controller is configured to: perform proportional integral (PI) control on a difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to

obtain a second reference current I_{q_ref} in the dq coordinate system; perform PI control on a difference between the second reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain the second reference voltage value V_{q_ref} ; divide the grid-connected active power reference value P_{g_ref} by the amplitude V_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system; and perform PI control on a difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter to obtain the first reference voltage value V_{d_ref} .

[0013] In some embodiments, the controller is configured to: according to the first current component I_d and the inductor value L_t of the low-pass filter, obtain a first voltage value V_{dt} corresponding to the inductor in the dq coordinate system; perform a difference operation between the second reference voltage value V_{q_ref} and the first voltage value V_{dt} to obtain the second voltage component V_q ; according to the second current component I_q and the inductor value L_t of the low-pass filter, obtain a second voltage value V_{qt} corresponding to the inductor in the dq coordinate system; and add the first reference voltage value V_{d_ref} to the second voltage value V_{qt} to obtain the first voltage component V_d .

[0014] In some embodiments, the low-pass filter is an LCL type

low-pass filter; the inverter is a single-phase inverter or a three-phase inverter; or the voltage converter is a Boost converter.

[0015] According to another aspect of the present disclosure, there is provided a photovoltaic grid-connected control system, comprising: a photovoltaic grid-connected control device described above; and a photovoltaic device.

[0016] According to still another aspect of the present disclosure, there is provided a control method of the photovoltaic grid-connected control device described above, comprising: obtaining a first voltage signal v_g and a first current signal i_g at an output terminal of a low-pass filter, and a second voltage signal V_{bus} on the DC bus side of an inverter; generating a switch driving signal of the inverter according to the first voltage signal v_g , the first current signal i_g , and the second voltage signal V_{bus} ; and controlling the switch driving signal of the inverter to adjust power of a noncritical load, so that a grid-connected active power output from the low-pass filter tracks a grid-connected active power reference value P_{g_ref} .

[0017] In some embodiments, generating the switch driving signal of the inverter comprises: generating the switch driving signal of the inverter based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g and the first current signal i_g at the output terminal of the low-pass filter, the second

voltage signal V_{bus} and a voltage reference value V_{bus_ref} on the DC bus side of the inverter, and an inductor value L_t of the low-pass filter.

[0018] In some embodiments, wherein generating the switch driving signal of the inverter comprises: obtaining a voltage component in a $\alpha\beta$ coordinate system based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g , the first current signal i_g , the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the inductor value L_t of the low-pass filter; obtaining a feedforward component of grid voltage v_f according to the first voltage signal v_g and a feedforward function $G_{ff}(s)$; and obtaining the switch driving signal according to the voltage component in the $\alpha\beta$ coordinate system and the feedforward component of grid voltage v_f .

[0019] In some embodiments, obtaining the voltage component in the $\alpha\beta$ coordinate system comprises: obtaining a first current component I_d and a second current component I_q in a dq coordinate system according to the first voltage signal v_g and the first current signal i_g ; obtaining a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system according to the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the grid-connected active power reference value P_{g_ref} ; obtaining a first voltage component V_d and a second voltage

component V_q in the dq coordinate system according to the first current component I_d , the second current component I_q , the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} , and the inductor value L_t of the low-pass filter; and obtaining a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system according to the first voltage component V_d and the second voltage component V_q .

[0020] In some embodiments, obtaining the first current component I_d and the second current component I_q in the dq coordinate system comprises: inputting the first voltage signal v_g to a PLL to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; obtaining a β current component $i_{g_ \beta}$ in the $\alpha\beta$ coordinate system based on the β voltage component v_β , and the first voltage signal v_g ; and obtaining the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g , the phase θ , and the β current component $i_{g_ \beta}$.

[0021] In some embodiments, obtaining the first current component I_d and the second current component I_q in the dq coordinate system comprises: inputting the first voltage signal v_g to a PLL to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; and obtaining the first current component I_d and the second current component I_q in the dq coordinate system

according to the first current signal i_g and the phase θ .

[0022] In some embodiments, obtaining the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} in the dq coordinate system comprises: performing PI control on a difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to obtain a second reference current I_{q_ref} in the dq coordinate system; performing PI control on a difference between the second reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain the second reference voltage value V_{q_ref} ; dividing the grid-connected active power reference value P_{g_ref} by the amplitude V_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system; and performing PI control on a difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter to obtain the first reference voltage value V_{d_ref} .

[0023] In some embodiments, obtaining the first voltage component V_d and the second voltage component V_q in the dq coordinate system comprises: obtaining a first voltage value V_{dt} corresponding to the inductor in the dq coordinate system according to the first current component I_d and the inductor value L_t of the low-pass filter; performing a difference operation between the second reference

voltage value V_{q_ref} and the first voltage value V_{dt} to obtain the second voltage component V_q ; obtaining a second voltage value V_{qt} corresponding to the inductor in the dq coordinate system according to the second current component I_q and the inductor value L_t of the low-pass filter; and adding the first reference voltage value V_{d_ref} to the second voltage value V_{qt} to obtain the first voltage component V_d .

[0024] According to still another aspect of the present disclosure, a controller is further provided, comprising: a memory; and a processor coupled to the memory, the processor configured to perform the control method described above based on instructions stored in the memory.

[0025] According to a still another aspect of the present disclosure, there is also provided a non-transitory computer readable storage medium having stored thereon computer program instructions which, when executed by a processor, implement the control method described above.

[0026] In the embodiments of the present disclosure, not only the power of noncritical loads can be adjusted in a wide range to absorb power fluctuations of photovoltaic power generation, but also inherent resonance peaks of the filter itself can be suppressed, so as to avoid the resonance instability of the grid connection system and reduce the grid connection harmonics,

ensuring that the grid-connected active power is relatively constant. Different from the goal of voltage stabilization, the control goal of the present disclosure is to achieve relatively constant photovoltaic grid connection power, which is more suitable for power generation and grid-connected applications, and can suppress the influence of photovoltaic power fluctuations at the source. In addition, by adjusting the impedance ratio of the noncritical load and the grid connection inductor, the present disclosure can adapt to grid scenarios with different impedance characteristics.

[0027] Other features and advantages of the present invention will become apparent from the following detailed description of exemplary embodiments of the present disclosure with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The accompanying drawings, which are incorporated in and constitute a portion of this specification, illustrate embodiments of the present disclosure and, together with the description, serve to explain the principles of the present disclosure.

[0029] The present disclosure will be more clearly understood from the following detailed description with reference to the accompanying drawings, in which:

[0030] FIG. 1 is a schematic structural diagram of a photovoltaic grid-connected control device according to some embodiments of the present disclosure;

[0031] FIG. 2A is a schematic structural diagram of a photovoltaic grid-connected control device according to other embodiments of the present disclosure;

[0032] FIG. 2B is a schematic structural diagram of a photovoltaic grid-connected control device according to still other embodiments of the present disclosure;

[0033] FIG.3 is a schematic curve diagram according to some embodiments of the present disclosure;

[0034] FIG.4 is a schematic curve diagram according to other embodiments of the present disclosure;

[0035] FIG. 5 is a schematic diagram of a grid-connected power tracking control model according to some embodiments of the present

disclosure;

[0036] FIG. 6 is a schematic diagram of a grid-connected power tracking control model according to other embodiments of the present disclosure;

[0037] FIG. 7 is a schematic flowchart of a control method of the photovoltaic grid-connected control device according to some embodiments of the present disclosure;

[0038] FIG. 8 is a schematic flowchart of a control method of the photovoltaic grid-connected control device according to other embodiments of the present disclosure;

[0039] FIG. 9 is a schematic flowchart of a control method of the photovoltaic grid-connected control device according to still other embodiments of the present disclosure;

[0040] FIG. 10 is a schematic flowchart of a control method of the photovoltaic grid-connected control device according to still other embodiments of the present disclosure; and

[0041] FIG. 11 is a schematic structural diagram of a controller according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0042] Various exemplary embodiments of the present disclosure will now be described in detail with reference to the accompanying drawings. Notice that, unless otherwise specified, the relative arrangement, numerical expressions and numerical values of the components and steps set forth in these examples do not limit the scope of the invention.

[0043] At the same time, it should be understood that, for ease of description, the dimensions of the various parts shown in the drawings are not drawn to actual proportions.

[0044] The following description of at least one exemplary embodiment is in fact merely illustrative and is in no way intended as a limitation to the invention, its application or use.

[0045] Techniques, methods, and apparatus known to those of ordinary skill in the relevant art may not be discussed in detail, but where appropriate, these techniques, methods, and apparatuses should be considered as part of the specification.

[0046] Of all the examples shown and discussed herein, any specific value should be construed as merely illustrative and not as a limitation. Thus, other examples of exemplary embodiments may have different values.

[0047] Notice that, similar reference numerals and letters are denoted by the like in the accompanying drawings, and therefore,

once an article is defined in a drawing, there is no need for further discussion in the accompanying drawings.

[0048] For a clear understanding of the object of the present disclosure, its technical solution and advantages, the present disclosure will be further described in detail below in conjunction with the accompanying drawings and embodiments.

[0049] The present disclosure can transfer power fluctuations of distributed photovoltaic power generation to noncritical loads, and reduce the impact on the power grid after grid connection.

[0050] FIG. 1 is a schematic structural diagram of a photovoltaic grid-connected control device according to some embodiments of the present disclosure. The device comprises a controller 1, and a voltage converter 2, an inverter 3 and a low-pass filter 4 that are cascaded in sequence.

[0051] The input terminal of the voltage converter 2 is configured to be connected to a photovoltaic device 5; the output terminal of the low-pass filter 4 is configured to be connected to a grid, wherein a filter capacitor of the low-pass filter 4 is configured to be connected in parallel with a noncritical load; the controller 1 is configured to control a switch driving signal of the inverter 3 to adjust the power of the noncritical load, so that the grid-connected active power output from the low-pass filter can track a grid-connected active power reference value.

[0052] In some embodiments, loads of end users of a distribution network can be divided into critical loads (CL) that are relatively sensitive to voltage fluctuations, and noncritical loads (NCL) that have a relatively large working voltage range. Noncritical loads widely exist in industrial loads such as electric arc furnaces, boilers, electric refrigerators and ice storage air conditioners, thermal comfort loads in buildings such as heating and cooling devices, and energy (such as electricity, gas, heat, and cold) storage devices.

[0053] In some embodiments, a photovoltaic device comprises a plurality of photovoltaic arrays.

[0054] In some embodiments, the voltage converter 2 is a Boost converter, the inverter 3 is a single-phase inverter or a three-phase inverter, and the low-pass filter 4 is an LCL type low-pass filter.

[0055] As shown in FIG. 2A, the voltage converter 2 comprises: a first capacitor C_{bus} , a diode D , a fifth switch K , and a first inductor L_i . A first terminal of the first capacitor C_{bus} is connected to a first input terminal of the inverter 3, and a second terminal of the first capacitor C_{bus} is connected to a second input terminal of the inverter 3. The cathode of the diode D is connected to the first terminal of the first capacitor C_{bus} . A first terminal of the fifth switch K is connected to the anode of the diode D ,

and a second terminal of the fifth switch K serving as a second input terminal of the voltage converter 2 is connected to the second terminal of the first capacitor C_{bus} . A first terminal of the first inductor L_i serves as a first input terminal of the voltage converter 2, and a second terminal of the first inductor L_i is connected to the anode of the diode D . The voltage converter 2 also comprises a second capacitor C_{pv} arranged between its first input terminal and second input terminal. The second capacitor C_{pv} is connected in parallel with a photovoltaic array 5.

[0056] Taking single-phase power as an example, the inverter 3 comprises a first switch S_1 , a second switch S_2 , a third switch S_3 and a fourth switch S_4 . A first terminal of the first switch S_1 is connected to a first terminal of the third switch S_3 , and a second terminal of the first switch S_1 serving as a first output terminal of the inverter 3 is connected to a first terminal of the second switch S_2 . A second terminal of the second switch S_2 is connected to a first terminal of the fourth switch S_4 , and a second terminal of the third switch S_3 serving as a second output terminal of the inverter 3 is connected to a second terminal of the fourth switch S_4 . The first terminal of the third switch S_3 serves as a first input terminal of the inverter 3, and the first terminal of the fourth switch S_4 serves as a second input terminal of the inverter 3.

[0057] The low-pass filter 4 comprises: a first inductor L_{ff} , a second inductor L_{gf} , and a filter capacitor C_f . A first terminal of the first inductor L_{ff} is connected to the first output terminal of the inverter 3, and a second terminal of the first inductor L_{ff} is connected to a first terminal of the second inductor L_{gf} . A second terminal of the second inductor L_{gf} serves as a first output terminal of the low-pass filter 4. A first terminal of the filter capacitor C_f is connected to the second terminal of the first inductor L_{ff} , and a second terminal of the filter capacitor C_f serves as a second output terminal of the low-pass filter 4 and is connected to the second output terminal of the inverter 3. A noncritical load R_{ncl} is connected in parallel between the two terminals of the filter capacitor C_f , and the two terminals of the low-pass filter 4 are connected to the grid at the grid-connected points L and N . The grid can be equivalent to a voltage source V_g at the grid-connected points.

[0058] In some embodiments, the noncritical load R_{ncl} , the first inductor L_{ff} , the second inductor L_{gf} , and the filter capacitor C_f constitute a LCL low-pass filter with passive damping for filtering out high frequency components in the output voltage of the inverter 3. The noncritical load R_{ncl} is connected in parallel with the filter capacitor C_f to form a passive damper of the LCL low-pass filter, which can suppress the frequency response resonance peaks of the

LCL low-pass filter, so as to prevent resonance with the power system in the process of connecting to the grid, as well as system instability resulted from the resonance; moreover, it can also be used to form a key topology structure that, under the action of a control method, can automatically adjust the noncritical load power to absorb power fluctuations of photovoltaic power generation, so as to ensure that the grid-connected active power is relatively constant.

[0059] Taking three-phase power as an example, as shown in FIG. 2B, in which the voltage converter 2 is not shown, the inverter 3 comprises a first switch S1, a second switch S2, a third switch S3, a fourth switch S4, a fifth switch S5 and a sixth switch S6. A first terminal of the first switch S1 is connected to a first terminal of the third switch S3 and a first terminal of the fifth switch S5; and a second terminal of the first switch S1 serving as a first output of the inverter 3 is connected to a first terminal of the second switch S2. A second terminal of the third switch S3 serving as a second output terminal of the inverter 3 is connected to a first terminal of the fourth switch S4; and a second terminal of the fifth switch S5 serving as a third output terminal of the inverter 3 is connected to a first terminal of the sixth switch S6. The second terminal of the second switch S2 is connected to the second terminal of the fourth switch S4 and the second terminal of

the sixth switch S6. The first terminal of the first switch S1 serves as a first input terminal of the inverter 3, and the second terminal of the second switch S2 serves as a second input terminal of the inverter 3.

[0060] The low-pass filter 4 comprises: a first inductor L_{ff} , a second inductor L_{gf} , and a filter capacitor C_f . Since this embodiment involves three-phase power, there are three first inductors L_{ff} , second inductors L_{gf} , and filter capacitors C_f that are arranged on three lines, respectively. The first inductors L_{ff} are respectively connected to the three output terminals of the inverter 3 through three-phase lines. One terminal of each of the second inductors L_{gf} is connected to a first inductor L_{ff} on a corresponding phase line, and the other terminal is connected to the grid side. The filter capacitor C_f is arranged between the first inductor L_{ff} and the second inductor L_{gf} , and is connected in parallel with a noncritical load R_{ncl} on each phase line.

[0061] Those skilled in the art should understand that the structure of the voltage converter, the inverter and the low-pass filter illustrated in the above embodiment is only an example, and many other structures of the voltage converter, the inverter and the low-pass filter are also possible.

[0062] The circuit topology structure of the present disclosure, in a design of reasonable structural configuration, can increase

the range of a noncritical load to absorb photovoltaic power fluctuations, which will be introduced in detail below.

[0063] In some embodiments, taking a direction in which the grid connection current flows out of the grid-connected point as a reference direction, according to Kirchhoff's voltage law, the grid-connected point voltage phasor V_g , the grid-connected point current phasor I_g of the current flowing through the second inductor L_{gf} , and terminal voltage phasor V_{ncl} of the noncritical load satisfy a phasor relationship: $V_{ncl} = V_g - I_g \cdot j\omega L_{gf}$. According to the cosine law, a RMS voltage V_{ncl} of noncritical load can be obtained: $V_{ncl} = \sqrt{(I_g \omega L_{gf})^2 + V_g^2 - 2I_g V_g \omega L_{gf} \cos(0.5\pi + \varphi)}$, where ϕ is the phase at which I_g lags v_g .

[0064] Neglecting other losses of the system, the output power of the photovoltaic array 5 is equal to the output power of the voltage converter 2, equal to the output active power of the single-phase inverter 3, that is, equal to the input power of the low-pass filter 4. Taking $S_n = \frac{V_g^2}{R_{ncl}}$ as a power reference value, the per-unit value P_{ncl}^* of the power of the noncritical load, the per-unit value P_g^* of the grid-connected active power, and the per-unit value Q_g^* of the grid connection reactive power, and the per-unit value P_{pv}^* of the output power of the photovoltaic power generation system satisfy a relationship: $P_{pv}^* = P_g^* - P_{ncl}^* = P_g^* - [1 + a^2(P_g^{*2} + Q_g^{*2}) + 2aQ_g^*]$, where $a = \omega L_{gf}/R_{ncl}$.

[0065] It can be deduced from the above formula that when the photovoltaic power P_{pv}^* fluctuates, through adjusting the grid-connected reactive power Q_g^* according to a reasonable control method, the grid-connected active power P_g^* can be guaranteed to be constant. The grid-connected reactive power Q_g^* correlates to the per-unit value P_{ncl}^* of the power of the noncritical load, that is to say, through adjusting the power of the noncritical load, the grid-connected active power of the entire topology can be relatively constant.

[0066] In addition, according to the relationship between the per-unit value P_{ncl}^* of the power of the noncritical load, the per-unit value P_g^* of grid-connected active power, the per-unit value Q_g^* of grid-connected reactive power, and the per-unit value P_{pv}^* of the output power of the photovoltaic power generation system shown in the curve surface diagrams of FIGS. 3 and 4 as an example, when the parameter a (i.e., a ratio of the inductive impedance L_{gf} of the grid-connected inductor and the noncritical load R_{ncl}) changes within a certain range, the power relationship surface characteristics of the system can be changed. When the parameter a is 1, in order to ensure that the active power is constant at 1, the reactive power range is -0.5 to 1.5, which corresponds to a range of 0 to 8 of photovoltaic power fluctuations that can be suppressed. When the parameter a is 1.2, the range of photovoltaic

power fluctuations that can be suppressed is 0 to 20. With the increase of a , the ability to suppress photovoltaic power fluctuations becomes stronger. However, due to the limitation of grid-connected impedance, a cannot be increased indefinitely. For a series-type power spring, since the sum of the inverter output voltage and the noncritical load voltage is equal to the grid-connected voltage, its active and reactive characteristics are fixed, and its active power and reactive power cannot be changed by adjusting a parameter such as a . Compared with the series relationship of a power spring, the present disclosure can improve the range of photovoltaic power fluctuations that can be absorbed by a noncritical load through a reasonable configuration of a in design. In addition, by adjusting the impedance ratio of the noncritical load and the grid-connected inductor, the ratio of active power and reactive power can be adjusted, thereby adapting to grid scenarios with different impedance characteristics.

[0067] In some embodiments of the present disclosure, the controller 1 is configured to control a switch driving signal of the inverter 3 based on a grid-connected active power reference value P_{g_ref} , a first voltage signal v_g and a first current signal i_g at the output of the low-pass filter 4, a second voltage signal V_{bus} and a voltage reference value V_{bus_ref} on the DC bus side of the inverter 3, and an inductor value L_t of the low-pass filter 4. By

turning on and off the switch of the inverter 3, the current output by the low-pass filter 4 can be adjusted, thereby adjusting the power of the noncritical load, so that the grid-connected active power output by the low-pass filter 4 tracks the grid-connected active power reference value.

[0068] In some embodiments, for single-phase power, as shown in FIG. 5, the controller 1 is configured to obtain a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system based on a grid-connected active power reference value P_{g_ref} , a first voltage signal v_g , a first current signal i_g , a second voltage signal V_{bus} , a voltage reference value V_{bus_ref} , and an inductor value L_t of the low-pass filter; obtain a feedforward component of grid voltage v_f according to the first voltage signal v_g and a feedforward function $G_{ff(s)}$; and obtain a switch driving signal according to the α voltage component v_α and the feedforward component of grid voltage v_f . The inductor value L_t is equal to the sum of the inductance value L_{ff} of the first inductor and the inductance value L_{gf} of the second inductor. The feedforward function $G_{ff(s)}$ is $\frac{1}{K_{PWM}} + \frac{L_{gf}s}{(K_{PWM}R_{ncl})} + \frac{L_{gf}C_f s^2}{K_{PWM}}$. The purpose of setting the feedforward function is to eliminate the influence of the grid-connected voltage $v_g(s)$ on the current $I_g(s)$.

[0069] In some embodiments, a first current component I_d and a second current component I_q in the dq coordinate system are obtained

according to a first voltage signal v_g and a first current signal i_g .

[0070] For example, as shown in FIG. 5, the first voltage signal v_g is input to a phase locked loop (PLL) to obtain an amplitude v_g , a phase θ and a fundamental frequency ω of grid-connected voltage; a β current component $i_{g\beta}$ in the $\alpha\beta$ coordinate system is obtained based on a β voltage component v_β , and the grid voltage amplitude V_g ; a first current component I_d and a second current component I_q in the dq coordinate system are obtained according to the first current signal i_g , the phase θ and the β current component $i_{g\beta}$.

[0071] In some embodiments, the first current component I_d and the second current component I_q in the dq coordinate system are obtained using a fictitious axis emulator (FAE) and coordinate transformation. In the phase-locked loop, let the grid-connected voltage v_g be a α -axis component $v_{g\alpha}=V_g\cdot\sin\theta$, a β -axis component $v_{g\beta}=V_g\cdot\sin(\theta-\pi/2)$ with a phase lag of $\pi/2$ can be obtained. In the FAE, a β -axis main circuit composed of an inverter, a low-pass filter and a noncritical load in the topology is simulated by a s-function, wherein a delay function e^{-T} is used to simulate the modulation delay effect of the inverter, and K_{pwm} is a modulation scale factor. After a modulation signal v_β and a β -axis grid voltage signal $v_{g\beta}$ are input to the FAE, the β -axis component $i_{g\beta}$ of the grid-connected current can be obtained. After transformation from the $\alpha\beta$ stationary coordinate system to the dq rotating coordinate system

(the rotational angular velocity is θ), i_{g_α} and i_{g_β} can be converted into d-axis component I_d and q-axis component I_q . In the above steps, the AC signal is converted into a DC static component, which can facilitate subsequent control operations.

[0072] In some embodiments, a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system are obtained according to a second voltage signal V_{bus} , a voltage reference value V_{bus_ref} , and a grid-connected active power reference value P_{g_ref} .

[0073] For example, as shown in FIG. 5, PI (Proportional Integral) control is performed on the difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to obtain a second reference current I_{q_ref} in the dq coordinate system; PI control is performed on the difference between the second reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain a second reference voltage value V_{q_ref} ; the grid-connected active power reference value P_{g_ref} is divided by the grid-connected voltage amplitude V_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system; PI control is performed on the difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter

to obtain the first reference voltage value V_{d_ref} . The holder is, for example, a zero-order holder.

[0074] In some embodiments, a first voltage component V_d and a second voltage component V_q in the dq coordinate system are obtained according to the first current component I_d , the second current component I_q , the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} , and the inductor value L_t of the low-pass filter; According to the first voltage component V_d and the second voltage component V_q , a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system are obtained.

[0075] For example, as shown in FIG. 5, according to the first current component I_d and the inductor value L_t of the low-pass filter, a first voltage value $V_{dt}=\omega I_d(L_{gf}+L_{ff})$ corresponding to the inductor in the dq coordinate system is obtained; a difference operation between the second reference voltage value V_{q_ref} and the first voltage value V_{dt} is performed to obtain a second voltage component V_q ; according to the second current component I_q and the inductor value L_t of the low-pass filter, a second voltage value $V_{qt}=\omega I_q(L_{gf}+L_{ff})$ corresponding to the inductor in the dq coordinate system is obtained; the first reference voltage value V_{d_ref} is added to the second voltage value V_{qt} to obtain a first voltage component V_d .

[0076] Coordinate transformation is performed on the first voltage component V_d and the second voltage component V_q to obtain a α

voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system. a switch driving signal is obtained according to the α voltage component v_α and the feedforward component of grid voltage v_f .

[0077] In the above embodiment, according to a grid-connected active power reference value P_{g_ref} , a first voltage signal v_g and a first current signal i_g at the output of the low-pass filter, a second voltage signal V_{bus} and a voltage reference value V_{bus_ref} at the DC bus side of the inverter, and an inductor value L_t of the low-pass filter, a switch driving signal of the inverter is controlled, so as to adjust the current output by the low-pass filter, and in turn the power of the noncritical load, so that the grid-connected active power output by the low-pass filter can track the grid-connected active power reference value. Different from the goal of voltage stabilization, the control goal of the present disclosure is to achieve relatively constant photovoltaic grid-connected power, which is more suitable for power generation and grid-connected applications, and can suppress the influence of photovoltaic power fluctuations at the source.

[0078] For three-phase power, as shown in FIG. 6, similar to single-phase power, the part before the first reference current I_{d_ref} and the second reference current I_{q_ref} is not shown, the controller 1 is configured to obtain voltage components v_{g_alpha} and v_{g_beta}

in the $\alpha\beta$ coordinate system based on a grid-connected active power reference value P_{g_ref} , a first voltage signal v_g , a first current signal i_g , a second voltage signal V_{bus} , a voltage reference value V_{bus_ref} , and an inductor value L_t of the low-pass filter; obtain a feedforward component of grid voltage v_f based on the voltage signal v_g and a feedforward function $G_{ff(s)}$; and obtain a switch driving signal according to the voltage components v_{g_a} and v_{g_b} and the feedforward component of grid voltage v_f . The inductor value L_t is equal to the sum of the inductance value L_{ff} of a first inductor and the inductance value L_{gf} of a second inductor. Since this embodiment is a three-phase power embodiment, the β current component i_{g_b} is not required when a first current component I_d and a second current component I_q are obtained. That is, according to a first current signal i_g and a phase θ , a first current component I_d and a second current component I_q in the dq coordinate system are obtained. H_i and H_v in FIG. 6 are current and voltage sampling coefficients, respectively. For three-phase power, the first current signal i_g comprises i_{g_a} , i_{g_b} and i_{g_c} , and the first voltage signal v_g comprises v_{g_a} , v_{g_b} and v_{g_c} . After the first voltage signal v_g is sampled and coordinate-transformed, voltage values v_{g_a} and v_{g_b} in the $\alpha\beta$ coordinate system can be obtained.

[0079] In other embodiments of the present disclosure, a photovoltaic grid-connected control system is also protected, the

system including photovoltaic devices and the photovoltaic grid-connected control device described in the above embodiment. As shown in FIG. 2A, the DC input terminal of a voltage converter is cascaded with photovoltaic devices. With this architecture, the noncritical load power is adjusted to absorb power fluctuations of photovoltaic power generation and ensure that the grid-connected active power is relatively constant. In addition, the circuit topology of the present disclosure does not require an energy storage device, which can weaken the dependence of photovoltaic power generation on energy storage, reduce the increase in the overall cost of energy storage, facilitate the promotion of distributed photovoltaics in distribution networks, and has significant practical value. Moreover, the circuit topology of the present disclosure itself does not consume additional active power.

[0080] FIG. 7 is a schematic flowchart of a control method of the photovoltaic grid-connected control device according to some embodiments of the present disclosure.

[0081] In step 710, a first voltage signal v_g and a first current signal i_g at the output terminal of a low-pass filter, and a second voltage signal V_{bus} on the DC bus side of an inverter are acquired.

[0082] In step 720, a switch driving signal is generated for the inverter according to the first voltage signal v_g , the first current signal i_g , and the second voltage signal V_{bus} .

[0083] In some embodiments of the present disclosure, the switch driving signal is generated for the inverter based on a grid-connected active power reference value P_{g_ref} , the first voltage signal v_g and the first current signal i_g at the output of the low-pass filter, the second voltage signal V_{bus} on the DC bus side of the inverter and a voltage reference value V_{bus_ref} , and an inductor value L_t of the low-pass filter. The grid-connected active power reference value P_{g_ref} , the voltage reference value V_{bus_ref} and the inductor value L_t of the low-pass filter are known quantities.

[0084] In some embodiments, a voltage component in the $\alpha\beta$ coordinate system is obtained based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g , the first current signal i_g , the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the inductor value L_t of the low-pass filter; a feedforward component of grid voltage v_f is obtained according to the first voltage signal v_g and a feedforward function $G_{ff}(s)$; and a switch driving signal is obtained according to the voltage component and the feedforward component of grid voltage v_f . For single-phase power, the switch driving signal is obtained according to a α voltage component v_α and a feedforward component of grid voltage v_f ; for three-phase power, the switch driving signal is obtained according to a α voltage component v_α , a β voltage component v_β and a feedforward component of grid voltage v_f .

[0085] In step 730, the switch driving signal of the inverter is controlled to adjust the power of a noncritical load, so that the grid-connected active power output from the low-pass filter can track a grid-connected active power reference value.

[0086] In the above embodiment, when photovoltaic power fluctuates or changes within a certain range, the power of the noncritical load can be adjusted according to a reasonable control method, so that the grid-connected active power of the entire topology can be relatively constant, which is, different from the goal of voltage stabilization, more suitable for grid connection power generation applications, and can suppress the impact of photovoltaic power fluctuations at the source.

[0087] In some embodiments of the present disclosure, a first current component I_d and a second current component I_q in the dq coordinate system are obtained according to a first voltage signal v_g and a first current signal i_g . For single-phase power, as shown in FIG. 8.

[0088] In step 810, a first voltage signal v_g is input to a PLL to obtain an amplitude v_g , a phase θ , and a fundamental frequency ω of grid-connected voltage.

[0089] In step 820, a β current component $i_{g\beta}$ in the $\alpha\beta$ coordinate system is obtained based on a β voltage component v_β , and the grid voltage amplitude V_g .

[0090] In step 830, a first current component I_d and a second current component I_q in the dq coordinate system are obtained according to a first current signal i_g , the phase θ , and the β current component $i_{g\beta}$.

[0091] In some embodiments, in the PLL, let the grid-connected voltage v_g be a α -axis component $v_{g\alpha}=V_g\cdot\sin\theta$, a β -axis component $v_{g\beta}=V_g\cdot\sin(\theta-\pi/2)$ with a phase lag of $\pi/2$ can be obtained. In the FAE, a β -axis main circuit composed of an inverter, a low-pass filter and a noncritical load in the topology is simulated by a s-function, wherein a delay function e^{-T} is used to simulate the modulation delay effect of the inverter, and K_{pwm} is a modulation scale factor. After a modulation signal v_β and a β -axis grid voltage signal $v_{g\beta}$ are input to the FAE, the β -axis component $i_{g\beta}$ of the grid-connected current can be obtained. After transformation from the $\alpha\beta$ stationary coordinate system to the dq rotating coordinate system (the rotational angular velocity is θ), $i_{g\alpha}$ and $i_{g\beta}$ can be converted into d-axis component I_d and q-axis component I_q .

[0092] In the above steps, the AC signal is converted into a DC static component, which can facilitate subsequent control operations.

[0093] For the three-phase power, a first current component I_d and a second current component I_q in the dq coordinate system are obtained according to a first current signal i_g and a phase θ ,

without the need of the execution of step 820.

[0094] In other embodiments of the present disclosure, a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system are obtained according to a second voltage signal V_{bus} , a voltage reference value V_{bus_ref} , and a grid-connected active power reference value P_{g_ref} . As shown in FIG.9.

[0095] In step 910, PI control is performed on the difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to obtain a second reference current I_{q_ref} in the dq coordinate system.

[0096] In step 920, PI control is performed on the difference between the second reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain a second reference voltage value V_{q_ref} .

[0097] In step 930, the grid-connected active power reference value P_{g_ref} is divided by the grid-connected voltage amplitude v_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system.

[0098] In step 940, PI control is performed on the difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter to obtain the first reference voltage value V_{d_ref} .

[0099] In some embodiments of the present disclosure, a first voltage component V_d and a second voltage component V_q in the dq coordinate system are obtained according to a first current component I_d , a second current component I_q , a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} , and an inductor value L_t of the low-pass filter. As shown in FIG.10.

[00100] In step 1010, according to a first current component I_d and an inductor value L_t of the low-pass filter, a first voltage value V_{dt} corresponding to the inductor in the dq coordinate system is obtained.

[00101] For example, $V_{dt}=\omega I_d(L_{gf}+L_{ff})$.

[00102] In step 1020, a difference operation between a second reference voltage value V_{q_ref} and a first voltage value V_{dt} is performed to obtain a second voltage component V_q .

[00103] In step 1030, according to a second current component I_q and the inductor value L_t of the low-pass filter, a second voltage value V_{qt} corresponding to the inductor in the dq coordinate system is obtained.

[00104] For example, $V_{qt}=\omega I_q(L_{gf}+L_{ff})$.

[00105] In step 1040, a first reference voltage value V_{d_ref} is added to the second voltage value V_{qt} to obtain a first voltage component V_d .

[00106] According to the first voltage component V_d and the second

voltage component V_q , a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system are obtained. For single-phase power, a switch driving signal is obtained according to the α voltage component v_α and a feedforward component of grid voltage v_f . For three-phase power, a switch driving signal is obtained according to the α voltage component v_α , the β voltage component v_β , and a feedforward component of grid voltage v_f .

[00107] If the system does not have a noncritical load, due to the inherent resonance peak of the LCL filter, the amplitude gain at the resonant frequency is infinite, which will show instability. After a noncritical load is connected in parallel between the two ends of the capacitor of the LCL filter, and through the control of the control system, the overall system can show better control performance.

[00108] Under normal circumstances, the grid-connected power of photovoltaic power generation changes with the illumination intensity. When the illumination suddenly decreases, the photovoltaic grid-connected power decreases, and the photovoltaic grid-connected current also decreases. However, with the circuit topology and control method of the present disclosure, when the illumination suddenly decreases, the power and voltage of the noncritical loads decrease, but the change of the photovoltaic grid-connected power is minor.

[00109] In some embodiments of the present disclosure, the circuit topology and control method of the present disclosure are applied to a building, the roof of which, for example, has a photovoltaic power generation system and a water heater installed, wherein the water heater is used as a noncritical load. When the illumination is sufficient and the photovoltaic power generation system is in an over-generating state, the power of the water heater increases accordingly; when the illumination is insufficient and the photovoltaic power generation system is in an under-generating state, the power of the water heater decreases accordingly. Finally, the grid-connected active power can be relatively constant, and the uncertainty and random fluctuations of photovoltaic power generation can be overcome.

[00110] FIG. 11 is a schematic structural diagram of a controller according to some embodiments of the present disclosure. The controller 1100 comprises a memory 1110 and a processor 1120. The memory 1110 may be a magnetic disk, flash memory or any other non-volatile storage medium. The storage device is used to store instructions of a corresponding embodiment described above. The processor 1120 is coupled to memory 1110 and may be implemented as one or more integrated circuits, such as a microprocessor or microcontroller. The processor 1120 is used to execute the instructions stored in the memory.

[00111] In some embodiments, the processor 1120 is coupled to the memory 1110 via a Bus 1130. The controller 1100 may be further connected to an external storage device 1150 through a storage interface 1140 to access external data, and may be further connected to a network or another computer system (not shown) through a network interface 1160, the details of which will not be described herein.

[00112] In this embodiment, through storing data and instructions in the memory and executing the above instructions by the processor to adjust the power of the noncritical load, the grid-connected active power of the entire topology can be relatively constant. The present disclosure can weaken the dependence of photovoltaic power generation on energy storage, reduce the increase in the overall cost of energy storage, facilitate the promotion of distributed photovoltaics in distribution networks, and has significant practical value.

[00113] In other embodiments, the present disclosure further provides a computer-readable storage medium having computer program instructions stored thereon that, when executed by a processor, implement the steps of the methods of corresponding embodiments described above. One skilled in the art should understand that, the embodiments of the present disclosure may be provided as a method, an device, or a computer program product. Therefore,

embodiments of the present disclosure can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. Moreover, the present disclosure may take the form of a computer program product embodied on one or more computer-usable non-transitory storage media (including but not limited to disk storage, CD-ROM, optical storage device, etc.) having computer-usable program code embodied therein.

[00114] The present disclosure is described with reference to flowcharts and/or block diagrams of methods, devices (systems) and computer program products according to embodiments of the present disclosure. It should be understood that each process and/or block in the flowcharts and/or block diagrams, and combinations of the processes and/or blocks in the flowcharts and/or block diagrams may be implemented by computer program instructions. The computer program instructions may be provided to a processor of a general purpose computer, a special purpose computer, an embedded processor, or other programmable data processing device to generate a machine such that the instructions executed by a processor of a computer or other programmable data processing device to generate means implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00115] The computer program instructions may also be stored in a

computer readable storage device capable of directing a computer or other programmable data processing device to operate in a specific manner such that the instructions stored in the computer readable storage device produce an article of manufacture including instruction means implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00116] These computer program instructions can also be loaded onto a computer or other programmable device to perform a series of operation steps on the computer or other programmable device to generate a computer-implemented process such that the instructions executed on the computer or other programmable device provide steps implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00117] Heretofore, the present disclosure has been described in detail. In order to avoid obscuring the concepts of the present disclosure, some details known in the art are not described. Based on the above description, those skilled in the art can understand how to implement the technical solutions disclosed herein.

[00118] Although some specific embodiments of the present disclosure have been described in detail by way of example, those skilled in the art should understand that the above examples are only for the purpose of illustration and are not intended to limit

the scope of the present disclosure. It should be understood by those skilled in the art that the above embodiments may be modified without departing from the scope and spirit of the present disclosure. The scope of the disclosure is defined by the following claims.

What is claimed is:

1. A photovoltaic grid-connected control device, comprising a controller, and a voltage converter, an inverter and a low-pass filter that are cascaded in sequence, wherein:

an input terminal of the voltage converter is configured to be connected to a photovoltaic device;

an output terminal of the low-pass filter is configured to be connected to a grid, wherein a filter capacitor of the low-pass filter is configured to be connected in parallel with a noncritical load; and

the controller is configured to control a switch driving signal of the inverter to adjust power of the noncritical load, so that a grid-connected active power output from the low-pass filter tracks a grid-connected active power reference value P_{g_ref} .

2. The photovoltaic grid-connected control device according to claim 1, wherein the controller is configured to:

control the switch driving signal of the inverter based on the grid-connected active power reference value P_{g_ref} , a first voltage signal v_g and a first current signal i_g at the output terminal of the low-pass filter, a second voltage signal V_{bus} and a voltage reference value V_{bus_ref} on the DC bus side of the inverter, and an inductor

value L_t of the low-pass filter.

3. The photovoltaic grid-connected control device according to claim 2, wherein the controller is configured to:

obtain a voltage component in a $\alpha\beta$ coordinate system based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g , the first current signal i_g , the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the inductor value L_t of the low-pass filter;

obtain a feedforward component of grid voltage v_f according to the first voltage signal v_g and a feedforward function $G_{ff(s)}$; and

obtain the switch driving signal according to the voltage component in the $\alpha\beta$ coordinate system and the feedforward component of grid voltage v_f .

4. The photovoltaic grid-connected control device according to claim 3, wherein the controller is configured to:

obtain a first current component I_d and a second current component I_q in a dq coordinate system according to the first voltage signal v_g and the first current signal i_g ;

obtain a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system according to the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} ,

and the grid-connected active power reference value P_{g_ref} ;

obtain a first voltage component V_d and a second voltage component V_q in the dq coordinate system according to the first current component I_d , the second current component I_q , the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} , and the inductor value L_t of the low-pass filter; and

obtain a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system according to the first voltage component V_d and the second voltage component V_q .

5. The photovoltaic grid-connected control device according to claim 4, wherein the controller is configured to:

input the first voltage signal v_g to a phase locked loop (PLL) to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage;

obtain a β current component $i_{g\beta}$ in the $\alpha\beta$ coordinate system based on the β voltage component v_β , and the first voltage signal v_g ; and

obtain the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g , the phase θ , and the β current component $i_{g\beta}$.

6. The photovoltaic grid-connected control device according to

claim 4, wherein the controller is configured to:

input the first voltage signal v_g to a phase locked loop (PLL) to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; and

obtain the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g and the phase θ .

7. The photovoltaic grid-connected control device according to claim 4, wherein the controller is configured to:

perform proportional integral (PI) control on a difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to obtain a second reference current I_{q_ref} in the dq coordinate system;

perform PI control on a difference between the second reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain the second reference voltage value V_{q_ref} ;

divide the grid-connected active power reference value P_{g_ref} by the amplitude V_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system; and

perform PI control on a difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter to obtain the first reference voltage value V_{d_ref} .

8. The photovoltaic grid-connected control device according to claim 4, wherein the controller is configured to:

according to the first current component I_d and the inductor value L_t of the low-pass filter, obtain a first voltage value V_{dt} corresponding to the inductor in the dq coordinate system;

perform a difference operation between the second reference voltage value V_{q_ref} and the first voltage value V_{dt} to obtain the second voltage component V_q ;

according to the second current component I_q and the inductor value L_t of the low-pass filter, obtain a second voltage value V_{qt} corresponding to the inductor in the dq coordinate system; and

add the first reference voltage value V_{d_ref} to the second voltage value V_{qt} to obtain the first voltage component V_d .

9. The photovoltaic grid-connected control device according to any one of claims 1 to 8, wherein:

the low-pass filter is an LCL type low-pass filter;

the inverter is a single-phase inverter or a three-phase

inverter; or

the voltage converter is a Boost converter.

10. A photovoltaic grid-connected control system, comprising:
a photovoltaic grid-connected control device according to any one of claims 1 to 9; and
a photovoltaic device.

11. A control method of the photovoltaic grid-connected control device according to claim 1, comprising:

obtaining a first voltage signal v_g and a first current signal i_g at an output terminal of a low-pass filter, and a second voltage signal V_{bus} on the DC bus side of an inverter;

generating a switch driving signal of the inverter according to the first voltage signal v_g , the first current signal i_g , and the second voltage signal V_{bus} ; and

controlling the switch driving signal of the inverter to adjust power of a noncritical load, so that a grid-connected active power output from the low-pass filter tracks a grid-connected active power reference value P_{g_ref} .

12. The control method according to claim 11, wherein generating the switch driving signal of the inverter comprises:

generating the switch driving signal of the inverter based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g and the first current signal i_g at the output terminal of the low-pass filter, the second voltage signal V_{bus} and a voltage reference value V_{bus_ref} on the DC bus side of the inverter, and an inductor value L_t of the low-pass filter.

13. The control method according to claim 12, wherein generating the switch driving signal of the inverter comprises:

obtaining a voltage component in a $\alpha\beta$ coordinate system based on the grid-connected active power reference value P_{g_ref} , the first voltage signal v_g , the first current signal i_g , the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the inductor value L_t of the low-pass filter;

obtaining a feedforward component of grid voltage v_f according to the first voltage signal v_g and a feedforward function $G_{ff(s)}$; and

obtaining the switch driving signal according to the voltage component in the $\alpha\beta$ coordinate system and the feedforward component of grid voltage v_f .

14. The control method according to claim 13, wherein obtaining the voltage component in the $\alpha\beta$ coordinate system comprises:

obtaining a first current component I_d and a second current

component I_q in a dq coordinate system according to the first voltage signal v_g and the first current signal i_g ;

obtaining a first reference voltage value V_{d_ref} and a second reference voltage value V_{q_ref} in the dq coordinate system according to the second voltage signal V_{bus} , the voltage reference value V_{bus_ref} , and the grid-connected active power reference value P_{g_ref} ;

obtaining a first voltage component V_d and a second voltage component V_q in the dq coordinate system according to the first current component I_d , the second current component I_q , the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} , and the inductor value L_t of the low-pass filter; and

obtaining a α voltage component v_α and a β voltage component v_β in the $\alpha\beta$ coordinate system according to the first voltage component V_d and the second voltage component V_q .

15. The control method according to claim 14, wherein obtaining the first current component I_d and the second current component I_q in the dq coordinate system comprises:

inputting the first voltage signal v_g to a PLL to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage;

obtaining a β current component i_{g_beta} in the $\alpha\beta$ coordinate system based on the β voltage component v_β , and the first voltage signal v_g ;

and

obtaining the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g , the phase θ , and the β current component $i_{g\beta}$.

16. The control method according to claim 14, wherein obtaining the first current component I_d and the second current component I_q in the dq coordinate system comprises:

inputting the first voltage signal v_g to a PLL to obtain an amplitude V_g , a phase θ , and a fundamental frequency ω of grid-connected voltage; and

obtaining the first current component I_d and the second current component I_q in the dq coordinate system according to the first current signal i_g and the phase θ .

17. The control method according to claim 14, wherein obtaining the first reference voltage value V_{d_ref} and the second reference voltage value V_{q_ref} in the dq coordinate system comprises:

performing PI control on a difference between the voltage reference value V_{bus_ref} and the second voltage signal V_{bus} , the result of which passes through a limiter and a holder to obtain a second reference current I_{q_ref} in the dq coordinate system;

performing PI control on a difference between the second

reference current I_{q_ref} and the second current component I_q , the result of which passes through a limiter to obtain the second reference voltage value V_{q_ref} ;

dividing the grid-connected active power reference value P_{g_ref} by the amplitude V_g , the result of which passes through a limiter and a holder to obtain a first reference current I_{d_ref} in the dq coordinate system; and

performing PI control on a difference between the first reference current I_{d_ref} and the first current component I_d , the result of which passes through a limiter to obtain the first reference voltage value V_{d_ref} .

18. The control method according to claim 14, wherein obtaining the first voltage component V_d and the second voltage component V_q in the dq coordinate system comprises:

obtaining a first voltage value V_{dt} corresponding to the inductor in the dq coordinate system according to the first current component I_d and the inductor value L_t of the low-pass filter;

performing a difference operation between the second reference voltage value V_{q_ref} and the first voltage value V_{dt} to obtain the second voltage component V_q ;

obtaining a second voltage value V_{qt} corresponding to the inductor in the dq coordinate system according to the second

current component I_q and the inductor value L_t of the low-pass filter;
and

adding the first reference voltage value V_{d_ref} to the second
voltage value V_{qt} to obtain the first voltage component V_d .

19. A controller, comprising:

a memory; and

a processor coupled to the memory, the processor configured to,
based on instructions stored in the memory, carry out the control
method according to any one of claims 11 to 18.

20. A non-transitory computer-readable storage medium on which
computer program instructions are stored, which when executed by a
processor implement the control method according to any one of
claims 11 to 18.