

ISLAND MICROGRID SYSTEM, AND INTERACTIVE OSCILLATION SUPPRESSION METHOD AND SYSTEM THEREFOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims rights and interests to Chinese Patent Application No. 202111332841.9 filed on November 11, 2021, which is incorporated by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to a low-frequency oscillation suppression technology for grids, in particular to an island microgrid system and an interactive oscillation suppression method and system therefor.

BACKGROUND OF THE INVENTION

In recent years, as energy shortage and environmental pollution problems become increasingly prominent, distributed microgrids composed of photovoltaic systems, wind power generation, energy storage, and voltage source converters (VSCs) have been widely used. However, with gradually increasing popularity of power electronic converters, low inertia of systems and random power generation of renewable energy threaten stability of island microgrids.

To solve this problem, virtual synchronous machines (VSMs) emerged, which simulate dynamic characteristics of synchronous motors and provide virtual inertia and damping for power systems. The virtual synchronous machines may be classified into two types: virtual synchronous generators (VSGs) and load virtual synchronous machines (LVSMs). Currently, the VSGs have received extensive research, including implementation, parameter design, applications, and small signal impedance modeling. In addition to power supply sides, power electronic loads connected to island microgrids are increasingly required to provide inertia and damping. Therefore, an operating LVSM may be introduced into a PWM rectifier in the absence of a phase locked loop. According to existing research, the VSGs or LVSMs may operate stably even in weak

grids, but it cannot be guaranteed that systems in which the VSGs supply power to the LVSMs are still stable. Moreover, due to negative resistance behaviors of the LVSMs in q-q channels in low frequency ranges, interaction dynamics between the VSGs and the LVSMs may lead to instability, which limits their large-scale application in the island microgrids. Therefore, it is necessary to study interaction dynamics between the VSGs and the LVSMs.

Generally, methods for suppressing interactive oscillations in the island microgrids are roughly classified into two types. One type is implemented by an external device, and the other type is implemented by an improved controller. Compared with additional external devices, it is more economical to suppress oscillations through the improved controller. It has been proposed in the literature to enhance stability of a VSG in a weak grid through virtual impedance, and harmonic virtual impedance has been designed to suppress harmonics of the VSG. However, virtual impedance control may cause voltage drop in the VSG. In addition, for similar island microgrids, methods for parameter optimization have been proposed in the literature to alleviate interaction between VSIs and VSRs. Moreover, an active compensation technology has also been proposed to maintain stability of an entire system composed of a plurality of VSIs and VSRs. However, due to different impedances of the LVSMs and the VSRs, existing technologies have not studied methods for suppressing interactive oscillations of the VSGs and the LVSMs.

SUMMARY OF THE INVENTION

A technical problem to be solved by the present invention is to provide an island microgrid system and an interactive oscillation suppression method and system therefor to effectively suppress interactive oscillations of VSGs and LVSMs in response to the shortcomings of the prior art.

To solve the above technical problem, a technical solution adopted by the present invention is as follows: An interactive oscillation suppression method for an island microgrid system, the island microgrid system includes a plurality of power supply units; each power supply unit includes a source-side virtual synchronous generator and a load-side virtual synchronous generator; the source-side virtual synchronous generator and the

load-side virtual synchronous generator are connected in series; the load-side virtual synchronous generator is connected to a load; and the method includes the following steps:

S1, obtaining an output voltage amplitude E_m of the source-side virtual synchronous generator according to a d-axis component u_d of three-phase output voltage of the source-side virtual synchronous generator, instantaneous reactive power Q of the source-side virtual synchronous generator and an instruction value Q_{set} of the instantaneous reactive power Q , where a calculation formula for E_m is as follows:

$$E_m = (D_q (U_n - u_d) + Q_{set} - Q) / (Ks),$$

where D_q represents a given reactive power-voltage droop coefficient; U_n represents a rated terminal voltage amplitude of the source-side virtual synchronous generator; K is a given excitation regulation coefficient; and s is a Laplace operator;

S2, obtaining a phase angle θ of the source-side virtual synchronous generator according to active power P of the source-side virtual synchronous generator and an instruction value P^* of the active power P , where a calculation formula for θ is:

$$\theta = \frac{P^* - P + D_p \omega_n^2}{(Js + D_p)s\omega_n};$$

where D_p represents a damping coefficient; ω_n represents a synchronous angular velocity of an island microgrid system; and J is a rotor inertia of VSG;

S3, subtracting a product of the current and impedance of the source-side virtual synchronous generator from the voltage amplitude E_m of the source-side virtual synchronous generator to construct virtual impedance, and obtaining a d-axis voltage instruction value u_d^* and a q-axis voltage instruction value u_q^* , which are calculated as follows:

$$\begin{bmatrix} u_d^* \\ u_q^* \end{bmatrix} = \begin{bmatrix} E_m \\ 0 \end{bmatrix} - \begin{bmatrix} L_v s + R_v & -\omega_n L_v \\ L_v & L_v s + R_v \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix};$$

where i_d and i_q are a d-axis component and a q-axis component of three-phase current of the source-side virtual synchronous generator respectively; and R_v and L_v are a resistance value and an inductance value of given virtual impedance respectively;

S4, solving a difference between the d-axis voltage instruction value u_d^* and a d-axis component of three-phase voltage of the source-side virtual synchronous generator, and solving a difference between the q-axis voltage instruction value u_q^* and a q-axis component of three-phase voltage of the source-side virtual synchronous generator, and respectively performing PI control on the differences to obtain current instruction values i_{d0}^* and i_q^* ;

S6, calculating an instruction value i_d^* of the d-axis current component of the three-phase output current of the source-side virtual synchronous generator by using the following formula: $i_d^* = i_{d0}^* - i_{d1}^* + i_{d2}^*$;

S7, solving a difference between the d-axis current instruction value i_d^* and the d-axis component i_d of the three-phase current of the source-side virtual synchronous generator, and solving a difference between the q-axis current instruction value i_q^* and the q-axis component i_q of the three-phase current of the source-side virtual synchronous generator, and respectively using the differences as input of a PI controller to obtain a duty ratio d_d of the d-axis and a duty ratio d_q of the q-axis; and

S8, obtaining duty ratios d_a , d_b and d_c in a three-phase static coordinate system according to the duty ratio d_d of the d-axis, the duty ratio d_q of the q-axis and the phase angle θ of the source-side virtual synchronous generator, and controlling on-off of a switch tube of the source-side virtual synchronous generator,

$$\begin{cases} d_a = d_d \cos(\theta) - d_q \sin(\theta) \\ d_b = d_d \cos\left(\theta - \frac{2\pi}{3}\right) - d_q \sin\left(\theta - \frac{2\pi}{3}\right); \\ d_c = d_d \cos\left(\theta + \frac{2\pi}{3}\right) - d_q \sin\left(\theta + \frac{2\pi}{3}\right) \end{cases}$$

The present invention remodels impedances of VSGs through a combination of d-axis inductive current feedforward control and d-axis voltage feedback control to reduce impedance amplitudes of the VSGs. Therefore, low-frequency interaction between the VSGs and the LVSMs may be alleviated, thereby suppressing interactive oscillations of the VSGs and the LVSMs and ensuring stability of the island microgrid system.

In step S6, i_{d1}^* and i_{d2}^* are a voltage feedback component and a current feedforward

component of the d-axis respectively, which are calculated as follows:

$$i_{d1}^* = \left(\frac{C_f s}{T_c s + 1} + \frac{L_f C_f s^2}{G_m G_i (T_c s + 1)} \right) u_d ;$$

$$i_{d2}^* = \frac{1}{T_c s + 1} + \frac{L_f s}{G_m G_i (T_c s + 1)^2} i_d ;$$

where L_f and C_f are an inductance value and a capacitance value of an LC filter of the VSG respectively; T_c is a time constant of a low-pass filter; $G_m = U_{dc0}/2$; and $G_i = k_{pi} + k_{ii}/s$, where k_{pi} and k_{ii} are a proportional gain and an integral gain of the current PI controller. The present invention further provides an interactive oscillation suppression system for an island microgrid system, including a computer device, where the computer device is configured or programmed to execute the steps of the interactive oscillation suppression method of the present invention.

The present invention further provides an island microgrid system, including a plurality of power supply units; each power supply unit includes a source-side virtual synchronous generator and a load-side virtual synchronous generator; the source-side virtual synchronous generator and the load-side virtual synchronous generator are connected in series; the load-side virtual synchronous generator is connected to a load; the source-side virtual synchronous generator is connected to a processor; and the processor is configured or programmed to execute the steps of the interactive oscillation suppression method of the present invention.

Because the VSGs and the LVSMs can independently participate in regulation of voltage and frequency of the system and do not rely on an additional communication network to achieve two-level control, the island microgrid system of the present invention may avoid potential network attacks. Meanwhile, the island microgrid system of the present invention avoids low-frequency interactive oscillations, which improves stability of the island microgrid system and enables the island microgrid system to be applied in engineering.

In order to facilitate obtaining corresponding data, the processor of the present invention samples the three-phase output current of the source-side virtual synchronous generator through a current sampling circuit; the processor samples the three-phase output voltage

of the source-side virtual synchronous generator through a voltage sampling circuit; and the processor outputs a duty ratio signal to a switch tube of the source-side virtual synchronous generator.

Compared with the prior art, beneficial effects of the present invention are as follows:

1. The method of the present invention may suppress interactive oscillations of VSG and LVSM, which ensures the stability of the island microgrid system;
2. The method of the present invention maintains dynamic performance of the island microgrid system, and is simple and economical in control; and
3. The island microgrid system of the present invention may support voltage and frequency stability from both the source-side and the load-side, may also omit secondary communication to avoid potential network attacks, and is safe and reliable in use.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an island microgrid system composed of source-side and load-side virtual synchronous machines in Embodiment 1 of the present invention;

FIG. 2 is a diagram of main circuits and control modes of virtual synchronous machines after impedance remodeling in Embodiment 2 of the present invention; and

FIG. 3 shows a simulation waveform of interface voltage of a system before and after impedance remodeling in Embodiment 1 of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Embodiment 1 of the present invention provides an island microgrid system including source-side and load-side virtual synchronous machines. As shown in FIG. 1, the island microgrid system in Embodiment 1 combines VSGs and LVSMs. The island microgrid system includes a plurality of power supply units, each power supply unit includes a VSG and an LVSM, and the LVSM is connected to a load. A connecting point between the VSG and the LVSM is referred to as a common coupling point.

There are totally n power supply units in Embodiment 1 of the present invention, so there are totally n VSGs (VSG1, VSG2, ..., VSG n) and n LVSMs (LVSM1, LVSM2, ..., LVSM n).

Embodiment 2 of the present invention provides an interactive oscillation suppression method for the island microgrid system in Embodiment 1. As shown in FIG. 2, the interactive oscillation suppression method in Embodiment 2 of the present invention performs control from source-side virtual synchronous generators. A source-side virtual synchronous generator includes an LC filter, a three-phase inverter circuit, a sampling circuit, a direct-current side energy storage capacitor, a controller, and a drive and protection circuit; the LC filter is connected to an output side of the three-phase inverter circuit; a bridge arm of the three-phase inverter circuit is connected in parallel to the direct-current side energy storage capacitor; an input end of the sampling circuit is connected to the LC filter; an output end of the sampling circuit is connected to an input end of the controller; the controller is connected to an input end of the drive and protection circuit; and an output end of the drive and protection circuit is used for driving the three-phase inverter circuit. The sampling circuit includes a voltage sampling circuit and a current sampling circuit, the current sampling circuit is connected to an input side of the LC filter, the current sampling circuit is used for sampling three-phase current i_a , i_b and i_c of the LC filter, the voltage sampling circuit is connected to an output side of the LC filter, and the voltage sampling circuit is used for sampling line voltage u_{ab} and u_{bc} of the LC filter.

The interactive oscillation suppression method in Embodiment 2 of the present invention includes the following steps:

- 1) sampling three-phase output current i_a , i_b and i_c of the LC filter and line voltage u_{ab} and u_{bc} of the LC filter;
- 2) calculating three-phase phase voltage u_a , u_b and u_c from the three-phase line voltage u_{ab} and u_{bc} ;
- 3) calculating a d-axis component u_d and a q-axis component u_q of three-phase voltage and calculating a d-axis component i_d and a q-axis component i_q of three-phase current respectively from the three-phase output current i_a , i_b and i_c of the LC filter and the three-phase phase voltage u_a , u_b and u_c of a grid side;
- 4) calculating instantaneous active power P and reactive power Q according to the d-axis component u_d and the q-axis component u_q of the three-phase voltage and the d-axis

component i_d and the q-axis component i_q of the three-phase current;

5) calculating an electromagnetic torque T_e of the virtual synchronous generator from the instantaneous active power P , $T_e = P/\omega_n$, where ω_n represents a synchronous angular velocity of a grid;

6) calculating a phase angle $\theta = \frac{T_{set} - T_e + D_p \omega_n}{(Js + D_p)s}$ of the virtual synchronous generator

from T_{set} , where D_p represents a damping coefficient; and T_{set} represents a mechanical torque of the virtual synchronous generator;

7) calculating an output voltage amplitude of the virtual synchronous generator from the d-axis component u_d of the grid side voltage and the reactive power Q , $E_m = (D_q(U_n - u_d) + Q_{set} - Q)/(Ks)$, where E_m represents the output voltage amplitude of the virtual synchronous generator; D_q represents a reactive power-voltage droop coefficient; U_n represents a rated terminal voltage amplitude of the virtual synchronous generator; K is an excitation regulation coefficient; and Q_{set} represents a reactive power instruction value of the virtual synchronous generator;

8) solving a difference between a voltage instruction value u_d^* of the d-axis of the source-side virtual synchronous generator and a d-axis component of the three-phase voltage of the source-side virtual synchronous generator, and solving a difference between a voltage instruction value u_q^* of q-axis of the source-side virtual synchronous generator and a q-axis component of the three-phase voltage of the source-side virtual synchronous generator, and respectively performing PI control on the differences to obtain current instruction values i_{d0}^* and i_{q}^* ;

9) obtaining an instruction value i_d^* of the d-axis current component of the three-phase current through output of the PI controller, a voltage feedback component i_{d1}^* of the d-axis and a current feedforward component i_{d2}^* of the d-axis, where a calculation formula for i_d^* is $i_d^* = i_{d0}^* - i_{d1}^* + i_{d2}^*$, and the voltage feedback component i_{d1}^* of the d-axis and the current feedforward component i_{d2}^* of the d-axis are calculated as follows:

$$i_{d1}^* = \overbrace{\left(\frac{C_f s}{T_c s + 1} + \frac{L_f C_f s^2}{G_m G_i (T_c s + 1)} \right)}^{T_{fb}} u_d;$$

$$i_{d2}^* = \overbrace{\left(\frac{1}{T_c s + 1} + \frac{L_T s}{G_m G_i (T_c s + 1)^2} \right)}^{T_{ff}} i_d;$$

where T_c is a time constant of a low-pass filter, $G_m = U_{dc0}/2$; $G_i = k_{pi} + k_{ii}/s$, where k_{pi} is a proportional gain of a current PI controller; and k_{ii} is an integral gain of the current PI controller;

10) solving a difference between the d-axis current instruction value i_d^* of the source-side virtual synchronous generator and the d-axis component i_d of the three-phase current of the source-side virtual synchronous generator, and solving a difference between the q-axis current instruction value i_q^* of the source-side virtual synchronous generator and the q-axis component i_q of the three-phase current of the source-side virtual synchronous generator, and respectively using the differences as input of the PI controller to obtain a duty ratio d_d of the d-axis and a duty ratio d_q of the q-axis;

11) obtaining duty ratios d_a , d_b and d_c in a three-phase static coordinate system according to the duty ratios of the d-axis and the q-axis and the phase angle θ ; and

12) controlling on-off of switch tubes of power electronic apparatuses according to the duty ratios d_a , d_b and d_c .

FIG. 3 provides a simulation waveform of a d-axis component of interface voltage of the island microgrid system in Embodiment 1 of the present invention. When the control process in the embodiment of the present invention is not added, the d-axis component of the interface voltage of the system induces low-frequency oscillation. After the oscillation suppression method in the embodiment of the present invention is adopted, the d-axis component of the interface voltage of the system gradually stabilizes, and the system can operate stably.

Claims

1. An interactive oscillation suppression method for an island microgrid system, wherein the island microgrid system comprises a plurality of power supply units; each power supply unit comprises a source-side virtual synchronous generator and a load-side virtual synchronous generator; the source-side virtual synchronous generator and the load-side virtual synchronous generator are connected in series; the load-side virtual synchronous generator is connected to a load; and the interactive oscillation suppression method comprises the following steps:

S1, obtaining an output voltage amplitude E_m of the source-side virtual synchronous generator according to a d-axis component u_d of three-phase output voltage of the source-side virtual synchronous generator, instantaneous reactive power Q of the source-side virtual synchronous generator and an instruction value Q_{set} of the instantaneous reactive power Q , wherein a calculation formula for E_m is as follows:

$$E_m = (D_q (U_n - u_d) + Q_{set} - Q) / (Ks),$$

wherein D_q represents a given reactive power-voltage droop coefficient; U_n represents a rated terminal voltage amplitude of the source-side virtual synchronous generator; K is a given excitation regulation coefficient; and s is a Laplace operator;

S2, obtaining a phase angle θ of the source-side virtual synchronous generator according to active power P of the source-side virtual synchronous generator and an instruction value P^* of the active power P , wherein a calculation formula for θ is:

$$\theta = \frac{P^* - P + D_p \omega_n^2}{(Js + D_p)s\omega_n};$$

wherein D_p represents a damping coefficient; ω_n represents a synchronous angular velocity of an island microgrid system; and J is a rotor inertia of the source-side virtual synchronous generator;

S3, obtaining a voltage instruction value u_d^* of the d-axis and a voltage instruction value u_q^* of the q-axis according to the voltage amplitude E_m of the source-side virtual synchronous generator, wherein the instruction values u_d^* and u_q^* are calculated as follows:

$$\begin{bmatrix} u_d^* \\ u_q^* \end{bmatrix} = \begin{bmatrix} E_m \\ 0 \end{bmatrix} - \begin{bmatrix} L_v s + R_v & -\omega_n L_v \\ L_v & L_v s + R_v \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix};$$

wherein i_d and i_q are a d-axis component and a q-axis component of three-phase current of the source-side virtual synchronous generator respectively; and R_v and L_v are a resistance value and an inductance value of given virtual impedance respectively;

S4, solving a differences between the voltage instruction value u_d^* of the d-axis and a d-axis component of three-phase voltage of the source-side virtual synchronous generator, and solving a difference between the voltage instruction value u_q^* of the q-axis and a q-axis component of three-phase voltage of the source-side virtual synchronous generator, and respectively performing PI control on the differences to obtain current instruction values i_{d0}^* and i_{q0}^* ;

S6, calculating an instruction value i_d^* of the d-axis current component of the three-phase output current of the source-side virtual synchronous generator by using the following formula: $i_d^* = i_{d0}^* - i_{d1}^* + i_{d2}^*$;

S7, solving a difference between the d-axis current instruction value i_d^* and a d-axis component i_d of the three-phase current of the source-side virtual synchronous generator, and solving a difference between the q-axis current instruction value i_q^* and a q-axis component i_q of the three-phase current of the source-side virtual synchronous generator, and using the differences as input of a PI controller respectively to obtain a duty ratio d_d of the d-axis and a duty ratio d_q of the q-axis; and

S8, obtaining duty ratios d_a , d_b and d_c in a three-phase static coordinate system according to the duty ratio d_d of the d-axis, the duty ratio d_q of the q-axis and the phase angle θ of the source-side virtual synchronous generator, and controlling on-off of a switch tube of the source-side virtual synchronous generator,

$$\begin{cases} d_a = d_d \cos(\theta) - d_q \sin(\theta) \\ d_b = d_d \cos\left(\theta - \frac{2\pi}{3}\right) - d_q \sin\left(\theta - \frac{2\pi}{3}\right) \\ d_c = d_d \cos\left(\theta + \frac{2\pi}{3}\right) - d_q \sin\left(\theta + \frac{2\pi}{3}\right) \end{cases}$$

2. The interactive oscillation suppression method for an island microgrid system

according to claim 1, wherein in step S6, i_{d1}^* and i_{d2}^* are a voltage feedback component and a current feedforward component of the d-axis respectively, which are calculated as follows:

$$i_{d1}^* = \left(\frac{C_f s}{T_c s + 1} + \frac{L_f C_f s^2}{G_m G_i (T_c s + 1)} \right) u_d ;$$

$$i_{d2}^* = \frac{1}{T_c s + 1} + \frac{L_f s}{G_m G_i (T_c s + 1)^2} i_d ;$$

wherein L_f and C_f are an inductance value and a capacitance value of an LC filter of the source-side virtual synchronous generator; T_c is a time constant of a low-pass filter; $G_m = U_{dc0}/2$; and $G_i = k_{pi} + k_{ii}/s$, wherein k_{pi} and k_{ii} are a proportional gain and an integral gain of the current PI controller.

3. An interactive oscillation suppression system for an island microgrid system, comprising a computer device, wherein the computer device comprises a processor and a memory; the processor is used for executing a computer program stored in the memory; and the computer program is configured to execute the steps of the interactive oscillation suppression method according to claim 1 or 2.

4. An island microgrid system, comprising a plurality of power supply units, wherein each power supply unit comprises a source-side virtual synchronous generator and a load-side virtual synchronous generator; the source-side virtual synchronous generator and the load-side virtual synchronous generator are connected in series; the load-side virtual synchronous generator is connected to a load; the source-side virtual synchronous generator is connected to a processor; and the processor is configured or programmed to execute the steps of the interactive oscillation suppression method according to claim 1 or 2.

5. The island microgrid system according to claim 4, wherein the processor samples the three-phase output current of the source-side virtual synchronous generator through a current sampling circuit; the processor samples line voltage of an LC filter in the source-side virtual synchronous generator through a voltage sampling circuit; and the processor outputs a duty ratio signal to a switch tube of the source-side virtual synchronous generator.